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LOGGING RESIDUES FROM REGENERATION FELLINGS FOR BIOFUEL PRODUCTION- A GIS-BASED AVAILABILITY AND SUPPLY COST ANALYSIS

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ABSTRACT

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Finland has large forest fuel resources. However, the use of forest fuels for energy production has been low, except for small-scale use in heating. According to national action plans and programs related to wood energy promotion, the utilization of such resources will be multiplied over the next few years. The most significant part of this growth will be based on the utilization of forest fuels, produced from logging residues of regeneration fellings, in industrial and municipal power and heating plants.

Availability of logging residues was analyzed by means of resource and demand approaches in order to identify the most suitable regions with focus on increasing the forest fuel usage. The analysis included availability and supply cost comparisons between power plant sites and resource allocation in a least cost manner, and between a predefined power plant structure under demand and supply constraints. Spatial analysis of worksite factors and regional geographies were carried out using the GIS-model environment via geoprocessing and cartographic modeling tools.

According to the results of analyses, the cost competitiveness of forest fuel supply should be improved in order to achieve the designed objectives in the near future. Availability and supply costs of forest fuels varied spatially and were very sensitive to worksite factors and transport distances. According to the site-specific analysis the supply potential between different locations can be multifold. However, due to technical and economical reasons of the fuel supply and dense power plant infrastructure, the supply potential is limited at plant level. Therefore, the potential and supply cost calculations are depending on site-specific matters, where regional characteristics of resources and infrastructure should be taken into consideration, for example by using a GIS-modeling approach constructed in this study.

Keywords: forest fuels, logging residues, supply chains, supply cost, logistics, geographical information systems
UDC 630*7 : 630*3 : 662.63

PREFACE

The inspiring research field of forest fuel supply chains and systems in combination with the innovative and supportive working environment that VTT Processes in Jyväskylä offers, have all contributed in order that I have managed to complete this thesis.

First of all, I would like to express my gratitude to my head supervisor professor Anita Lukka for guiding me to the finalization of my Ph.D. studies. I would also like to thank professor Rolf Björheden and docent Heikki Malinen for their supportive criticism and revision suggestions as the referees of this thesis and professor Antti Asikainen for the valuable advice and comments.

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The support from the Fortum foundation, Lappeenranta University of Technology, IEM-doctoral programme and VTT Processes is highly appreciated. This thesis would not have been possible without their crucial contribution.

Finally, I would like to express my deepest gratitude to my beloved wife, Minna, for her loving, understanding and support.

Jyväskylä, October, 2002.

Tapio Ranta

SYMBOLS AND ABBREVIATIONS

Basic units and unit of measures:

m^3 solid = Cubic meter solid volume.
Timber volume of unbarked round wood, refers to solid volume.
In this study m^3 solid used unless separately defined.

m^3 loose = Cubic meter of chips.
In this study unless separately defined, 1 **m^3 solid** = 2.5 **m^3 loose**

$\mathbf{q_v(net)} = \mathbf{q_v(gross)} - 2.45 \times 0{,}09 \times H_2 = \mathbf{q_v(gross)} - 0.22 \times H_2$, where:

q_v(net) = Net calorific value of oven dry biomass, MJ/kg of dry mass

q_v(gross) = Calorimetric value of dry biomass, MJ/kg of dry mass

2.45 = The latent heat of vaporization of water at 20 °C, MJ/kg

0.09 = Factor that expresses that one part of hydrogen and eight parts of oxygen form nine part of water

H_2 = Hydrogen content of oven dry biomass (%)

$$\mathbf{q_v(moist_{dr})} = \mathbf{q_v(net)} - 2.45 \times \frac{MC}{100 - MC}$$

$$\mathbf{q_v(moist_{wt})} = \frac{\mathbf{q_v(net)} \times (100 - MC) - 2.45 \times MC}{100}$$, where:

$q_v(moist_{dr})$ = Net calorific value of biomass with moisture, MJ/kg of dry mass

$q_v(moist_{wt})$ = Net calorific value of biomass with moisture, MJ/kg of wet mass

MC = The moisture content on a fresh mass basis (%)

$$MC = \frac{M_1 - M_2}{M_1}$$, where:

M_1 = Mass of moist sample, kg

M_2 = Mass of dried sample, kg

E_0 = Effective time, hour of productive machine time not including any delay times per occasion

E_{15} = Gross effective time, hour of productive machine time including delay times not exceeding 15 minutes per occasion

Metric prefixes with exponent values:

k = kilo = 10^3 = 1 000
M = Mega =10^6 = 1 000 000
G = Giga = 10^9 = 1 000 000 000
T = Tera = 10^{12} = 1 000 000 000 000
P = Peta = 10^{15} = 1 000 000 000 000 000

Conversion coefficient between different energy units:

	toe	**MWh**	**GJ**
toe	1	11.630	41.868
MWh	0.08598	1	3.600
GJ	0.02388	0.2778	1

toe = Ton of oil equivalent, energy content of one ton of crude oil

Wh = Watt hour

J = Joule

TERMINOLOGY

Bioenergy
Energy from biofuels.

Biofuel
Fuel produced directly or indirectly from biomass.

Biomass
Material of biological origin excluding material embedded in geological formations and transformed to fossil.

Biomass residues
Biomass originating from well defined side-streams from agricultural, forestry and related industrial operations.

Brown residues
Seasoned logging and thinning residues, including branches, tops and part of needles in brown form.

Brown supply policy
Forest fuels produced from seasoned logging residues in brown form.

Bundled biofuel, bundle
Solid biofuels which have been bound together and where there is a lengthwise orientation of the material. In this study also the term residue log is used for bundles of logging residues.

Firewood
Cut and split oven-ready fuelwood used in household wood burning appliances like stoves, fireplaces and central heating systems.

Forest chips
Forest wood in the form of wood chips.

Forest fuels
Wood fuel produced where the raw material has not previously had another use. Wood fuel is produced directly from forest wood by a mechanical process.

Forest wood
Woody biomass from forests and/or tree plantations.

Fuelwood, energy wood

Wood fuel where the original composition of the wood is preserved.

Geographical Information System (GIS)

An organized collection of computer hardware, software and geographical dat designed for capturing, storing, updating, manipulating, analyzing and displaying a forms of geographically referenced information and associated attribute data.

Green residues

Fresh logging and thinning residues, including branches, tops and the main part of th needles in green form.

Green supply policy

Forest fuels produced from fresh logging residue directly after felling in green form.

Gross reserve

Gross, technically available, logging residue reserve when the recovery rate (in thi study 65%) has been applied to the stand population.

Log wood

Cut fuelwood in which most of the material has a length of 500 mm and above.

Logging residuals

Live standing trees/stems remaining after a harvesting operation.

Logging residues, forest residues, slash

Woody biomass separated from the desired wood assortment during harvesting an usually left in the forest, including branches and tops. Also stumps and the under-size trees left standing or felled in regeneration fellings can be included into this category. I this study they are excluded.

Net reserve

Net, economically available, logging residue reserve when the selection criteria (in thi study forwarding distance, residue density per ha and residue volume per stand) with th recovery rate have been applied to the stand population.

Regeneration felling

A method of natural or artificial regeneration forest where all or most of the old generation trees in a felling area are felled. Artificial regeneration is by either plantin seedlings or direct seeding, while natural regeneration results from seeding by trees o the same site.

Smallwood
Fuelwood cut with sharp cutting devices and in which most of the material has a particle length typically 50 to 500 mm.

Solid biofuel
Solid fuels produced directly or indirectly from biomass.

Stump
Part of the tree stem below the felling cut.

Thinning
Selective felling designed to promote the growth of the remaining trees. Thinning normally provides merchantable wood, e.g. pulp wood and wood fuel.

Thinning residues
Woody biomass originating from thinning operations, such as small diameter stem wood with or without branches.

Wood chips
Chipped woody biomass in the form of pieces with a defined particle size produced by a mechanical process with sharp tools such as knives.

Wood fuels, wood-based fuels, wood-derived biofuels
All types of biofuels originating directly or indirectly from woody biomass.

Woody biomass
Biomass from trees, bushes and shrubs.

CONTENT

ABSTRACT

PREFACE

SYMBOLS AND ABBREVIATIONS

TERMINOLOGY

APPENDIX 1 Initial values of supply cost calculation

APPENDIX 2 Supply cost analysis around the city Jyväskylä region

APPENDIX 3 Basic information of power plants

APPENDIX 4 Logging residue reserve at national level

APPENDIX 5 Regional variation of logging residue potential and worksite factors

APPENDIX 6 Stand location density map

APPENDIX 7 Logging residue availability map

APPENDIX 8 Logging residue location allocation analysis

APPENDIX 9 Plant-specific procurement areas and logging residue density per area

APPENDIX 10 Plant-specific logging residue supply potential inside procurement area

APPENDIX 11 Plant-specific logging residue supply potential vs. supply cost

APPENDIX 12 Plant-specific logging residue supply potential, allocation between sites

APPENDIX 13 Plant-specific logging residue supply potential as a function of transport distance, allocation between sites using the transport LP-model

APPENDIX 14 Plant-specific logging residue supply potential as a function of supply cost, allocation between sites using the transport LP-model

1 INTRODUCTION

1.1 Research problem

Biomass fuel sources, e.g. logging residues, and production techniques are more often than fossil fuels systems dependent on local conditions concerning biomass feedstock supply and energy use. The utilization of biomass is partly geographically constrained by the energy demand. The local nature of bioenergy systems fuelled by various biomass sources also means that the cost-structure can vary between different bioenergy projects (Roos & Rakos 2000). The low energy density of harvested biomass and the dispersed nature of biomass production imply that the production of modern energy carriers (electricity, liquid, gaseous and processed solid fuels) from purely biomass feedstock should be carried out at dispersed installations that are relatively small, in order to avoid high transportation costs. Since biomass production and collection are generally geographically dispersed and transport intensive, geographical aspects play an important role in the development of biomass fuel markets (Roos et al. 2000).

Another complicating factor is that biomass production varies seasonally, which complicates the supply and logistics of a total system. Varying weather conditions also affect year-to-year production, as well as the quality of the biomass produced, e.g. via the moisture content (Björheden 1997). The required logistics to fuel a larger biomass production system is therefore a complex matter especially when a variety of biomass streams are involved. Organizational aspects, variations in availability, storage required and backup fuel, especially in winter months, are issues that require plant-specific analysis (Faaij 1997). Therefore, logistics play a key role in the supply of biomass to combustion plants and the development actions should be directed to logistics activities between supply stages within a supply chain.

Biomass resources are dynamic and capable of changing appreciably over time. The demand for biomass like logging residues and harvesting technologies are all subject to significant changes over the lifetime of a plant. Analysis of biomass resources, especially at the plant level, requires a model platform, which can flexibly incorporate both the dynamic natures of biomass resources over time and the variation in biomass resource distribution across the geographical setting. Each worksite will represent a unique configuration of harvesting features such as concentration of logging residues, size of the harvesting area, technical collecting difficulties and transport distance. Knowledge about biomass resources is used in the strategic decision making as well as in planning of new plant investments and biomass harvesting at the operational level. Therefore, reliable in different situations applicable estimation methods of biomass availability are needed.

Regional variations in availability, utilization and production costs are typical in particular for forest fuels. For example, logging residue harvesting systems work in a large geographic area, where the conditions vary significantly. Therefore, also the availability and supply cost of forest fuels vary significantly geographically. The worksite factors must be identified to analyze productivity in different conditions. Also working conditions, supply season and storage-time might affect productivity. In order to calculate availability and supply cost of different supply chains there is an obvious need to take this geographical variation into consideration. Due to these variations different types of calculation methods have been developed to determine the regional procurement potential, and to take the factors of procurement policy and transportation distances into account in the determination of the supply costs. In practice, most of the calculation methods used so far have been applied to long range availability calculations with average production costs.

From a forest fuel user's point of view the availability of forest fuels, the reliability of deliveries, the cost competitiveness, and the quality of fuel defined by the combustion process are the most substantial factors controlling the usage of forest fuels. When starting or increasing the use of forest fuel, there is an obvious need for suitable analyzing tools for those in charge of supply to keep the supply as competitive as possible. While productivity factors vary at national level, it is obvious that these factors can and do vary appreciably even between different regions. As a consequence, assessing the potential for co-combusting at a particular plant requires a site-specific analysis, even in a region perceived to be fairly homogenous. Site-specific analysis is essential for locating new forest fuel combusted plants and it helps to plan the fuel supply for plants in use.

So far the use of forest fuel on a large-scale has been less common, but according to ongoing projects and investment plans, there will come many potential large-scale users in Finland, especially within the forest industry. For this reason, transport distances of forest fuels will increase and the problem related to the transport economy with low energy intensity will be emphasized. So far the transport economy has limited the supply area. For the time being, even the longest transport distances have been less than 100 km. The economy of a large-scale supply will contrary to many other fuels increase supply costs after a certain supply level has been achieved. The decentralized location and small unit size of pure forest fuel users is one consequence of this cost effect. Practically, only in small-scale heating can forest fuels be used as a main fuel, which often are high-quality chips from delimbed small stems. The major share of forest fuel from regeneration fellings is used in multifuel boilers applying advanced fluidized-bed combustion technology.

In practice estimates of the potential for utilizing biomass for energy should be made by first developing supply curves, which show how much biomass can be obtained at various cost levels from each source. The value of biomass for each application should then be determined from the technical and cost characteristics of the conversion technology and from energy prices in the markets where the biomass would compete. The potential supply is the quantity that is recoverable at costs up this value. Unfortunately, biomass supply curves can be constructed only in isolated instances where good cost data are available (Johansson et al. 1993).

The expected performance and cost per hour alone do not determine the profitability of a harvesting system. The level of annual production is an important factor in the system selection. The scale of forest fuels procurement affects on productivity and costs of harvesting. As the harvested quantity increases, forest fuels must be recovered over a larger geographic area. Transport distances become longer and residues must be gathered from less favorable areas from a harvesting cost point of view. Knowledge on cost factors is required to direct the harvesting to the feasible logging sites and also in planning of operations. Selection of suitable harvesting methods calls for information on the effect of conditions at the logging sites on productivity and costs.

1.2 Objectives of the research

The main task of this research is to evaluate the availability of logging residues for biofuel production using a GIS-based availability and supply cost analysis. It is presupposed that the regional variations in availability and the related level of supply costs vary significantly geographically and the site-specific economical availability is highly restricted and this calls for calculation methods suitable to examine this phenomenon.

In order to analyze supply-cost and geographical differences a cost-calculation model and a GIS-based analysis model (Ranta 1999) is further developed. This GIS-model enables a nationwide supply and demand side potential analysis, based on the forest stand data and location data of power plants. By using of stand-data it is possible to make detailed regional plant-specific supply-cost analysis and analyze spatial differences of forest fuel resources. Forest fuel supply cost with alternative supply chain options both for green and brown supply policy is analyzed. The productivity functions for different supply chains based on the latest time and follow-up studies are formulated. Especially determining the productivity of different production stages as a function of geographical worksite factors is emphasized. This makes it possible to analyze how the supply cost varies when different stand selection criteria are applied with different production methods. The suitability of the used GIS- and calculation environment for availability and cost analysis is evaluated.

According to the case studies conducted by the GIS-model, the variation of forest fuel resources between different regions is analyzed to find the most suitable regions to increase forest fuel usage in Finland. The analysis includes both resource and demand focusing approach using both green and brown supply policies. Also the spatial variation of worksite factors (forwarding distance, residue density and volume per stand) is analyzed using geoprocessing and cartographic modeling tools. It is examined how these worksite-factors limit the potential availability, i.e. gross technically available reserve vs. net economically available reserve. By using the resource focused analysis the fuel resources are clustered through location-allocation modeling to find optimal plant locations.

Demand side analysis includes determining the potential procurement area sizes and supply potential inside the procurement areas around the selected power and heating plant locations. By using the GIS-model it is analyzed the usage potential of selected power plant sites according to allocation rule based on transport distance minimization (resource allocation between overlapping procurement areas) without demand-side constraints or according to transportation LP-model with demand side constraints. Usage potential is classified according transport distance and supply cost both for green and brown supply policy. It is examined how well the forest fuel resource and demand side is matched and where are the deficit and surplus areas at forestry centre level in Finland.

1.3 Research methods

The research method in this study is empirical quantitative analysis, where literature review, field study results and GIS-databases are used from different sources processed by GIS-based analysis model. The empirical data consists of time consumption data gathered using time and field studies and stand data with location and other characteristic data. The modeled data, which are processed by a calculation model, consists of forest fuel volume and supply cost data at stand or larger regional level. The literature review is done to get a general picture of the forest fuel role and situation in Finland, supply chain solutions and related logistics planning factors. The field studies such as follow-up and time studies are used to construct the time consumption functions of supply stages for productivity and supply cost analysis. Data collection is done in such a way that makes it possible to analyze the results as a function of worksite factors using regression analysis.

GIS-databases consist of primary digital geographical data in vector format like regions (parish, forestry centre, province), road network and land-use classes in grid format. Other data sources for GIS-analysis are felling data at stand level from three major forest companies in Finland and potential power plants suitable for large-scale usage of forest fuel. According to location coordinates, the supply and demand sides are located to have spatial identity. This allows to draw on derived spatial aspects of the data as well as the range of normal mathematical and statistical functions like the logging residue to stemwood ratio. The GIS-software environment consists of desktop mapping software MapInfo, including the following add-on systems: MapBasic, Vertical Mapper and RouteView Pro. Vertical Mapper is a grid-based contouring, modeling and display system that transforms point data into a continuous surface. RouteView Pro is a network-add-on tool used within MapInfo. MapBasic is Basic-type programming language used to create custom applications for use with MapInfo.

This GIS-software environment is used to perform spatial analysis by using its geoprocessing and cartographic modeling functions, such as map overlay, selection SQL (Structured Query Language) and thematic analysis and to manipulate and display the data in a mapped format for geographical visualization purposes. The network analysis consists of routing along road networks and allocation of resources to predefined or hypothetical centers, based on minimizing total distance traveled. By using custom-made programming models this environment is used for a decision support system, which integrates spatially referenced data in a problem-solving environment.

1.4 Scope and limitations of the research

Biomass availability and calculation models discussed in this study is related to biofuel, e.g. forest fuel, production, numerous other biomass-related reserve studies are omitted. The forest fuel source in this study is exclusively logging residues. Logging residues or slash is defined as all above-ground residue left on the ground in industrial round wood harvesting, including crown material, unmerchantable tops, undersized trees, culls, defective stem sections, unmerchantable tree species, breakage, and possibly even some merchantable timber (Hakkila 1989). In this study the main research focus is logging residues from regeneration fellings excluding stumps. When logging residues are chipped or crushed into such form that it could be used as a fuel, the term forest fuel or forest chips are used. Residues from broad-leaved trees are generally used as traditional firewood or as chips for heating purposes in small-scale end-use and are not incorporated in this connection.

Logging residue potential calculations are based on actual fellings for year 2000 in Finland. A recovery rate of 65% is used throughout the study. Also the logging residue supply productivity and cost calculations are based on current harvesting technology and the most used supply methods in Finland. Input cost factors of supply chains as labor, capital and operating expenses come from current cost levels. Therefore subsequent studies should be referred to the year 2000. Power plant population will be valid in the near future, since part of the population is in the investment phase at the time of this study. Besides Finnish calculation models also some Swedish experiences of logging residue supply and availability calculations and American experiences from location allocation studies of cultivated biomass are exploited.

This thesis focuses on the supply of forest fuel from regeneration fellings and the system boundaries are defined from the forest to the receiving station of the power plant. The calculation of energy production cost is excluded. The fuel end user view is expressed through plant type and size, location, current fuel base and quality demand, which defines the technical and economical potential for forest fuel usage. Finally the supply and demand side calculations of availability vs. supply cost define the feasible potential. Also, socio-economic assessment of forest fuel supply remains out of the scope of this thesis. The competitiveness of forest fuel is based on commercial supply and demand analysis without environmental or socioeconomic externalities caused by fossil fuels.

1.5 Structure of the thesis

This thesis consists of three parts. In the first introductory part, consisting of chapters 1-4, forest fuel characteristics, supply methods, logistical elements and cost factors related to forest fuel supply planning are discussed to constitute a framework for availability and supply cost calculations presented in the second part, consisting of chapter 5. In the third part, consisting of chapters 6-7, the models and algorithms constituted in the second part, are applied in real operational environments by means of a case study in chapter 6 and finally discussed in the conclusions in chapter 7.

In chapter 2 the forest fuel role and situation in Finland is discussed. Current statistics from different sources are exploited and the forest fuel relevance in the energy sector and future prospects is evaluated. Logging residue supply and demand prospects are evaluated by means of supply resources, availability, quality parameters and combustion technology.

Chapter 3 examines the supply chain options of logging residue recovery for energy purposes and supply cost factors and discusses the cost factors related to supply logistics of logging residues. Supply is divided into separate production activities, like piling, forwarding, comminution, bundling and transporting. Production cost issues are enlarged upon organization, stumpage-prize and storage related cost.

In chapter 4 the logistical system and different planning phases of forest fuel supply are presented. Various planning and design techniques applicable for decision supporting under different phases are discussed. Especially, applicability of the geographical information systems (GIS) for biomass (e.g. logging residues) supply planning is evaluated by means of a literature review.

Chapter 5 presents a framework of calculating the supply cost and analyzing logging residue availability. The modeling environment consists of modeling supply chain options and supply stage-based cost analysis, which are linked to regional worksite factors and other cost factors related to the decision making of supply policy and logistics. Some production stages like forwarding of logging residues and terrain chipping, is further divided into production time-elements to formularize time consumption as a function of most relevant worksite factors. Felling data used in this study and the calculation method for logging residue volume are introduced. The aggregation method for original felling data to make regional availability calculations is evaluated. The location-allocation method to find optimal locations for a power plant or conversion plant for upgraded wood fuel, e.g. liquid wood fuel, is presented. In order to manage the problem related to overlapping procurement areas, a transportation model is illustrated, where the supply of logging residues between selected power plant population is allocated.

In chapter 6 the models and algorithms constituted in the first part, are applied in a real operational environment by means of a case study. The cost structure of supply chains is defined on decentralized production method, like terrain and roadside chipping and centralized production method like end-use facility crushing of loose logging residues or logging residue bundles. Also the supply cost and separately transportation cost around the city Jyväskylä region (Central Finland) as a function of distance is analyzed between different supply chain options. Two supply polices, as the supply of fresh green or seasoned brown residues, are analyzed and compared with each other. The availability and supply cost analysis include both resource and a demand focusing approach. The logging residue potential is analyzed at national, regional and plant level. The spatial variation of resources and worksite factors are analyzed using geoprocessing and cartographic modeling tools. The supply possibilities to selected plant population are evaluated with different supply methods and storing policies. Plant specific demand constraints and resource allocation inside overlapped procurement areas are managed using a LP-transport model. The deficit and surplus areas in Finland are mapped and the potential usage potential under various circumstances is evaluated.

2 THE ROLE AND SITUATION OF FOREST FUELS IN FINLAND

2.1 Definition of forest fuel

Wood fuels can be classified according to their source of origin (Fig. 1). Nowadays, the majority of wood fuels in use originate from by-products from the wood processing industry. Among these are black liquor, bark, sawdust and other residues from wood processing industry. Forest industry by-products are also a raw material source for upgraded wood fuels like briquettes, pellets, wood powder and liquid pyrolysis oil. Also the terms primary and secondary biomass residue are used (Berndes 2001), where primary refers to the harvest of cultivated crops or to wood extraction and sivilcultural treatment and secondary to the processing of the harvested biomass and by-products. Tertiary residue refers to the final use of the used wood such as demolition wood.

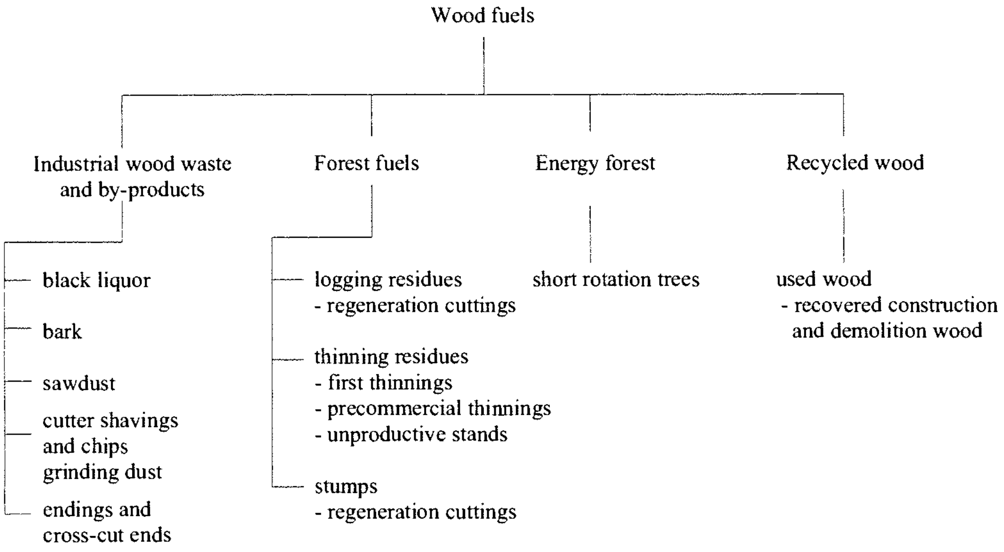


Fig. 1. Wood fuels grouping according to source of origin.

Another large wood fuel reserve is so-called unmerchantable forest residues, which are not suitable raw material to wood processing industries because of quality, quantity or location. This kind of reserve consists of forest fuels made of small trees from pre-commercial thinning, first commercial thinning and unproductive hardwood stands or forest fuels made of logging residues from regeneration fellings. Recently also stumps have been used again as forest fuel source in Finland. Traditionally, there have also been used small diameter or pulpwood stems as firewood in the form of log wood or smallwood. Pottie & Guimier (1986) divide woody biomass from forests into two major types, logging residuals and logging residues. Logging residuals are standing trees or unmerchantable stands bypassed during roundwood harvesting; logging residues are tree tops, branches, needles and stumps, which are left at site during logging of merchantable roundwood. In Finland the term logging residues are restricted to the above-ground residues and does not include stumps.

The European technical specification on terminology of solid biofuels (CEN TC 335, 2002) defines the forest fuels as wood fuel, where the raw material has not previously had another use. Forest fuel is produced directly from forest wood by a mechanical process (see terminology section). Forest fuel is a slightly limited concept included in the wood fuel category, which means energy produced under sustainable forest management conditions direct from forest to power plants. Short rotation forests for energy purposes are not included in forest fuels but are however included in the wood fuel concept (Hakkila & Fredriksson 1996).

Short rotation forestry (SRF) does not have an important role in the Finnish energy production. Finland has an abundant potential of woody biomass from forests, and hence there have not been special needs to grow SRF in the fields. Nowadays also the use of non-wood crops like agricultural waste (straw, reed canary grass, etc.) is very low in Finland. However, the potential is large and their role in energy production may increase in the near future.

The main advantages of biofuels such as wood fuels compared with fossil fuels are connected to low greenhouse gas and sulfur dioxide emissions. Wood fuels are regarded as neutral in terms of greenhouse gas emissions, since the carbon dioxide (CO_2) released from their combustion is considered to bind to growing biomass. For example the input energy requirement of the production phases is only 1-4% of the energy content of logging residue-based forest fuels used in Finland (Laihanen & Tarjanne 2001). In addition, the CO_2 emissions in forest fuel production is low, 4-7 kg CO_2-ekv/MWh, originated mainly from the machines using fossil fuel in different production stages (Wihersaari & Palosuo 2000). Therefore, replacing fuels of higher total emissions with forest fuel produced from logging residues can reduce CO_2 emissions. In many cases life cycle analysis (LCA) is used in the comparison of environmental burdens between different fuel sources applying the complete supply chain analysis (Blinge 1998).

The use of biomass in energy production has also positive socio-economic effects on a regional and national level. On the regional level, it can create new markets for foresters and farmers, by contributing to the preservation of rural areas, and improve the local infrastructure (Krotscheck & Obernberger 2000). As an indigenous fuel in Finland, woody biomass can contribute to the dependency on energy imports and increasing security of supply, as well as on employment and local and regional development in many sectors such as engineering, manufacturing, energy production and business. This has lead to different types of incentive and support activities promoted by the government such as investment and R&D grants.

2.2 Wood fuels in energy production

Wood-derived energy is an important source of energy in Finland. The use of wood fuels (including black liquors) accounts for about 20% of the annual primary energy supply, amounting to 6.4 Mtoe out of a total supply of 32.3 Mtoe in 2001 (Energy statistics, 2002). Wood fuels usage consists of black liquors and other concentrated liquors, 3.2 Mtoe (~ 37 TWh), industrial wood wastes and by-products, 1.9 Mtoe (~ 22 TWh) and firewood, 1.1 Mtoe (~13 TWh). The use of forest fuels is only about 0.2 Mtoe (~ 1.8 TWh). Some 10% of electricity is generated using wood fuels. More than two-thirds of the wood fuel consumption took place at pulp and paper mills in 2001 (The Confederation of Finnish Industry and Employers, TT). It has been evaluated (Hakkila et al. 1998), that more than 40% of the harvested stem wood in Finland is exploited as energy. This has been achieved by utilizing practically all by-products of the forest industry (e.g. bark, sawdust and black liquor). These figures mean that Finland belongs among the leading industrialized countries as a wood fuel user.

In Finland the use of wood fuels has increased since the end of the 1970's (Fig. 2). The main reason for this development has been the production growth of the forest industry. These by-products from the forest industry used for energy production have however been almost totally utilized and their production is derived from forest industry production development. There is however some technology improvement possibilities to upgrade this fuel fraction to get a higher heat value and increase energy production possibilities. During 2001 the main part of the use of solid wood fuels, (12.4 Mm^3, 23.1 TWh), firewood excluded, came from bark (14.4 TWh) and sawdust (4.5 TWh). The upgraded wood fuels like briquettes and pellets made only 0.1 TWh (Metsätilastotiedote 620, 2002). The total peat consumption reduced from the top level in 1996 (23.5 TWh) to some extent. Part of this reduction resulted from changes in taxation and part from the changes in electricity markets and other reasons (Valtion energiapolitiikka..., 2000).

The aggregate use of forest fuels depends to a large extent both on the development of the price on fuels from other fuel sources and on possible changes in the production volume of the Finnish forest industry. A critical factor is the high cost of recovery due to the small unit size, low yield per area, low bulk density, and need for specific equipment. Therefore, high harvesting costs, compared with alternative, mostly fossils energy sources, are the main obstacles in the endeavor towards profitable utilization of forest fuel in Finland. Most forest fuel projects related to usage development encounter competition with peat, which is a fuel widely available throughout Finland. Sometimes, the energy sector must compete with the demand from the forest industry for pulpwood with the exception of enough small diameter wood (minimum top diameter for pulpwood is 6-7 cm). Logging residues are the only raw material that can be harvested for energy generation without competition from the industrial wood sector.

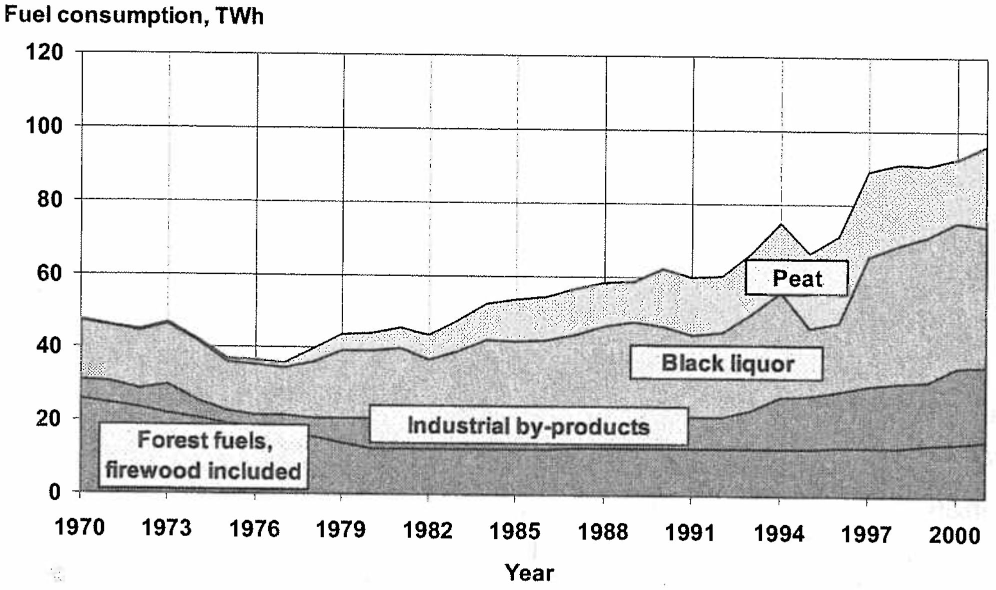


Fig. 2. Wood fuels and peat consumption in Finland in 1970-2001 (Energy Statistics, 2002).

Despite the upward trend of wood fuel consumption, the use of forest fuels has declined since mid 1980's, but it began to increase again at the end of the 1990's. However the total use of forest fuels is still modest, according to the survey made by the Finnish Forest Research Institute, it was about 1.342 Mm^3 corresponding to 0.22 Mtoe for 2001 (Metsätilastotiedote 620, 2002). It is 8% of the total use of solid wood fuels (firewood excluded). More than half (58%) of forest fuel consists of logging residues from regeneration fellings and the rest from small-sized trees from precommercial thinning and unproductive hardwood stands. The major part of the future growth of forest fuels use will consist of logging residues from regeneration fellings, which are the largest and the most easily accessible unutilized wood fuel resource in Finland.

In Finland, the wood combustion capacity available in boilers of more than 1 MW is 1 600 MW_e when expressed as electrical output and 5 000 MW_{th} as thermal output in 1997 (Finergy). Nowadays there are some 35 co-generation users and 307 users in total utilizing forest fuel in Finland (Table 1). In 2001, altogether 40% of all forest fuels are used in co-generation, and the share is likely to rise, because many power plants have made or intend to make changes in their fuel receiving, handling and boiler retrofits to increase the use of forest fuels. Also a large number of new co-generation plants suitable for forest fuels enters the market in the period, 1997-2010, amounting to a 3 450 MW fuel capacity (860 MW_e as electrical and 2 015 MW_{th} as thermal output). The estimated usage potential of forest fuels according to the end of 2010 will be as high as 8.4 TWh. (Puupolttoaineiden kysynnän..., 2000).

Table 1. The consumption of forest fuel divided into different user groups in Finland in 2001 (Metsätilastotiedote 620, 2002).

	Solid volume	**Energy content**		**Users**
User group	**Mm^3**	**TWh**	**Share, %**	**Number**
Co-generation	0.547	1.044	39.9	35
Forest industry	0.251	0.484	18.5	10
Others	0.296	0.560	21.4	25
Heat production	0.413	0.808	30.9	272
Forest industry	0.003	0.006	0.2	7
Others	0.358	0.703	26.9	135
Heat entrepreneurs	0.052	0.100	3.8	130
In total	0.960	1.853	70.8	307
Small scale use	0.381	0.763	29.2	
In total 2001	1.342	2.615	100	

Intensive technological development, learning and scale effects and a widening raw material base have been a few reasons that have caused the price of forest fuels to decline (Fig. 3). The rapid fluctuation of world market prices has been the main reason for oil-product price development in recent years. The variation of peat price has been minor despite the trend of fossil fuels.

Different political instruments have been used to steer energy policy towards environmental and economic goals. The main steering instruments have been environmental taxes, investment grants and technological research, development and demonstration. The competitiveness of wood in energy production has also improved due to changes in taxation. Taxes are removed from the fuels used for power generation, instead taxes are transferred to power consumption. The tax paid by the consumer on the electricity produced with wood fuels are refunded as subsidy to the producer. Wood fuel is tax-free, and the consumers of wood fuels obtain a support equivalent to the electricity tax (0.0042 €/kWh$_e$) in power generation. The heating power plants with a nominal capacity of no more than 40 MVA that generate power from peat are entitled to obtain equal support.

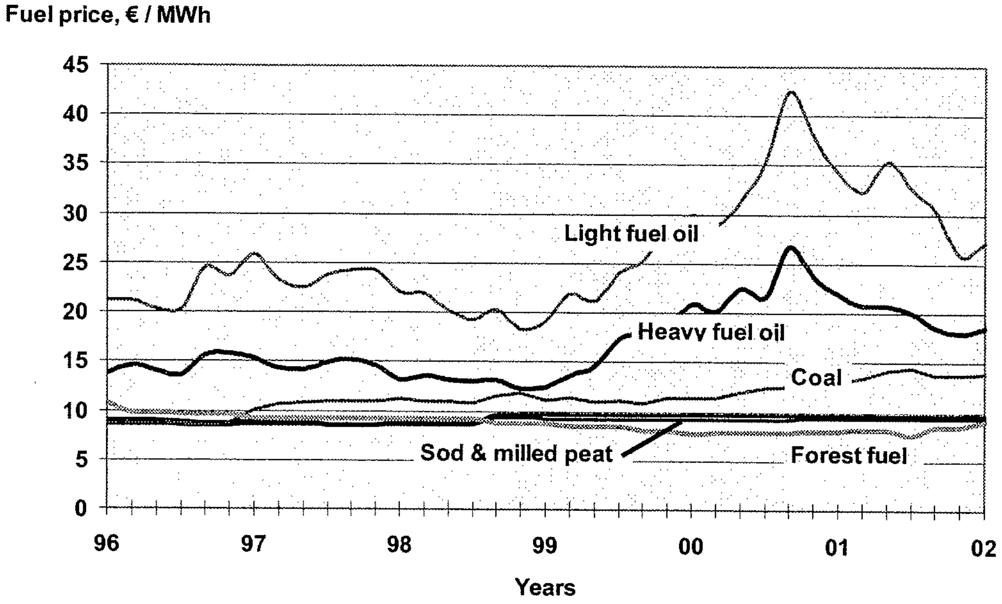


Fig. 3. Fuel prices (nominal) in heat production (excise tax included, VAT excluded) in Finland in 1996-2002 (price data: statistics of Electrowatt-Ekono Ltd.).

Fuels in heat production are taxed on the basis of carbon content. According to the latest tax-regulation (9/1998) the excise tax level is 17.16 €/tonCO_2. The excise tax for peat (3.87 €/tonCO_2) is 23% from the reference level and for natural gas (8.58 €/tonCO_2) 50 % correspondingly (Alakangas & Janka 2000). Other fuels have 100% level and light fuel oil has also basic-tax. However, peat is tax-free in heat production, if the consumption is less than 15 GWh/a.

Plants will have varying readiness to pay for forest fuels, where the main fuel will act as a reference value. Also plant type and size regarding power to heat ratios will affect the competitiveness of forest fuel. Typically the larger the capacity of the power plants, the higher the magnitude of the subsidy to fuel price. This subsidy corresponds to 1.68 €/MWh in condensing plants (150 MW$_e$) and 0.84-1.18 €/MWh in municipal and 0.50-0.84 €/MWh in industrial co-generation plants. In most cases the reference fuel will be peat as in the power plant selected in this study, which has an excise tax, 1.51 €/MWh, in heat production. The average price of milled peat without excise and value added tax is 7.4-7.9 €/MWh (transport distance 50-100 km) in 2001. The electricity tax subsidy will raise the comparable price of forest fuel theoretically over 8.4 €/MWh to some degree. However, in reality according to the survey (Hakkila et al. 2001), prices paid for forest fuel have been 7.4 €/MWh from regeneration felling sites, whereas the average price from all felling sites has been 8.9 €/MWh.

2.3 The role of wood fuel in the national action plans and energy programs

The Ministry of Trade and Industry has launched a new program for Renewable Energy Sources (Uusiutuvien energialähteiden edistämisohjelma, 1999). The Action Plan sets objectives for the use of renewable energy sources in 2010 and gives a prognosis on developments by 2025. The baseline for the Action Plan is the Finnish Energy strategy approved Council of State in 1997 and the Kyoto protocol of climate changes and White Paper of the European Commission, which deal with community strategy and an action plan concerning renewable energy. National actions are in a key position when planning how to meet the targets of the White Paper.

The Action Plan for Renewable Energy Sources is a national program comparable to the White Paper of the European Commission. Using data from 1995, the proposed target is to increase the use of renewable energy sources by 50% (3 Mtoe) by the year 2010 and by 100% (6 Mtoe) by the year 2025. The target set in 2010 is about 1 Mtoe more than expected in the outlook based on the Finnish Energy Strategy (Suomen energiastrategia, 1997). Over 90% of this increase is expected to consist of bioenergy (peat not included). Almost half of the total target (3 Mtoe) is estimated to be met alongside with the growth of forest industry. This share will mainly consist of by-products suitable for energy production. Almost one third of the growth will happen in the district heating sector and the rest in domestic use. Additional use of biofuels, 2.8 Mtoe, will be divided into forest industry by-products 50%, forest fuel 30% and recycled wood 20%. The growth of forest fuel use by the year 2010 is 0.9 Mtoe, i.e. about 5 Mm^3 (Fig. 4). Main part of this, 3.5 Mm^3, consists of forest chips made of logging residues. The rest consists of forest chips made from first thinning and precommercial cuttings. Also according to the National Forest Programme 2010 there is an aim to increase the annual use of forest fuel by 5 Mm^3 by the year 2010. Most of this increase will come from forest chips made of logging residues.

In order to promote the competitiveness of the biomass sector by technological means, Tekes (National Technology Agency) has launched technology programs, like the finished Bioenergy Research Programme (1993-1998) and the ongoing Wood Energy Technology Programme (1999-2003) and some other close-related programs. These programs are characterized by close co-operation between industry, the universities and research institutes. The most important objective is to create business opportunities in the biomass sector based on the results from the program.

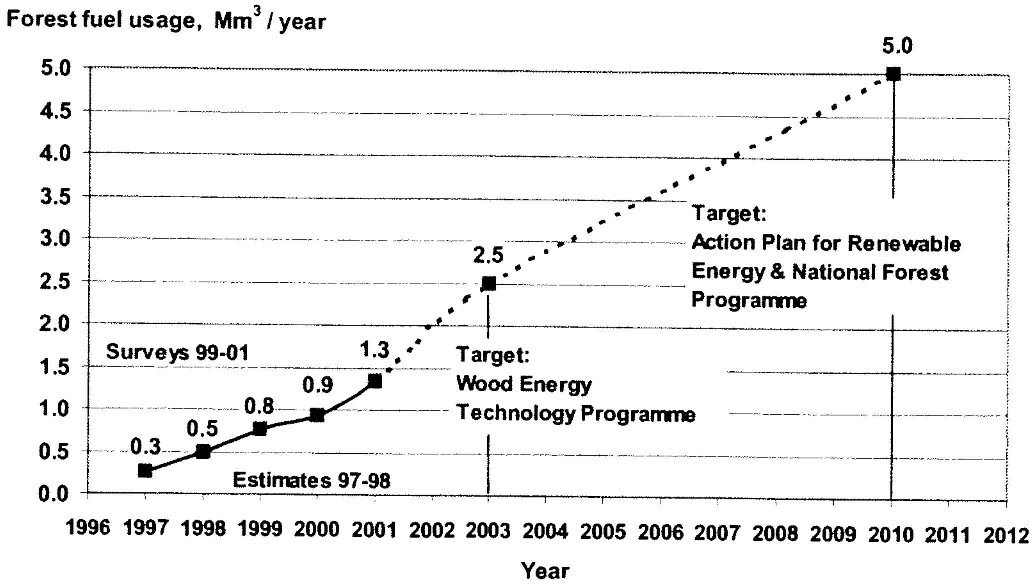


Fig. 4. Forest fuel use and targets in Finland in the future.

The target set for the Wood Energy Technology Programme (1999-2003) is to create suitable conditions for increasing the annual use of forest chips fivefold, i.e. to 2.5 Mm^3 by the year 2003 (Fig. 4). Hence, the energy produced from forest chips would amount to about 5 TWh, i.e. close to 0.5 Mtoe. The Wood Energy Technology Programme focuses on developing the production technology and improving the quality of forest chips from logging residues and small-sized trees. It is obvious that the target can be achieved mainly by increasing the use of logging residues from regeneration fellings, since the recovery of them is more cost competitive than harvesting smallwood from young stands and early commercial thinnings. Nevertheless, chip production from young thinning stands will be developed as well because of major sivilcultural benefits. However, the sivilcultural practices applied will depend largely on government subsidies and forest owner's attitudes.

2.4 Wood fuel combustion technologies

A characteristic feature of the Finnish energy management is the versatility of energy sources and a highly diversified electrical power generation platform. In Finland, the co-generation of electricity and heat (CHP) accounts for a high proportion of energy production. It represents about a third of the electricity and almost 80% of district heat production. For this reason the fuel efficiency of electricity generated is extremely high. In CHP the total efficiency is very high, 85-90% of the fuel input will be utilized. This is much higher than the 40-45% efficiency of a condensing power plant, which only generates electricity.

Grate combustion has been the most common form of wood fuel combustion in the past, but is seldom applied in new large-scale boiler investment, due to higher investment costs, higher emissions and limited availability for multifuel use. In boilers owing capacity less than 20 MW_e, and for wet fuels like bark in sawmills, grate-firing methods still offer competitive solutions with minor fuel pre-handling investments and low emissions (Sipilä et al. 2000).

In Finland, the most common technology for co-combustion is fluidized-bed boilers at atmospheric pressure, both circulating (CFB) and bubbling fluidized bed boilers (BFB). The fluidized bed combustion process allows multi-fuel use and wide variations of fuel particle size and moisture, which is difficult with other technologies. The conversion of several grate and pulverized fuel combustion boilers (PF) to fluidized bed combustion boilers during the last 15 years has made it possible to use a wider variety of biomass fuels in many boilers. Another way of modernizing is to include a biomass gasifier with an existing large coal plant to reduce CO_2 emissions. It is also possible to burn wood fuels directly in a separate combustor in an existing PF boiler (Energy visions..., 2001).

Most of the CHP plants providing heat and electricity for municipalities and mills are located close to the city-centre or a pulp and paper mill. These plants are usually BFB/CFB plants having a capacity of 50-500 MW. The operation of a CHP-plant is typically based on the heat demand, which means that the output is controlled to match the load curve of the district-heating network or mill. However, some of the largest biomass-based CHP-plants have also been equipped with turbines having a condensing section, which is utilized when low heat loads limit power production.

CFB gasification technology has been developed for various biomass-based fuels since the 1970's. The gasification approach to co-combustion has significant potential since it permits the use of biomass in natural gas-fired systems, boilers and combined cycle-installations. One solution is a atmospheric circulating fluidized-bed gasification combustion system. CHP plants on an integrated pressurized gasification combined-cycle (IGCC) enables essentially higher power to heat ratios than conventional steam boiler and steam turbine cycles. A timetable for commercialization of IGCC technology has a major impact on the large-scale power production capacity that is based on biomass (Helynen 1999). So far this technology for biomass has been in a demonstration phase.

Technically wood fuels could substitute for the major share of peat in most fluidized bed combustion plants with minor investments. The main problems in co-combustion and gasification are fuel handling and feeding. Many practical problems have been directly or indirectly caused by disturbances in the fuel supply. Some modifications are required for fuel handling, because of different properties of biomass-based fuels (different moisture content, particle size and density). The best choice may be to construct separate feeding lines for each fuel. Usually biofuel is mixed with the main fuel and the mixture is fed into the boiler. Mostly combustion technology functions properly, but it is difficult to homogenize biofuels suitable for combustion. Also mixing of different fuels is difficult, since properties of biomass are not homogenous and they can vary over a wide range (Järvinen & Alakangas 2001). Some corrosion problems may arise also due to chlorine by logging residue needles, when using "green" chips. This can be prevented by co-combustion of sulphur-containing fuels, like peat. The laboratory test indicated that it would be favorable to co-combust at least 10-20% of peat, depending on its sulphur content, with logging residue chips (Orjala et al. 2000).

Electrowatt Ekono Ltd. updated the cost assessment of biofuels in power and heat generation (Kosunen & Rauhamäki 1999). Wood fuels seem to be the most competitive in small heating plants and small-scale power plants where wood can be used to replace either oil or peat. The competitiveness of wood fuels in larger CHP-plants will probably be limited by the supply of sufficient volumes from distances short enough to keep the price of wood fuels competitive. Also the sufficient quality regarding energy density all year-round usually will be the limiting factor. Therefore, at larger plants the fuel supply will be based on multi-fuel use and the fuel produced from logging residues will form a small part of the total fuel consumption. Seasonal variation of heat production is wide at municipal district heating plants. The heat demand and fuel delivery peaks tend to fall in midwinter, whereas in plants producing process steam for industrial purposes, the degree of utilization is generally even throughout the year. Thus the availability of fuels is secured by buffer supplies as peat and fossil fuels, that are more suited for long-term storing due to their production methods and better storability.

From the facts mentioned in this section, it may be concluded that the increasing use of wood fuels will have the following limitations:

- Fuel receiving and handling equipment, which should be designed and dimensioned for fuel-specific characteristics.

- Drop of boiler capacity and operating efficiency due to lower energy content of fuel alongside high moisture content.

- Risk of hot corrosion due to chlorine from green chip combustion in boilers with high steam temperatures.
- Availability, quality and supply cost.

2.5 Quality parameters of forest fuels

The quality of a solid biofuel can be characterized by various fuel properties. Firstly there are properties focusing on the physical/mechanical condition of the fuel and its behavior during handling (loading, transportation, storage, feeding). Secondly there are fuel properties influencing the process of energy conversion (e.g. combustion or gasification). And lastly there are chemical properties needed to calculate the flue gases and to assess the emissions. Energy provision systems and conversion technologies can be better designed and their operation optimized both technically and environmentally if fuel quality is well defined (Rösch et al. 2000).

Moisture content, ash-content, particle-size distribution and percentage of fine particles, are the factors for defining the technical quality of wood fuel. On purely economic terms wood fuel is often at a serious disadvantage, having low energy content and high heterogeneity of quality. This is characterized by the variability of seasonal and regional availability as well as by the physical technological properties such as moisture content of the material at harvest, the specific weight, and the content of compounds for combustion (Fig. 5). Hence, the material is not available in standard quantities and suitability for transportation is low. For this reason the quality properties of wood fuels do not always meet the requirements for modern fuels. The requirements of the fuel quality are mainly dependent on the fuel handling system and combustion technology in the plant. The significance of quality factors is greatest in small plants. The homogeneity of moisture content is one of the most important fuel characteristics from the end user's point of view. If the moisture content varies widely, problems may occur concerning the decrease in efficiency of the boiler as well as an increase in flue gas emissions. Typically peat is used to level the quality variations and to lower the specific peak capacity of forest chip production.

In Finland the quality classification of wood fuels is reported in the form of a manual (Impola 1998), where the quality properties of wood fuels (fuel chips, sawdust and bark) are classified. The quality of wood fuels is determined for every wood fuel category by choosing limiting values from a classification table for energy density, moisture content and particle size of wood fuels. This quality classification will be used as a part of a wood fuel delivery agreement, and are assumed to improve the quality of wood fuels.

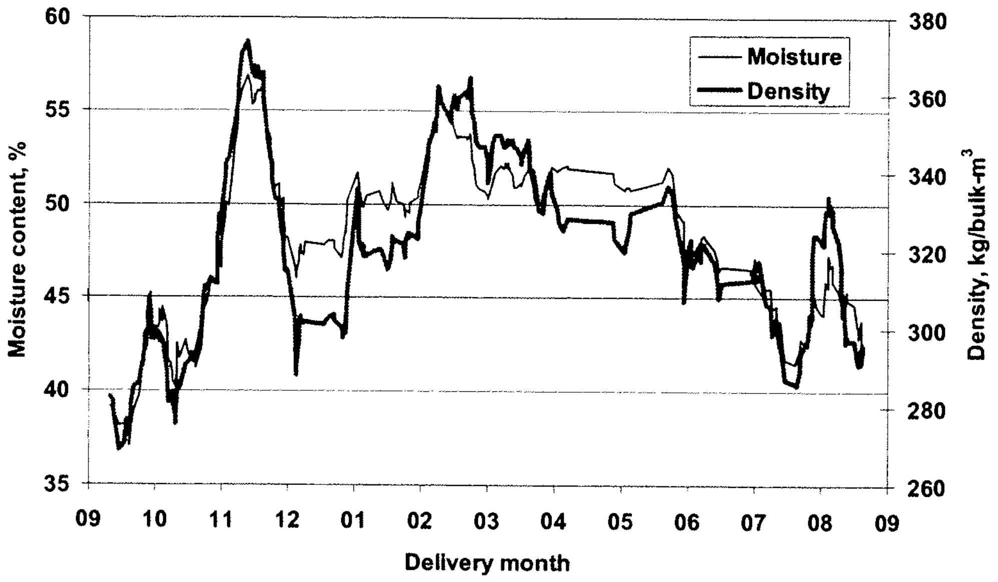


Fig. 5. The variation of density and moisture content of forest chips within one-year in a power plant (moving average 15 loads) (Ranta et al. 2002).

The total heat released from the biomass is called the gross calorific or higher heating value (Nurmi 1997). It is independent of the moisture content of biomass. The higher heating value per unit of dry mass of biomass may change during storage, if dry matter loss caused by decay is directed to only certain constituents of biomass like needles. However, in practice the changes are usually small. The net calorific or lower heating value is effected by the gross calorific value, moisture and hydrogen content of the biomass (see the formulas in symbols and abbreviation section).

The changes in heating value are mainly a product of changes in moisture content and loss of dry matter in the stored material. The changes derive from a complicated interplay of chemical, microbiological and physical processes influenced by the chemical composition, the water content and the texture of the stored material. The length of the storing period, weather conditions and storage facilities are also of importance for the development of energy changes. The moisture content of solid biofuels has a strong influence on the storability, heating value, combustion temperature, flue gas emission and the combustion behavior and is thus of great importance to the operator (Rösch et al. 2000). The most sophisticated combustion plants may overlook the moisture content to some extent, since they are capable of retrieving the heat of condensation from the flue gases.

In separate contexts, logging residues are classified as green or brown, because the color of the needles indicates indirectly the drying degree of the material. The moisture content of fresh, "green", logging residues varies according to the wood species between 50-60% on a green weight basis. In summer, as the result of the drying process, the moisture content of the fresh mass of logging residues can be reduced to as low as 25-30%.

According to Orjala et al. (2000) utilization of logging residue chips can cause deposition on heat exchanger surfaces and corrosion due to chlorine of wood ash. The harmful formation of alkaline and chlorine compounds on boiler surfaces could be prevented by co-combusting sulphur-containing fuel. Co-combustion of solid biofuels with fuels that contain sulphur and, in larger amounts, silicate-based ash reduces agglomeration of bed materials. Laboratory tests indicate that it would be favorable to co-combust at least 10-20% of peat, depending its sulphur content, with logging residue chips. This reduces bed agglomeration and the amount of detrimental alkaline chlorides.

2.6 Availability of logging residues

Finland's forest land area is 26.3 million hectares, which is 86% of Finland's total land area according to the National Forest Inventory (NFI8-NFI9). The growing stock of forest biomass is estimated at 2 002 Mm^3 (Metsätilastollinen vuosikirja, 2001). It has been estimated (Hakkila & Fredriksson 1996) that at the level of annual removal of 56 Mm^3 of merchantable stem wood, some 29 Mm^3 of forest residues are left in the forests in Finland, which gives the theoretical potential. At the same time the annual growth of above-ground forest biomass is some 110 Mm^3 and annual drainage of forest biomass about 85 Mm^3. Nowadays the annual removal of stemwood has risen to some extent, and this gives rise also to the relevant logging residue potential (Fig. 6).

In 2001 the annual removal of merchantable wood was 59.4 Mm^3, (timber 44%, pulpwood 47%) and the drainage of stem wood was 68 Mm^3 (Metsätilastotiedote 629, 2002). The share of commercial wood was 90%, 53.3 Mm^3 (timber 48%, pulpwood 52%). The major share from commercial roundwood production came from private forests, 45 Mm^3 (standing sales 35.9 Mm^3, delivery sales 9.2 Mm^3). The rest came from forest industry companies, 3.5 Mm^3 and from the Finnish Forest and Park Service, 4.6 Mm^3 (Metsätilastotiedote 625, 2002). According to these logging levels, 36 Mm^3 of logging residues remained in the forests and only 1.3 Mm^3 was collected for biofuel production purposes (Fig. 6). Also some 5.2 Mm^3 of traditional firewood was used and it was included in the stem mass share of logging residues (Metsätilastotiedote 631, 2002). In practice several technical, economical and also some ecological aspects like nutrient losses restrict the usable potential. However, compared to present use, the raw material potential of forest fuels is 15-20 fold. In view of the costs and quality of forest fuels, procurement can thus so far be directed to the most cost-effective logging sites within as short a distance as possible. The selection criteria is based on the structure of the logging sites, the dimension and quality requirements set for pulpwood, the development of harvesting technologies and in fuel receiving, handling and combustion facilities of the plants.

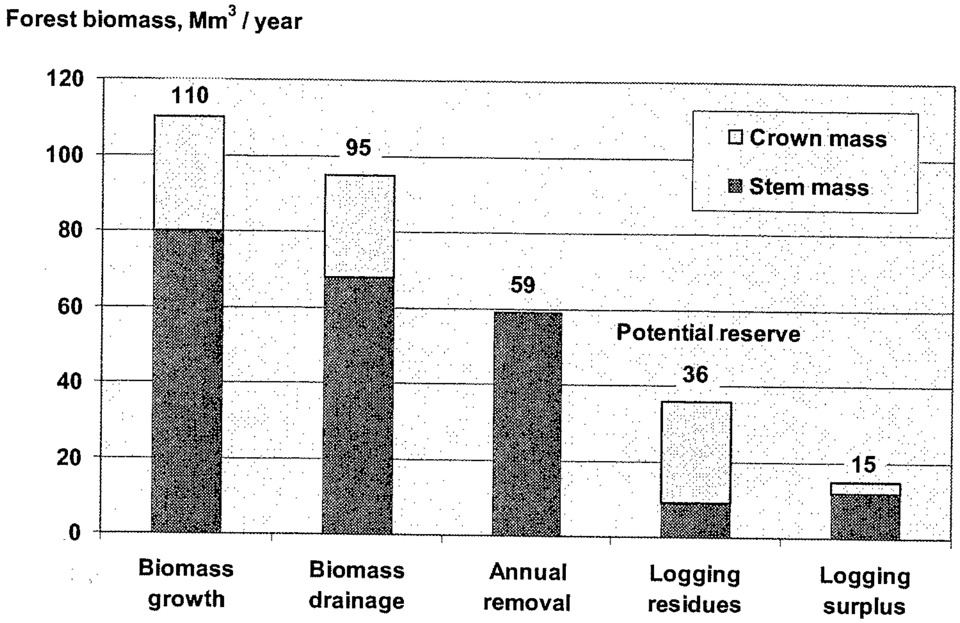


Fig. 6. The growth, drainage, annual removal of stem mass and reserve of forest biomass in Finland in 2001 (adapted from Hakkila & Fredriksson 1996).

According to Finland's National Forest Programme 2010, logging will be gradually increased to 63-67 Mm^3 by the year 2010. By that time the annual increment of stem wood should reach a level of 90 Mm^3 according to the so-called MELA-calculations carried out by the Finnish Forest Research Institute (Metsätilastollinen vuosikirja 2001). This will stabilize the volume of the growing stock at the current level. However the development of forest resources in the future depends on the level of fellings and forest management.

The gross supply of logging residues increases with an increase in gross felling and is dependent on the residue to stemwood ratio. If a single tree measurement is lacking and only average stem or gross stand stem volumes are available, as may be the case with some conventional forest inventory data, approaches permitting direct mass estimates on a stand gross stem volume basis are needed. In this case, previously established ratios between stand mass and stand stem volume of a given stand type by age, spacing, and site quality classes must be provided (Johansson & Lundqvist 1999). The quantity of forest residues may be predicted from the stem volume on a percentage basis of different mature tree species. With reference to stemwood, the crown mass of managed mature stands contains 21% additional biomass for Scots pine (Pinus sylvestris), 54% for Norway spruce (Picea abies) and 16% for birch (Betula sp.) in Finland (Hakkila 1991). There is however, a wide variation in the amount and composition of logging residues between different felling sites. Previous management, tree species, standing volume, the branchiness, size of trees and the extent of decay will determine the quantity of logging residues.

Generally, variation in tree component masses is explained better by tree-level information than stand-level information. The breast height diameter is the most appropriate independent variable for predicting green or dry masses of tree components and groups of components. The relationship between a component mass and breast height diameter is exponential (Hakkila 1991). Also other variables such as tree height and crown ratio could be used as independent variables. If the majority of the logging residues are crown material and tops, as it happens in a well-managed forest, the quantity and composition may be predicted from timber cruise data with biomass functions and tables. The total mass of the residue is computed by multiplying the number of trees in each breast height diameter-class by the expected crown and top mass for that class.

Equations have been developed to predict the biomass of tree components, but these equations seldom estimate the mass of the unmerchantable tops separately. The top mass is primarily dependent on the minimum top diameter of merchantable timber. Therefore, a method has been developed (Harstela & Kiljunen 2001), which operates in the data processing system of a harvester and uses data from the measuring device of the harvester as the basic material for estimation of the amount of logging residues. This method is based on regression models, which make it possible to calculate separately the dry matter content of the stemwood, smaller than the diameter of pulpwood i.e. unmerchantable tops, and the crown like branches and needles. The independent variables are diameters and lengths measured from stems. It is possible to use the height of the minimum altitude of the treetop and the corresponding diameter, as well as the geographic location of the stand to assist the information obtained from the taper curves. Although the yield of logging residues can vary significantly between different stands, this method gives a more accurate estimation of the logging residue potential at stand level than ratio-based methods (Harstela & Kiljunen 2001).

The amount of logging residues available for energy purposes is also dependent on harvesting methods, machinery used, harvesting season and additional losses in the system, for example, during seasoning and transportation. Also utilization standards, which are the regulations defining what material could be harvested and what material should be left at the site, have a significant effect on the amount of residue. Factors such as top diameter, stump height and allowances for defects are among these standards. The residue material can also include dead trees and non-commercial species, oversize and decayed parts of logs.

Logging residues consisting of branches and tree tops after regeneration felling of conifer trees corresponds to about 25-30% of the biomass constituted of stem wood when the actual harvesting yield has been taken into consideration. On a typical regeneration felling site in southern Finland, the volume of residue, needles included, is about 50 m^3/ha in pine stands and about 120 m^3/ha in spruce stands, i.e. a gross energy content of 95 MWh/ha and 230 MWh/ha respectively (Hakkila et al. 1997). Net energy content will depend on recovery percentage and heating value, which on the other hand is dependent on the moisture content, wood species and remaining wood components. Recovery percentage is dependent on the logging method, season and storage time The recovery rate from fresh residue piles left by a single-grip harvester varies within a range of 60-75% of the potential logging residue mass (Nurmi 1994). In the winter season, when logging residues are forwarded directly after logging, the recovery percentage will be better than in the summer season. Snow separates the logging residue pile from the ground, which leads to a better and cleaner harvest than in the summer.

Unnecessarily scrupulous recovery of logging residues results in the impoverishment of the soil, increases the unit costs of harvesting, and increases the amount of impurities in the residue. The portion of residue that is advantageously harvested depends on the abundance of residue, terrain conditions, the cost and the development of harvesting techniques. If logging residues are left to shed their foliage through transpiration drying before removal, the yield of biomass for fuel will be radically reduced. Compared with the recovery rates of fresh or "green" residue, to harvesting dried or "brown" residue may lead up to a 20-30% loss of biomass potential with spruce and 15-20% with pine, mainly due the shedding of needles.

A fraction of the logging residues should be left and normally are left for practical reasons at the site to ensure long-term productivity, by minimizing nutrient losses and preserving the organic content of the soil. The most sensitive forest soils, like peatland forest are assumed to be excluded from forest residue harvesting (Nurmi & Kokko 2001). Nutrient losses can also be counteracted for by the recirculation of ash from energy conversion sites (Gustavsson et al. 1995). However, this ash should be based on wood fuels. Recycling of ash may make it possible to remove more residues than currently recommended without endangering long-term productivity. However, the primary target for ash recycling is peatland forest (Nurmi & Kokko 2001), where logging residue collection is unusual.

According to Hakkila et al. (1997), the technically harvestable logging residue annual reserve is estimated to be 8.6 Mm^3 biomass, needles included, or 5.6 Mm^3 needles excluded, corresponding to 18.1 or 12.3 TWh/a respectively. When calculating the volume of harvestable logging residue on a national basis, it can be seen that some technical (recovery rate), economical (felling cycle, accumulation) and ecological restrictions (land with low in nutrients or otherwise delicate ecological balance should be dropped out) have been used. Transport distance, being one economical restriction, is omitted, since it is site and production method specific. Despite these deductions, logging residues from regeneration fellings are the most abundant source of forest fuel making up 50-60% of the whole forest biomass reserve in Finland. The minimum diameter requirement for pulpwood in precommercial thinning is either 5 cm or 7 cm. Therefore, also first thinning can be an abundant forest residue reserve. For instance in pine stands the pulpwood share is 61% when the minimum top diameter is 5 cm. The rest 39% i.e. the top and other crown mass, and bark of the pulpwood are potential forest fuel sources (Hakkila & Fredriksson 1996).

2.7 Calculation models of availability

Forest residue potential calculations are based typically on either sampling methods of forest inventory (NFI), e.g. Keskimölö & Mattila (1994), or forestry plans recorded at compartment-level, e.g. Keskimölö (1997). All the forest planning work will be performed using the new SOLMU-program, which replaced the former TASO-program. The data will be stored into the LUOTSI-database maintained by the Forest Development Centre TAPIO. The advantage of methods based on forest inventory, are objectivity, conformity, actuality, versatility and the possibility to evaluate reliability. On the other hand an inventory method calls for a large geographical region while the accuracy of positional data inside that area is weak. The forestry plans contain accurate positional data, which makes it possible to use operative plans. The disadvantage of using forestry plans, is subjectivity, biased and limited data of growing stock. Problems may arise also from the discontinuity of plans especially with large areas. Also the coverage of plans will vary significantly (Keskimölö 1997). Wood harvesting plans based on the above mentioned forestry plans will describe the potential felling activity in the next 10-years. However there may exist a large variation concerning felling activity in the short period due to the development of the forest product market.

In a project conducted by Keskimölö (1997) a model, "AluEpuu", is developed for estimating the procurable volumes of energy wood, i.e. forest residues. The model is based on forestry planning data on private forests and numeric map data. The geographical information system is used to produce forest and road haulage distances for each forest figure. The procurement costs of forest fuels are established by using cost models based on productivity functions. The model calculates the amount of forest residues in a figure and the procurement cost according to selected transport distance-range. There is a possibility to make queries about on forest residue potential from the database according to technical and economical restrictions. This model has been used in forest residue reserve surveys in Central Finland (Kauppinen 1996) and in South Savo (Saksa 1996).

Based on the information of the National Forest Inventory, the MELA (MetsäLAskelma)-model (Siitonen et al. 1996) produces alternative timber production programs and predicts the corresponding volume and increment development. The MELA-system modified for energy wood, i.e. forest residues (Energy-MELA) are used for forest residue surveys (Malinen et al. 2001, Malinen & Pesonen 1996, Mielikäinen et al. 1995), where forest residue recovery (logging residues from spruce-dominated regeneration felling sites, separate or integrate harvesting from pine-dominated first thinnings) has been included in forest treatment options. Energy wood cutting alternatives and industrial roundwood harvesting alternatives are simulated using Energy-MELA allowing simultaneous analyses of industrial roundwood and energy wood cutting possibilities. Stand development and treatments are simulated stand by stand in the MELA-system. Energy wood calculations are based on alternative cutting scenarios and the results, forest residue reserve and production cost level, are represented regionally e.g. between forestry-centers. Worksite factors, like forwarding distance, average stand size and transport distance, are estimated through an average value for the whole area under examination. Pesonen & Määttä (1999) have used Energy-MELA for forest residue reserve scenarios of North-Savo, where energy wood calculation is based on the forest-figure data from the SOLMU-planning system.

Also in Sweden the model developing for forest residue potential calculations has been intensive in recent years. Systems such as Hugin, based on plot data from the Swedish National Forest Inventory and remote sensing from satellite images, are comparable to the Finnish MELA-system. Also the model, "Biosims", has been programmed with forest data derived from actual conditions reported in individual sample plots in the National Forest Inventory (NFI) (Parikka 1997a, Parikka 2000). Since the data used in these models are obtained from a very sparse sample of plots, the precision of local estimates is inferior (Bååth et al. 2002). Forest residue calculations are based either on the regression estimate method, where residue biomass inventory has been calculated by means of regression functions or the ratio method, where residue biomass inventory has been based on traditional forest inventories and conversion functions between timber volume and residue biomass. Both methods can be used to calculate forest residue biomass at the stand level and at regional level. The ratio method is more feasible with calculations applied the regional level. In the stand level method diameter and height distributions are used for calculations. The forest residue biomass is measured as oven dry weight per unit area. The results can be transformed into energy equivalents using assumptions for the heating value and moisture content.

The model, "Biosims", is evaluated (Parikka & Vikinge 1994) and been used in several studies in Sweden, like surveys of forest residue biomass supply potential in nationwide (Hektor et al. 1995) and regional level (Nilsson et al. 1995, Parikka 1997b). The principal issue has been the ability to measure the long-term supply of residue biomass with a reasonable degree of reliability. Possible effects caused by stricter environmental restrictions have also been assessed (Parikka 1997b). These recommendations are based on the following variables: soil moisture, soil ground/peatland, soil texture, ground layer and vegetation class included in the NFI-data. The set of variables and their values have been selected by the Regional Forestry Board. The primary aim of this selection has been to transform the current general principals into a form that the Biosims model can handle. As the forest data includes precise local coordinates, it is possible to use the model for local forest fuel supply systems, e.g. for district heating plants. It is also possible to use a separate GIS-software to plot results on the map (Parikka 2000). Possible technical and economical restrictions have not been included within the model whereupon they should be applied separately, like in the survey, which consisted of potential forest fuel supply from different types of forest fuel sources (Lönner et al. 1998). In the study of Lönner et al. (1998) the potential supply of forest fuel of various types is distributed on different cost influencing factors like terrain class, forest residue concentration and location in relation to the nearest road and final user. Estimates of the cost influencing factors have been performed for the same NFI-data as applied with the Biosims-model.

Bååth et al. (2002) have used existing national forest inventory data as reference data for satellite image based estimates of forest condition, with techniques such as the "kNN" (k Nearest Neighbor) to evaluate field data to all cell elements in a satellite image. With the help of map masks in overlay analysis, they have evaluated the forest residue potential located within 300 m of existing roads. This may act as an economic restriction for forest residue recovery in the study area. However the inferior geometrical accuracy in the satellite images make the fit between the digital road network and the location of the roads in the satellite images poor.

3 SUPPLY METHODS IN FINLAND AND SUPPLY COST FACTORS OF LOGGING RESIDUE-BASED FOREST FUEL – A STATE OF THE ART

3.1 Integration of supply stages

Forest chips made of logging residues have traditionally been acquired by production methods based on both crushing and chipping. Currently the production of them is mainly decentralized, including chipping on the terrain, chipping or crushing at roadside storage and at a local terminal. What these methods have in common is that the transported material is either chipped or crushed. Lately, it has become more common to use centralized end-use facility crushing, which means that the transported material is loose or compacted into bundles i.e. so-called residue logs.

In order to supply biomass (e.g. logging residues) from the production site to a power plant the following activities are typically needed (e.g. Allen et al. 1998):

- ➢ Harvesting

The term harvesting includes all processes on the terrain up to and including the material at the primary landing. So the harvesting can be broken into the following three phases:

- Initial contact phase like logging and piling (in more detail at section 3.4)
- Processing on the terrain like chipping (in more detail at section 3.6)
- Primary off-road transport to loading like forwarding (in more detail at section 3.7)

- ➢ Storing (in more detail at section 3.5)

Forest residue harvesting is characterized by long-term planning where storage is of vital importance to the fluent fuel supply during the winter months when the heat load is the highest. Unfortunately the disadvantage of such storage is dry matter losses, increased handling costs and capital costs. The storage point can be located in the forest, at the power plant or at an intermediate site. Most end user sites to which the biomass-based fuels are supplied will have limited on-site storage facilities. This is due to the space and facilities required for storing and the financial costs of storage. The size of the storage facility at the power plant also affects the transport arrangements. A power plant with relatively small on site bstorage (e.g. a few days supply) requires more regular, evenly spread deliveries than plant with a large storage capacity. Low levels of storage at the power plant will increase the importance of reliable and flexible transport.

- ➢ Processing (in more detail e.g. at section 3.8 and 3.10)

Processing can involve increasing the bulk density of the biomass (e.g. comminution into chips) or compressing the biomass (e.g. bundling into bundles) to improve its handling efficiency and the quantity that can be transported. Comminution or bundling marks a major turning point in the fuel properties of forest residue biomass. The location of the comminution phase in the supply chain is important as it determines the form of material to be transported. Processing can occur at any stage in the supply chain but will often precede road transport.

According to Björheden (2001) chipping is the most common way of comminuting forest fuel in Sweden. Only small volumes are crushed. Most of the forest fuel, some 80%, is chipped after storing in piles at the roadside, another 10% is chipped on the logging site and the remainder at a terminal or at the heating plant. Roadside chipping has become more and more dominate. New methods, e.g. based on new bunching technologies or crushers, have not made a breakthrough as in Finland.

- ➢ Loading, transporting and unloading on-road transport vehicles (in more detail at section 3.12)

Thereafter the biomass has to be moved from the roadside, it will need to be transferred to on-road transportation vehicles for transportation to the power plant. Logging residues are often too bulky to be transported and handled economically by conventional methods. Processing of logging residues to chips or bundles allows the use of standard systems designed for pulp chips or round wood and hence more cost effective transport and handling systems. At the power plant the biomass is typically unloaded straight from the vehicles using their own unloading systems.

Processing can be carried out by either a "hot" or "cold" operation. A "hot" operation is where the processing is directly linked to the transport at the primary landing. The processed material is transported as soon as it is processed at the primary landing. A "cold" operation is where the material is piled at the landing so that the processing and transporting are separate. There are advantages and disadvantages for each type of operation. A "hot" operation requires a higher degree of organization and compatibility between the landing processing and transporting phases. A "cold" operation requires a larger landing area to facilitate the storage of the harvested material.

In general, the development of forest fuel chains must be studied by observing the material flow logistically through the process, because the harvesting methods influence the processing, harvesting costs as well as storage and transportation. Both the preceding and the following operations affect each phase of harvesting system. In practice the quality of the fuel may be lost already at the beginning of the chain, imposing problems for the whole chain.

Integrated harvesting is defined as the harvesting of forest residue biomass in a single-pass operation in such way that forest fuel can be produced along with conventional forest products (Puttock 1995). Variations in integrated operations are most notable at the processing point in the system. Both landing- and central unit-based operations are widely used (Hudson & Mitchell 1992). When conventional products are first removed from the harvested area, and biomass for energy purposes like residues and residuals are harvested in one or several subsequent passes, it is a question of multiple pass non-integrated harvesting (Pottie & Guimier 1986). Integrated methods do not necessarily require specialized equipment; they can use the same or modified machinery in forest fuel operations that have been used in normal forest operations. Besides using the same harvesting machines, cost savings also occur through using the same information and management systems for roundwood and forest fuel harvesting.

In Finland the term, integrated method, is used, when logging residues are collected from regeneration felling and this has been taken into consideration in logging operations to distinguish it from the separate harvesting methods used for small-tree harvesting. The level of integration also varies concerning the harvesting of logging residues. This refers to the applicability of the logging equipment and machinery for various work stages and to how the stages of merchantable wood and logging residue harvesting are simultaneously implemented. According to the definition of integrated harvesting methods by Pottie & Guimier (1986) it will not purely belong to integrated methods. However more common in Finland is the integration at an organizational level, where the same organization does both the timber and forest fuel harvesting. The Finnish shortwood or in other words the cut-to-length system requires a separate pass if the residues are harvested. In the shortwood system both delimbing (i.e. removing branches from trees or parts of trees) and crosscutting into tree assortments usually takes place at the felling site. There have been some experiments (Vesisenaho et al. 1998) with the full tree systems, where trees are felled by a single grip harvester and skidded by a modified forwarder equipped with a clam-bunk to the primary landing with no processing on the terrain. The processing of trees to assortments takes place at the roadside with a single grip harvester. This harvesting method can be classified as a pure integrated harvesting method.

There is some debate regarding the costing approach, which should be followed when estimating the cost of producing forest fuels (Desrochers et al. 1993). The first approach, known as marginal costing, treats the forest residue as a by-product of the production of the primary products and assumes that the forest residue is available at zero cost. Under this scenario, the costs of felling, forwarding, processing, road construction and stumpage are fully allocated to the primary products. For instance in integrated harvesting systems discussed by Hudson & Mitchell (1992) and Knutell (1992), both conventional roundwood and energy products are produced. So the introduction of the energy element into the harvesting operation increases total revenue from the operation, but also raises harvesting costs. The means of comparing costs between integrated and conventional systems must take into account total revenue and total expenditure, net revenue from the integrated system can then be compared with the revenue for the conventional system. The use of the breakeven analysis takes into account both cost and revenue streams of both harvesting systems to determine the target price for the forest fuel at which the integrated harvesting system and the conventional system are in balance. When the market value of the forest fuel is more than the target price, the system competes successfully with the conventional system. When the market value is below the target price, the integrated system is unable to compete.

The second approach, called joint product cost, suggests that the total cost of harvesting and forwarding should be shared between the conventional forest products and the wood fuel. Under this approach, some appropriate percentage of the cost of common operations is allocated to the wood fuel. This approach results in higher wood fuel cost, while lowering the cost of the primary products (Puttock 1995). When it is a question of collecting logging residues from regeneration areas using multiple pass non-integrated harvesting, such as in this study, the marginal costing is the proper method. Joint costing can be adapted to a single-pass operation, where small diameter energy wood is produced along with conventional forest products, to aid estimating the economy of harvesting such stands.

3.2 Organization of procurement activities

Logging residues may be delivered to the end-use facility by a forest company, separate procurement organization for wood fuels, forestry society or by an organization in the SME-sector (Small and Medium-sized Enterprises). For instance in Sweden (Hillring 1997) the majority (63%) of the wood fuel producing companies are associated with the forest industry, 20% are associated with the Forest Owners Association and 17% are independent wood fuel producing companies. Many forest industry companies in Finland are also developing themselves towards self-sufficiency in the field of wood fuels, both in fuel supply and in energy production. Because the delivery chain consists of several suppliers, smooth co-operation between them is a prerequisite for procuring competitive forest fuel. Through co-operation there will be better possibilities to secure total quality including material and immaterial goods involved in the supply-chain. Long-term supply contracts will be one approach to achieve better quality management and also partnership-like agreements (Männistö 2000) within the wood fuel sector has been discussed.

If there is a power plant owned by the forest company using wood fuels in the region, it seems most appropriate that also the procurement of logging residues takes place through the company's own organization in the same manner as the merchantable wood procurement. If the fuel is used in other plants, and the company is not willing to trade fuel, the procurement must be based on co-operation agreements between the forest industry and fuel producers. Forest organizations play an important role in communication and in providing support for organized procurement, even though production and trade are in the hands of other entrepreneurs.

Asikainen (2001) has pointed out different forest fuel harvesting strategies according to the degree of integration in industrial roundwood procurement in large Finnish forest companies. In full integration the company's forest office undertakes the procurement of logging residues as one of its activities. This means that the forest office is responsible for the whole operation and its information and management systems handle logging residues as one roundwood assortment. It supplies forest fuels with its own group or partner alliances. This system seems most applicable with residue bundling supply systems. Another approach is to create an affiliate whose responsibility is with the wood energy business within the group. It supplies forest and other wood fuels also to users outside the group such as municipal CHP-plants. The management of energy business is separate from roundwood procurement, but works in close co-operation in the field of raw-material procurement logistics. The third alternative is to consider forest fuel as any other fuel or energy source. The whole wood energy business is outsourced and independent entrepreneurs undertake the harvesting and supply of forest fuel to plants in the group. In this case there may be co-operation in the buying of forest fuels. Forest companies and fuel suppliers work in a buying alliance and at suitable stands forest companies agree with the seller of roundwood, that also residues will be recovered.

The organization costs are connected to the selection of stands, planning and supervision of work, organization and scheduling of chipping and transportation. In this respect, the harvesting methods that can use the existing logistical planning systems of harvesting and transportation of merchantable wood may have a competitive advantage. The better the integration of logging residue procurement into merchantable wood procurement the easier it will be to further reduce organizational costs. According to (Asikainen et al. 2001) the range of procurement organization cost for decentralized supply chains is 0.67-1.0 €/MWh. There are also organization costs of subcontractors in the supply chain, which are normally included in the charge of work in question. The responsibility of the subcontractor to plan and organize the supply will define the cost level.

3.3 Stumpage

Usually a stumpage price is not paid for logging residues, because of poor competitiveness of forest fuels in Finland. The advantages of harvesting logging residues are gained in the forest regeneration phase, which has so far been enough for most forest owners. The physical presence of logging residues affects the drivability of the terrain, work-difficulty of timber harvesting, and efficiency of subsequent activities of the stand establishment, such as site preparation, manual or mechanized planting. Removal of logging residues could have an impact on early survival and growth of regeneration due to changes in micro-climatic conditions and increased exposure to the sun. On the other hand planting and seeding become easier and can be completed earlier than expected. Also regular stocking is easier to achieve when the residues are removed (Saksa et al. 2001). Also recreational and scenery effects are often mentioned in favor of collecting logging residues.

However, there have been pressures to pay a stumpage price to acquire harvesting rights for logging residues. In practice buying of logging residues basically means obtaining the harvesting rights for it. This may take place at the same time as signing a contract on the sale of merchantable wood with the harvesting company. Since it will be difficult to estimate the amount of logging residues before the chipping phase and the time period between harvesting and chipping may be long, it is therefore rational to have a straightforward payment policy like hectare-based compensation.

Regarding Rämö et al. (2001) the private forest owner's willingness to supply energy wood to commercial markets, indicates that only 41% of forest owners are willing to supply the logging residues without compensation. Because of regional differences of demand and supply potential of forest fuels, it is expected that pressure to pay a stumpage price will increase in the western part of Finland due to the imbalance of demand and supply (Rämö & Toivonen 2001). Bohlin & Roos (2002) found in their survey concerning forest owners in Sweden, that the stumpage price has little significance on the decision to sell forest fuels, whereas the most important reason for selling is the soil preparation effect of the harvesting operation. On the other hand the concern for soil fertility is the main reason for refusing to sell.

3.4 Piling

Practically all mechanized regeneration cuttings in Finland are performed with a single-grip harvester. If the residues are to be recovered for energy, the harvesters should pile residues along the strip roads instead of directly in front of the machine (Brunberg et al. 1994). The residue will then accumulate in heaps alongside the strip road for easy recovery instead of being run over by forwarders on the strip road. Whereas in a conventional harvesting operation the harvester leaves only one third of the residue mass in heaps higher than 50 cm, in modified methods the proportion is two thirds (Nurmi 1994). The piling method reduces contamination of the logging residues, promotes drying and prevents ground moisture from entering the residues.

Two piling methods can be applied. The one-sided method denotes piling on only one side of the strip road, into long formations, whereas the two-sided method results in two individual piles on both sides. The double-sided logging method has been found to be more suitable at sites where large-size stems are felled or in the winter period to avoid a large contact surface against soil surface. When the residue piles are high, it is easy to collect with the grapple of the forwarder or terrain chipper. Only the logging residues that are easily and quickly collected are recovered. The logging method has an impact on the yield, which is slightly better for the two-side method. Nurmi (1994) has found, that after the two side method the yield is 70-80% and after the one side method it is 60-70%.

The working method that takes the piling of logging residues into consideration does not necessarily decrease the profitability of tree felling. Obviously, some productivity reductions will be incurred, but these are low in most situations (Wigren 1992). Training for a new working method has a great effect on the result. The handling of wood further than normal from the driver's cab of the harvester and the lack of space at the side of the felling track are considered difficult. The lack of space is affected by the variety of wood species. If there are several types of wood assortments, and logging residues are collected, the separate piling of the various types becomes more difficult and the time consumption increases (Jäkälä & Mäkinen 2000).

Logging residue piles at the sides of the skidding trails may also decrease the profitability of the forwarding of merchantable wood, in particular as regards the loading time, with the stacks being further from the driving track. The piling of logging residues may also affect the driving speed and load size especially at terrain where poor bearing capacity makes forwarding more difficult. The driving speed and load sizes decrease if there is no logging residue on the tracks to improve its bearing capacity. The separation of wood species is also difficult in forwarding. Oijala et al. (1999) found that the productivity of forwarding of merchantable wood is on average 6% lower when the logging residue piles left on the terrain, but on the other hand it has no effect on the felling stage.

The productivity changes in roundwood harvesting is thus based on the working method, equipment, residue accumulation at felling site and terrain properties. It can be concluded, that the productivity of modified logging methods does not necessarily differ much from the productivity of the conventional working method. The recovery rate and productivity of the forwarding of logging residues are notably improved if logging residues have been piled at the felling stage. The cost and accumulation efficiency obtained at harvesting may surpass the possible loss in merchantable wood harvesting (Hakkila et al. 1998). Also the amount of impurities in the fuel decrease. For this reason logging entrepreneurs typically gain compensation from logging residue piling.

3.5 Storing

Storing is an essential part of the logging residue production chain and logistics, because it secures the availability of fuel throughout the year and improves its quality. The starting-point to plan the storage stage includes the storing time, storage location, scheduling of storing in relation to other actions in the production chain and the form in which the material is stored. The practical implementation of storing depends on the production chain used. Within one chain, storing may take place in several stages. Logging residues can be stored in small piles formed by a harvester at a terrain, in bigger piles formed by a forwarder at a roadside storage or when centralized chipping is applied, in big piles at a terminal or end-use facility.

The motives for seasonal storing include the co-ordination of the periods of production and use. Typically this means that the storage levels are increased in summer to prepare for the consumption peaks in winter. The motives for short-term storing include both the buffering of the sequential stages in the production chain to improve the certainty of deliveries, and having an end-use storage depot to secure energy production. By dividing the vulnerable hot production chain into separate and independent sections, the cost-efficiency of the production chain can be improved. End-use storage depots consist of either silo or stack storing. The vast majority of forest chips used in heat and energy production are directly unloaded into silos for immediate use. The size of silo stores at plants typically amounts to some hundreds or at the most some thousands of cubic meters. The aim is to secure necessary energy production during a few days. However, to ensure the fluent supply of wood fuels, power plants are often forced to maintain buffer storage of different wood fuel assortments on the plant yard. The sizes of the stacks vary from some thousands up to a hundred thousand cubic meters depending on the size and fuel assortments of the plant. They may be sufficient for several months and are basically meant for periodical storage.

The method where wood is left on the ground or in a pile to dry is called seasoning. Seasoning is the most common method used to increase the net calorific value of forest fuel. The weather conditions largely determine the time necessary for drying. The most recommendable alternative in logging residue harvesting is to dry the residue in the terrain in piles left by the single harvester over the spring and summer, when the vapor pressure deficit is the lowest. The residues piled at the logging site dry faster, due to their larger surface area and the loose structure of the heaps, than the residues at intermediate roadside landings. According to the study by Hillebrand & Nurmi (2001), the optimum length of a drying period on the terrain is 1-3 weeks depending on the weather conditions. The residues should be collected in good time before autumn rains into high intermediary windrows. If the storage on the terrain site takes place to late autumn or even winter, the advantage gained by transpiration drying is lost, as the material regains moisture directly from the air and through precipitation. Another possibility is to collect the residue immediately after round wood harvesting for maximum accumulation. However, if fresh logging residues are transported to roadside piles immediately after harvesting, the moisture content is not reduced as much during summer, as on the terrain site. Whatever method is used, the storing time of the logging residue chips should be kept to a minimum to avoid dry-material losses.

Natural drying is most suitable for stems and slash like logging residues. For chips, natural drying is not so effective because the ambient air cannot penetrate into the chip pile and internal heating and microbial degradation may occur (Gigler et al. 1999). Numerous studies (e.g. Nurmi 2000) on wood storage from conventional forestry operations have shown that if comminution of wood by chipping, shredding or hammer-milling is followed by storage in piles, the dry matter losses can be significant, especially if the wood has not been dried before chipping.

There is a significant difference between nutrient losses depending whether logging residues are collected green or brown. Needles and green foliage in general contain a considerable share of nutrients. If needles are left in the stand for instance by leaving the crown mass to dry on the terrain for a few weeks or months so that the needles fall down, most of the nutrients are released to the soil (Nurmi 1999). However, at the same time the rate of forest residue biomass accrual decreases and cost of harvesting increases. This is the trade-off that needs to be taken into account for each case.

Nowadays it is common to cover piles at roadside storages with reinforced cardboard or impregnated paper. It prevents wetting and microbiological decomposition. This covering should be carried out on seasoned dry logging residues. Covering fresh and moist logging residues is not advantageous. Several empirical trials are executed to determine moisture content and dry matter changes in piles of different wood fuel assortments. For example, according to Swedish studies (Jirjis 1995), chips made from covered logging residues in winter are about 10 percent drier than chips produced from uncovered logging residues. Substance losses in such a system are below 1% of the dry matter per month. However in studies, comes out in Finland (Nurmi 2000), covering has no essential effect on the quality of the fuel produced from logging residues. Later, when the covering method had been developed further, better results were obtained from covering, since the moisture content was 10-15% lower compared to the uncovered piles (Hillebrand & Nurmi 2001). However, it should be pointed out that the results are only relevant for the given set of conditions under which the trials were conducted.

Storing costs may become significant, which is often underestimated in cost accounting. Storing costs are affected by the capital costs and the changes in energy content during storage due to solid material loss and heat-value change. Capital costs are affected by storage time and current value of the raw material that can be defined in the form of a so-called cost accumulation curve. The cost-accumulation curve presents the increase in the value of the raw material, i.e. the accumulation of costs along the logistics chain. The later the storing phase of the raw material or end product in the supply chain, the higher the storing costs are per unit time. The costs of setting up a storage depot and the costs linked with the covering of logging residue piles must also be included in the storing costs.

3.6 Terrain chipping

Terrain chipping is based on a single vehicle unit that is capable of performing several work phases like chipping and forwarding. The chipper moves freely at the terrain after the regeneration felling or along strip roads after first thinning. When the high-dumping bin of the chipper is full, the terrain chipper returns to the landings and unloads the bin into an interchangeable container (Fig. 7). After unloading the bin, the chipper is ready to start a new cycle. The size range of terrain chippers is wide and they are typically built on a forwarder chassis and are either side or front-fed. There are also so-called chipper-cassette solutions in the market, with a forwarder that is easily convertible into a terrain chipper with the help of a separate chipper-cassette unit. The volume of chipper's container is typically 10-20 m^3 loose. The chip container is emptied by tipping either to the side or to the back.

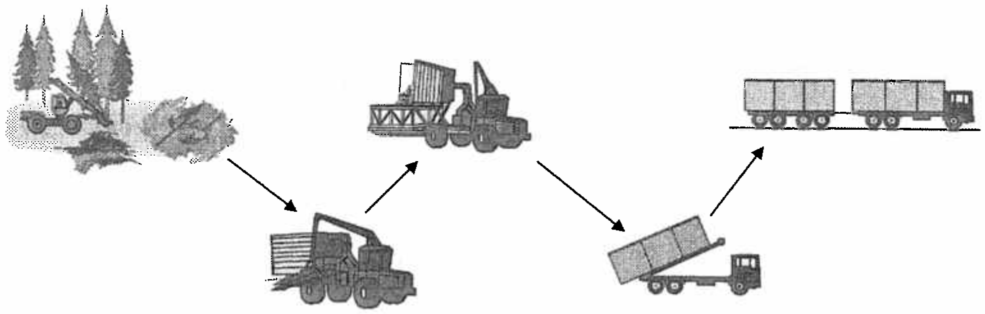


Fig. 7. Terrain chipping of logging residues (VTT Processes).

Terrain chipping of logging residues requires practically similar operations in timber harvesting as forwarding. Logging residues have to be piled along the logging track or strip road from where they can easily be loaded to the feeding table of the terrain chipper. The output of a heavy terrain chipper depends primarily on the location of the bunches in relation to the strip road, residue yield per hectare, terrain topography and forwarding distance.

If the forwarding distance is short enough the chipper moves to the roadside and dumps the chippers own container to a waiting chip truck or interchangeable container. Where longer forwarding distances are obtained then the chips can be dumped from the chipper to a chip shuttle forwarder with a container for transfer to the chip truck and the chipper can stay at the logging site. Forwarding takes a considerable proportion of the worksite time, lowering the productivity of chipping. With a shuttle the chipping time of a terrain chipper is increased. Such systems are best operated on relatively firm ground as a lack of residues can lead to a bog down of the machines or compaction of the soil if operated on soft ground (Mitchell 1992).

Moving from one working site to another can be accomplished either on a trailer or for short distances, by driving the terrain chipper on roads. This enables operation at small sites if they are located close to each other. The space requirements of logging residue stores and forwarders at the roadside are smaller than in roadside chipping, because the chipper can be used for so-called extended short-distance forwarding on the forest road. The storage area should be large enough, flat and bearing in order to load full and unload empty containers.

Terrain chippers carrying chip loads off-road, are more sensitive to soft or stony terrain and sidewise slopes than normal forwarders. Logging residues on softer grounds cannot be collected when the ground is not frozen, because in such conditions, logging residues are needed to improve the bearing capacity of the strip roads. Rockiness slows down the moving of the machinery and there is a high risk from impurities in the logging residues. Another difficulty may occur during wintertime when it can be difficult to achieve a satisfactory quality level of chips, due to the moist or snowy season. In winter, terrain chippers are often used also at the roadside worksites.

When chipping is done on site with a forwarder-type terrain chipper using interchangeable containers for transport to a power plant, the interdependence of chipping and transport can be avoided. Chip trucks use typically 35-45 m^3 bulk chip containers, 2-3 of which can be transported at the same time, raising the total volume of the load to 90-115 m^3 loose. The minimum number of containers must be double; one set at the storage area and the other used in transporting. However, despite the possibility of using extra truck containers as buffer storage at the landing site, the close link between the operations of the chipper and the chip truck presupposes careful planning and synchronization (Hakkila 1989). The transportation of empty containers to the working area in advance means more driving in terrain chipping than in roadside chipping. To solve this problem, a so-called case-container system has been developed (Kokko 1998). In some situations when using a full trailer combination truck, the trailer can be left at the better accessible roadside and a truck can be used to collect the interchangeable containers. If the loads and transporting distances are small, only the truck can be used for transporting.

The use of interchangeable containers requires a flat and bearing storage area and enough space to move the empty containers from the full trailer combination truck and consequently to load the full ones. Uneven ground at the storage area may cause problems for the tipping of the chips from the container of the terrain chipper into the interchangeable container, if the chipper cannot be driven close enough.

3.7 Forwarding

Logging residues are forwarded according to the organization of work and vehicles either simultaneously with merchantable wood or through separate operation at the worksite. The forwarding of logging residues may involve using the same forwarder as in merchantable wood forwarding, or a separate forwarder equipped for logging residue forwarding. Forwarding of logging residues and logs in mixed loads is not profitable, even though logs compact the logging residues (Alakangas et al. 1999). Logging residues are best forwarded in separate loads. Because the bulk density of logging residues is only 75-150 kg/m^3 piled, the mass of a load stays considerably below the capacity of a forwarder. Hence the productivity can be increased simply by increasing the load space and modifying the grapple to suit the residue handling.

A medium-size forwarder with a regular load space can load about 4-5 m^3 of solid fresh logging residues. By extending the load space backwards and by installing extra bolsters, a load size from 8 to 14 m^3 solid can be attained (Korpilahti 1997). Load base can also be enlarged laterally by the aid of hydraulic compacting equipment, like sliding bolsters (Mutikainen 1999). There are some limitations to enlarge laterally when the strip road goes through the remaining treestock. Ahonen & Tervo (2000) found in their study that even a 11.5 m^3 solid load size can be reached, when using the crosswise loading technique with a frame volume of 21 m^3. When using sliding bunks the average load size is 7.2 m^3 solid with a frame volume of 22 m^3 in the same study.

Additional machine movements are avoided if logging residues are forwarded with the same vehicle as roundwood, although forwarding of different assortments is carried out in different loads. A forwarder or forest tractor equipped with an expandable load space and a so-called logging residue grapple has become the basic solution for forwarding in Finland. Use of a residue grapple reduces the risk of contaminating the residue with rocks and soil. Also the grapple load size is larger and loading and unloading is faster, which makes productivity higher. Often the tight work schedule of a harvester and a forwarder does not enable the use of forwarders in logging residue forwarding. Therefore the use of a separate forwarder or forest tractor will also make it possible to season the residue on the terrain over the summer period.

Farm tractors are also suitable for the forwarding of logging residues, even though their load size and productivity are normally lower than forwarders. In practice, the load space of farm tractors could be expanded in the same way as that of forwarders. A forest trailer with a regular load space takes an average load of 1-2 m^3 solid logging residues but with an increased width of load space and extended bolsters, load volumes of 4-7 m^3 solid have been reached (Mutikainen 1999, Nätt & Mutikainen 2001). Compared to forwarders, costs are reduced due to lower capital costs with the use of the forest owner's own equipment and the faster moving time from one stand to another.

The forwarding of logging residues can also be combined to the soil preparation of the renewal ground by using the same equipment for both work stages. The method has been demonstrated by equipping a normal forwarder with scarifier discs (Hartikainen & Karppinen 2001). The bunks of the load deck of the forwarder are hydraulically spread to increase load space. The vehicle both scarifies the ground and loads the dried brown logging residues. Both functions are integrated so that when a load is collected, the area that has already been cleared from logging residues is scarified. The advantage of this method is increased cost-efficiency by minimizing of transporting costs of the equipment between different worksites and an increased machine-operation time.

An integrated method for harvesting of logging residues is the whole-tree skidding method, tested in Finland (Vesisenaho et al. 1998). The method includes skidding of the stems that are felled in regeneration felling including branches to be handled at the landing. In the Finnish modified method, the trees are felled and piled into skidding loads with a one-grip harvester. The stems are skidded with a forwarder equipped with a hydraulic clambunk to the side of the forest road. At the roadside, the stems are delimbed and crosscut either to wood assortments or tree sections with the same one-grip harvester. Logging residues are left in big piles at the roadside, and later chipped with a terrain chipper. Problems appeared primarily in piling different wood assortments and logging residues in separate storage piles, and in the large space needed for handling of whole trees at the roadside. Moreover, the skidding of the trees cannot be executed through the remaining stand because of the risk of damage. This limits the use of this method mainly to roadside stands. There may occur also more contamination with soil when skidding. The method is not currently used in Finland but in the USA it is the most common harvesting method and it is used also in short rotation tree plantations (Spinelli & Hartsough 2001b) as a extraction method between feller-bunchers and flail-chipper units.

3.8 Roadside chipping

The roadside chipping method includes the forwarding of logging residues to the side of the forest road with a forwarder, and chipping the material later (Fig. 8). Comminution at an upper landing presupposes forwarding of the material to the chipper instead of moving a mobile chipper. The system may be regarded as the basic organization for forest residue biomass harvested in Finland (Hakkila 1989).

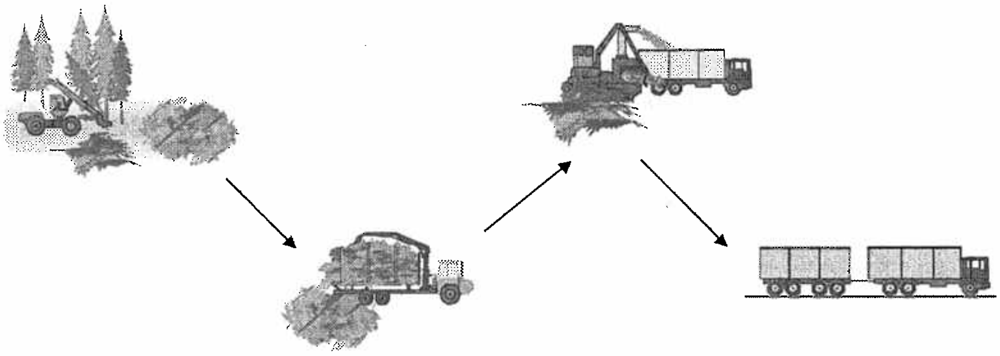


Fig. 8. Roadside chipping of logging residues (VTT Processes).

The features of the chipper and its status in the chain have an important impact on the whole chain. The organization and execution of the other phases of biomass delivery are determined partly by the location, mobility, capacity, and technical characteristics of the machines used for comminution. The capacity of the chain is typically defined on the basis of the comminution stage, because that involves the most expensive operating time of the machinery. The aim is to reach maximum productivity and hence to reduce the idle time of the chipper. The chain capacity is easily adjusted by changing the capacity of the other stages in the supply chain.

Roadside chipping or crushing is typically carried out with vehicle-based drum chippers and hammer or rotor crushers. Drum chippers are usually most suitable for chipping logging residues, because they produce more homogenous material than disc chippers and are less sensitive to impurities than disc chippers. Disc chippers perform well with solid wood, but small, flexible branches easily pass through the disc slots uncomminuted, resulting in a high content of slivers. In contrast, the knife pockets of a drum chipper effectively trap and comminute thin branches. For instance, in a survey of Italian chipping operations (Spinelli & Hartsough 2001a) it was observed that the insufficient infeed side of chippers especially with bushy material would decrease the productivity essentially. Logging residues are loaded into the feeder by the chipper grapple and feeder rolls. Both drum chipper and crusher can be equipped with an internal sieve that helps to get a more homogenous particle-size distribution of chips.

Road-based chipping equipment allows for higher chipping capacity per unit than in terrain chipping. Crushers are typically heavy and powerful units and it is difficult to transport them, whereas chippers can easily be mounted on a truck and a forwarder chassis so that forest fuel processing can be carried out at the source. However, a firm bearing landing area is required. Truck-mounted chippers have a high operational availability. They move rapidly between sites, and the equipment has a short set-up time. The flexible mobility of the equipment on roads also enables a varying raw-material range in a wide geographic area to be used.

Crushers tolerate small-sized impurities such as stones notably better than chippers (Rinne 1998). The advantage of a chipper is the better quality of chips and smaller energy consumption. The disadvantage of a chipper is the fast blunting or even breaking of blades when there are impurities in logging residues. This also leads to lower chipper productivity. Due to wear and tear caused by stones and sand, knives are a considerable cost factor in comminution when using mobile equipment. The lower quality of crushed residue material may cause difficulties on the feeding conveyors due to long splinters. This is why crushers are suitable to be used at such operational environments, where the chip quality requirements are not so high and the feeding of fuel to the boiler along the conveyors normally does not cause problems. Also the space requirements at storage sites are typically large with heavy crusher units mounted at semitrailer chassis.

The forest chips are mostly blown directly into the chip truck. The supply chain is especially sensitive for additional costs caused by an interlinked chain, because the total productivity of the chipper and chip truck depends on interruptions. The logistics management of the chipper and chip truck affects strongly on the costs. Because of the space requirements of the chipper and truck unit, this operation is limited to better quality roads. Also, turning points (forks in the road, entrances, turnouts, etc.) are needed at frequent intervals (Desrochers et al. 1993).

In Finland, there are a couple of examples of such multi-purpose units where chipper and chip truck are combined in one unit. The idea of this method is that a combined chipper-container truck is suitable for chipping logging residues at intermediate landing sites and transporting of chips, and thus the "hot-chain" problem is avoided. The "hot chain" refers to a method with consequent work stages tightly linked with each other. The method has been applied in particular when the same entrepreneur delivers wood chips to several heating plants from short distances. The advantages of the method are that it is not dependent on the other stages in the supply chain, avoiding unnecessary moving or preparations for moving the chipper and accessing small and narrow storage areas, which increases the number of sites that can be classified as suitable for harvesting.

For instance, the multi-purpose chipper-truck (Hämäläinen & Pankakari 1998) enables storage and subsequent chipping of logging residues at the felling site, which facilitates roadside activities. In practice this method also demands a second piling, after piling in conjunction with cutting. Owing to the mobility of a chipper-truck it can not be compared with a forwarder or a terrain chipper. The combination would be particularly suitable for small logging sites. This unit is especially competitive when the road transport distance to the end user is less than 25 km (Ikäheimo & Asikainen 1998). Also another combined non-terrain drum-chipper container truck, built on a truck base, especially for roadside chipping operation has been developed in Finland. The trailer has a log crane and chipping and hook deck equipment. The chipper located behind the driver's cab blows the chips directly into the interchangeable container in the trailer. The full-trailer combination includes three interchangeable containers. The combination is particularly suitable for small harvesting sites. The load capacity of the chipper combination is not as good as that of chip trucks, because of its own weight, 32 tons.

3.9 Terminal chipping

In the terminal chipping method, logging residues are forwarded as so-called continued short-distance haulage to a centralized terminal, where it is chipped (Fig. 9). In this way the interdependence between the comminution and trucking operations can be eliminated. Rather than moving a mobile-processing machine into the woods, the loose residue material is thus hauled to heavy-duty stationary or semistationary machines for processing at a terminal. The amount of work at the felling site is minimized by shifting tasks from the site to a centralized installation, thereby taking advantage of mass processing of the raw material under controlled conditions (Hakkila 1989). The terminal production of forest fuel can be integrated with peat production by using the economy of joint production with peat by means of same machinery and same terminal areas (Silpola 2001, Leinonen 2000). The tractors can be used in peat production in the summertime and in forest fuel production in the wintertime. The same wheel loaders and trucks can be used for the loading and transportation of both fuels.

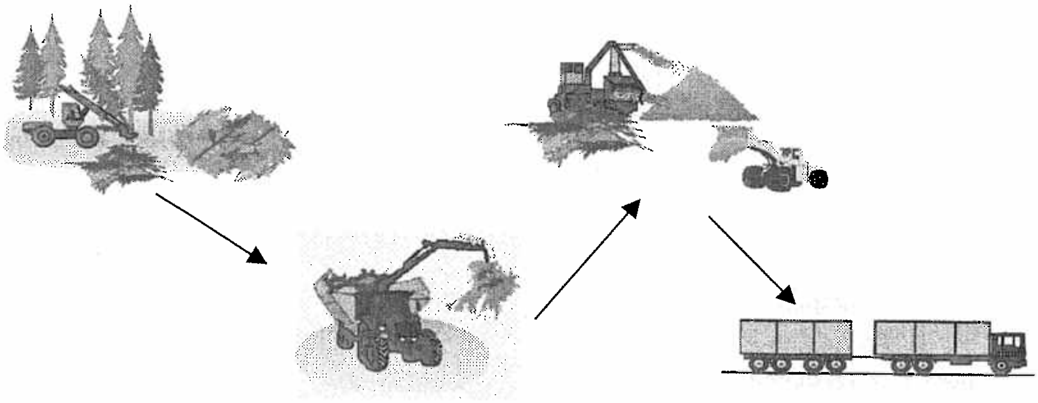


Fig. 9. Chipping of logging residues at a regional terminal (VTT Processes).

The serious drawbacks to the centralized processing of forest residue biomass are connected with long-distance forwarding of the raw material to the terminal. The low bulk density of unprocessed residue and the low driving speed of the tractors increases the cost of transport. One solution is to use logging residue trailers equipped with compacting equipment and towed by a tractor. The same vehicle collects both the raw material from the stand and transports it to the terminal. The load size of the unit is higher than with normal forwarders. The trailer has closed sides that will compact logging residues. The sides are open during loading. When the load is full, hydraulic cylinders press the sides in. With the sides pressed in, the frame volume of the trailer is about 45 m^3 with the capacity to contain about 8-12 m^3 solid of fresh logging residues. The maximum economical transport distance between the forest terrain and the terminal is 10-15 kilometers (Silpola 2001). The method enables for logging residues to be harvested at worksites smaller than usual if they are located close to the terminal.

Another drawback is the higher storing and handling costs, since at the terminal, logging residues are unloaded into a storage stack where they are left to dry over summer. The terminal stores of logging residues are typically 400 - 2 000 m^3 solid. The stacks are covered so that the residue remains as dry as possible until chipping. Chipping operations can be performed either by using heavy-duty or light-duty machines due to the possibility to comminute directly into field-storage at the terminal. At the terminal, the storage of logging residues and chipping as well as the long-distance transport from the terminal can be performed in a more rational way than at small storage areas as at forest roadsides. Terminal time for trucks can be decreased due to faster loading operation by a wheel loader. Also buffer-storage capacity and quality control can be organized easier in the same area.

3.10 Bundling

In the most common baling or in this case bundling method in Finland, the logging residues are bundled into cylindrical bales, log-like units using the bundler machine, which is installed on a top of a normal forwarder deck (Fig. 10). In this study also the term logging residue logs are used in this context. Besides this method also other bundling solutions exist like easy interchangeable cassette-solutions between forwarder and bundler.

The bundling-method, selected in this study, is divided into three phases. In the first phase, collected logging residues are pressed by feeder rolls, after that the compacting continues in a rectangular presser. The last compacting phase ends with the roping of the pulse-fed logging residue bundle, and finally the bundle is cut into the desired length with a chainsaw. The bundles are wrapped with strings every 40 cm. The length of a bundle can be selected, normal length being 3,2 m and diameter about 700 mm to get optimal transport economy (Poikola 2002). The weight of the bundles is 450-550 kg per unit. Due to the operating cycle of the bundler being completely computerized, the operator can concentrate on operating the loader. A continuously operating bundler unit rotates, which enables feeding of material from both sides.

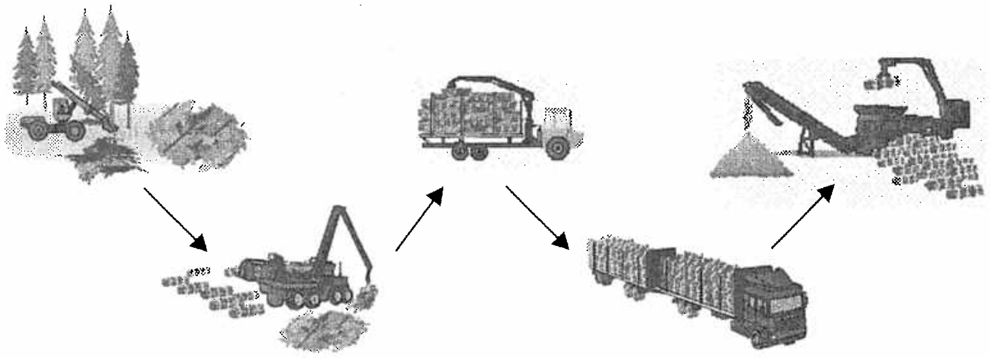


Fig. 10. Supply chain for logging residues based on bundling and crushing of logging residue bundles, i.e. residue logs, at the end-use facility (VTT Processes).

The bundling method offers some operational and logistical advantages, which naturally have to balance the cost of compaction (UK Industry..., 1996). A major advantage of bundling systems is that the same handling and administrative routines can be used as in conventional roundwood logging (Andersson 2000a). Bundles could easily be handled with ordinary timber cranes and conventional bunk-type roundwood rigs. They would require only minor modifications. This can to result in the bulk density being increased to more than double, which would allow full use of the mass capacity in most truck rigs.

The bundling method facilitates buffer storage in all stages of the production chain and thus increases the reliability of supply. The advantages of the method also include better forwarding economy and less need for storage space. The handling and temporary storing of logging residues in bundles at various stages of the chain is easier than with loose residue or in the form of wood chips. Bundles can be left scattered on the logging site or stored in the landing area or at terminals without major problems of biomass loss or contamination. However, according to a study made by Lehtikangas and Jirjis (1998), storing of logging residues in windrows is presumably better from a quality point of view than storage of bundles.

After the bundling stage the residue logs are forwarded to the roadside with a regular forwarder. No changes in the structure of the forwarder are needed, but if the load space is lengthened, bigger loads and better productivity can be gained. A maximum of 20 residue logs can be forwarded to roadside storage at the same time, if there are two bunches sequentially on the load. By using the cassette solution the forwarding stage is managed with the same unit as the bundling. The residue logs are handled like other assortments and will create similar stacks on roadside landings. For full employment, the bundling machine should operate at worksites after 2-3 harvesters.

Regular timber trucks, length 22 m, width 2.6 m and gross truck weight 60 tons, can be used in transporting logging residue bundles. There is space for 65-70 residue bundles in a typical truck with a trailer, which means 35-38 tons load (Korpilahti & Suuriniemi 2001). The timber truck may require the use of netting or solid sideboards to prevent material falling during transit (Andersson 2000a). Unloading the logging residue bundles takes place at the end user site with similar equipment as in unloading pulpwood. In the most efficient cases the residue bundles are unloaded directly from the truck to the feeding table of the crusher.

3.11 End use facility chipping

When chipping or crushing is carried out at the end-use facility, the production can be organized to avoid so-called hot chain problems. Each stage of the production chain can be made as efficient as possible with the equipment used. Other functional advantages as compared with roadside or terrain chipping include good productivity and better reliability and operational availability of the machines. The chipping at the end use facility method has been developed for decreasing the costs of chipping. However, it should be noted that the chain-based on chipping at the end user site requires a relatively high annual consumption at the plant in question to achieve the cost competitiveness. The piling and forwarding of logging residues are performed as in roadside chipping (Fig. 11).

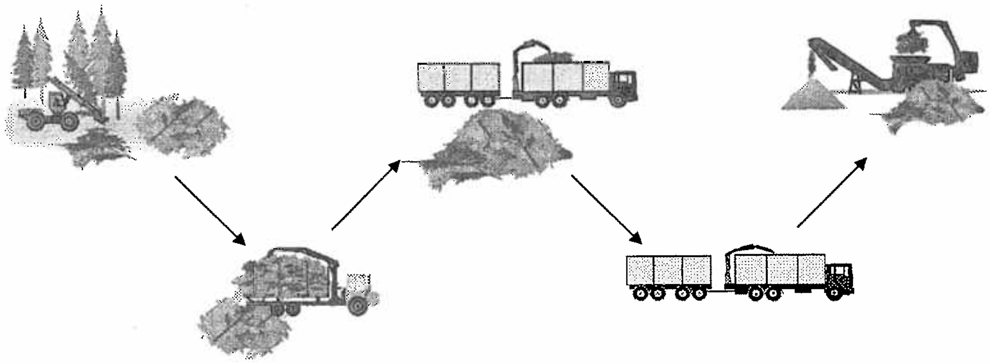


Fig. 11. Crushing of logging residues at the end-use facility (VTT Processes).

Slow or high-speed crushers and high power chippers are best suited to the end site processing of logging residues. Powerful crushers are typically heavy units and therefore difficult to move. Also at the end site processing causes noise and dust, as well as the need for a large storing and processing space. On the other hand, they require little maintenance and can easily be automated.

The productivity varies by a large scale, from 25-40 m^3/h for slow speed crushers to 80-120 m^3/h solid for high-speed crushers (Asikainen et al. 2001). The feeding efficiency affects significantly productivity. For instance, it is easier to handle and feed logging residue bundles than loose residues. Korpilahti & Suuriniemi (2001) have found that the best productivity of bundles can be achieved by a drum chipper, as high as 167 m^3/h solid, whereas by crushers the productivity will be lower.

The problem with end use facility chipping lies in the truck transportation of unprocessed logging residues, because load sizes remain small without compacting or bundling of logging residues, i.e. the economical transport distance is short. The long-distance transporting of logging residues requires a vehicle like timber truck with sides and a base. The use of a heavy-duty loader boom with an extra large grapple is an essential requirement for long-distance transport of unprocessed logging residues. This also boosts productivity in loading, since the residue can be compacted in the same operation. The logging residue load can be compacted by pressing it against the sides by a grapple that is stronger than normal. By using a heavy-duty grapple instead of a normal one, the productivity and transporting density can be clearly improved. Compared to the 15-20% density of a load that has not been compacted, the compacting with the grapple raises the level to 25-26%. In order to achieve the target level of 30%, separate hydraulic compressing cylinders and bolster bars should be used (Rinne 1998). The disadvantages of this system include extra weight and a complicated structure of the equipment. By using Finnish full trailer combinations that have 110 m^3 of load space, compacting can increase load sizes from 23 to 29 m^3 solid. In a follow-up study made by Korpilahti & Suuriniemi (2001) from a truck, which was rebuilt to accommodate a 130 m^3 loose extendable load space, the average density of a load was 22%, load size 28,6 m^3 solid and weight 25 ton.

3.12 Long-distance transport

The aim of the transporting phase is to move the logging residues in its various forms from the primary landing to the utilization facility. The efficiency, productivity and cost of long-distance transportation depends on such factors as the form in which the material is transported, the material solid volume content, the moisture content, transportation distance and type of transport vehicle used. As a result of the low bulk density of logging residues, the size of the truck is usually limited by volume rather than mass capacity with the exception of fresh material in chip form. Through comminution or bundling of loose residues to achieve a higher bulk density, it is possible to improve the load capacity utilization of a truck.

The most likely improvements to the transportation phase of the logging residue handling chain is divided two main areas. The first is the maximization of the delivered load up to the legal weight and dimensional limits. The second is the minimization of terminal time. Obviously loading and unloading times depend on the system employed. Loading time can be extended where trailers are loaded at the same time as material is being chipped. If these stages are interlinked, any delays in the chipping operation are extended to the transportation phase. Similarly, the unloading techniques at the utilization facility can affect terminal time. Typically the receiving facility is not the source of major delay time unless poor scheduling overwhelms the unloading facilities. Minimization of terminal time is therefore essentially a management problem rather than a technical one (Angus-Hankin et al. 1995). A significant factor, which often prevents optimal working, is the power plant's delivery window. Trips have to be scheduled so that the vehicle arrives at its destination at the predefined time, which may be inconvenient from the point of view of the fuel supplier.

Truck transportation consists of many interrelated work-elements starting from arriving at the storage site at the forest and ending at the unloading at the end-use facility storage-site. It includes all actions related to the transport vehicle, loading, transporting and unloading, as well as waiting time between actions. Transport season, weather conditions, road type and condition, vehicle type, forest storage site condition, chipping phase at forest site and arrangements at the unloading site are among factors, which will affect time consumption in different work-elements.

Transportation economy of forest chips is low due to low volume weight and low energy density of chips. A need to minimize the moisture content of the material before transport further increases the difficulty in reaching maximum payload due to the low volume weight of the chips and insufficient filling rate of the load space of the truck. Also the particle size distribution of the chips, method of loading into the transport vehicle, and any setting due to vibration either applied or occurring during transport influences the bulk density of the chip load. The method of loading the chips affects the compaction of the load as in a study (Ranta et al. 2002), where a belt conveyor equipped with a mechanical ejector gave better results than the blowing device. However, the low transport economy due to low volume weight is actually a problem regardless of the loading method in summer time when the moisture content is low enough.

Also vehicle features, like load carrying capacity, and loading and unloading equipment affects the economy of forest chip transportation. Truck type selection seems to be connected with chipper type used, since interchangeable systems are used with terrain chipping and fixed systems with roadside supply methods. According to survey (Asikainen et al. 2000) half of the chip truck population are full trailers with a fixed platform, 40% are trucks with an interchangeable chip container and the rest are trucks or semi-trailers. Two trucks out of three, equipped with interchangeable containers, use three containers. The load space of a full-trailer combination is 110-120 m^3 for permissible load weights of 34-37 tons. With moist chips, overloads are possible, whereas with dry chip loads the total weight stays well below the upper limit (Fig. 12). Semi-trailer combinations are unusual for forest chip transportation due to the lower carrying capacity. The legally maximum total weight is 48 tons, length 16.5 m for a load space of 75-95 m^3. Continuous load space and the possibility to use the cold chipping-transportation chain by using two trailers and one truck tractor gives some logistical advantages at terminal stages (Ranta et al. 2002). Also the drivability on forest roads and processing at roadside storage may be difficult due to a longer trailer (Oivanen 1995).

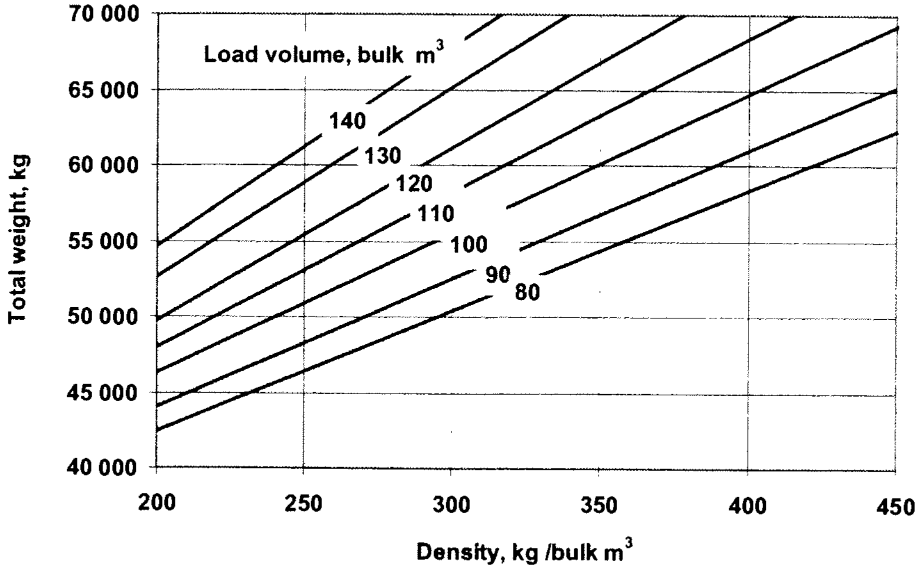


Fig. 12. Total weight of chip trucks as a function of volume weight (Ranta et al. 2002).

Mastering the logistics of the chipper and the chip trucks can also reduce transportation costs of forest chips. This means that the full occupation of machinery with as little waiting time as possible is crucial. This requires inspection of the total delivery chain from a forest terminal to the power plant. The aim of truck scheduling is to maximize the utilization of a truck's capacity. This is achieved for example by organizing return loads, by double-shifting and by minimizing turn a round times so that, the driver does not have to wait while trailers are being loaded. Development of the navigation systems of vehicles so that extra driving of the trucks can be eliminated would also increase operating time and lead to considerable cost reductions. Information systems based on mobile positioning technologies and internet-based solutions of digital maps have been developed for planning and control activities of forest chips transportation (Ranta et al. 2002). When the procurement quantity of forest chips increase, the advantage of utilization of such systems will become higher.

3.13 Cost factors of supply logistics

A significant proportion of the total supply costs of forest fuel originates from the logistics activities, i.e. transportation, storing and handling. Energy density of forest fuels is typically low and, consequently the transportation distance has significant effect on the procurement costs. It follows that the procurement is transport-intensive due to large volumes to be transported. Moreover, the proportion of the costs of the management of forest fuel procurement in total costs is large compared with, for example, the proportion of merchantable round wood.

The commercialization of new technologies for forest residue harvesting, handling and energy production have a major role in improving the competitiveness of biofuel from forest fuels. Large-scale harvesting of logging residues with current harvesting methods is demonstrated to be cost-effective from favorable production conditions. Nevertheless, the unreliable logistics and distribution systems are considered difficult areas on the technical side. The improvement of logistics and management of forest fuel supply chains is considered essential to improve efficiency and economics of the operations.

The economics of forest fuels has been examined by using computer models. Such studies enable the situations under which forest fuel supplies become more competitive to allow commercial development to be determined. Equally they can be used to calculate the delivered fuel cost under different production and supply scenarios. Expert systems and decision support systems have been developed to aid commercialization of the technology. For instance The Aberdeen University Harvesting Decision Support System (AUHDSS) covers the forest residue biomass supply chain from the stand of trees to delivery of forest chips to conversion facility (Mitchell 2000).

The profitability of a harvesting system is not determined exclusively as expected productivity and cost per hour. A significant cost factor is the scale of operation i.e. the level of annual production. Also the term economy of scale can be used in this context, which implies reductions in average costs attributable to increases in scale. Highly mechanized capital intensive harvesting systems cannot bear extended periods of downtime and remain economically viable, and therefore necessitate year-round operation. One solution is to use flexible equipment that can switch between tasks. Increasing scale admits the efficient use of more large-scale equipment on full time. This decreases the share of the fixed costs of machinery and organization and hence also the costs of the machinery per hour.

Underemployment, irregular use, and unforeseen fluctuations always increase costs and lessen the profitability of the entrepreneurs in supply chain. An optimal situation as regards an individual harvesting and transportation chain is one where all contractors in the chain operate near their full annual capacity. The production organization must employ new resources when the capacity of existing chains is fully utilized. This will increase procurement costs, because none of the chains can operate at full capacity at first. In practice, the situation is less rigid because in transitional periods the number of working hours is increased in the existing chains, and temporary equipment is additionally rented to even out the operation peaks. On the other hand, the more potential used the more expensive the procurement becomes. For spatially distributed material as logging residues, the economy of scale is limited. As the size of the procurement area grows the harvesting should be directed at less suitable sites. The geometry of the procurement area, main road and forest road network density, harvesting sites as well as the end-use facility location relative to the procurement area affect transportation distances. However, other transportation models, like train or ship, can make the supply less dependent on distance, although they are used mainly for other wood fuel sources like demolition wood or upgraded wood fuels (e.g. Roos et al. 2000).

It is difficult to reach similar economies of scale with forest fuel as for instance with the forest industry by-products and peat. The reasons for this are the periodical changes in procurement, low usage, long transporting distances, the small size of worksites and lower yield per ha (e.g. logging residue production site on average, 2 ha with 150 MWh/ha, once in renewal period of 80 years vs. peat 100 ha with 500 MWh/ha, annually in production period of 20 years). The increasing use of logging residues throughout the year and higher volumes aid to reach the economies of scale by directing various supply chain alternatives according to their suitability at different operating environments.

Cost efficiency can also be improved by using economy of scope, where it is less costly to combine two or more product lines in one firm than produce them separately. Also, the terms economy of joint production or distribution are used in this connection. The benefits of joint production are exploited in the integration of merchantable wood and logging residue procurement, which refers to taking logging residue harvesting into consideration when round wood is harvested, and to the sharing of both the equipment and procurement organization. Logging residue procurement has also been integrated into peat production by utilizing partly the same harvesting equipment and storage network. The economy of scope makes it possible to reach procurement areas, in which separate production would not be profitable. For example, the logging residue procurement can be extended to the vicinity of peat production bogs, based on the previous discussed regional terminal production chain. The potential energy wood reserves around peat production bogs and possibilities for joint production in fuel supply has been analyzed and discussed among others Leinonen (2000), Ahonen & Tervo (2000) and Keskimölö (2000).

Cost factors depending on the work policy and environmental aspect include season and the type (green/brown) and moisture content of the raw material. These factors have a direct impact on the productivity of individual work stages and partly also on the hourly costs of the machinery, for example, through the blade costs of chipping. They also have an indirect impact on production costs, as for instance the drying of logging residues at terrain reduces the site-specific residue concentration and requires extension of the procurement area, which will affect worksite factors.

The geographical zone determines the type of forest growing and growth rate in that area. For instance, the structure of forests, the density of logging residues per felling area and the impact of water systems on the transporting distances vary between different parts of Finland. Due to these factors, there are big differences in the procurement costs and availability of raw material between areas. The competitiveness and availability of logging residue-based fuel must be studied regionally. In certain areas, especially in coastal areas, the availability of residues is a limiting factor for increased use.

The cost structure of logging residue production depends on the harvesting technology and conditions. On the basis of a monitoring survey of the alternative logging residue production chains, the competitiveness of different methods has been assessed on the basis of forest fuel supply cost. The mutual cost comparison of the chains has been typically based on the transportation distance (e.g. Asplund et al. 1999). However, productivity and cost comparisons between different chains in average harvesting and organizational conditions do not provide enough accurate data for practical decision-making, because the chain-specific profitability changes as the conditions change. The harvesting methods of logging residues should not be ranked into a strict hierarchical order. Each method has corresponding ideal operational conditions in which it is more suitable than the other options.

The performance of a system, and therefore its cost, is very much influenced by site-specific conditions. Extensive sensitivity analyses are carried out to study and the influence of site-specific conditions, factors and uncertainties. Currently only a minor part of logging residues are collected. Hence the selection of most economical harvesting sites are highlighted, based on the site specific harvesting costs. Information about the cost factors of harvesting is needed for selecting the most suitable production chains in all situations. As a result, a given system can have widely different productivity and costs depending on where it is implemented and on the characteristics of the material harvested. Also human factors, such as driver's skills and motivation, play an important role behind tangible cost factors. Moreover, ecological aspects also have to be taken into account, both during the selection of suitable stands and in the treatment of the logging residues. Hence, far-reaching conclusions of the mutual competitiveness between supply methods cannot be made and the results should be considered.

As a summary, the cost factors of the logistics can be listed as follows:

- ➢ Scale of operation
    - Economy of scale, seasonal variation

- Degree of integration
    - Economy of joint production and distribution
- Vehicle and chain characteristics
    - Vehicle and chain dimensioning, vehicle mobility and carrying capacity, material handling capacity, integration of different work stages, hot/cold-processing interactions
- Geography
    - Distances, variation of worksite factors
- Storage policy
    - Green/brown, fresh/dry, storage location and size, material type (loose, bundle, chip)

4 LOGISTICAL PLANNING OF FOREST FUEL SUPPLY – A LITERATURE REVIEW

4.1 The logistical system

The logistical system can be illustrated as an overall supply chain focussing on integrated management of all logistical operations including suppliers and customers (Fig. 13). Fig. 13 has some modifications related to a forest fuel logistical system from the one illustrated by Bowersox & Closs (1996). Instead of the traditional functional areas or subsystems within logistics (Ballou 1992) the process perspective will be emphasized. The whole supply chain process can be divided into smaller parts of consecutive procurement and delivery cycles that are performed more or less independently of each other by inventory keeping. The logistical system is not normally a simple supply chain from raw material source to customer. It resembles a set of parallel and sometimes interlocked chains. A supply network is probably a better description (Andersson 2002).

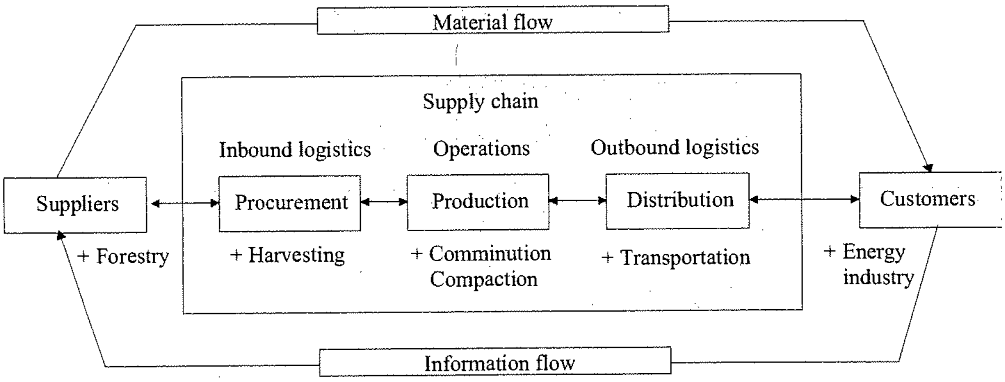


Fig. 13. A logistical system (adapted from Bowersox & Closs 1996).

The material flow in Fig. 13 consists of raw-material flow from suppliers through the supply chain to customers, where the logistical process adds value at each step of its transformation into a finished product, here combustible forest fuel. Information flow involves two major types of flows, co-ordination and operational flows. The overall purpose of information co-ordination flow is to integrate specific activities within a supply chain and to facilitate overall integrated performance. Whereas the overall purpose of operational information is to provide the detailed data required for integrated performance of procurement, production and distribution to assist the daily logistics work.

Logistical operations are divided into three areas, procurement, production and distribution, which are typically carried out by a group of subcontractors under a main supplier in the biofuel supply sector. Inbound logistics consists of harvesting operations, which include all the processes on the terrain up to the primary landing and raw material storing on terrain. Outbound logistics consists of distribution operations, which includes all the processes from the primary landing to the end-user and raw-material or finished product storing at a primary landing or terminal. Production operations are linked either more closely to operations of inbound or outbound logistics, depending on the comminution place (terrain - primary landing - terminal - end-user).

The supply chain perspective shifts the channel arrangement from a loosely linked group of independent businesses to a co-ordinated effort focused on efficiency improvement and increased competitiveness. In essence, overall orientation is shifted from inventory management by each individual participant to a pipeline perspective. The basic notion of supply chain management is grounded on the belief that efficiency can be improved by sharing information and by joint planning (Mentzer 2001). By taking an entire supply chain perspective of forest fuel supply from the point of harvest through to delivery at the power plant, it is possible to consider the interrelationship between all activities necessary to deliver fuel in an efficient manner and the delivered cost of different supply systems.

The activities that take places in biomass, like forest fuel, supply chains are highly interconnected (e.g. Mol et al. 1997, Björheden 1997, Asikainen 1995). The biomass supply chain is transparent and it is easy to understand how upstream decision-making affects later activities in the chain. So there is an obvious need to take a total supply chain perspective when planning any single activity in the chain rather than considering that activity in isolation. The harvesting approach fundamentally affects the storage, handling and transport requirements in the supply chain. If the planning of the supply system takes place from the other end of the chain as commonly, i.e. demand-driven system, the choice of power plant technology, size and location will dictate how all the upstream activities are to be carried out so that biomass arrives at the power plant at the correct time, in the correct quantity, and in the desired shape, size and quality.

The fundamental belief is that co-operative behavior will reduce risk and improve the efficiency of the overall logistical process. To achieve a high degree of co-operation, it is necessary for key supply chain participants to share information. Such information sharing should not be limited to transaction data. Equally or more important is a willingness to share strategic information so that firms can jointly plan the best ways and means to satisfy requirements. Christopher (1998) emphasizes the utilization possibilities of modern information technology between different groups linked to a supply chain. This is especially essential with short-term activities, like scheduling production and distribution operations. In recent years sophisticated computer programs have been introduced to support the control of operations in supply chains operated in the forest fuel sector as vehicle computers with positioning systems (Ranta et al. 2002).

The second paradigm according to Bowersox & Closs (1996) is elimination of waste and the duplicate effort. At the root of this is the fundamental belief that substantial amounts of inventory deployed in a traditional channel constitutes a risk (e.g. material loss and decrease in quality). Sharing information and joint planning can eliminate or reduce risk associated with much of this inventory speculation. One practical attempt to reduce risk and improve efficiency has been vertical integration, where a single company covers many functions of the supply chain either in a forward or backward direction. The co-operation or integration in a vertical direction seems to involve more logistical potential for improvements than in a horizontal direction between contractors.

The biomass supply chain is made up of a range of different parties including forest owners, forestry contractors, transport and distribution companies, fuel suppliers, i.e. organizations sharing the risk and responsibility for supplying fuel to power plants, and power plant operators. Given the large number of different organizations involved, it is essential that they work closely together in planning and co-ordinating the fuel supply in order that the correct quantity and specification of biomass is able to arrive in time at the power plant. All parties need a detailed knowledge of upstream and downstream activities in the supply chain when determining how to optimize their work and responsibilities.

The primary goal of a logistics system analysis is the design of a logistics system that supports, in the best possible way, the strategic goals of the enterprise. Enterprise strategy, that is, the choice of products, markets and service levels, will affect procurement, production and distribution processes. The logistics system, encompassing procurement, production, inventory, and distribution, must be integrated with and support this strategy. The most prominent strategy at forest fuel business within large-scale users appears to be the cost minimization through integration or scale effects because of the product and process features. Other possible strategies like value-added maximization and control/adaptability enhancement (Bowersox & Closs 1996), are more suitable with different goods, but also with upgraded wood fuels like briquettes and pellets within small-scale users.

The most current biomass activities are integrated with other industry sectors by using their by-products as fuel. This biomass may be residues from forest industries, from agricultural processes or municipal solid waste. The use of existing resources or infrastructures such as machines, storage sites and organizations are other examples of integration. Integration can be used both to get cheap input factors and to reduce transaction costs and risks. Forest fuel production can take advantage of co-production by the side of commercial roundwood or peat production to decrease forest fuel supply costs (Asikainen 2001).

Currently the bioenergy industry is taking advantage of scale effects. The growth of a bioenergy business creates markets for specialists, who will improve the overall market performance through more competitive solutions. The bigger series of machinery and equipment and larger volumes of biomass contribute to reduced production costs (Roos et al. 1999). With regard to the security of energy supply it is essential to maintain a level of production, organizations as well as research and development that will guarantee an increased use of the indigenous energy sources in emergency situations. Under normal conditions, these sources must be used in sufficient amounts, ensuring that they are available in exceptional situations.

The logistics planning consists of spatial, vertical and time dimension. According to Thore (1991) the transportation problem represents the spatial dimension of the logistics process – the movement of goods and services from the original locations where natural resources are being tapped to the retail outlets where the finished goods can be bought by consumers. Activity analysis, i.e. cost element analysis, represents the vertical dimension of the logistics process – the flow of material from one stage of production to the next. The inventory problem provides the time dimension – the intertemporal problem of smoothing the time paths of inputs and outputs through keeping inventories. By combining the transportation problems and activity analysis, it is possible to investigate flows of goods through a production chain. Combining the transportation problem and the inventory problem provides a tool for the analysis of regional inventory systems. In combining activity analysis and the inventory problem, it is possible to understand the multistage inventory systems of intermediate goods in the production and distribution of final consumer goods. All these dimensions should be taken into account also within logistics planning of biomass-based fuel, e.g. forest fuel.

One approach to logistics planning can be addressed by the following questions (Magee 1985):

- What are the major trade-offs in logistics analysis?
- What characteristics about the process and product should be used in logistics system design and analysis?
- How can logistics systems analysis be divided into component stages or hierarchies to reduce the decision problems to manageable proportions, so that an appropriate analysis method can be applied? (discussed in more detail in section 4.2).

- What are the different types of analysis available, and how does one determine the appropriate analytical technique to use? (discussed in more detail in section 4.3).

Characteristic features of logging residues, which affect the logistics system, is the need for intensive transportation volumes of low value bulk material from numerous small production sites. Logistics cost is very sensitive to worksite factors, organization and transportation distance. Economy of scale and joint production will be the most prominent areas owing to development potential for cost reductions.

Central to the scope and design of the logistics system is a trade-off analysis, which, in turn, leads to the total cost concept (Magee 1985). The total cost concept of logistics management requires that all logistics system costs are evaluated when considering any component or subsystem of the system. The cost trade-off is the recognition that cost patterns of various activities display characteristics that put them in conflict with each other. This conflict is managed by balancing the activities so that they are collectively optimized. The total cost concept is necessary to extend the boundaries of the system beyond either the logistics function or the single actor to include all parties in the supply chain (Ballou 1992). Aronsson (2000) has handled the increased complexity in the supply chain design due to several activities and companies, by using several perspectives and levels. Supply chains have been studied using perspectives like function, organization and process and within each perspective, different levels such as construct, concept and activities. The fundamental issue is to make the overall design first and secondly the more detailed functional and organizational designs to avoid suboptimizations due to a perspective-specific approach. For example, reducing or minimizing the cost of one subsystem may produce higher total costs by increasing costs in other areas. In order to test the impact of changes in the value of individual critical factors on the value of component logistics cost, sensitivity analysis should be used. Sensitivity analysis is used to determine the degree to which apparently important factors in the problem affect the results.

Trade-offs generally include (Magee 1985):

- Transport cost vs. storage cost
- Proximity to raw materials vs. proximity to customers
- Manufacturing scale vs. other logistics costs
- Customer service vs. logistics cost
- Mode choice and cost vs. travel time

Especially with logging residues the trade-offs can be:

- Processing site vs. transportation cost (decentralized-centralized)
- Storing site and time vs. harvesting cost (seasoning effect)
- Integration of different supply chain stages vs. supply cost (chain dimensioning)
- Supply scale vs. supply cost (utilization degree, economy of scale)

4.2 Logistics planning phases

The logistic planning of a wood fuel supply can be divided according to time into hierarchical phases with various emphasis, starting from long-term planning and approaching everyday operation (Fig. 14). The separation of strategic or long-term logistics decisions, medium-term tactical logistics decisions, and short-term operational decisions simplifies logistics systems analysis. The hierarchical framework provides basis for an analytical solution. Selection of an appropriate technique or methodology depends on the scope of the logistics problem and the complexity of the analysis. These modeling techniques should be viewed as decision-support systems only.

The various phases differ from each other according to the time-span of decision-making involved. Long-range questions in logistics systems include those concerned with major investments in facilities such as plants and major distribution facilities, with basic product policy, or with production strategy. Answers to such questions set the framework of policy, strategy, and facilities within which short term or tactical questions in logistics systems management must be resolved. Tactical planning often deals with annual and operative planning for weekly and daily issues (e.g. Asikainen 2000, Mitchell 2000 and Ranta 1999).

The basis of decision-making becomes more specific moving from strategic planning towards operative planning. The higher planning level sets certain requirements for the planning at the lower level, where the plans of the higher level are applied in practice. Planning is an iterative process, where the experiences and knowledge gained at a shorter time-span are used for longer-term planning by the help of feedback. The availability of raw material and costs involved are highlighted in strategic planning. In annual tactical level planning the quality of raw material and its procurement security are highlighted, whereas in operative planning cost management is emphasized.

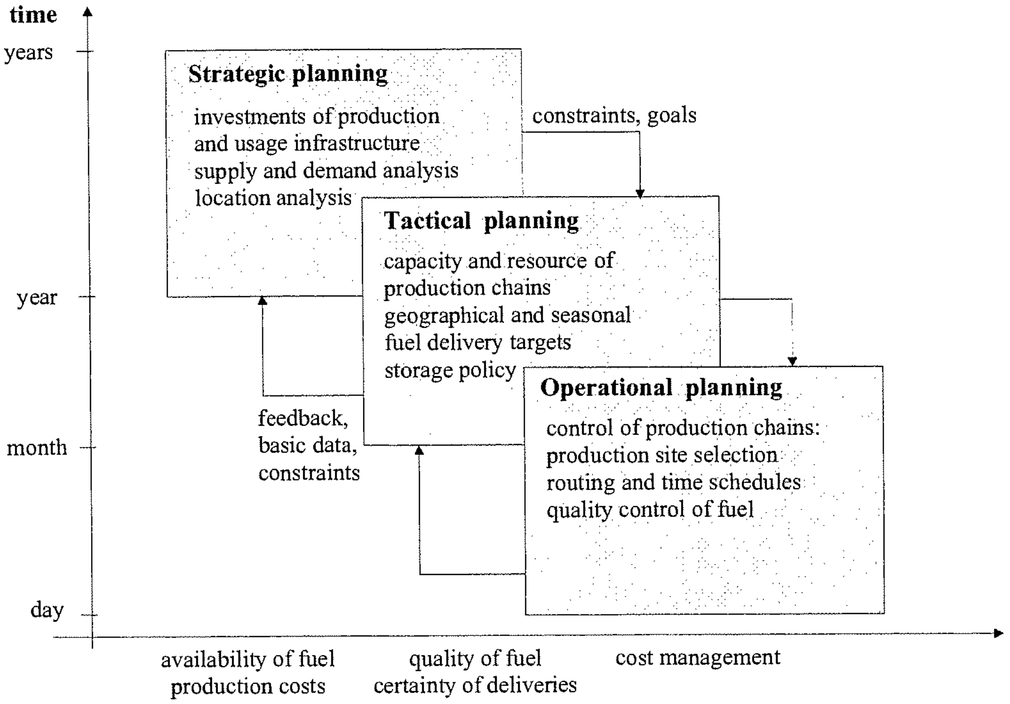


Fig. 14. Phases of logistics planning of forest fuel supply.

The aim of strategic planning is to study the user-based possibilities to use forest fuel, which is affected by the availability of forest fuel from different sources and the related level of procurement costs. Based on these studies, decisions can be made on investments in facilities and the forest fuel production capacity (e.g. chippers and crushers) and their schedules, either to begin or to increase the use of forest fuel in existing or new facilities. As a decision is made on the location of a power or heating plant, the availability and harvesting costs of the fuel on the alternative sites for the plant must be assessed. Availability at a certain cost level is connected to the selection of the supply chain. Moreover, a decision must be made on the form of the fuel arriving at the end-use facility so that arrangements can be made for receiving and storing the material.

Tactical annual planning aims at reaching the objectives of the fuel user as regards the certainty and quality of forest fuel delivery. To reach this, the supplier must plan storage-policy so that it supports the objective. On a tactical level, harvesting managers must decide, for example, the different raw material volumes for forest fuel production from each area periodically or annually. The average costs of harvesting and transportation must also be known so that the procurement amount can be optimized regionally. The aim is to use existing resources effectively throughout the year. The planning must give particular attention to seasonal changes in both forest fuel procurement and use. If the use of forest fuel at a power plant clearly varies periodically, the demand and supply must be balanced through storing.

The objective of short-term operative planning is to use the production resources in as appropriate a manner as possible to minimize procurement costs (e.g. Bowersox & Closs 1996, Christopher 1998). This includes selection of stands to be harvested and of harvesting methods, as well as scheduling of the harvesting process. A detailed handling order of stands and the operation schedule is usually made out to cover at least a week, while the long-term weekly or monthly user-specific delivery plans are implemented. The logistic planning highlights cost-management at this stage, which is aimed at using the existing forest fuel resources in an optimal way by paying attention to the limits of operation. When new procurement sites are adopted, an assessment method must be used to study for instance the productivity linked to the stand features of the site at least to some accuracy and its co-ordination with other resources by scheduling and location.

It is necessary to assess the harvesting costs of forest fuel at all decision-making levels. The costs are linked with the service level offered. Service level refers to satisfying the customers' needs. If the end-user values some specific technical quality or service, its cost impact must be assessed (Mentzer 2001). For instance, the certainty of the delivery of forest fuel throughout the year increases storage size, capacity need and planning, all of which add to the costs (Männistö 2000). The same applies to the drying of forest fuel. It is not unusual that different consumers place different demands on the fuel fraction depending on the size and type of plant, storing and processing facilities (Björheden 2000).

In logistics planning it should also be taken into account the degree of integration of forest fuel supply to industrial roundwood supply. The degree of integration may vary (Björheden 2000 and Asikainen 2001). While the higher level of integration gives the opportunity to exploit all the positive combinatory effects, it also raises the risk and degree of commitment. The highest degree of integration means the use of the same machinery for roundwood and forest fuel harvesting and running the whole operation under one management organization. The lower degree of integration can be the integration of information and management systems for roundwood and forest fuel harvesting. Due to different customer service level needs for roundwood and forest fuel, e.g. quality; fresh vs. seasoned, demand; even vs. bound to season, transported material type; unprocessed vs. processed, size and amount of customers; few vs. several, presupposed tailored logistics planning activities in each phase for both products. This adds complexity to the traditional forestry activities.

4.3 Logistics planning and design techniques

Logistics planning and design techniques are typically used during planning phases discussed earlier in section 4.2. In this context the decision support techniques are used in location, inventory and transportation analysis. The discussion includes the types of decisions that must be made, alternative analytical techniques, and typical analysis data requirements. The tools used to support decision making generally fall into the categories of analytical techniques, optimization or linear programming techniques, and simulation.

Medium and long-range strategic logistics planning and systems design, employ methodologies such as (Magee 1985):

- Cost element analysis
- Grid and graphic techniques
- Computerized "what-if" analysis
- Advanced programming techniques

The cost element analysis determines component logistics cost as a function of design variables and other important factors. It can be used for the determination of cost relationships for use in a more sophisticated model or comparison of alternative logistics system designs. The basic form of cost element analysis simply determines alternative cost functions (transportation, inventory, and other operating costs) as a function of basic variables. A more advanced form of cost element analysis allows a direct comparison of alternative logistics strategies, such as alternative networks of storage terminals. The interdependence of the elements of a logistic system requires accurate cost information for all of the system's elements when evaluating the entire logistic system, specific trade-offs, or individual components.

Grid- and graphic techniques can be used to determine where specific facilities should be located. GIS-based computer techniques are more powerful and versatile than manual Cartesian coordinate analytic techniques. Analytic grid- and graphic techniques generally describe methods that identify the center of gravity of logistics geography. They can be used to identify the general region where the best location appears and to estimate the cost of shifting the plant site away from this location. In the term, Geographical Information System (GIS), geographical relates to the fact that we are interested in data and attributes which have some sort of spatial identity and information system, is a set of organized procedures which, when executed, provides information to support decision-making (Fotheringham & Rogerson 1994). Location applications based on GIS-models are discussed in more detail in section 4.3.2.

Simulation modeling is simply an evaluation of all the costs of the logistics system based on approximate behavior for a given set of inputs. It has characteristics like an evaluation of a scenario, direct evaluation of logistics cost and iterative computerized implementations. Static simulation replicates the material flows and related costs of existing or potential logistics channel networks. The state of a system is defined in terms of the numeric values assigned to the attributes of the entities. For example the biomass in the network can be divided into lots, where each lot is followed through the network from the source of the location to the energy plant. The biomass flows can be based on a pull model (Mol et al. 1997), where the demand of the energy plant activates flows of lots in the network. The characteristics of the biomass, like dry matter losses, changes of moisture content and calorific value during storage, can be taken into account via the simulation model as Gallis (1997) has achieved via probability distributions. Nilsson (1999) has integrated geographical, climatic and biological data into the simulation model to analyze the performance and costs of various harvesting systems of straw. The replication capabilities of simulation mode create almost unlimited design possibilities and it does not require an explicit functional relationship.

Asikainen (1995) has applied discrete-event simulation in the modeling and analysis of timber and forest residue harvesting and transport at the operational level. The interactions that cause waiting and queuing have been modeled in alternative production systems. Instead of only average conditions being used in calculations via GIS-interaction it is possible to incorporate the regional aspect into the simulation model. Harvesting systems work in a large geographical area, where the conditions and worksite factors vary significantly. One approach is to select and describe stand characteristics to be used in the simulation through the use of library of mapped stands or through a stand simulator. The key variables could be described in terms of random distributions. For instance Asikainen & Nuuja (1996) have used the regional stand data from TASO-forest inventory database (include wood harvesting plans of private forest owners maintained by the Forest Development Centre TAPIO) for the simulation model concerning terrain chipping and long-distance transport, where the transport distances are based on exponential distribution function and the volume of logging residues per ha on the Erlang distribution function.

Optimization means finding the best single logistics design or the best flow of materials within a given or constrained design. Linear programming (LP) methods are used as an optimization technique. These methods are used to select the optimal course of action from several available options while considering specific constraints. The typical management problem with biomass-based fuels is to satisfy the energy demands at minimum cost under the constraints of limited amounts of available raw materials and processing capacities. It can be formulated as linear programming problem (e.g. Björheden 1997). Typically optimization models are used in an interactive manner like what-if simulations. The user poses scenarios and applies the model for their evaluation. The optimization model can be used to select the best network structure or the optimal mixture of biomass types. It may be used for decisions on the strategic level. The simulation model on the contrary will be preferred when the network structure is fixed or when only a few possibilities are taken into account. Simulation gives more detailed results on the biomass supply logistics. Through simulations also the risk connected with different solutions can be investigated. These can be useful for tactical decisions and sensitivity analyses. Further detailing on the simulation model can also make it applicable for operational decisions.

For a mathematical programming formulation, cost element analyses must be made for each relevant cost. When grid- and graphic or what-if simulation techniques are used, the assignment of a facility to a market is often a matter of least cost or shortest distance (Magee 1985). When capacities exist, the allocation of facilities to market, particularly when there are multiple items, becomes a complex problem with significant interactions. In those situations, mathematical programming and optimization represent the only reasonable approach. The simplest type of mathematical programming problem involving capacities is a logistics system known as the transportation problem, solved by network optimization. Network optimization treats the distribution channel as a network consisting of nodes (distribution centers) and arcs (transport links). Costs are accumulated for handling material at nodes and for moving material between nodes. The network model objective is to minimize the variable production, inbound and outbound transportation costs subject to supply, demand and capacity. The linear programming computer models are based on matrix-form of the Simplex-method, commonly called the revised Simplex-method (Dykstra 1984). Besides the use of the Simplex-method, many network models can be solved more efficiently by using problem-specific transportation algorithms, which take advantage of their simple geometric structure. Also GIS has been used together with transportation LP-models to point out potential LP-decision variables that do not meet certain spatial criteria (Palander 1998). Through visualization capabilities of map-representation within GIS, it is possible to use a participatory approach in the model formularization.

Sometimes there is a need to incorporate a dynamic time-element into linear-optimization models, especially with tactical decisions. For example the time-element of inventories can be programmed instead of the multiple period LP-model with the DLP-model (Väätäinen et al. 2002, Palander 1998). In the DLP-model the supply period is divided into sub-periods and the raw-material flow is controlled by balance equations between supply periods within a range of storage restrictions. If decision-rules of the model are time-dependent, the dynamic programming (DP) or simulation methods can be used. Dynamic programming has been used for example (Gigler et al. 2002) on optimization of biomass supply chains, where the biomass appearance and quality state as a function of process conditions has been incorporated into the DP methodology.

Typically the DLP or multiple period LP-models become larger and the demands for computing capacity will increase rapidly. For example Eriksson & Björheden (1989) used a multiple period LP-model to optimize forest fuel supply, i.e. to yield optimal production flows, storing and procurement from different raw-materials sources, supply regions and supply methods. Optimal solutions are derived for a problem with an infinite sequence of years, where each year is divided into six periods. Since storing affects the properties of the forest fuel and is dependable on raw-material type and storage period, most of the model is made up of string of activities as a result of the irregular pattern of energy-content changes during storing. Storing activities have been defined by type of material, period of purchase, period of delivery to consumer and, for processed material, the period of processing to keep track of the energy content.

4.3.1 GIS-modeling approach

The GIS is composed of digital geographic data (digital maps and tables of attributes linked to map identities) and the hardware and software needed to manipulate and display the data in a mapped format. The GIS, contrary to conventional maps or even computer mapping systems, is able to store, retrieve and display spatially referenced data. More definitely, GIS allows planners to perform spatial analysis by using its geoprocessing or cartographic modeling functions, such as map overlay, selection SQL (Structured Query Language) and thematic analysis, effectively synthesizing multiple layers of information. The GIS can be used to distinguish relationships among the data layers, and ultimately create new spatial data from the results of the queries and/or analyses. In essence, a GIS is a decision support system (e.g. Voivontas et al. 2001, Graham et al. 2000), which integrates spatially referenced data in a problem-solving environment. As such, a GIS is a management tool for analyzing systems characterized by a significant spatial component.

Another area of potential benefits involves a direct linkage of basic statistical techniques to the spatial query and selection functions of the GIS, and at the same time to derive spatial properties or relationships, such as area, distance, neighborhood, or distance along a network. This allows data transformation to draw on derived spatial aspects of the data as well as the range of normal mathematical and statistical functions. One could, for example, compute spatial averages of zones with a common boundary, or plot the correspondence between the values at locations and those at neighboring locations, where neighbors could be defined by a number of different spatial criteria. Spatial query would allow the user to interactively redefine the region studied and then summarize or plot values within that area or alternatively to partition the map into different regions and compare various summaries or plots between them. These would provide particularly useful tools for the exploration of heterogeneity and in distinguishing between local and global properties of any spatial variation (Fotheringham & Rogerson 1994).

Data linkage is one of the most fundamental methods of adding value to data. In most GIS the concept of polygon overlay is central to the process of linkage, where data is stored in layers which can be retrieved from GIS and then overlaid on top of each other to answer for example questions which production sites are most suitable for development of various biomass-types. Priorities may be attached to different criteria by using weighted polygon overlay. This simply allows one criterion to have more importance than others do in this elimination process. The overlay procedure is often undertaken in conjunction with spatial buffering, another standard feature of all proprietary GIS. Buffering enables the user to determine an area at a chosen distance from either a point location or a line feature.

Network analysis is one of the most frequently used components of a GIS and underpins much of its use in the utilities and transportation. Typical network analysis is the routing along routeways, which may have restrictions, like speed restrictions, one way systems or temporary blockages. Another important use of network analysis is the allocation of resources to predefined centers, normally based on minimizing total distance traveled. In a sense, this operates as a form of simple catchment-area analysis. GIS also offers the flexibility of adjusting parameters or customizing analyses to study possible changes associated with biomass resources. GIS is well suited for analyzing transportation costs in the cases where wood fuel must come from numerous sources in a wide procurement radius.

4.3.2 Location-allocation modeling in biomass supply

Biomass supply costs associated with logistics are affected by variable topographies and transportation infrastructures. It is therefore important to consider the location of power plants when reviewing the availability of biomass and the cost of biofuels. The importance of transport costs implies that regional differences in infrastructure and distribution of biomass resources in relation to the location of the end user will be an important factor in explaining regional differences in the economy of scale. Producing economically competitive biofuels from biomass, be it solid or liquid fuels, is strongly dependent on the availability of low-cost fuel sources, which will have spatial variation.

Power plants are likely to be located in proximity to fuel sources. The power plants location and the fuel supply problem can be approached through location-allocation modeling (e.g. Graham et al. 1996, Noon & Daly 1996, Cole at al. 1996).

In theoretical analysis, biomass procurement areas are often represented by perfect circles in inland regions or circle sectors for coastal areas. If the procurement area has a complete and uniform coverage by biomass and an infinitely dense net of perfectly straight roads stretching from the centre to the periphery, the average transport distance can be calculated from the radius of the procurement area. The average distance for a circle or a sector of a circle is 2/3 of the radius (Sundberg & Silversides 1988). The mathematical proof is formularized among others by Folin & Silver (1997). The practical transportation distance can be an average of about 10-20% longer, sometimes up to 30% longer, than the theoretical distance depending on local conditions. The difference depends on e.g. how developed the road infrastructure is and the straightness of the roads, i.e. the winding factor. These factors vary strongly between geographical regions (e.g. Haartveit & Fjeld 2000, Börjesson & Gustavsson 1996, Börjesson et al. 1997).

In many studies the winding factor is estimated for forest off-road transport (Sundberg & Silversides 1988, Samset 1990, Uotila & Viitala 2000), where it has varied between 1.2-1.6. Haartveit & Fjeld (2000) analyzed the winding coefficient also for a road network in Norwegian timber supply conditions, where it varied between 1.5-1.8, whereas under Swedish conditions values as low as 1.2-1.3 have been used (Börjesson & Gustavsson 1996). These values are more representative of southern Sweden, where the road infrastructure is more developed with mainly agricultural land than in northern Sweden where mainly forest and sparse road networks exists. For Finnish conditions varying values such as 1.3 (Väätäinen et al. 2002) and 1.7 (Viitala & Uotila 1999) have been used, but they are based on general assumptions, since no research results exist.

Another conclusion drawn from studies of this kind is that if a procurement area increases by factor X, the average transport distance will increase by square root of X, assuming that the area increases proportionately in all directions. If the procurement radius is doubled then the procurement area will be quadrupled. Assuming an even supply of material (here biomass) per unit area, the size of the procurement area is given by the ratio between the consumption of biomass of the plant and the quantity of biomass supplied per unit area. This could serve as a base case, which is compared with the actual situation in different regions like Haartveit & Fjeld (2000) have carried out in their study concerning timber supply to sawmills. The effects of the distribution of forest and the road net upon the average transport distance is explored to give a relative regional measure of raw-material availability.

Typically the location-allocation modeling attempts to find the optimal location of new facilities, which supply existing facilities in a least cost manner. The existing facilities are partitioned into groups. In each group the total demand of existing facilities equals the supply capacity of the new facility associated with that group. The global objective is to minimize the total transport cost, typically expressed in product of demand and distance (Lowe et al. 1988). With the biomass fuel supply problem the supply takes place in the opposite direction, where the new facilities will be power plants and the existing facilities fuel sources. There may exist a need to cluster these sources geographically in a least cost manner.

For plant location problems the objective is typically to minimize the combined costs of production and distribution of a product. For instance in the study (Folin & Silver 1997) concerning sawmill location, it is shown that the optimal location in relation to market depends on the relationship between the distribution cost and the timber transportation cost together with the yield of sawn wood and chips at the sawmill. High distribution cost and high yield draw the sawmill towards the demand centre whereas high timber transport cost, is indicative of the need for a location closer to the supply of timber. This kind of problem may be found also in forest fuel supply, when locating optimal terminal places for storing and comminution purposes.

Clustering analysis attempts to assign a population of individuals to groups with similar characteristics. In biomass fuel supply it is a question of finding the group centroids and clusters of geographical points that result from minimizing distances. Additionally geographical analysis frequently requires spatial contiguity of the grouped individuals. The simplest and most widely used clustering technique is the K-mean algorithm. The K-mean algorithm constructs a number of small subareas from the total area (Hartigan 1975). Each subarea consists of a number of supply demand points and a leading demand point such that every demand point in a certain subarea is within a selected distance from the leading demand point. The distance is selected so that it creates no more than the required number of subareas, i.e. clusters. This algorithm has been used for instance to identify potential power plant locations and their fuel capture areas (Scholes 1998).

A common method of defining regions of influence is constructing Voronoi polygons. Given discrete locations in the Cartesian space, Voronoi polygons are processed of splitting up a study area such that all points in the sample area are grouped into tiles according to the minimum distance between them and a previously sampled point (Boots 1986). Voronoi polygons are a special case of location-allocation modeling for the situation where all points will have weights equal to unity. The Voronoi polygons associated with the new facility locations contain all points to which the new facilities allocate resources. With reasonable assumption of high correlation between land area and available biomass supply, the Voronoi polygon definition of energy catchment is practical for systems strongly reliant on biomass. A fundamental process in such systems is the flow of biomass towards the energy demand centroids.

4.3.3 GIS applications in biomass supply

In addition to the development of a specific model there has been a significant number of reports on the application of geographic information systems to map the availability of biomass-based fuel resources with respect to the power plant or end-user facility (e.g. (Voivontas et al. 2001, Graham & Downing 1995, Withrow & Wichert 1996, Husain 1997, Roos et al. 2000). Candidate power plants are initially located at the centroids of the region objects and their technical characteristics are defined (Joutz 1992). The biomass collection area for each power plant is defined taking into account the maximum allowable biomass transportation distance and feasible power plants are identified. Also the competition for biomass among neighboring plants may be defined (Roos et al. 2000). Based on the potential suitability map and the size of the supply area, the plant-specific transport distances can be calculated (Broek et al. 1997). Moreover, the selection and design of biomass power plants have been the important issues of various supply studies in relation to the availability of biomass within a certain distance from the plant site (e.g. Voivontas et al. 2001). Along with the production and siting information, the developers of this modeling approach are beginning to define factors which may affect supply and cost and to consider the probable socio-economic impacts of conversion facility on the rural community (e.g. Perlack et al. 1997, Graham & Walsh 1995).

According to Cole et al. (1996) resource mapping and analysis have sometimes been carried out first for supply resource data and second there has been a developed algorithm to take these data, together with data sets on road networks and electricity grid interconnections, to show how much of this resource can be feasibly exploited. In many cases resource mapping has been based on a grid-type data format, where grids form a continuous spatial surface over the area under examination and each grid has aggregated attributes (Husain 1997). The results are presented as a thematic map of the various ranges of available potential and constitute one of the criteria used in the next steps for the site selection of the biomass conversion facility.

The purpose of geographical information is twofold. It shows the relevant stand data for the particular area under consideration, and provide information relating to the feasibility of locating biomass conversion facilities (i.e. power plants, conversion plant for upgraded wood fuel, comminution and grading terminals) in particular procurements areas. Comprehensive geographical databases are required to provide resource and stand information in order to assess procurement areas, and provide constraints for harvesting optimization rules (Knutell 1992). For example the estimated annual quantities of logging residues from a plot can be modeled as a function of the physical characteristics of the stand and the stand's likelihood of being harvested according to the owners willingness to give off residues. An inherent assumption can be set that regional harvesting characteristics are similar to those occurring over the past decade, but the levels were changed.

The GIS approach can also be used to model the demand side of the biomass economy by considering energy end-users and their willingness to pay for biomass fuel as in the nationwide survey of Finland (Puupolttoaineiden kysynnän..., 2000). This market price will be based on the end users current fuel base and price, production type (heat/electricity), the age of the energy conversion equipment, and annualized cost of biomass conversion facility. Availability of site specific data and privacy of end-user information may however make it impossible to use this approach.

Analysis of biomass resources, especially at plant level, requires a flexible platform, which can incorporate both the dynamic nature of biomass resources over time and the geographic variation in biomass resource distribution. Noon and Daly (1996) have developed a GIS-based system, "BRAVO", to address the challenges and uncertainties associated with biomass fuel resources using a plant-level approach. In essence, BRAVO, is a decision support system, which uses a GIS as its platform. It calculates marginal cost of delivering wood chips to a specific location along the road network and maps of farmgate prices with cultivated energy wood or roadside prices with forest residues from forestry. In a typical BRAVO run, the demand point is identified and a procurement area radius is specified by the user. All eligible resources are identified and their individual transportation costs per dry ton are calculated. The supply curves are determined by sorting the piles based on their delivered cost and then loading the demand point from these piles in a least-cost fashion. This model has been applied to produce cost-supply curves e.g. for delivered wood chips from short rotation woody crops (Graham et al. 1995) or switchgrass (Noon et al. 1996) for alternative, hypothetical, bioenergy plant locations.

Graham et al. (1996) at Oak Ridge National Laboratory (United States) have further developed the above mentioned plant-level GIS-based modeling system to be able to evaluate large geographical regions and capture the geographic variation in the major factors that determine supply and cost of biomass feedstock derived from energy crops. The system incorporates soil quality, climate, land use and road network information, with transportation, economic, and environmental models to predict both where energy crops are grown and the marginal cost of supplying biomass from energy crops to specific locations. The resulting set of marginal price represent a spatially continuous cost surface for delivered energy crop. The modeling system has five basic components. The first component maps cropland that is potentially available for biomass production. The cropland map is at 1 km^2 resolution (i.e., 1 km^2 pixel size). The second component of the system defines both the expected farmgate price of biomass production and the environmental characteristics of growing conventional crops and growing biomass for each 1 km^2 area. The third component calculates the potential farmgate supply of biomass and maps the marginal cost of delivering biomass to any destination in the predefined region. The fourth component identifies, maps and ranks, based on minimizing the marginal cost of delivered biomass, all the sites in the region where bioenergy facilities might be located. The identification and ranking, which are based on minimizing the marginal cost of delivered biomass feedstock, take into account both facility size (i.e. annual demand for feedstock) and intersite competition for potential biomass supplies. The marginal cost of supplying a certain amount of biomass to the destination is the supply cost of biomass from the pixel that would supply the last lot of that amount of biomass. The fifth component quantifies the changes in soil erosion, nutrient loss, runoff, and pesticide movement off site that is associated with growing the biomass supplies for each of the predicted facility sites. This model has been used also for sizing and locating analysis of ethanol plant facilities (Graham et al. 1996) with biomass feedstock derived from switchgrass.

5 MATERIAL AND METHODS

5.1 Material and methods for supply-cost calculations

5.1.1 Time study method

Time studies are used to determine the input-element of productivity, to study factors affecting productivity and to develop work methods by eliminating ineffective time (Harstela 1991). The aim of time studies is to analyze how the time consumption varies with the influencing factors, sometimes by means of average times for each of the influencing factors and sometimes by means of functions describing the relationship between time consumption and influencing factors. The time input per output unit, i.e. efficiency, will be used such as min/m^3 (solid). The time unit will be converted to monetary values by multiplying the time consumption with the hourly cost of resources (manpower, machines, tools) used. The other aim of a time study is to investigate the productivity as a result of performance in individual studies. It is the ratio of output to a particular input. For operational methods in forestry the productivity is usually given as quantity per time such as m^3/h. The function for the time consumption will afterwards be transformed into productivity by calculation. Dry mass data are important from the utilization point of view, whereas fresh mass data are more useful for transport cost calculations and machine design.

The most important factors of working conditions having effect on productivity in forest residue harvesting are:

- Work object: tree species, form, volume and concentration of logging residues.
- Terrain conditions: slope, soil type and bearing capacity, size and number of obstacles and other unevenness, snow cover.
- Climatic factors: temperature, rainfall and humidity.
- Site conditions: size and location of work-sites and landings (e.g. off-road and on-road transport distances).

Productivity of forest activities should be studied from a holistic perspective over the whole supply chain. The factors of working conditions will have a significant effect on productivity via their effects on specific sub-operations. These sub-operations are divided in to work-cycle elements with detailed motion studies. The work is broken into elements to obtain a more detailed view of the work-cycle. An element is a distinct part of a specified job selected for convenience of observation, measurement and analysis. A work-cycle can be defined as the sequence of elements, which are required to perform a job or yield a unit of production. The sequence may sometimes include occasional elements. Elements should be easily identifiable, with definite beginnings and endings so that, once established, they can be repeatedly recognized. A break point is the point of time at which one element in a work-cycle ends and another begins Kanawaty 1992). Different elements require different inputs for the worker or a machine. Furthermore, separate elements are affected by different worksite factors (Samset 1990). The operations of forest machines working at terrain can be divided into two main sub-operations, moving and raw material handling. Terrain conditions, forwarding distance and concentration of raw material, will be factors, which affect time consumption of moving operations. Correspondingly raw material types, piling (location, size and shape) and climatic factors will affect time consumption of raw-material handling.

In this study the operations, like logging residue forwarding by forwarder or terrain chipping were divided into further sub-operations, like loading, driving, forwarding with or without load and unloading, which were further divided into time elements on the grounds of loader arm motions of the machine in question. These time elements were illustrated by the aid of box charts (see Fig. 16, Fig. 15 and Fig. 19).

The time elements are usually within the limits, which the timekeeper can master. The smallest units are recorded by stop-watch recording equipment. These may be divided into direct element times (main time), which directly changes a work-object, and indirect element times (by-time) which indirectly changes the work-object. The smallest time elements, which are observed during the time study, are the main times and the by-times as well as delay times. The total working time per object is the sum for all these elements during the work on the object, per day on the working place and per season (Samset 1990).

In this study the time elements and related time-motion data were recorded on a Husky Hunter 16 handheld field computer equipped with Siwork3 time study software maintained by Danish Forest and Landscape Research Institute. Time studies were carried out as cumulative timing, where the watch ran continuously throughout the study. It was started at the beginning of the first element of the first cycle to be timed and was not stopped until the whole study was completed. At the end of each element the watch reading was recorded. The individual element times were obtained through successive subtractions after the study was completed. The purpose of this procedure was to ensure that all the time during which the job was observed was recorded in the study. According to Kanawaty (1992) the cumulative timing has the advantage that, even if an element is missed or some occasional activity not recorded, it will not have any effect on the overall time.

Time studies are based on observations of a short period. Thus reliable material for seldom-occurring work elements have not been obtained. Many of the delay times happen at irregular intervals and their duration varies discontinuously. Therefore, it is difficult to find a time function for most of the delay times. They are, however, period dependent and it is generally accepted that the length of the delay time consumption varies in proportion to the length of the effective time. Usually the delay time is given as a percentage of the effective time. It takes usually a longer period to find a good average for the delay times than to find the function describing the variation of the effective time with the influencing factors. It is often necessary to carry out one study for the effective time and a longer statistical study to find a good average for the delay times (Samset 1990). Also commonly used constants or percentage-figures have been used to predict these time elements. It should be also noticed that the short-term time studies almost always give a higher productivity than in practice. Long-term surveys give a more correct conception about real productivity (e.g. Kuitto et al. 1994).

In this study effective time was measured as E_0 and gross effective time E_{15}. Effective time was the time required to perform a specified work-element, directly or indirectly changing the work-object in regard to its form, position or state. Effective time was divided into main time and by-time. Gross effective time (E_{15}) included the effective time with the addition of delay times shorter than 15 minutes. This was useful with follow-up studies, where rougher methods were used for timing and some of the delay times were shorter than the registration accuracy, for instance 15 minutes. Owing to the phenomena of irregularity in delay times, they were based on existing follow-up studies concerning the same kind of operations.

In this study the follow-up studies were based on blank-sheets, that the operators filled in after each working shift. These blank-sheets included information on time consumption, work condition factors and production output. The disadvantage of this kind of method was that the people who were involved in daily production were too occupied to place the necessary enthusiasm in this kind of extra work. Some machines like chip trucks also had recording instruments like GPS (Global Positioning System) to assist in the analysis of time consumption. Also the power plant's truck scaling data were used, like time of arrival, unloading time, time of departure and loads weight and moisture content.

Based on the existing literature (e.g. Kärhä 1994, Kuitto et al. 1994) and experience, only the most important influencing factors were selected to avoid a too large experimental operation in this study. These selected factors, like forwarding distance and residue concentration, were varied at a range covering the typical practical working conditions.

5.1.2 Operators

Time consumption in forest harvesting operations is affected by many factors that are difficult to record or even estimate. Among these are human-oriented factors like operator concentration and external pressure. They heavily affect the process, but are difficult to monitor with precision. Therefore, they are bound to introduce a comparably high level of uncertainty into any harvesting model (Spinelli & Hartsough 2001a).

If the research operations take place at different work places and with different workers at each place, errors may arise due to the variation in the worker's performance capacity. If the influencing factors differ from one work place to another, the variation of the worker's performance capacity may lead to incorrectly estimated functions between the dependent and independent variables. Some kind of adjustment for the worker's or operator's individual performance level is needed to eliminate the influence of the worker's or operator's performance capacity on the time consumption (Samset 1990).

Performance rating, however, is based on subjective estimates and is difficult to carry out on forest work. Therefore it can not be approved as a scientifically acceptable method (Nordisk avtale..., 1978). In industrial time studies subjective performance rating is widely used. This may lead to an acceptable result since the working conditions are constant and mostly standardized. In the forest time studies the working conditions are not homogenous. They vary from place to place and season to season depending on climatic conditions and amount of light. There are hardly two trees with identical conditions as regards the working environment. Therefore the forest is vastly different as a working place compared with more even working conditions found in industry.

One approach to deal with the problem of performance rating has been developed in Scandinavia by the design of comparative studies, the principle being that a workers are not representing a population of workers but they are compared with themselves. The biological variation in man is thereby excluded (Sundberg & Silversides 1988). In a comparative time study the same workers has been working in varying work conditions. It is assumed that workers react to the changes in conditions in such a way that their ratio of time consumption remains at the same level and it is independent of the worker. Harstela (1991) has found, that the principle of comparative studies seems to work, if the work methods require similar abilities, and the motivation (and effort) of the worker is consistent.

5.1.3 Time study of terrain chipping

Time studies of terrain chipping were made both in spruce and pine-dominated regeneration stands with terrain chippers to achieve time consumption functions. The productivity per m^3 solid and per MWh was determined based on these time consumption functions. Time consumption was linked to worksite factors, which were easily measured, like forwarding distance and residue concentration and to machine factors like load capacity.

Time study raw material were gathered in 1999-2000 (Asikainen et al. 2001) and in 1998-1999 (Oijala et al. 1999). All details related to time study material can be found in these reports. Time studies were made in both cases using the same research-methods and research personnel to be as comparable as possible. This time study material was further analyzed and calculated for the purposes of this study.

In total 40 separate loads were studied, produced both from seasoned (brown) and fresh (green) raw material (see Appendix 1). The term, brown was used, when it was a question of seasoned material, where part of the needles had dropped off and the color of needles had changed to brown. However, the moisture content varied regardless of material color, due to various weather conditions and harvest time.

It was assumed that there were not any considerable differences of working skill between drivers. All drivers were experienced in forwarding of round wood, but the work experience from logging residue forwarding was minor. However, all drivers could be regarded as having adequate practice concerning the working technique.

The terrain chipping of logging residues was divided into five separate work elements (Fig. 15). Each element was further divided into immediate part-time, which was explained by the features of the stand, and into so-called indirect auxiliary time.

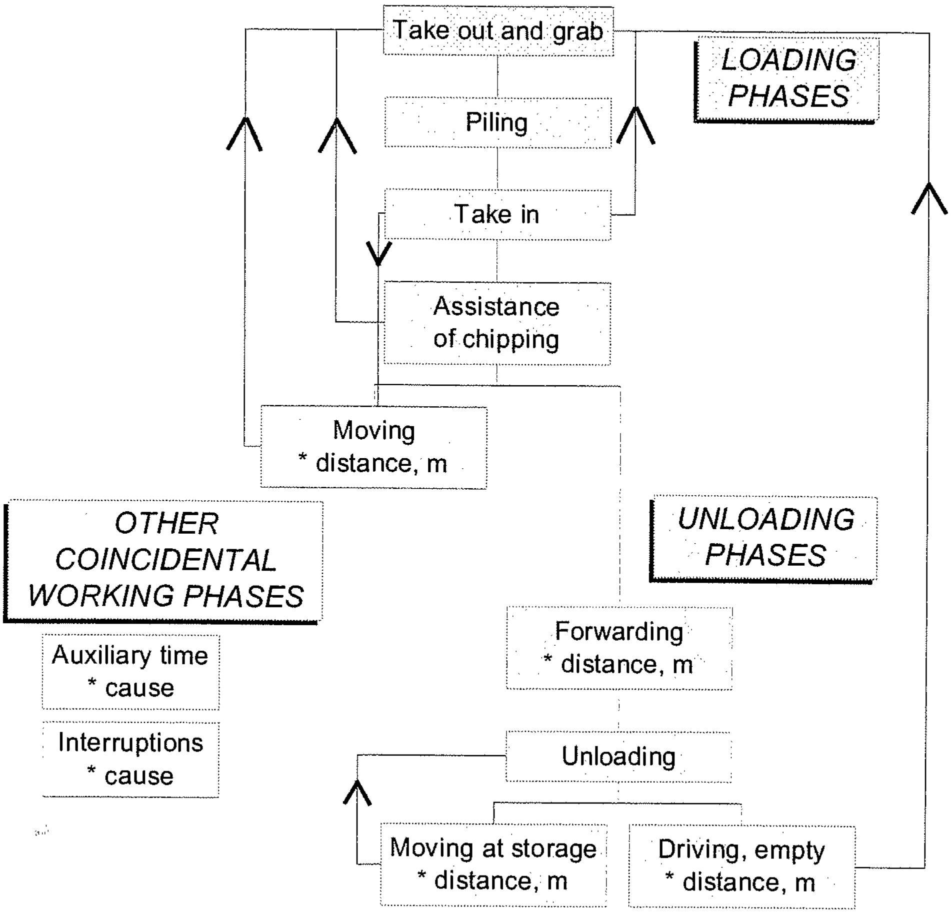


Fig. 15. Production time-elements of terrain chipping.

The empty driving element began, when the chipper started from the landing and ends, when the chipper reached the first loading site at the terrain. The loading element began, after the chipper had reached the first loading site and extended the loader arm. The loading element ended, when the last grab of residues had been taken in and the loader arm had been put into the drive position. The loading element included the out and in movements of the loader arm, piling movements, loading assistance movements at load and other auxiliary loading functions. The driving element included movements between logging residue piles and other auxiliary driving functions. Forwarding element with load began, when the chipper set off for the landing with a full load and ended, when the chipper had reached the roadside container storage at landing. The unloading element began, when the chipper had reached the roadside container storage at landing and ended, when the load was emptied and the chipper was ready to go back to the terrain. The unloading element included movements at the container storage site and unloading assistance.

Forwarding distance, load size, residue concentration and the moisture content of raw material were selected as the dominant independent variables of time consumption of terrain chipping because of common knowledge and previous experiences. Residue concentration had a larger effect on the terrain chipping like on logging residue forwarding, since the loading phase took the main part of the time consumption. Moisture content of raw material and composition of stand was taken into account when the productivity was calculated per energy content. Also in the survey made for Italian chipping operations (Spinelli & Hartsough 2001a) the material density per area was observed to have a distinct effect on productivity in terrain operations, where the repositioning time per residue ton was inversely related to density.

Loading on terrain

The grapple load size was the main independent variable of the time consumption in the loading time-element. Pile size at the stand was on the other hand the main independent variable of the grapple load size. The larger the piles at stand the easier it was to grab larger grapple load sizes The pile sizes were calculated on the grounds of residue concentration. The relationship between residue concentration and pile size was assumed to be linear. The grapple load size was to some extent dependent of chipper type.

Time consumption of loading was formulated as:

$$t_l = t_{laux} + \left(b_0 + b_l \times \ln(V_{grapple}) \right) \qquad (5.1 - 1)$$

$R^2 = 0.84$, $|z_t| = 14.3 \geq t_{0.975}(38)$

Where:

t_l = Loading main time, min/m^3

$t_{laux} = 0.64 \pm 0.36$, Loading auxiliary time, min/m^3, average ± dispersion

$V_{grapple}$ = Grapple load size, m^3

$b_0 = -2.49$, $b_l = -1.78$, Regression coefficients

Grapple load size function was formulated as:

$$V_{grapple} = b_2 + b_3 \times \ln(a_l \times d) \qquad (5.1 - 2)$$

$R^2 = 0.47$, $|z_t| = 5.0 \geq t_{0.975}(28)$

Where:

$V_{grapple}$ = Grapple load size, m^3

$b_2 = 0.072$, $b_3 = 0.022$, Regression coefficients

$a_1 = 0.06$ = Regression coefficient, $a_1 * d$ = Pile size, m^3

d = Residue concentration, $m^3/100$ m strip road

Driving at terrain

The main independent variable in the driving time-element was residue concentration. The pile size was defined as in the loading element by the aid of residue concentration. The auxiliary consumption time of driving varied mainly due to chipper type.

The driving main time was defined as a regression model, where the correlation between time consumption and residue concentration was formulated in the form of an inverse function. The correlation was good, since the coefficient of determination (R^2) was 0.93.

Time consumption of driving was formulated as:

$$t_2 = \left(\frac{t_{2aux}}{a_1 \times d}\right) + \left(b_0 + \frac{b_1}{d}\right) \qquad (5.1 - 3)$$

$R^2 = 0.93$, $|z_t| = 25.9 \geq t_{0.975}(33)$

Where:

t_2 = Driving main time, min/m^3

$t_{2aux} = 0.023 \pm 0.052$, $t_{2aux} \geq 0$, Driving auxiliary time min/driving time

$b_0 = 0.14$, $b_1 = 3.07$, Regression coefficients

$a_1 = 0.06$ = Regression coefficient, $a_1 * d$ = Pile size, m^3

d = Residue concentration, $m^3/100$ m strip road

Forwarding to roadside storage and driving empty back to terrain

The forwarding distance was the independent variable for time consumption in forwarding time. Driving speed was to some degree higher without loads than with loads. Also the driving distance was shorter without loads than with load contrary to the time study made for the forwarder. In addition, the load size did not have any significance on driving speed contrary to logging residue forwarding by a forwarder. On the other hand, there was not a large variation of load size within the chipper type. Typically some part of the forwarding took place along the forest road, where the driving speed was higher than in an off-road part at stand.

Time consumption of empty driving was formulated as:

$$t_3 = \frac{\left(b_0 + b_1 \times l_{empty}\right)}{V_{load}} \qquad (5.1 - 4)$$

$R^2 = 0.84$, $|z_t| = 13.0 \geq t_{0.975}(33)$

Where:

t_3 = Time consumption of empty driving, min/m^3

l_{empty} = Driving distance, empty, m, $l_{empty} = 0.94$ * Average forwarding distance

$b_0 = 0.26$, $b_1 = 0.017$, Regression coefficients

V_{load} = Load size, m^3

Time consumption of forwarding with load was formulated as:

$$t_4 = \frac{\left(b_0 + b_1 \times l_{load}\right)}{V_{load}} \qquad (5.1 - 5)$$

$R^2 = 0.83$, $|z_t| = 12.6 \geq t_{0.975}(33)$

Where:

t_4 = Time consumption of forwarding with load, min/m^3

l_{load} = Forwarding distance with load, m, $l_{load} = 1.06$ * Average forwarding distance

$b_0 = 1.11$, $b_1 = 0.017$, Regression coefficients

Unloading at landing

The circumstances at the landing and the chipper type also influenced time consumption of unloading. The variation of the main time of unloading was small due to the speediness of the dumping method. If the storage place was not suitable for instance due to terrain conditions, the auxiliary time formed the major share of the time consumption.

Time consumption of unloading was formulated as:

$$t_5 = t_{5aux} + t_{5main} \qquad (5.1 - 6)$$

Where:

t_5 = Unloading time, min/m^3

$t_{5aux} = 0.27 \pm 0.32$, $t_{5aux} \geq 0$, Unloading auxiliary time min/m^3

$t_{5main} = 0.31 \pm 0.13$, Unloading time, min/$m^3$

The time consumption of terrain chipping of logging residues, min/m^3, was calculated as a sum of production elements.

$$t_{total} = t_1 + t_2 + t_3 + t_4 + t_5 \qquad (5.1 - 7)$$

The time consumption per load, t_{load}, was calculated multiplying time consumption, t_{total} by load size, V_{load}.

$$t_{load} = t_{total} \times V_{load} \qquad (5.1 - 8)$$

The share of interruptions under 15 minutes was only 1% of the gross effective time. So there was not a large difference between the gross effective E_{15} and effective E_0 time consumption in this kind of short time study. By the aid of a long-term follow-up study, the level of interruptions and the level of productivity could be defined. For instance Laurila & Vesisenaho (1997) found in their time and follow-up study of terrain chipping, that the share of under 15 minutes interruptions was 25% higher than the average level observed in this time study. In their study, the productivity (E_{15}) of terrain chipping was 15-20 m^3/h loose when the average forwarding distance was 200 m. Oijala et al. (1999) observed even higher productivity, 23-26 m^3/h loose, but it was a short time study, where the share of working interruptions was lower than normal in longer follow-up studies.

The work element-based time consumption model was simplified to a multivariate linear regression model, where the independent variables were forwarding distance, load size and residue concentration. The model was constructed by using followed ranges for independent variables: forwarding distance 100-400 m, load size 4-10 m^3 and residue concentration 4-16 m^3/100 m strip road.

The regression model was formulated as:

$$p = b_0 + b_1 \times l + b_2 \times V_{load} + b_3 \times d \qquad (5.1 - 9)$$

Where:

p = Productivity, m^3/ E_0-h

b_0, b_1, b_2, b_3 = Regression model coefficients

l = Forwarding distance, m

V_{load} = Load size, m^3

d = Residue concentration, m^3/100 m strip road

The reason for the coefficient of determination being below one (0.96) for all independent variables was, that the time consumption model presented earlier was not completely linear as a function of independent variables. The most significant independent variable for the terrain chipping was forwarding distance, which accounted for 60% of productivity, m^3/h, variation. Load size accounted for 24% and residue concentration 12% correspondingly.

The regression model for terrain chipping is as follows:

$$p = 7{,}69 - 0{,}010 \times l + 0{,}49 \times V + 0{,}21 \times d \qquad (5.1 - 10)$$

When the productivity was calculated per energy content, the direct conversion from volume basis, m^3/h, productivity was used instead of using moisture content as the additional independent variable. There was the same problem of correlation between residue concentration and moisture content for the seasoned material as was with the logging residue forwarding.

5.1.4 Time study of forwarding

Time studies of forwarding were made both in spruce and pine-dominated regeneration stands during the same period and in the same manner as residue forwarding. All details concerning time study material can be found from the study by Asikainen et al. (2001).

In total 65 loads were studied (see Appendix 1). Separate forwarding loads were not weighed, but load sizes were individually estimated on a volume basis at the forwarding stage. Later material flow or output was analyzed on the basis of chip truckloads after roadside chipping. The loads of the chip truck were weighed at the power plant, where also the moisture content was analyzed for each load. The volume of chips, m^3 loose, was obtained on the basis of the volume of the chip truckload. Volume of logging residues, m^3 solid, was calculated by multiplying the loose volume by the conversion factor 0.40, i.e. the average density of chips.

The period between forwarding and roadside chipping was short, except in stands where both green and brown logging residues were forwarded to roadside storage. The storage period for forwarded green material, was 10 months, and for forwarded brown material, 8 months. According to storage studies in that particular stand (Hillebrand & Nurmi 2001), the needle mass decreased during storage to half the forwarded green material and to one third of the forwarded brown material compared with the initial state before forwarding. There was already significant needle loss in the initial state before forwarding of green material. The needle mass was less than a quarter of the average fresh material, because of the dry weather conditions between the logging and the forwarding phase. The needle loss during the storage period was taken into account, when calculating the material flow in the forwarding phase. The possible material loss during the chipping stage was not taken into account. On the basis of an ocular estimate the loss was minor, since at the loading phase, most needles were carried along with a grapple to the wide feeding table of the chipper. Also the piling techniques affectd the degree of loss.

The forwarding phase was divided into five separate work elements as in forwarding of logging residues with a forwarder (Fig. 16). Similar work element analysis was used by Kuitto et al. (1994) for commercial wood forwarding and Kärhä (1994) for logging residue forwarding. However, the time consumption functions applied to forwarding of logging residues (Kärhä 1994) were mainly obtained by adjusting the functions for forwarding of industrial roundwood (Kuitto et al. 1994). Modification was done on the basis of Swedish studies from logging residue forwarding (Wigren 1992).

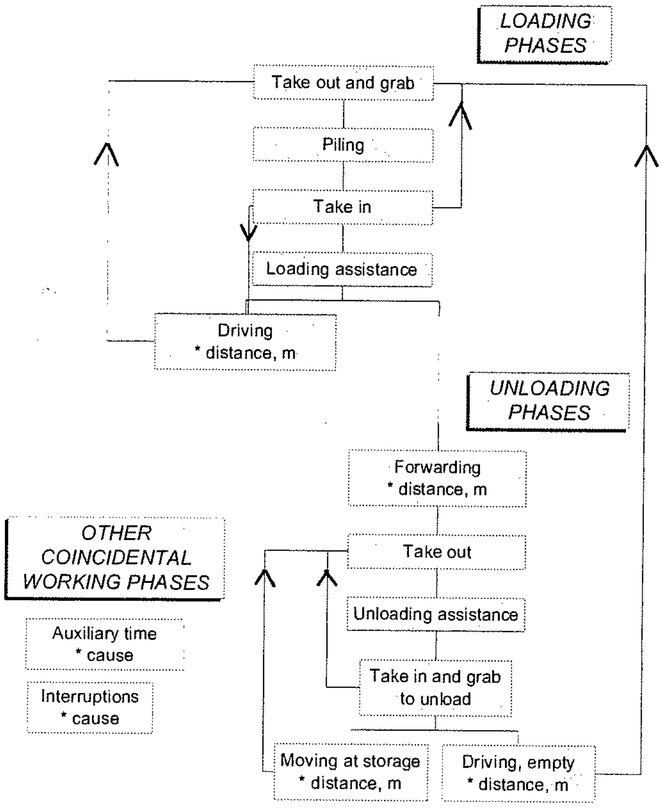


Fig. 16. Production time-elements of forwarding.

In this study the independent variables, like forwarding distance and residue concentration were the same as in the study made by Kärhä (1994), but the contents and format of functions differed to some extent. In this study, time consumption of separate time-elements were described as a function of forwarding distance, load size and residue concentration. It was discovered that the logging residues were piled alongside with round wood logging and the forwarders had special equipment such as a logging residue grapple.

The forwarding distance, load size, residue concentration and moisture content of raw material were selected as the dominant independent variables of time consumption of forwarding like in the terrain chipping. Also the driving speed had an effect on the productivity, since the driving speed defined the forwarding performance of the vehicle together with the load capacity. For off-road vehicles, driving speed is typically low, only some kilometers per hour, due to the uneven ground surface and slopes (Asikainen 2000). Also the share of off-road and on-road forwarding affected the driving speed. Variation in load sizes resulted from different forwarder types for different load spaces, driver preferences and loading techniques. Load capacity effected strongly on the productivity, since the output of each work-cycle equaled the load volume. Limits for load capacity were set by the gross mass of the machine, which effected the vehicle mobility and rut formation on the other hand. Large load volumes caused problems when the machine had to be drive on narrow skid trails or forest roads on uneven terrain.

Loading on terrain

The loading time-element was constructed like for terrain chipping. The variation in pile sizes was large due to the variation of success in piling. For instance in wintertime the degree of success in piling was poorer when part of the branches were broken into smaller pieces alongside commercial wood logging. In this study the average pile size during the winter period was 0.58 m^3 solid and during the summer period 0.82 m^3 solid, i.e. 42% larger during summertime. The same kind of phenomenon was noticed also in other studies (Oijala et al. 1999, Ahonen & Tervo 2000).

A special grapple suited to logging residue handling was used in all experiments. Ahonen & Tervo (2000) compared both a traditional timber grapple and a logging residue grapple with the same tractor. By using a logging residue grapple, the productivity of loading rose by 33% and unloading by 18% compared with a timber grapple. By using the logging residue grapple, load size was almost 45% larger than by using the normal timber grapple. The reason for this was that the grapple sank into the pile better and the grapple was wider than the timber grapple (Alakangas et al. 1999).

Time consumption of loading was formulated as:

$$t_l = t_{laux} + \left(b_0 + b_1 \times \ln(V_{grapple}) \right) \qquad (5.1 - 11)$$

$R^2 = 0.86$, $|z_t| = 19.5 \geq t_{0.975}(63)$

Where:

t_l = Time consumption of loading, min/m^3

$t_{laux} = 0.59 \pm 0.26$, Loading auxiliary time, min/m^3

$b_0 = 0.059$, $b_1 = -0.78$, Regression coefficients

The grapple load size function was formulated as:

$$V_{grapple} = b_2 + b_3 \times \ln(a_1 \times d) \qquad (5.1 - 12)$$

$R^2 = 0.74$, $|z_t| = 15.1 \geq t_{0.975}(63)$

Where:

$V_{grapple}$ = Grapple load size, m^3

$b_2 = 0.29$, $b_3 = 0.12$, Regression coefficients

$a_1 = 0.06$ = Regression coefficient, $a_1 * d$ = Pile size, m^3

d = Residue concentration, m^3/100 m strip road

Driving on terrain

The driving main time was defined as a regression model, where the correlation between time consumption and residue concentration was formulated in the form of an inverse function like for terrain chipping. The accumulation per hectare for pine was smaller than that for spruce, and thus also the time-loss for forwarding per cubic meter was bigger. Seasoning on terrain also reduced the accumulation, as did winter harvesting, if for instance, covering snow or frosty weather caused problems for harvesting. The pile size was defined as in the loading element by the aid of residue concentration. The auxiliary consumption time of driving varied mainly due to forwarder type features.

Time consumption of driving was formulated as:

$$t_2 = \left(\frac{t_{2aux}}{a_1 \times d}\right) + \left(b_0 + \frac{b_1}{d}\right) \qquad (5.1 - 13)$$

$R^2 = 0.74$, $|z_t| = 15.2 \geq t_{0.975}(63)$

Where:

t_2 = Time consumption of driving, min/m^3

$t_{2aux} = 0.04 \pm 0.03$, Driving auxiliary time, min/driving time

$a_1 = 0.06$ = Regression coefficient, $a_1 * d$ = Pile size, m^3

$b_0 = 0.25$, $b_1 = 2.44$, Regression coefficients

d = Residue concentration, $m^3/100$ m strip road

Forwarding to roadside storage and driving as empty back to terrain

The driving speed was to some degree higher and the driving distance longer when driving empty than for forwarding. In time study stands, the load sizes were 3.3-9.1 m^3 solid. The distance did not have any significance in off-road driving speed such as load size. The larger the load sizes the slower the speed.

Driving speed of forwarder as a function of load size:

$$v_{load} = b_0 + \frac{b_1}{V_{load}} \qquad (5.1 - 14)$$

$R^2 = 0.59$, $|z_t| = 3.6 \geq t_{0.975}(9)$

Where:

v_{load} = Driving speed, m/min

$b_0 = 24.6$, $b_1 = 96.3$, Regression coefficients

V_{load} = Load size, m^3

Time consumption of forwarding was formulated as a linear function of the forwarding distance. The effect of load size to driving speed was taken into account, by the aid of a delay factor.

Time consumption of empty driving was formulated as:

$$t_3 = \frac{(b_0 + b_1 \times l_{empty})}{V_{load}} \qquad (5.1 - 15)$$

$R^2 = 0.89$, $|z_t| = 26.2 \geq t_{0.975}(63)$

Where:

t_3 = Time consumption of empty driving, min/m^3

l_{empty} = Driving distance, empty, m, l_{empty} = 1.06 * Average forwarding distance

$b_0 = 0.50$, $b_1 = 0.018$, Regression coefficients

V_{load} = Load size, m^3

Time consumption of forwarding with a load was formulated as:

$$t_4 = \frac{(b_0 + b_1 \times l_{load})}{V_{load} \times z} \qquad (5.1 - 16)$$

$R^2 = 0.85$, $|z_t| = 21.2 \geq t_{0.975}(63)$

Where:

t_4 = Time consumption of forwarding with load, min/m^3

l_{load} = Forwarding distance with load, m, $l_{load} = 0.94$ * Average forwarding distance

$b_0 = 0.87$, $b_1 = 0.019$, Regression coefficients

V_{load} = Load size, m^3

z = Delay factor, larger loads slow down the driving speed

$$z = \frac{v_{load}}{v_{empty}} \qquad (5.1 - 17)$$

Where:

v_{load} = Driving speed as a function of load size, m/min

v_{empty} = Average driving speed without load = 50 m/min

Unloading at landing

Forwarders were equipped with a logging residue grapple, which made it possible to use larger grapple load sizes than with a timber grapple. The grapple size was the main independent variable for time consumption in unloading as in the loading element, although the correlation was not so evident. The grapple load size in the unloading element was almost double compared with the loading element.

Time consumption of unloading was formulated as:

$$t_5 = t_{5aux} + (b_0 + b_1 \times \ln(V_{grapple})) \qquad (5.1 - 18)$$

$R^2 = 0.23$, $|z_t| = 4.3 \geq t_{0.975}(63)$

Where:

t_5 = Unloading time, min/m^3

$t_{5aux} = 0.20 \pm 0.23$, $t_{5aux} \geq 0$, Unloading auxiliary time, min/m^3

$b_0 = 0.28$, $b_1 = -0.40$, Regression coefficients

$V_{grapple} = 0.38 \pm 0.09$, Grapple load size, m^3

Also in this case the difference between gross effective (E_{15}) and effective (E_0) time consumption was minor (1%) and the statistics from long-term follow-up studies were needed. For instance Kuitto et al. (1994) found in their time and follow-up study of commercial wood forwarding, that the share of under 15 minutes interruptions was 8%. Also the time consumption was on average 22% longer in a follow-up study than in a time study. Ahonen & Tervo (2000) found in their study the same kind of results for logging residue forwarding, since the share of under 15 minutes interruptions was 9% and time consumption on average 22% longer in a follow-up study than in the time study. Whereas in the time study of logging residue forwarding by a agricultural tractor, the share of interruptions was as high as 18% (Nätt & Mutikainen 2001).

The work element-based time consumption model was simplified to a multivariate linear regression model in the same manner and using the same ranges for independent variables as with terrain chipping of logging residues. The most significant independent variable for the forwarder was forwarding distance, which accounted for 68% of the observed variation of productivity. Load size accounted for 16% and residue concentration 12% respectively.

The regression model for forwarding by a forwarder is as follows:

$$p = 10{,}80 - 0{,}015 \times l + 0{,}42 \times V + 0{,}21 \times d \qquad (5.1 - 19)$$

The above mentioned worksite factors affected the time consumption distribution of forwarders and terrain chippers. The example, presented in Fig. 17 provides a given value for productivity factors: forwarding distance 250 m, residue concentration 10 m^3/100 m strip road and load size 6 m^3. The results were based on the time consumption functions presented in this chapter. The share of loading was clearly higher in terrain chipping than in logging residue forwarding with a forwarder, since the grapple size was smaller and the auxiliary time higher with a terrain chipper. However, the time-loss per cubic meter of loading was notably smaller than in forwarding of logging residues, despite the smaller grapple size. This depended on the speed of the loader operation. The unloading time-element consisted of 10% of the total time consumption, which was clearly less than in logging residue forwarding.

With long forwarding distances, the time spent driving both without and with load increased appreciably, which clearly reduced the productivity of both methods (Fig. 18). However, the driving speed and load sizes were typically higher with terrain chippers than with forwarders. The range of productivity resulted from variation in load sizes and residue concentrations. The residue density had less effect on the time-loss and forwarding was quicker than in forwarding of logging residues with a forwarder.

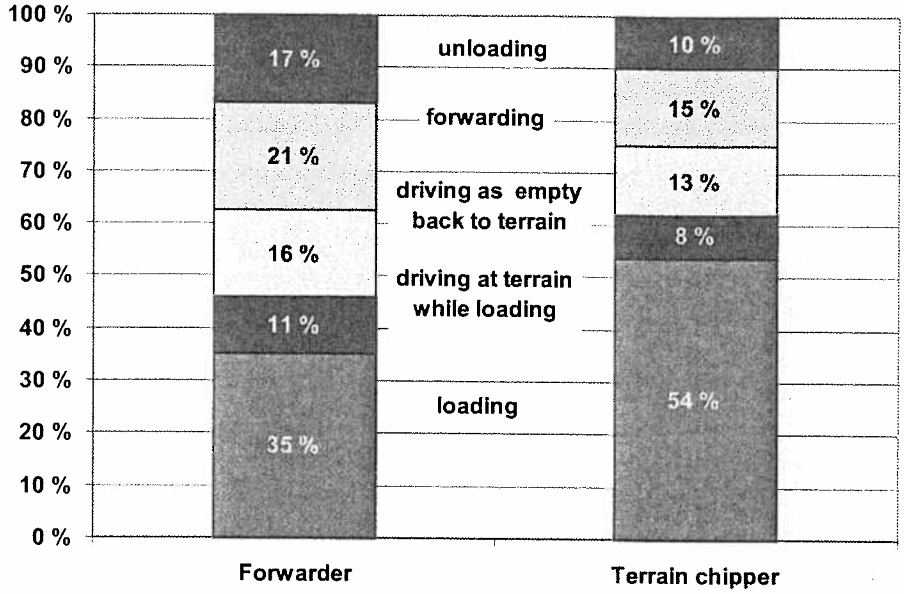


Fig. 17. Average relative proportion of the elements in forwarding and terrain chipping of logging residues.

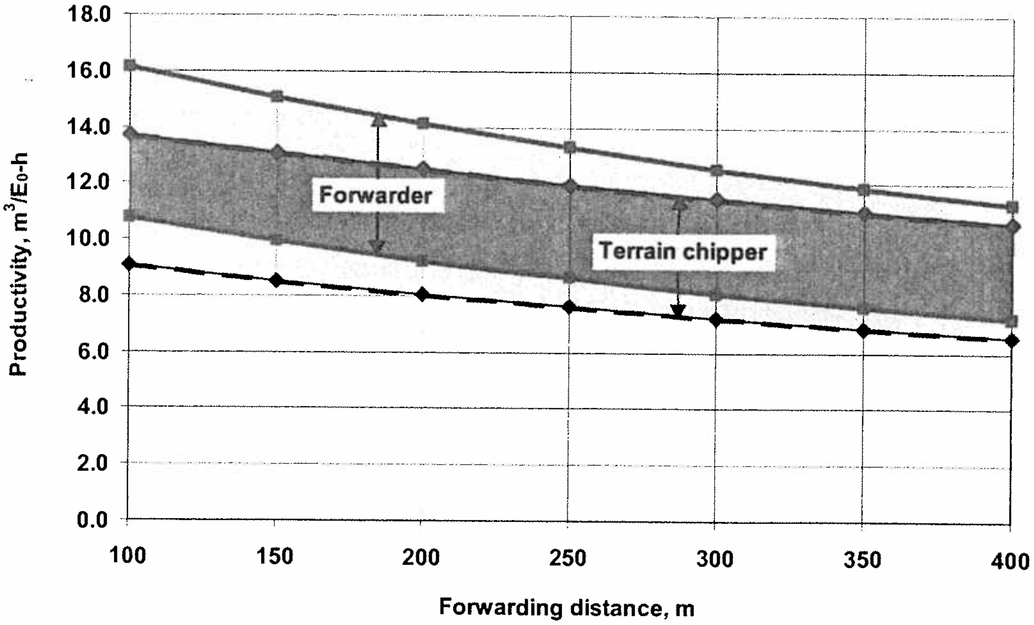


Fig. 18. Productivity, m^3/E_0-h, of forwarding and terrain chipping as a function of forwarding distance for different load sizes, 4-8 m^3, and residue densities, 4-16 m^3/100 strip road.

Despite the previous results (Asikainen et al. 2001), that the productivity of both forwarding and terrain chipping of logging residues from pine-dominated stands will be to some extent lower than those obtained for spruce stands at the same forwarding distance, stands with good terrain conditions, enough accumulation and near end user site should be considered feasible recovery sites. The terrain of the pine-dominated stands time studied were better than on average, and hence its results cannot be generalized to include all pine stands or compare directly with results of spruce stands. However their contribution to residue recovery can be significant in pine-dominated areas.

5.1.5 Time study of roadside chipping

The effect of the raw material, chipping period and productivity on roadside chipping or crushing was time studied by making paired comparisons: spruce/pine logging residues, fresh/dry, summer/winter period and logging residues/whole tree. Time study material were gathered in 1999-2000 (Asikainen et al. 2001) and in 1998-1999 (Oijala et al. 1999). Time studies were made on both drum chippers and hammer crushers. These mobile, truck-mounted machines represented a comprehensive sample of used machine types in Finland. The chips were moved to the chip truck either by a blower or by a conveyor belt.

In the time study the roadside chipping time was divided into immediate loading time, which was further divided into work elements in the work-cycle, and into so-called indirect auxiliary time (Fig. 19).

The productivity of roadside chipping was affected by the characteristics of raw material, storage and working site arrangements and the features of the chipper, like engine power and characteristics of the infeed table. According to the time studies made by different chippers and crushers, the average productivity was calculated from each machine and raw material used. Also the average grapple load size was defined (see Appendix 1).

According to these calculations, average proportional productivity per material and chipping period were defined, where fresh spruce logging residues in summer time had the reference level 100 (Fig. 20). In general, the productivity varied between 60 and 100 m^3 loose per effective working hour. As a result, the raw material and the seasoning (fresh/dry) had a significant effect on productivity. The whole-tree chipping was faster than logging residues due to an easier and more efficient feeding and also the features of the material and its behavior in the chipping process. Also the impurity content was typically lower in the whole tree piles, which made the chipping process faster. The proportion of various wood species in the chipped material did not seem to have any significant effect on the productivity of roadside chipping.

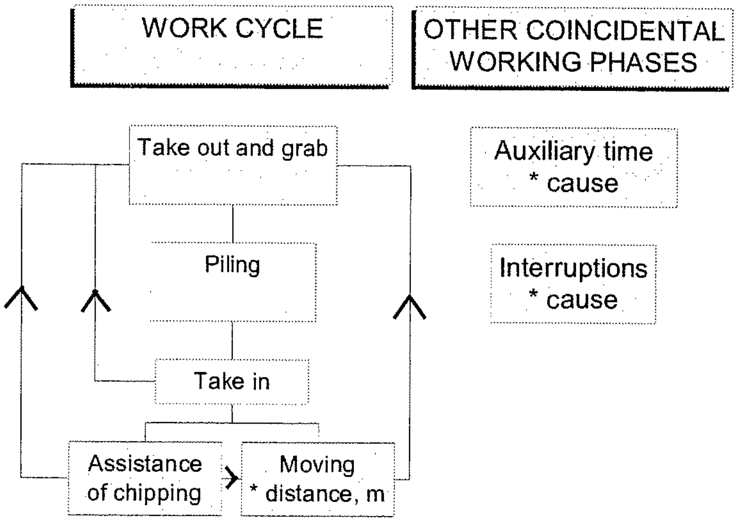


Fig. 19. Production time-elements of roadside chipping.

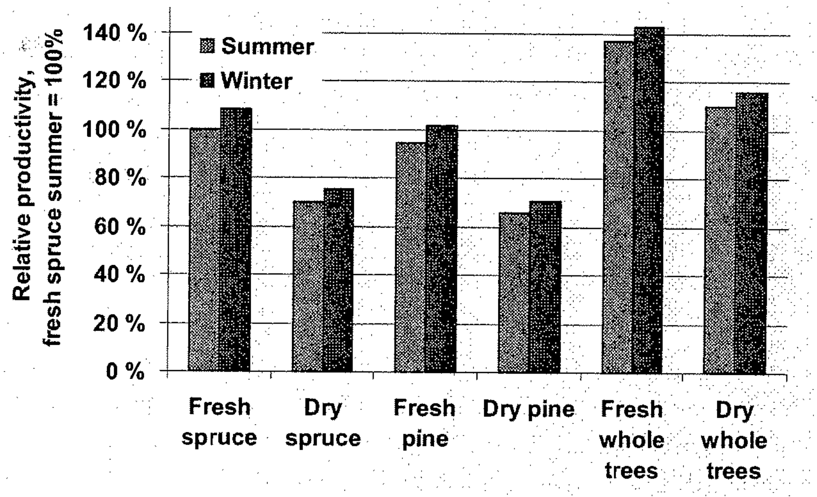


Fig. 20. The relative productivity of the roadside chipping with different raw materials, logging residues from fresh spruce in summer = 100% (Asikainen et al. 2001).

Fresh logging residues were faster to chip than dried, because dried material was harder to cut. Green slash was easier to handle with the grapple and caused less wear on the chipper blades but it had a high moisture content. Also older slash does not hold together well, making it harder to manipulate (Desrochers et al. 1993). The drying up of logging residues may reduce the productivity of chipping by up to 25-33% (Asikainen et al. 2001, Hämäläinen 2000). With hammer crushers, this kind of reduction in productivity did not exist. The chipping period also affected the productivity of chipping. Chipping was more productive in winter than in summer. This seemed to be because frozen logging residues were more easily fed into the chipper and their structure were more easily broken. Hence the power needed for chipping was reduced and productivity increased. However sometimes there was snow on top of the pile and material was frozen throughout. This was considered as a work-difficulty factor, which slowed down the work efficiency. For instance in some follow-up studies of a mobile roadside chipper, the snowiness and frozenness were reported to make the chipping more difficult (Vesisenaho 1995, Spinelli & Hartsough 2001a).

5.1.6 Time study of bundling

The effective productivity (E_0) of bundling was 22.8 logs per hour for green spruce, 19.3 for brown spruce and 22.0 for pine residues in Finnish conditions. The volume of logs as m^3 solid was 0.59 m^3 for fresh spruce, 0.47 m^3 for seasoned spruce and 0.44 m^3 for fresh pine residues correspondingly. The freshness, i.e. seasoning time, and composition of stand had an obvious relationship to the productivity of bundling with the Fiberpac-370-bundling-machine. The productivity was highest with fresh spruce, 13.4 m^3/E_0-h. With seasoned spruce the productivity was 4.4 m^3 units lower and with fresh pine residues 3.7 m^3/E_0-h respectively. One reason for this difference in productivity was that residue logs remained looser with seasoned or pine raw material. In addition the residue density alongside strip roads was one explanatory factor for time consumption, since the share of driving time increased due to lower residue densities and the productivity decreased. In pine stands, where the time study was made, the residue density alongside strip roads was on average 5.5 $m^3/100$ m, whereas in fresh spruce stands it was 14.7 $m^3/100$ m and seasoned spruce stands 9.3 $m^3/100$ m (see Appendix 1).

In Swedish conditions the productivity (E_0) of bundling with Fiberpac-370 was as high as 27.6 logs per hour for fresh and 23.5 logs per hour for seasoned spruce logging residues (Andersson & Nordén 2000). Also in that study the productivity was lower for seasoned material. In Sweden, the experience from this method is longer and therefore also its productivity has reached higher levels than in Finland. The stand features has also been more favorable for the method in Sweden. For example during a time study made by Korpilahti (2001), the productivity was 20 logs per E_{15} and by Poikola (2002) 18 logs per E_{15}. Due to the method is new and it is in the early stages of the learning curve, there seems to be potential to improve the productivity further in Finland.

5.1.7 Time study of long-distance transportation

The economics of trucking is affected by terminal work at the loading and unloading phases, travel speed, work organization, effective annual working time, and the skill and motivation of the drivers. Terminal times at the end-use facility and storage site are production chain- and end use site-specific, and there exist large variations. Time consumption of transporting is typically formulated as a function of driving distance (Asikainen 1995, Ahonen & Tervo 2000) and they are based on functions made for timber trucks. The general assumption of a linear relationship between distance and time consumption may not be true in reality. For instance, the longer the distances, the higher the average transport speed will be within certain limits due to e.g. a better average road class.

According to the follow-up study of chip trucks (Ranta et al. 2002, Halonen & Vesisenaho 2002) the driving speed as a function of distance was formulated as:

$$v_{load} = 14.96 + 9.86 \times \ln(l) \qquad (5.1 - 20)$$

$R^2 = 0.51$, $|z_t| = 10.3 \geq t_{0.975}(110)$

$$v_{empty} = 14.79 + 10.30 \times \ln(l) \qquad (5.1 - 21)$$

$R^2 = 0.51$, $|z_t| = 10.7 \geq t_{0.975}(110)$

Where:

v_{load} = Driving speed with load, km/h

v_{empty} = Driving speed as empty, km/h

l = Driving distance, km

In total there was 112 loads. There was no major difference between driving speed with or without load. In theory the driving speed approached the maximum allowable driving speed alongside with increasing transport distance.

According to the follow-up study (Ranta et al. 2002, Halonen & Vesisenaho 2002) made for chip trucks or trucks using interchangeable chip containers, the time consumption between terminal times and driving time was distributed as in Fig. 21. Loading and unloading took 32-41 % of the total time cycle of transportation, with a two or three container system, when the transportation distance was 60 km. The time consumption of terminal times was to some extent higher compared with results obtained in a Swedish operational environment (Andersson 2000b).

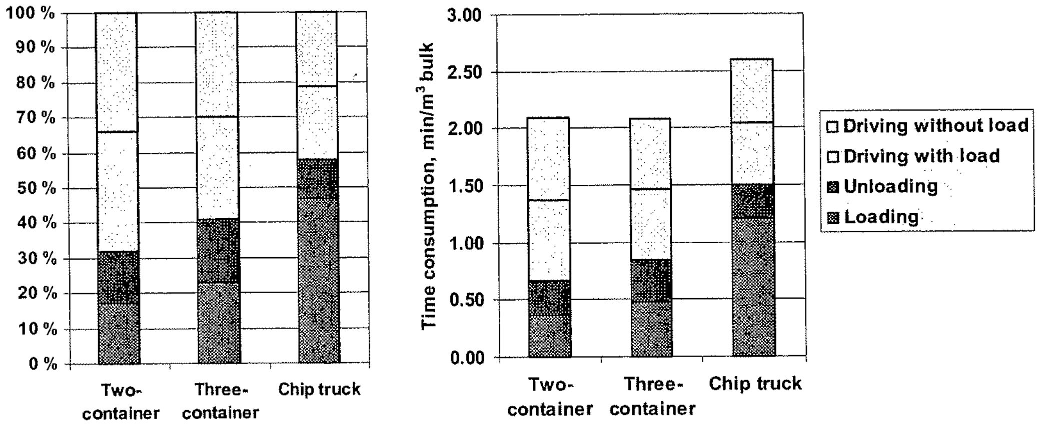


Fig. 21. Time consumption of long-distance transportation of chips, transport distance 60 km (Ranta et al. 2002).

5.1.8 Cost calculation method

The definition of the procurement costs of fuel produced from logging residues can be defined as in Fig. 22 and Fig. 23. The scale of operation and operational environment are the starting points of procurement logistics planning. The selection and scaling of production chains were based on the desired annual amount of forest fuel delivery and the storing policy required by the availability and quality of fuel. The availability at a desired cost level depended on worksite and work policy factors that affect the productivity of the individual work stages of the various production chains differently.

One important implication was that many of the cost elements within a single supply chain were interdependent. For example, if there were losses in storage, the quantity of dry matter at purchase and harvest was proportionately increased to compensate the loss. The quantities at handling and transport were be adjusted together with the storage quantity itself. The increased quantities for each activity element were reflected in increased elemental costs and in increased total cost.

The starting point for analyzing logging residue supply systems was to use the supply chain option models. These models represented alternative systems for delivering logging residues from the stand, where it was a by-product of the timber logging, to the power plant, where it must meet specifications as a fuel. The different systems were distinguished by a processing method and the location of the processing, by transport methods, and by storing policy.

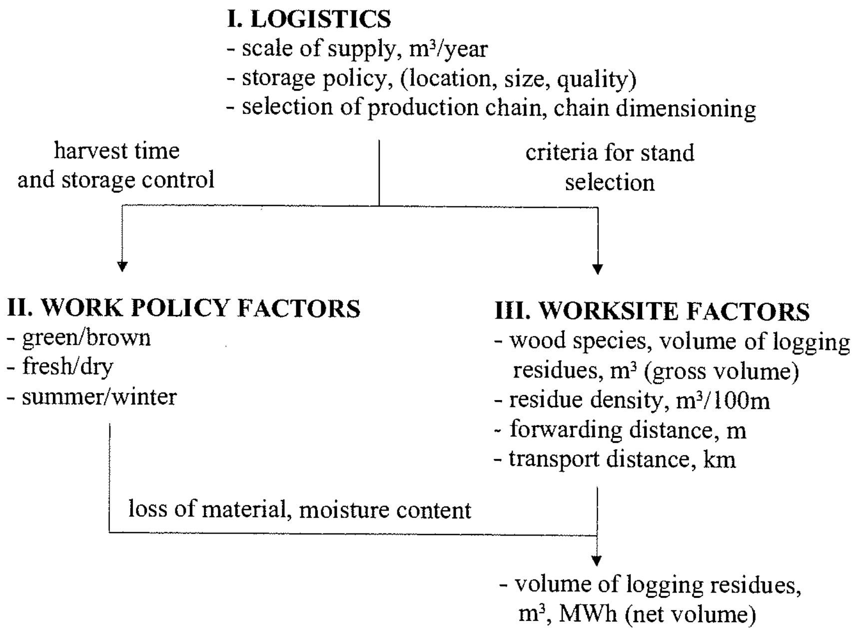


Fig. 22. Cost factors of forest chip production.

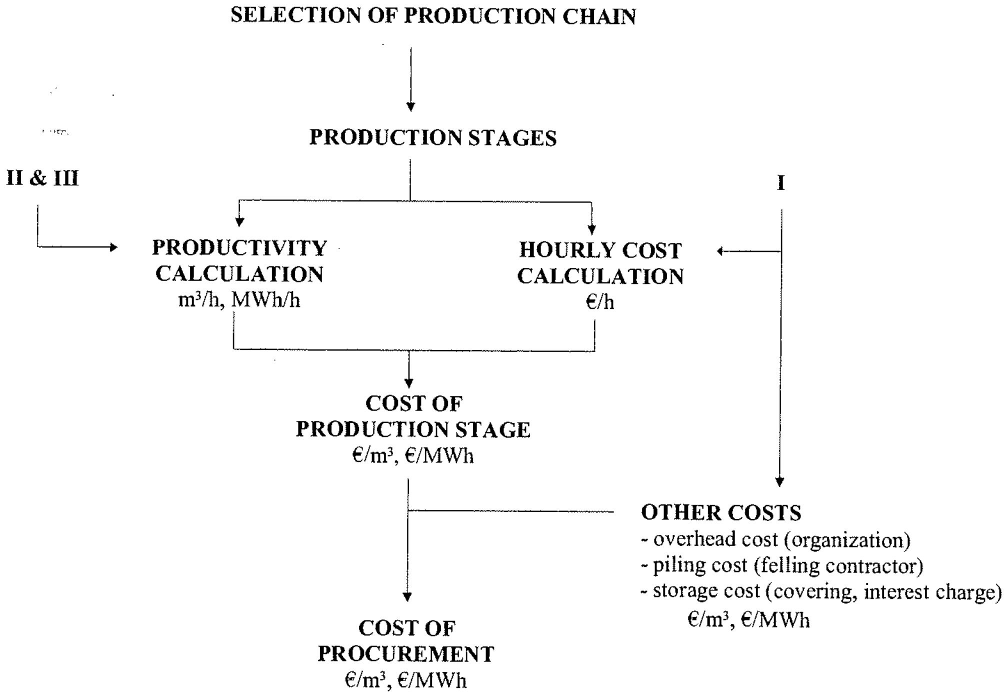


Fig. 23. Production cost of forest chips (I, II, III see Fig. 22).

In this study the annual working time of machines was assumed to be 3 000 h, which was equivalent to a two-shift operation over 9 months. For chip and container truck the working time was assumed to be lower, 2 250 h, since they had typically excess capacity in relation to chipping capacity. Investment cost was based on the survey made by Asikainen et al. (2001). Capital cost was calculated by the annuity method, by using an interest rate of 6% and residual value of 45% for machines and 35% for chip- and container trucks. The lifetime of machines and transport vehicles was estimated to be 15 000 h. Hourly cost of transport vehicles was divided between driving and terminal time. All cost were per gross effective hour, which included delays shorter than 15 min. Replacement values instead of second-hand values as investment cost were used. Initial cost data is listed in Appendix 1.

The cost structure of supply chains was defined by the decentralized production method, like terrain and roadside chipping and centralized production method like end-use facility crushing of loose logging residues or logging residue logs (Fig. 24).

The cost structure of the supply chain was divided on the grounds of type of costs, where the cost types were capital, operating and labor cost. They were further divided between the variable and fixed costs. Variable costs were dependent on the level of activity, i.e. how much of the capacity was utilized over a certain period. Fixed costs were not dependent on the level of activity instead they were time dependent. Capital cost consisted of depreciation of machines and interest on capital, which were fixed costs. Operating costs consisted of fuel and lubricant costs, maintenance and repair of machines being as variable cost part, insurance and administrative costs being as fixed cost. Labor costs consisted of wages including side costs and profit margins. Labor costs were either variable or fixed costs or partly both depending on the payroll system. According to comparison of cost types between different supply chains, there were no significant differences (Fig. 25). The share of capital costs was on average 25%, labor cost 35% and operating cost 40%.

Productivity of different production stages and costs were based on time-consumption functions reported earlier in this chapter and hourly costs, which are reported in Appendix 1. Details concerning initial data of calculation are reported in Appendix 1. Cost calculations as a case study were based on stand data of regeneration fellings around the city of Jyväskylä region at a maximum of 100 km transport distance along a road-network. The content of the stand database, the calculation method of logging residue amount and stand selection criteria are reported in more detail at section 5.2.2. The average values of worksite factors in this procurement area were as follows: spruce 60%, pine 24%, broadleaf 16%, felling area 2.6 ± 2.3 ha, forwarding distance 181 ± 84 m, logging residue density, 66 ± 45 m^3/ha, residue concentration along a strip road 9.5 ± 3.0 m^3/100 m, transport distance max 100 km. For seasoned residues, the logging residue density was 59 ± 40 m^3/ha and residue concentration along the strip road was 8.4 ± 2.6 m^3/100 m.

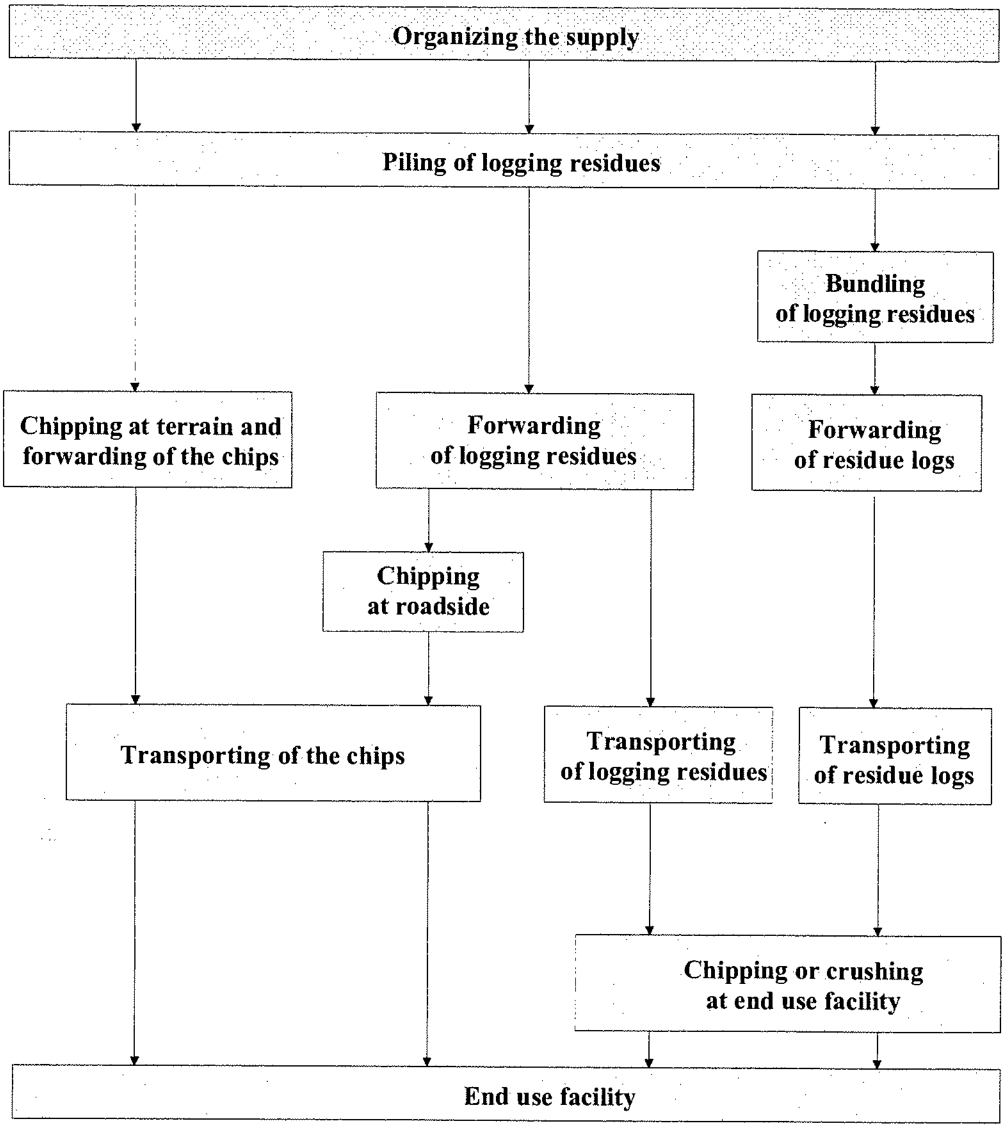


Fig. 24. Production stages of different production chains.

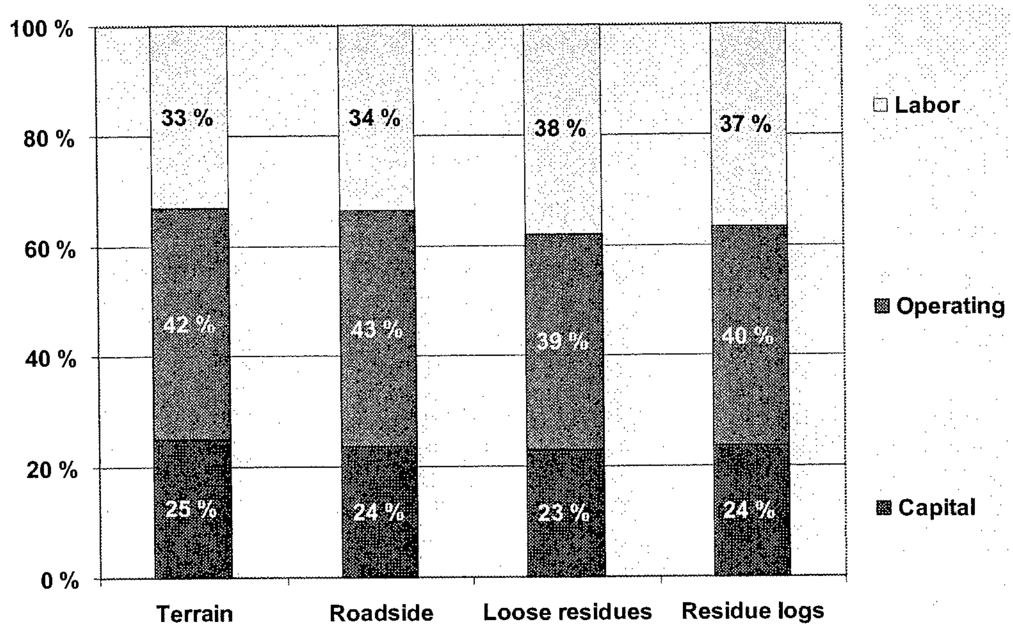


Fig. 25. Cost structure of logging residue supply chains by type of cost (Asikainen et al. 2001).

Seasoning of logging residues presupposes storing at terrain or at roadside before comminution. At the end use facility the period will normally be short due to limited storage capacity. When the comminution stage was based on terrain chipping, the material was seasoned at the terrain. In wintertime the terrain chipping method produced mainly green chips unless it was used at roadside terminals. Therefore the terrain chipping option should be kept as rather theoretical in this context, since an all year round operation in terrain conditions will not succeed for seasoned material. When the comminution was based on roadside chipping or end facility chipping of loose residues, the material was first seasoned at the terrain in summertime and later at the roadside before comminution or the transport stage. When the comminution was based on end facility chipping of logging residue logs, the material was bundled in the form of green and the storing phase took place at the roadside before transport stage. The bundling of seasoned material led to much higher production costs due to lower bundling productivity and smaller residue logs (see section 5.1.6). Therefore it was assumed that the bundling and forwarding stage of residue logs had been made with green material prior to the storage period at the roadside.

For seasoned supply policy there were the following cost effects:

- The moisture content of logging residues was lower, which led to a higher net calorific value per volume unit recovered (for initial values, see section 5.2.3).

- Due to shedding of needles during seasoning there were material-losses, which led to a lower logging residue density m^3/ha and lower yield per stand (for initial values, see section 5.2.3). For logging residue logs the material loss was lower, since the bundling and forwarding stage took place in the green form. During storage of residue logs it was assumed that 5% material loss occurred. The seasoning led to longer transport distances and increased moving activity between stands to get the same amount of material. The trade-off between changes of material loss and moisture content gave the final result for production cost.

- Due to lower logging residue density, the productivity of terrain chipping and forwarding per m^3 were lower. Productivity per MWh was higher due to a higher calorific value (see sections 5.1.3 and 5.1.4).

- The productivity of chipping at the terrain or the roadside was lower due to changes in material handling. In this calculation case, the productivity was 10% lower for seasoned material. At the end-use facility the productivity stayed at the same level for green and brown material due to the comminution method, i.e. hammer mill or rotor crushers (see section 5.1.5).

- The storing phase caused storage costs like the covering cost of the piles and interest capital tied to storage. In this case the interest rate was 6% and the average storage period 8 months.

Supply costs nhave also divided into roadside cost, transportation cost and overhead cost. With the centralized method the term roadside cost can be replaced by terminal cost including central comminution after transport.

The supply cost function was formulated as:

$$y_{cost} = b_0 + b_1 \times l \qquad (5.1 - 22)$$

Where:

y_{cost} = Marginal/Average cost of supply, €/MWh

b_0 = Roadside + overhead cost, €/MWh

b_l = Transport cost, (€/MWh)/km

l = Transport distance, km, 0-100 km

5.2 Material and methods for GIS-analysis

5.2.1 Model description

A great deal of attention has been focused on national and regional biofuel potential assessment during the past decade in Finland. The purpose of these surveys (Helynen & Nousiainen 1996, Malinen & Pesonen, 1996, Pesonen & Määttä 1999, Helynen 1999) has usually been the estimation of the logging residue potential and other biomass sources and their contribution on energy supply nationally or in a certain area. The execution of surveys has been for example (Helynen 1999, Helynen & Nousiainen 1996) to evaluate alternative scenarios under different assumptions of energy technology and economics in the long term. Although the gross statistics are valuable for broad national calculations, they are seldom specific enough for residue management planning or feasibility studies. Also province-level surveys (Pesonen & Määttä 1999) concerning forest residue recourses and potential user locations have been studied. However the wood fuel supply is not restricted according to province frontier, which might cause problems when interpreting the results of the survey, although the supply is typically restricted at a procurement area with a maximum of 100 km transport distance.

Typically the forest residue potential is calculated as ratio basis according to forest management plans (e.g. Helynen & Nousiainen 1996, Keskimölö 1997), which has been further restricted by different percentage estimates in order to evaluate the technical, economical and ecological criteria. In some studies also forest owner's willingness to give off forest residues without compensation (Rämö & Toivonen 2001) or expectations of stumpage price (Pesonen & Määttä 1999) is taken into consideration in residue potential calculations.

Some demand-driven studies estimate the market penetration of bioenergy, given specified development of energy end-use demand and competitiveness of other energy sources (Helynen 1999, Helynen & Nousiainen 1996). Energy scenarios at national level (Energy Economy..., 1997 & Energy Visions..., 2001) have been based on factors of vital importance to the consumption and production of energy. The demand analysis has contained a study of different alternatives for the supply of energy as well as estimations of CO_2 emissions based on different supply structures and the role of bioenergy within it. Other resource-focusing studies estimate the physical biomass resource base that may be available for energy purposes (Malinen & Pesonen 1996, Pesonen & Määttä 1999). These studies could be described as inventories of potential biomass sources, with an evaluation of possibilities to use the sources for energy purposes.

The targets for developing a model in this study were to create a spatially scalable and flexible, easily updated decision system that could predict and analyze regional geographic variation in logging residue feedstock costs and supplies. The other purpose was to evaluate the existing power plant locations and identify the optimal locations for new forest residue conversion facilities in Finland. The modeling environment and interrelationships are illustrated in Fig. 26. Besides regional potential calculations, there was a possibility also for site specific either resource or demand side focusing analysis, which has not been possible with the models discussed earlier in this section.

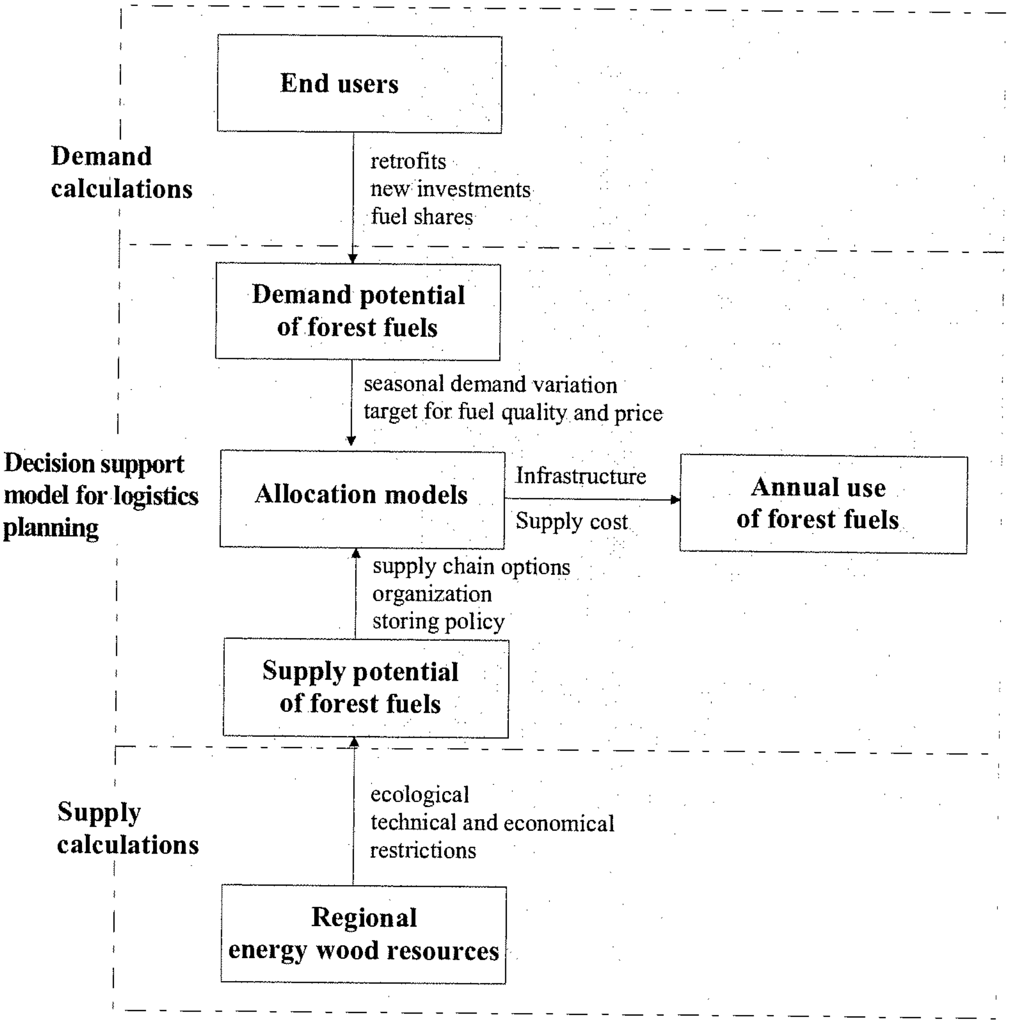


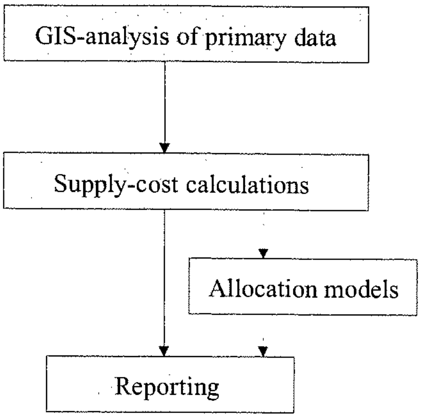
Fig. 26. Environment of the calculation model.

The modeling environment consisted of modeling supply chain options and supply stage-based cost analysis, which were linked to regional worksite factors and other cost factors related to the decision making of supply policy and logistics. Schematic cost calculation models were presented and discussed earlier in section 5.1.8. This modeling environment was based to some extent on some earlier modeling systems, which were based mainly on a spreadsheet model (Laihanen 1995) or a relational database model environment (Ranta 1997). They were spatially coarser without geographically site-specific resource data. Typically the source data had been either at forestry centre or municipality level without knowledge of the spatial variability inside this area. Also the productivity functions were not formularized according to worksite factors. This model was further developed (Ranta 1999) to become more suitable to spatial analysis via GIS-modeling tools and map-based user-interference. In this study the supply cost functions and variables suitable for stand-level analysis were updated. Also the spatial analysis tools concerning site specific data manipulation and location-allocation analysis were added.

The modeling process can be divided into separate modeling stages (Fig. 27). The first stage included in the GIS-analysis of primary data. The following data were included: geographical location of demand side and supply resources, distance calculations between geographical entities, queries and filtering according to location attributes (distance, worksite factors). Supply chain structure and supply policy were selected at first in the supply cost calculation stage. Thereafter supply stage-specific cost calculations according to functions and cost parameters and regional supply cost and supply volume calculations were executed. The allocation model was used for allocating the supply resources between demand sites from overlapped supply areas or finding the optimal locations according to supply resources. Allocating was based either on LP-optimization models or user-defined heuristic rules, using for example plant-specific priorities (Ranta 1999). Subroutines included in the reporting stage illustrated the results of supply cost and availability using graphical charts and map representations. The logging residue availability was calculated with respects to the function of transport distance or supply cost to the selected demand site. Supply costs were defined both as average and marginal cost. Thematic map representation was used to illustrate spatial variation of supply cost and availability, and to find causal connections using worksite factors and other spatial element like location and size of procurement area and accessibility via road networks.

Availability as a function of transport distance made it possible to include regional geography to potential calculations. Availability maps illustrated the effect of regional geography to residue potential. Location-allocation modeling pointed out the most feasible plant sites according to forest fuel resources, which could be compared with actual plant locations and infrastructure. This kind of analysis was especially useful to find out new potential conversion sites for upgraded wood fuels, e.g.. liquid wood fuel, because they were not so bound to existing infrastructure, such as heat demand.

Hypothetical plant locations resulted from regional geography, predefined demand levels and maximum transport distances.



Supply sources and demand points location
Attributes of geographical identities
Spatial relationships like area, distance and adjacency

Selection of supply chain and stages
Supply policy, storing options
Chain-specific productivity and cost calculations
Other cost items
Availability vs. supply cost

Allocation of resources between demand sources
Optimization and heuristic models

Availability as a function of transport distance
Availability as a function of supply cost
Spatial variation of availability
Spatial variation of supply cost

Fig. 27. Schematic progress of the calculation model process.

5.2.2 Regeneration fellings data

Calculation of forest fuel resources was based on the data of regeneration fellings of three major forest companies in Finland, UPM-Kymmene Corporation, Cooperative Metsäliitto and Stora Enso Corporation. Regeneration fellings consisted of all clear, seed- and shelterwood fellings in 2000. Fellings were arranged in a database, where stands were segmented into felling parcels. Each stand or parcel carried information of the composition of stand, felling method, timber volume, felling area, forwarding distance, stand location co-ordinates and municipality, date of timber forwarding, felling suitability (winter, summer, every time). In total there were 55 598 separate stand and parcel locations.

The total area of clear fellings of three major forest companies was 117 140 ha and seed- and shelterwood fellings 21 339 ha in 2000 (Table 2). The total merchantable wood volume from these fellings was 24,9 Mm^3. Clear felling was the primary target for logging residue recovery due to better yield of residues, but also seed- and shelterwood fellings were considered suitable for logging residue recovery, if the stands were valid on the basis of selection criteria. The total area of clear fellings, which included all forest ownership categories (private, forest industries, state), was 156 060 ha and seed- and shelterwood fellings 50 583 ha in 2000. The clear felling area in recent years has risen to a high level compared to the last decade, whereas the area of seed and shelter felling has been kept at the same level (Fig. 28).

Table 2. Timber volume of regeneration fellings used in this study.

Timber volume	Clear fellings	Seed- and shelter fellings	In total
Pine, Mm^3	6.4	1.7	8.0
Spruce, Mm^3	13.3	1.2	14.5
Broadleaf, Mm^3	2.1	0.2	2.3
In total, Mm^3	21.8	3.1	24.9
Number of stands	48 520	7 078	55 598
Area, ha	117 140	21 339	138 480

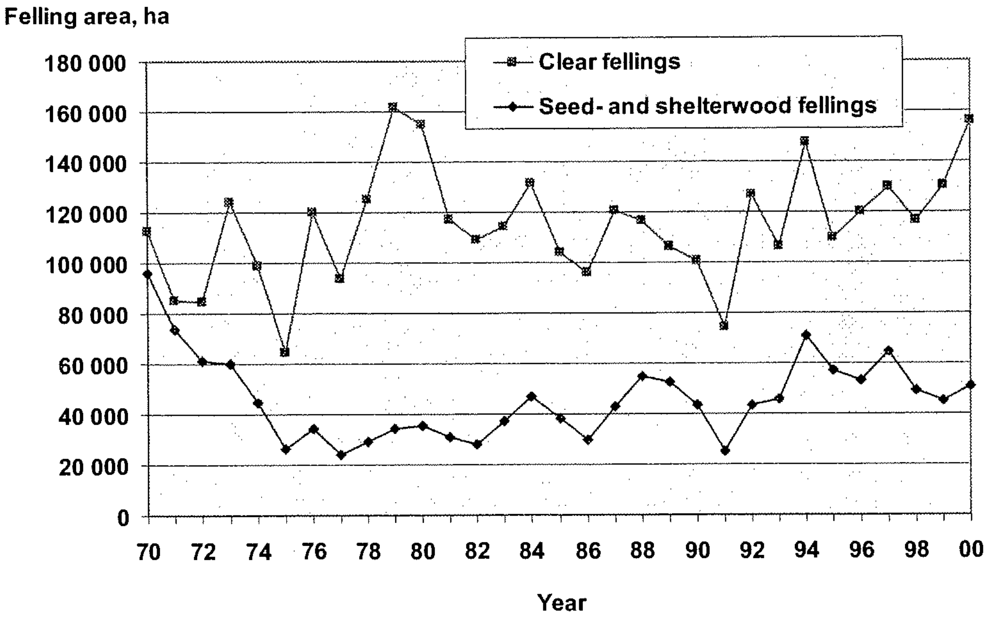


Fig. 28. Development of regeneration fellings in 1970-2000 (Metsätilastollinen vuosikirja 2001).

The share of the clear fellings area used in this study represented 75% of the total clear fellings area in Finland and seed- and shelter fellings 42% correspondingly in 2000. However the share of logging residue potential in the cubic meter basis from regeneration fellings was higher, due to regional variations in residue recovery. Especially in northern parts of Finland, where the recovery rate was lower due to composition of stands and low residue density per ha, the Finnish Forest and Park Service had the major share of fellings (Fig. 29). If the northern part, forestry centre of

Lapland, were omitted from the potential, the share of clear felling areas rose to 83% and seed- and shelter fellings to 65% correspondingly.

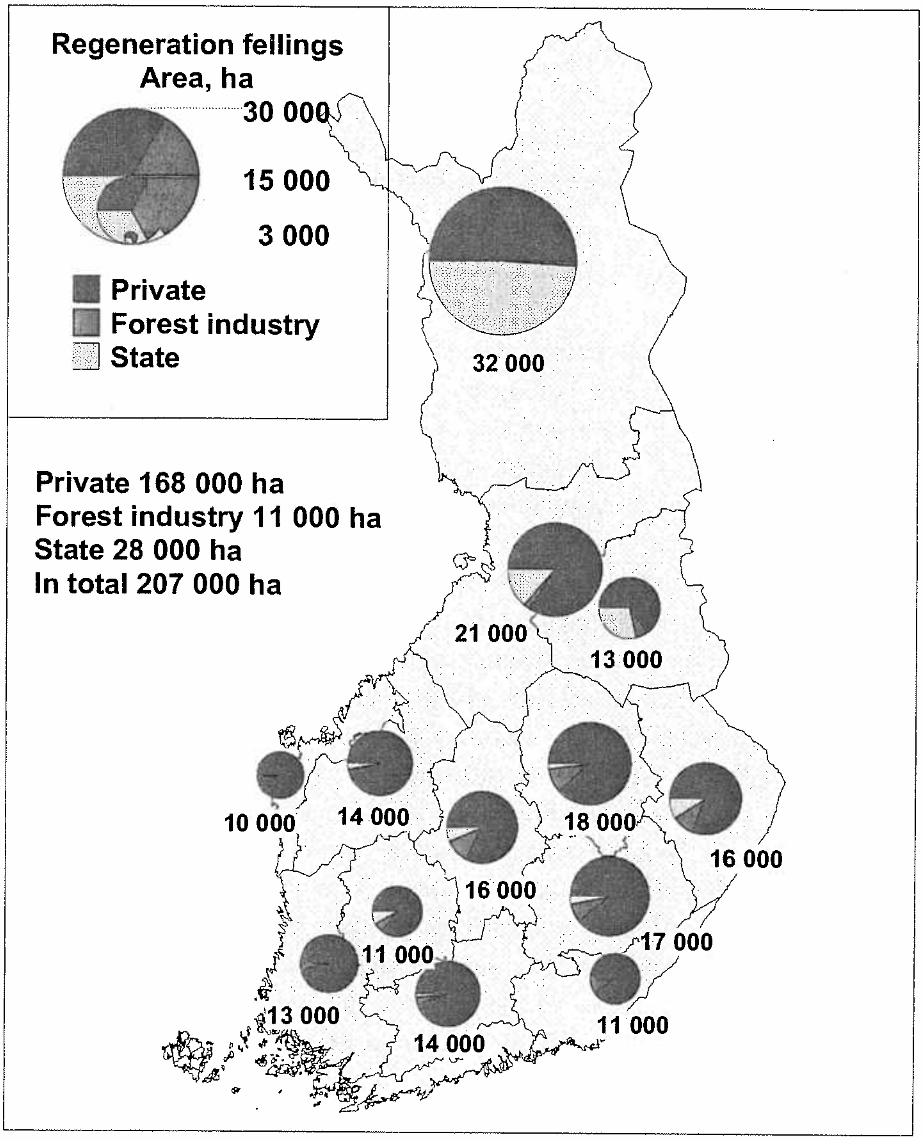


Fig. 29. Regeneration fellings in 2000 by forest ownership category and forestry centre (Metsätilastotiedote 596, 2001).

Outside the scope of this study were some large felling contractors, (because stand-level data was not available and included in the felling database). The other felling actors carrying out regeneration fellings, were the members of the Association of the Finnish Sawmills, i.e. independent family-owned sawmills. The total output was an average over 2 Mm^3 of sawn goods. The major part of the timber supply of the members of the Association of the Finnish Sawmills however came from three major forest companies.

Also some Forest Management Associations supply and trade merchantable roundwood, like the most significant regional felling actor, Södra Skogsreviret, in the coastal area with an annual supply of 0.9 Mm^3 came from timber and pulpwood. The Finnish Forest and Park Service is a state enterprise operating within the administrative sector of the Ministry of Agriculture and Forestry. Most of its turnover is generated by timber sales. The total area of clear fellings was 14 256 ha and seed- and shelterwood fellings 13 289 ha in 2000. Most of the felling areas were situated in Eastern and Northern Finland. The total supply of roundwood was 3.2 Mm^3 from regeneration fellings in 2000.

5.2.3 Methods for logging residue potential at national level

The amount of logging residues was estimated from stem volume on a percentage basis of different mature tree species (Table 3). Coniferous trees consist of Scots Pine (Pinus sylvestris) and Norway Spruce (Picea abies). Broadleaf consists mainly of birch (Betula sp.). Different ratios were used in the southern and the northern parts of Finland due to larger crown mass share of whole biomass in the northern part of Finland. The estimates of crown mass, dry mass per cubic meter of stem volume, were based on the results of a study by Hakkila (1991). According to the results of a study by Harstela & Kiljunen (2001), the top mass of unmerchantable tops were added to crown mass to get the whole logging residue potential. The residue material also included dead trees and non-commercial species, oversize and rotten parts of logs, but these were ignored due to a lack of information at stand-level. The dry masses of logging residues were converted to cubic meters according to the average basic densities of composition of crown mass according to the results by Hakkila (1978). Lower calorific values of logging residues were calculated according to the moisture content, which was defined seasonally (Table 4). The default absolute values of the moisture content was chosen in such a way that in winter period the moisture content was higher as well as for fresh green material compared to green seasoned material. The summer and winter period was defined according to the transpiration potential of the residues. In summer time the moisture content of "fresh" material was decreased due to short storage time before the comminution stage.

If logging residues were let to shed their foliage through transpiration drying before removal, the yield of biomass fraction to fuel was radically reduced. It was assumed that on average half of the needle mass would shed during the seasoning period. This reduced to some extent the ratio of brown stand mass and stem volume. Also the basic density changes to some extent due to changes in the composition of crown mass, but in this study it was kept unchanged. Besides this the average recovery rate was further reduced the potential residue mass. In Finland the recovery rate has varied from 60-75%

of the potential logging residue mass. In this study a recovery rate of 65% was chosen both for the green and brown supply.

Table 3. Initial calculation data of logging residues.

Logging residues	**Spruce**	**Pine**	**Broadleaf**
Dry-kg/stem volume, m^3, southern	186	81	106
Dry-kg/stem volume, m^3, northern	289	112	178
Basic density, kg/m^3	425	395	500
Calorific value, MJ/dry-kg	19.8	20.5	19.7
Lower calorific value (green), MWh/m^3	2.02	1.95	2.34
Lower calorific value (brown), MWh/m^3	2.11	2.04	2.47
Logging res.(green)/stem vol. m^3, southern	0.44	0.21	0.21
Logging res.(green)/stem vol. m^3, northern	0.68	0.28	0.36
Material loss due seasoning, w-%	15%	10%	-
Logging res.(brown)/stem vol. m^3, southern	0.37	0.19	0.21
Logging res.(brown)/stem vol. m^3, northern	0.58	0.25	0.36

Table 4. Moisture content according to the harvest period.

Logging residues	**Summer-period**	**Winter-period**
Months	5-8	1-4 & 9-12
Green, moisture content	45%	55%
Brown, moisture content	35%	45%

Logging residue potential, both as green and brown supply, was defined according to the following assumptions:

- Residue gross, theoretically available, reserve without any limitations from all stands with a recovery rate of 100%.
- Residue gross, technically available, reserve without any limitations from all stands, recovery rate of 65%.
- Residue net, economically available, reserve, where stand selection criterion was used: logging residue volume ≥ 40 m^3/stand with recovery rate of 65%.
- Residue net, economically available, reserve, where stand selection criterion was used: logging residue density ≥ 30 m^3/ha with recovery rate of 65%.

- Residue net, economically available, reserve, where stand selection criterion was used: forwarding distance ≤ 350 m.
- Residue net, economically available, reserve, where stand selection criterion was used: composition of stand, share of spruce must be largest.

The stand selection criteria were based on the practice used on average among supply organizations. In practice the values were suggestive and also other aspects could be taken into account. The last limitation, composition of stand, was incorporated to find out the contribution of pine-dominated stands. Although nowadays the harvesting of logging residues are focusing on regeneration felling of spruce stands, where the logging residue potential is largest, pine stands prove to be also suitable for residue recovery. Due to the climatic conditions, pine-dominated forests were dominant in northern and western regions and excluding them reduced the residue potential significantly in those areas. Therefore, in this study the terms used were a gross reserve, for technically available reserve, where a recovery rate of 65% was used and a net reserve, where all stand selection criteria with a recovery rate of 65% were used except composition of stand-criterion.

5.2.4 Methods for logging residue potential at regional level

Logging residue potential per area and the availability within a certain distance were defined for the whole country and the effects of different stand selection criteria were analyzed. The regional variation of potential within the country and different selection criteria were analyzed by using a Vertical Mapper ver. 2.5 (Northwood Geoscience) operating under MapInfo ver. 6.5 (MapInfo Corporation). MapInfo is a desktop mapping software and Vertical Mapper is a grid-based contouring, modeling and display system that transforms point data into a continuous surface. The regional potential output was defined as m^3/km^2, where the areas of subregions were defined according to stand locations. The location data were aggregated to a polygon coverage and then analyzed using techniques for area data.

The selected aggregation technique, conducted by Vertical Mapper, was forward stepping (Fig. 30), which uses a circular search radius about an existing stand to select those stands that will be aggregated. This technique begins by presorting the data into coarse cells and then selecting the farthest left an uppermost point into the data set. It selects all points that are within the specified search radius (aggregation distance). Aggregation distance was the minimum separation allowed between data points before aggregation of the points was initiated. Data points that fall within this search zone were mathematically averaged and a new data point was placed at the geometric centre of the aggregated points. All points were aggregated to one location only during the aggregation process. Aggregation calculations (i.e. statistical parameters associated with each aggregated point) were performed on the selected points and the results were then attributed to the geocentered point. The residue potential of this geocentered point was formulated as the sum of selected stand-specific values, and the site-specific factors (like residue volume, m^3/stand, density, m^3/ha and forwarding distance, m) as an average of selected stand-specific values. The search radius was set both at 5 km and 10 km (Fig. 31). The selection of the search radius resulted from the regional density of original data and the change in spatial resolution after aggregation. The fewer the new aggregated point data, the more variability was lost upon aggregation and the greater the difference in a statistic's values between the original level and the aggregated level. The change in statistics caused by a change in spatial resolution was called the scale or aggregation effect. Dissimilarity and variance among larger units was less than among smaller units because a summary measure such as the spatially weighted average from aggregation was used to represent the values of larger units.

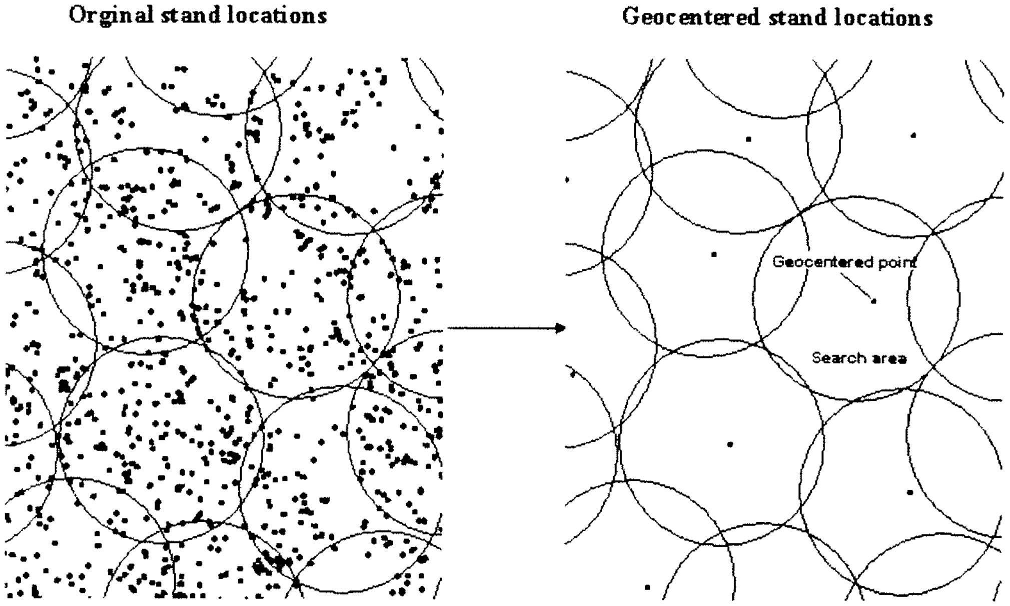

Orginal stand locations **Geocentered stand locations**

Fig. 30. Forward stepping aggregation for a 10 km search radius.

Regeneration maturity is reached when the forest has reached an age of 70-100 years for Finland. This will be the time span, i.e. renewability time between possible logging residue recovery at the same stand-location. However in a certain larger area, it is possible to estimate felling activity per certain period based on earlier activities and future plans. This area can be based on municipal, forestry centre division or subregions constituted by some decision making process, but in this case the formed area was constituted on the basis of stand data from regeneration fellings per one year to find the regional variation without any beforehand defined regional structure.

Also in forestry there can be found the phenomenon of positive spatial autocorrelation. It is question that geographical values close together in space tend to be more similar than values located further apart. Spatial autocorrelation refers to relationships that variable values will have as a result of their relationships to each other in space. In statistical terms, the data behaves as partially repeated measures of a single observation rather than as single independent observations (Griffith 1987). Therefore, it is possible to form representative aggregated values of these calculated areas based on single stand features inside them.

Autocorrelation statistics are basic descriptive statistics for any data that are ordered in a sequence, because they provide basic information about the ordering of the data that are not available from other descriptive statistics such as the mean and variance. When data are mapped, the map contains not only information about the values of variables but also information about how those values are arranged in space. According to mapped stand data, it was visually analyzed if there was spatial autocorrelation between stand-site factors, like residue volume, density and forwarding distance. There are also statistical tests based on sampling theory, like Moran's I and Gearys's c (Odland 1998), to test hypotheses about map patterns. Heterogeneity in a spatial context means that the values describing the data vary from place to place. If the distribution function of the stochastic process remains unchanged when distance changes by an arbitrary amount then the process is stationary and spatially homogenous. That is, space-homogeneity is restricted to be a function of the distance between the elements of the distribution in question. Spatial dependence is a special case of spatial homogeneity. It implies that the data for particular spatial units is related and similar to data for other nearby spatial units in a spatially identifiable way (Fotheringham, & Rogerson 1994). In this case the visual map information using thematic mapping showed the phenomena of spatial dependence.

According to aggregated stand data, natural neighborhoods were built around data points using Delanay triangulation. A network of Thiessen polygons (also known proximity polygons) were generated from the point locations, creating what is called a Voronoi diagram. Voronoi diagrams are mathematical constructs around points in which each location on the surface is associated with the point closest to it (Boots 1986). It is a question of splitting up a study area in such way that all points in the sample area are grouped into tiles according to the minimum distance between them and a previously sampled point (Fig. 31). All points within a Thiessen polygon are closer to the aggregate stand point inside the polygon than to any other aggregate stand point. Once the natural neighborhoods (i.e. Voronoi diagram areas) had been mapped, it was visually analyzed and compared with aggregated stand information attached to the Voronoi diagram areas using the MapInfo thematic mapping tools. In Table 5 it was summarized how the original point data decreased with a different aggregation search radius and what was the average size of the neighborhood area (i.e. Voronoi polygon) around these points.

When the search radius was 5 km for gross stand reserve, on average 17 stands were aggregated to a new geocentre from the average area of 79 km^2 surrounding it and with search radius of 10 km, 52 stands and 250 km^2 correspondingly (see Table 5). The area was a weighted average of Voronoi diagram areas, using the residue potential inside each area as weight. For the estimation and presentation of available logging residue potential, it was assumed that the residue was uniformly spread over the entire area of the geographic objects, i.e. Voronoi polygons were expressed in terms of volume per unit area.

Table 5. Number of aggregated points and average size of Voronoi polygons.

	Original	**Aggregation 5 km**		**Aggregation 10 km**	
Residue reserve	**Number**	**Number**	**Area, km^2**	**Number**	**Area, km^2**
Green/Brown, gross	59 489	3 383	79	1 138	250
Green, net	25 460	2 570	89	921	265
Brown net	22 617	2 450	92	894	283

In this study the thematic map referred to the colors used in a choropleth map. Selection of the number of residue potential or site factor range divisions defined the amount of detail that the choropleth map showed. The color scheme chosen for choropleth map was a gradation of shades from the color representing the lowest class to that representing the highest class because of continuous variables. Thematic maps were produced from logging residue regional potential (m^3/km^2), average forwarding distance (m), average logging residue volume (m^3/stand), average logging residue density, (m^3/ha) and composition of stand. According to upper limits of stand selection criteria ($\leq$ 350 m, $\geq$ 40 m^3/stand, $\geq$ 30 m^3/ha), areas which were disadvantageous for residue recovery were colored with the lightest color.

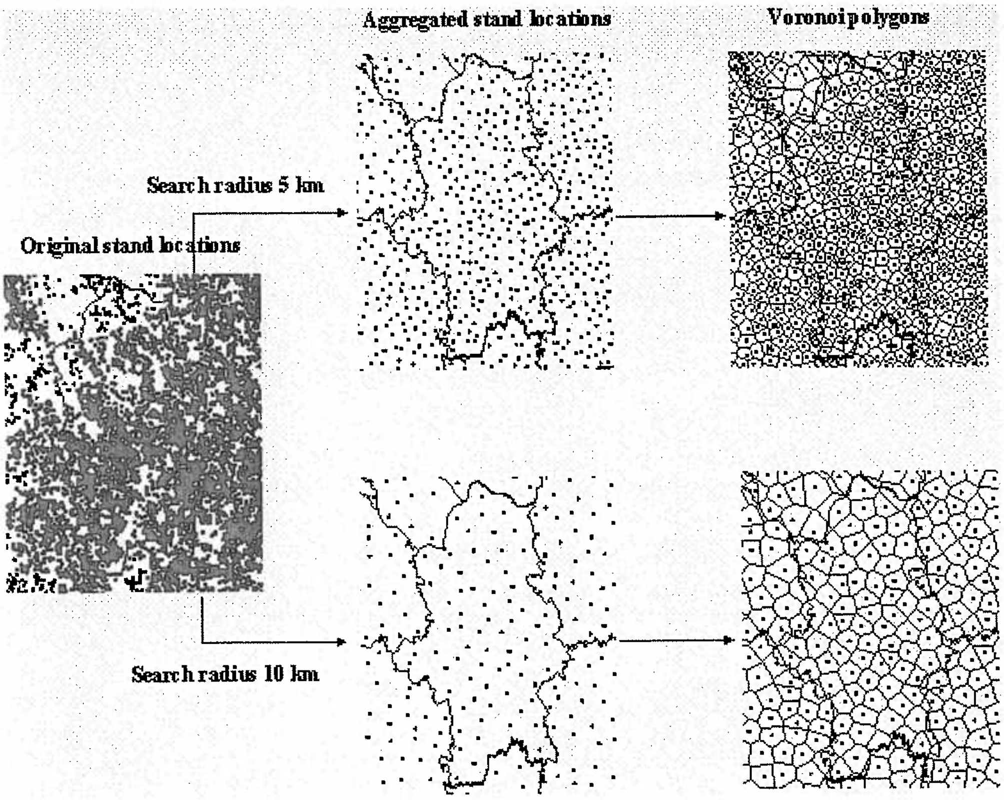


Fig. 31. Stand data aggregation and Voronoi diagrams with 5 km and 10 km search radius.

Regional logging activity was analyzed by the Location Profiler modeling tool, included in Vertical Mapper, which computed average distances to a series of points from anywhere within a map area. The algorithm generated a grid, where at each cell, a value was calculated that represented the average distance to all stand locations surrounding that cell and lying within a defined search radius. By identifying those locations on the map that were the shortest average distances to all or some of the stands according to the search criterion, this grid file was used to represent geographic centers of the activity e.g. logging sites within one year. Here, the search criterion was set by a maximum number of stand locations measured from each grid cell. The model stopped searching for stand locations once the maximum criterion was achieved. By using different maximum criteria for example from 100 to 1 000, it was possible to visualize how regional characteristics emerged by using smaller values of criterion. The grid format was converted into attributable-coded vector format, threading contour lines through the grid network. Contour lines are paths along which grid values are constant. Contour regions were generated according to the contour interval.

Logging residue availability as a function of distance was analyzed regionally both with green and brown supply options. To analyze the effect of regional geography (coastal areas, inland waters, road network, and national frontier), the potential was calculated according to a maximum of 100 km transport distance along the road network. In practice the 100 km limit was appropriate, because of the uncompetitiveness of supply with larger distances. Also the location map of the end-user was in most of Finland so dense, that there was no need for longer transport distances due to overlapping procurement areas (see map representation Fig. 32 in section 5.2.5). Before distance calculations, the original stand data were aggregated using forward stepping aggregation (see previous Fig. 30) with a 10 and 20 km search radius. The reason for aggregation was the need to reduce the distance calculation intensity caused by a large amount of original data points. For each aggregated point the supply potential was calculated as a function of the transport distance. In this case the potential was calculated for net stand reserve (see previous Table 5) at a distance of 100 km. Distance calculation was carried out by RouteView Pro 1.2-software (Dataview Solutions), which was a network-add-on tool used in MapInfo. Supply potential database calculations were performed by using a software-programming tool of the MapInfo, MapBasic. MapBasic is a full-featured programming language, which bears a resemblance to newer versions of Basic (e.g. Microsoft's Visual Basic language) and is used to create custom applications for MapInfo.

After point data availability calculation, interpolation was used to form a continuous evenly spaced grid surface from point data. The grid (cell size 5 * 5 km) was an estimation of the logging residue availability according to potentials calculated from point data. The Natural Neighbor method was selected as the interpolation technique that used natural neighborhood regions generated around each stand as in Voronoi polygons. The new grid value was calculated as the average of the surrounding point values proportionally weighted according to the intersecting area of each point. The calculation results were visualized by aid of contour regions classified into divisions according to supply potential.

With the help of preceding availability analysis, a power plant location analysis was made. The idea was to find out optimal locations for a power plant or a conversion plant for upgraded wood fuel, e.g. liquid wood, where the objective was to minimize the fuel transportation cost at predefined supply levels. This kind of problem can be analyzed by means of the location-allocation model. The location-allocation model was in this case concerned with the location of facilities, i.e. power plants to sites, which minimized the fuel supply cost and in practice minimized the transportation distances. Despite that the most power plants were already located in certain places, the search for optimal solutions was still an interesting analysis especially for pyrolysis oil production plants.

The model both located facilities and allocated supply sources i.e. stands or aggregated geocentered stand sites to these facilities. The interest was based on what was commonly known as the equity-efficiency problem (Birkin et al. 1996). This recognized that any network of facilities had to be efficient in relation to scarce resources. The best known and most important of the location-allocation models was the "p-median problem". After some modifications, like the predefined demand level d, to the model presented by Birkin et al. (1996), the problem related to this study was formulated as:

$$\min_{\{S_j^d\}} z = \sum_{j=1}^{p} \sum_{k=1}^{q} V_k h_{jk} l_{jk} \qquad (5.2 - 1)$$

Subject to:

$$\sum_{k=1}^{q} h_{jk} = 1 \qquad (5.2 - 2)$$

Where:

h_{jk} = Boolean, zero-one allocation variable, which allocate each supply point to nearest facility

$$h_{jk} = \begin{cases} 1, \text{allocated} \\ 0, \text{not allocated} \end{cases}$$

$S_j^d = (x_j, y_j)$ is the facility j location, with demand level d, GWh

p = Number of facilities, j = 1,.., p, q = Number of supply points, k = 1,..,q

x_j = facility j co-ordinate, longitude, y_j = facility j co-ordinate, latitude

V_k is the supply at k, measured as energy unit, MWh

l_{jk} is the distance from j to k, km

The problem was to find optimal locations for p facilities, hence the name p-median, relative to q supply points or supply zones. In the basic model optimization meant transport-cost minimization and the allocation element of the problem came through the zero-one variables $\{h_{jk}\}$, which allocated each supply point to the nearest facility. The distance, l_{jk}, was based on actual road network distance and it was restricted to not exceed 100 km, due to practical reasons of transport economy. The demand level was predefined at d, measured as energy unit, GWh.

The MapInfo and associated programs were used both in the modeling system calculations and in the display of the modeling system's output. The MapInfo was used to create a single digital map that identified the stand reserve, created a digital road map, calculated the distances between nodes along the road network, displayed the results of analysis in mapped output. The constructed customized modeling program, created by using MapBasic, had three basic components. The first component, processed by Vertical Mapper-software, aggregated stand point data into geocentered points as in availability maps (see Fig. 30). The aggregation distance for net stand reserve was in this case 5 x 5 km. The second component calculated distances between geocentered points along a road network using RouteView-software. The algorithm was run for all destinations (i.e. geocentered points) inside national territory to create a surface availability map for a specified transport distance. In this case the maximum distance was set at 100 km, as in availability maps. The third component identified, mapped and ranked, based on maximizing the availability of logging residues, all the geocentered point inside national territory where forest residue conversion facilities might be located. The algorithm ranked from highest to lowest the potential availability of all the supplies from points within 100 km transport distance and calculated the cumulative potential supply of logging residues from those ranked points.

In mapping the optimal locations of multiple bioenergy facilities, one must account for the result that logging residues used for one facility were not available for another facility. Those logging residue supplies should be excluded that were already being used to meet the demands of another location. The level of demand, which was used in allocation calculations, was user-defined. Potential facility locations were selected sequentially, based on maximum logging residue availability. The availability algorithm was rerun, the next highest availability location was identified, and the logging residue supplies use to source that locations were removed from the map. These steps were repeated until the potential logging residue supplies had all been allocated.

Different maps were created by specifying different maximum distance limits, which affected the forest residue availability per destination or by assuming different supply reserve (green or brown using varying stand selection criteria). The demand limitation affected the number of potential locations, the lower the demand the higher number of potential locations. The effect of aggregation distance was minor to the results of map layout, but major to the intensity of distance calculations.

To summarize, the variables which were selected before calculations are as follows:

- Supply reserve
- Aggregation distance
- Demand limitation
- Maximum transport distance limitation

5.2.5 Methods for logging residue potential at plant level

Logging residue potential at plant level was determined according to the size of procurement area and the logging residue area-based potential within this procurement area, i.e. m^3/km^2 or MWh/km^2. Economic reasons limited maximum transport distance as previously discussed. Besides this transport distance, the size of procurement area was determined according to the user location in relation to national frontier and coast, which reduced the size of the potential area. Also the road infrastructure and its efficiency had an effect on the size of the procurement area. Logging residue area-based potential inside procurement area was defined according to land-use classes (forest land, arable land, peat land, inland waters, urban area and other), and the share of forest land of the whole area was calculated. The forest type and resources and stand selection related to worksite factors (see details from previous section 5.2.3) determined the potential volume of logging residues inside the procurement area.

Logging residue potential was defined for selected locations (56 different geographical sites) according to an isodistance area of 100 km. The isodistance is the area within a given distance along a road network from a given point. The RouteView was used to create a vectored digital road map. The digital road network used in this study, Suomen Tiestö, consisted of all trafficable roads in Finland, in total over 350 000 km. Road segments were classified into 26 different road classes, which had modifiable properties like driving speed limits. The location accuracy of road segments in urban areas was 5-10 m and in rural areas 50-100 m. Stand location points were linked to the nearest node of road segments to calculate distances between stands and power plants. Distances were calculated using the Dijkstra-algorithm (Dykstra 1984), which found the shortest path between selected nodes. For each predefined power plant locations was calculated gross and net potential using a recovery rate of 65% both for green and brown supply basis. The net potential consisted of restricted stand reserve due to used stand selection criteria.

Availability analysis was targeted to locations, where the largest potential forest fuel users in Finland were located. Some of the power plants already used large volumes of forest chips and several had plans to increase the use in the near future. There were also a few locations, where the boilers were in the reinvestment phase. The selection criterion was set so that the usage potential was over 40 GWh of forest fuel per year. The reason for this limit was that this study concentrated on production methods suitable for large-scale production. Also logging residue-based forest fuel was mainly used in large power plants due to production cost and quality reasons. Also most of the future supply in volume basis will be targeted to large power plants despite the large number of small heating plants. In total there were 58 different geographical locations with 70 boilers, since some plants had many boilers suitable for forest fuel use. More detailed information concerning these boilers, like location, combustion technology, plant type, customer to heat and plant fuel capacity MW are listed in Appendix 3.

Fig. 32 illustrates the geographical location according to the address of the plant. On the grounds of ownership, 40 boilers were located alongside with industry, mostly with forest industry and 30 were boilers alongside with municipal plants. Most of the plants were located inland in the Western and Eastern province of Finland. In addition most of the plants were co-generation plants, since only 7 boilers were producing purely heat. There was no pure condensing power plant in the plant population. The most common combustion technology of selected plant population was fluidized-bed (CFB/BFB) technology, since only 7 plants were based on grate technology. Also some pulverized-coal and -peat burners (PF) were selected, since they owned a large forest fuel usage potential after receiving equipment or a boiler retrofit.

Around every plant location, within a 100 km procurement radius, a winding coefficient was calculated to find out the differences of accessibility to raw-material resources along road-network in different parts of Finland. The winding coefficient for each individual observation was used as a measure of the straightness of a real transport route from the source point to the user location (e.g. Sundberg & Silversides 1988, Haartveit & Fjeld 2000). It was defined for each individual observation by the ratio between driven and straight-line distances. The winding coefficient gave a relative measure of the extra transport distance that arose because of non-linear transport routes. A high winding coefficient implied a longer road transport distance for a given straight-line distance. Since average transport distances increased at a faster rate in areas with high values of the winding factor, this led to smaller economical procurement areas. Theoretically the proportion of procurement areas with winding factors w_1 and w_2, were $(w_2/w_1)^2$.

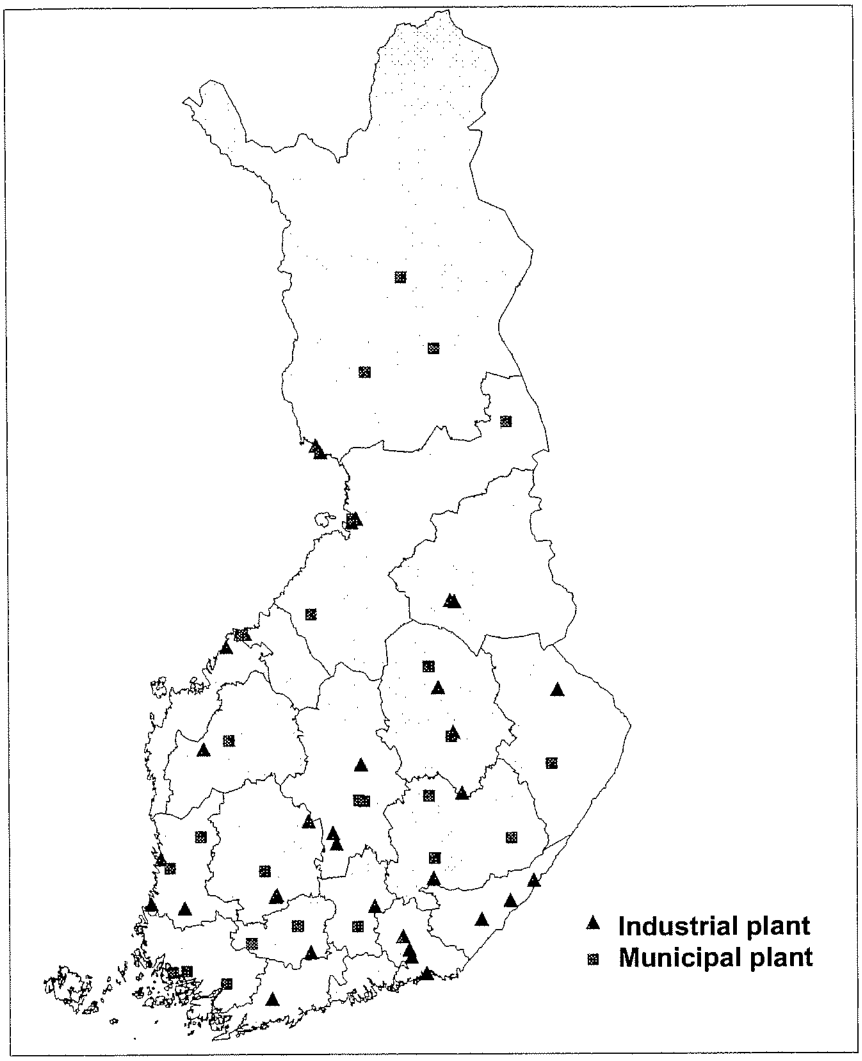


Fig. 32. Plant location and status of ownership.

The winding coefficient for individual stand was estimated as:

$$w_{ij} = \frac{l_{2ij}}{l_{1ij}} \qquad (5.2 - 3)$$

Where:

i = Stand, i = 1,..,m, j = End user, j = 1,..n

w_{ij} = Winding coefficient for stand i and end user j

l_{1ij} = Straight-line distance from stand i to end user j

l_{2ij} = Distance along roads from stand i to end user j

The winding coefficient around a certain end user j was estimated as:

$$w_j = \frac{\sum_{i=1}^{m} l_{2ij} \times V_i}{\sum_{i=1}^{m} l_{1ij} \times V_i} \qquad (5.2 - 4)$$

Where:

V_i = Volume in stand i, which is used as weight

w_j = Average winding coefficient for end user j

The winding coefficient was interpolated over the whole country to analyze the regional variation. Besides the above-mentioned plant locations interpolation was based also on supplementary calculation points in areas of sparse location points. The interpolation method was Natural Neighbor because of the clustered phenomenon of spatial data. The results of interpolation were illustrated via a thematic contour map.

Around selected plants the winding coefficient was illustrated as a function of transport distance. Selected plants, which were from the power plant base used in this study, were among the largest forest fuel users in future and the geographical coverage was representative from the procurement point of view (see the exact locations from Fig. 44 in section 6.4). Also the procurement area as a function of distance, km^2 vs. km, and the logging residue potential per area, MWh/km^2 vs. km, were illustrated for the same group. The area was classified according to land-use classes to calculate the potential per total land area including watercourses or only per forest land. Finally the cumulative potential was calculated as a function of distance within a 100 km procurement area. In this context the possible overlap of procurement areas between individual plants had not been taken into consideration. In this case, it was question to compare different plant site characteristics with each other. Overlapping was taken into consideration in later analysis through transportation model.

Land-use classes were calculated according to a digital raster map, Maputu, Maankäyttö- ja puustotulkinta by National Land Survey of Finland (NLF). This material included the land-use class for each 25*25 m grid in Finland. There were some 50 different land-use classes. Forest land was further divided according to main tree species and volume, m^3/ha, and forest type (mineral and peat soil) according to source data of National Forest Inventory (NFI) by Finnish Forest Research Institute. Maputu will be replaced by SLICES-database in the near future. This study used to some extent a rougher source material from Maputu with a grid level of 200*200 m and 15 classes produced by National Land Survey of Finland.

The analysis, related to logging residue potential inside procurement areas, evaluated the differences of supply potential between actual plant sites and the effect of worksite factors to the potential at different sites, i.e. location analysis on the point of view characteristics of supply resources. Logging residue potential was also defined according to supply cost with different supply methods. Supply was based both on decentralized and centralized supply methods. Supply cost was calculated as a function of transport distance both as marginal and average cost inside a 100 km procurement area. Logging residue availability was defined within supply cost classes with different supply methods using a green or brown supply policy. The results were illustrated in detail around the city of Jyväskylä region as supply curve representations. Sensitivity analysis of supply-cost was also made, as for chipping productivity and end moisture content to compare green and brown supply policy. Chipping productivity was assumed to drop 10% for seasoned brown material in availability calculations (Asikainen et al. 2001). The regional variation of competitiveness of different supply methods was analyzed. This analysis evaluated the differences of supply potential according to supply cost between actual plant sites, i.e. the location analysis from an economical supply resources point of view.

In order to manage the problem related to overlapping procurement areas, a transportation model was made, where the supply of logging residues between power plants were allocated. The LP-model developed for this study was a least cost transportation model to meet the demand for logging residue resources for a given set of cogeneration facilities. The least cost solution was based on minimization of transportation cost or in this case transport distance, since there was only one type of raw-material and transport mode in this model. In the transportation model the objective function and all of the constraints were estimated as linear functions of decision variables, hence it was formulated as a linear programming (LP) problem.

The LP-optimization was performed using the Premium Solver Platform with plug-in Solver engines (Frontline Systems) bundled with Microsoft Excel. It was an upgrade to the Solver that came with the Microsoft Excel. The Solver engine, used in this study, the Large-Scale LP Solver, uses a sophisticated implementation of the Simplex-method like sparse matrix representation, advanced basis creation and advanced matrix factorization methods such as the LU decomposition and dynamic Markowitz refactorization, for both speed and numerical stability. Owing to of the structural simplicity, the main limitations of the size of LP problems that could be solved were time, memory, and the possibility of numerical instabilities, which were the cumulative result of the small errors intrinsic to finite precision computer arithmetic. The larger the model, the more likely it was that numerical instabilities were encountered in solving it.

Like most large LP-models, also in this case the used transportation model was sparse in nature, which the Solver engine fully exploited. It was capable of handling problems of up to 65 000 variables and 65 000 constraints. With the help of Excel macros, also the larger model could be handled, when the irrelevant variables according to distance matrix were eliminated, which was also achieved in this study.

The transportation model was formularized as:

$$\min z = \sum_{i}^{m}\sum_{j}^{n} l_{ij} V_{ij} \qquad (5.2 - 5)$$

Where:

z = Transportation distance, in this case equivalent to transportation cost

l_{ij} = Transportation distance from source location i to destination j

V_{ij} = Amount of raw-material, MWh, transported from source location i to destination j

m = Number of different source sites, i = 1,..,m

n = Number of different destinations, j = 1,...,n

Model constraints:

Demand constraints at destination locations:

$$\sum_{i}^{m} V_{ij} \geq D_j, j = 1,...,n \qquad (5.2 - 6)$$

Where:

D_j = Raw-material demand at destination j

Supply constraints at source locations:

$$\sum_{j}^{n} V_{ij} \leq S_i, i = 1,..,m \qquad (5.2 - 7)$$

Where:

S_i = Raw-material supply from source location of i

Demand targets were not allowed to exceed the supply potential at selected calculation area:

$$\sum_{i}^{m} S_i \geq \sum_{j}^{n} D_j \qquad (5.2 - 8)$$

Non-negativity constraint of transported raw material:

$$V_{ij} \geq 0 \qquad (5.2 - 9)$$

The transportation model can be extended by variables like raw-material type and production method, if for example part of the raw-material flow was processed at an end-use facility. The production method will have an effect on transportation cost. Different alternative regional solid raw-material types consist of peat, by-products like bark and sawdust, and other forest fuel sources like smallwood from young sapling stands and early commercial thinning. The allocation among these fuels can be based on procurement cost, where cheaper sources would allocate first under quality constraints.

In the first phase the whole supply potential was allocated without demand constraints to power plants to find the minimum transportation cost as reference solution. This inherent solution assisted to set the feasible power plant demand levels beside the user's technical potential. This allocation model was formularized as:

$$\min z = \sum_{i}^{m} \sum_{j}^{n} w_{ij} l_{ij} \qquad (5.2 - 10)$$

$$\sum_{j}^{n} w_{ij} = 1, \; i = 1,..m \qquad (5.2 - 11)$$

Where:

w_{ij} = Boolean, zero-one allocation variable, which allocate each supply point to nearest source location

$$w_{ij} = \begin{cases} 1, \text{allocated} \\ 0, \text{not allocated} \end{cases}$$

Allocation was made both for stand-level and aggregated (10/20 km) supply reserve to estimate the variation of allocated supply potential between stand and aggregated reserves. Calculations were made both for green vs. brown and gross vs. net reserve to estimate the range of variation of allocation results. The transportation LP-model was constructed only for aggregated (10 km) supply potential, because of the size of model and calculation intensity. The size limit of 65 000 decision variables and constraints was bypassed by using Excel macro, which sought the most relevant decision variables according to maximum allowable transport distance.

Plant-specific demand potentials were classified according to class division of 50 GWh with the exemption of the lowest class of 20 GWh. According to defined demand potential the supply potentials of selected logging residue reserve (green vs. brown and gross vs. net) were allocated to plants by using the transportation LP-model. Supply potential was measured using class divisions of transport distance (40-60-80-100 km) with different supply reserves for each plant. This analysis classified the supply potential according to transport distance and took the overlapping procurement areas into consideration and also found the most conflicting areas according to demand vs. supply potential. The results were illustrated as a table and map representation to find the deficit and surplus areas regarding logging residue usage and supply potential. Logging residue usage and supply potentials were also allocated at forestry centre level, since many forestry statistics were represented according to this geographical grouping.

In addition transport distance, the availability was calculated according to supply cost. In this case the selected supply method was roadside chipping, which stood for an average supply cost level. Supply cost calculation was based on the allocation result and supply cost functions defined in section 5.1.8 (see example from Table 6). Supply cost functions were plant-specific, where the marginal and average supply costs were defined as a function of transport distance. The regional geography and worksite factors were taken into account through these functions. Supply potential was classified into supply cost class divisions 8.41-8.83-9.25 €/MWh (i.e. 50-52.5-55 FIM/MWh) with both green and brown net reserve.

However, since in this study it was not the question of allocation between alternative fuels, such as peat vs. wood fuels as in study of "Puupolttoaineiden kysynnän..." (2000) or between biomass-based fuels from different sources as in study of Joutz (1992), the plant-specific readiness to pay from fuel was not taken into consideration in the transport LP-model. Also the forest fuel allocation between plants resulted only from supply cost and forest fuel use target instead of for plant-specific cost issues, because of the subsidiary status of forest fuel in this study. Also the lack of mature markets with well developed price mechanisms between the seller and buyer had an effect on plant-specific fuel cost as in Sweden (e.g. Hillring 1997).

6 RESULTS

6.1 Cost structure of production chains

According to comparison of the cost structure divided into production stages between different supply chains, there were significant differences due to a variation in production cost in the chipping and transportation stages. The most significant part of the costs with the traditional chipping chains was linked to chipping, with the loose residue chain to transportation and with logging residue log chain to the bundling (Fig. 33). These work stages also formed the most significant development potential for the improvement of the competitiveness of the chains in question. The competitiveness of the chains varied within Finland due to regional differences in relation to stands and according to the size of the procurement area. This was why the competitiveness of the chains was defined as power plant-specific, paying attention to local conditions. Regional differences concerning supply cost is analyzed in more detail in chapter 6.3.

When comparing the absolute values of fresh, green logging residue supply cost, the variation between supply options was a minor exception of loose residues (Fig. 34). Residue logs was the most competitive way to supply, 9.0 €/MWh, and loose residues the least competitive, 10.0 €/MWh, due to poor transport economy at the maximum transport distance of 100 km. These was a so called average supply cost, which was a weighed average value of all stands inside a 100-km supply area. The component "other cost" included stumpage price, piling compensation, organization cost and for seasoned material also storage cost. Stumpage price was 16.82 €/ha (direct conversion from the Finnish previous currency unit, 100 FIM/ha), which meant 0.13 €/MWh for fresh and 0.15 €/MWh for seasoned logging residues due to lower yield per ha. Piling compensation for the logging stage was 0.21 €/MWh. Organization cost was 0.66 €/MWh with terrain, roadside and loose residue options and 0.33 €/MWh for residue logs due to competitiveness gained through economy of joint production with timber supply (see reasoning from section 3.2). Storage cost included the covering cost of the piles and interest charge of tied capital to storage. The relative competitiveness of the loose residue supply option became better with shorter transport distances. The relative competitiveness between other supply options was not varied significantly as a function of distance.

The cost structures of different supply chains with seasoned material were similar to the green supply (Fig. 33). The share of other costs was higher due to storage cost. Their share of total cost was 7-10% with green and 9-12% with brown supply within a 100 km procurement range. The cost of covering piles was 0.042 €/MWh. The capital cost varied according to the cost-accumulation curve of the supply chain. In the terrain chipping chain the capital cost was the lowest, 0.03 €/MWh and at the bundling chain the cost was highest, 0.21 €/MWh due to higher cost accumulation before the comminution or transport stage. At roadside chipping and loose residue supply chains the capital cost was 0.12 €/MWh. The share of comminution in cost structure was higher and forwarding lower with terrain and roadside supply options due to reasons listed in section 5.1.8. In the transport stage the net load was higher due to lower moisture content, which led to lower costs for the same transport distance. When comparing the absolute values of supply cost the roadside and terrain supply options became slightly more expensive and loose residue more competitive. The bundling option became more expensive than roadside and terrain options contrary to the situation with green residue supply (Fig. 34).

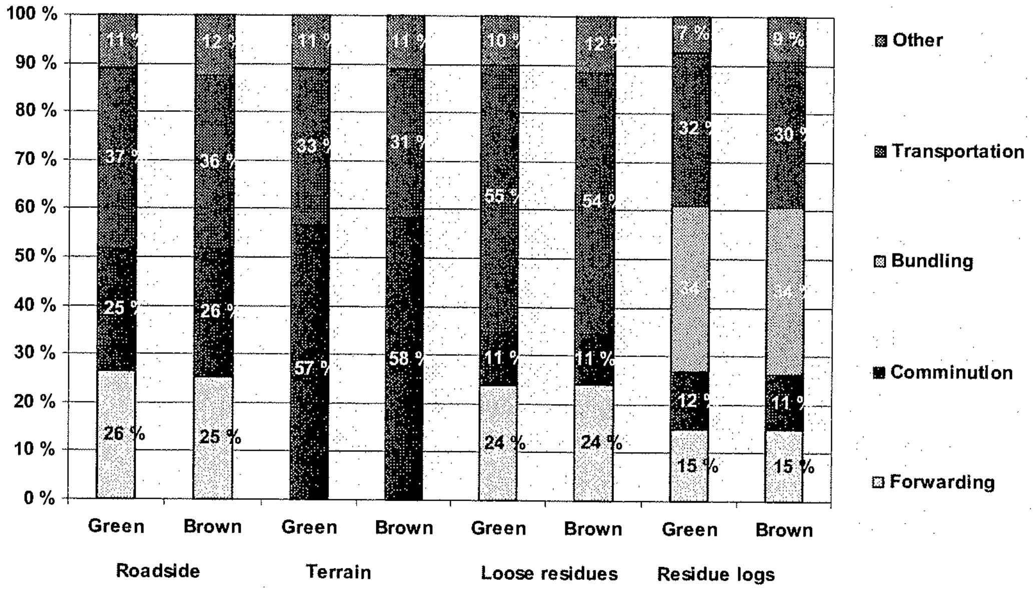


Fig. 33. Proportional cost structure of logging residue supply chains by production stage, fresh green and brown seasoned residues, transport distance of 100 km. An example from the city of Jyväskylä.

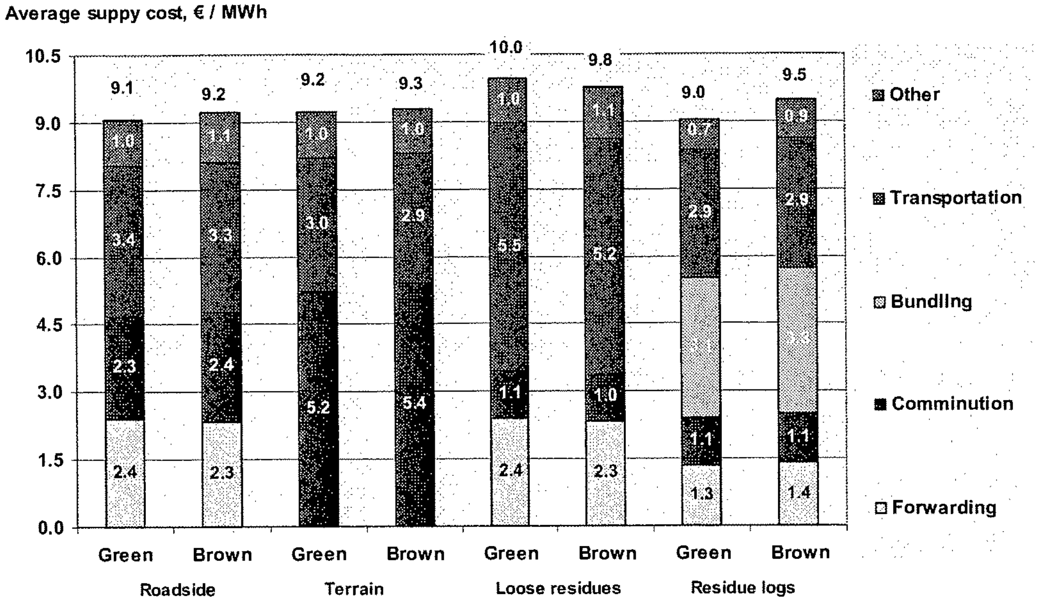


Fig. 34. Cost structure of logging residue supply chains by production stage, green fresh or brown seasoned residues, transport distance of 100 km. An example from the city of Jyväskylä.

The geographical variation of roadside cost was due to different worksite factors. The variation of transportation cost was due to local geography and its effect on transport distances. Different harvesting methods reacted differently to worksite factors. Represented in Appendix 2 are the marginal and average supply costs of different chains around the city of Jyväskylä as a function of the transport distance and the comparison of supply cost among supply methods. Supply cost was defined both on green and brown supply. There was also visualized the variation of supply cost due to variation of the worksite factors. Methods like terrain chipping and bundling were strongly dependable on worksite factors, since terrain chipping and bundling formed the main share of production costs. Also the variation of roadside cost with them was larger than with other methods. Whereas methods like roadside chipping and transporting loose residues to end-use facility were more sensitive to the transport cycle. The method based on loose residues was most sensitive to transport distance, since the transport distance accounted for 81% of the variation of supply cost. This example was from the city of Jyväskylä with a procurement area, where the transport distance was at a maximum of 100 km (see Appendix 2). With the terrain chipping method the transport distance accounted for only 48%. This meant, that worksite selection had a large effect on the supply cost. The most favorable worksites prior to minimizing the transport distance should first be selected.

When the transported material was forest chips or residue logs in green form, the marginal cost of supply increased to 0,26-0,27 €/MWh for every 10 km and the average cost increased to 0.15-0.16 €/MWh, whereas with loose residues increased to 0.40 €/MWh and 0.24 €/MWh respectively. With seasoned material the increase in supply cost was of the same order but the level of the roadside cost was to some extent higher. Owing to the geographical variation of worksite factors, the examples represented in Table 6 were the average values for the whole country and the variation of each regression coefficient for alternative production methods of green and brown residues (calculation supply areas consisted of the whole plant population, see Fig. 32). Supply cost rank between methods varied because of geographical characteristics in different parts of the country (see more details in section 6.4).

Table 6. Supply cost as a function of distance for alternative production methods.

Reserve, supply cost	**b_0, (avg ± stdev)**	**b_1, (avg ± stdev)**	**R^2, (avg ± stdev)**
Roadside chipping method			
Green net, marginal	7.72 ± 0.17	0.024 ± 0.002	0.58 ± 0.06
Green net, average	7.55 ± 0.17	0.016 ± 0.001	
Brown net, marginal	7.95 ± 0.17	0.023 ± 0.002	0.59 ± 0.06
Brown net, average	7.80 ± 0.19	0.015 ± 0.001	
Terrain chipping method			
Green net, marginal	7.77 ± 0.24	0.026 ± 0.002	0.47 ± 0.06
Green net, average	7.67 ± 0.26	0.016 ± 0.002	
Brown net, marginal	7.89 ± 0.22	0.024 ± 0.002	0.48 ± 0.06
Brown net, average	7.81 ± 0.27	0.015 ± 0.002	
Residue logs			
Green net, marginal	7.79 ± 0.34	0.025 ± 0.003	0.47 ± 0.09
Green net, average	7.58 ± 0.29	0.016 ± 0.002	
Brown net, marginal	8.26 ± 0.36	0.025 ± 0.003	0.44 ± 0.09
Brown net, average	8.03 ± 0.31	0.016 ± 0.002	
Loose residues			
Green net, marginal	7.62 ± 0.15	0.039 ± 0.002	0.82 ± 0.03
Green net, average	7.52 ± 0.17	0.025 ± 0.002	
Brown net, marginal	7.50 ± 0.15	0.037 ± 0.002	0.84 ± 0.03
Brown net, average	7.42 ± 0.17	0.025 ± 0.003	

The effect of distance to transport cost varied according to transport economy and terminal times. For instance the terminal times of roadside chipping were longer compared to terrain chipping, which led to higher transport costs despite better transport economy. The relative competitiveness of seasoned loose residue supply options was clearly better, compared with the green supply. Due to better transport economy, the transport cost decreased with the exception of residue logs, since with other options there had been an assumption of lower moisture content after seasoning (see Appendix 2). It was more competitive than the other options when the transport distance was shorter than 40 km. However since cost sensitivity changes according to cost parameters, the breakeven distance may vary within a large range (see Fig. 35). For example, if the hourly cost of machines used in the supply chain changed ± 5% due to scale effects or the cost changes in input factors, the cost range within the supply methods varied 0.7-0.8 €/MWh. The supply cost curves in Fig. 35 are average trendlines where the variation, caused by worksite factors, is omitted (see for comparison in Appendix 2).

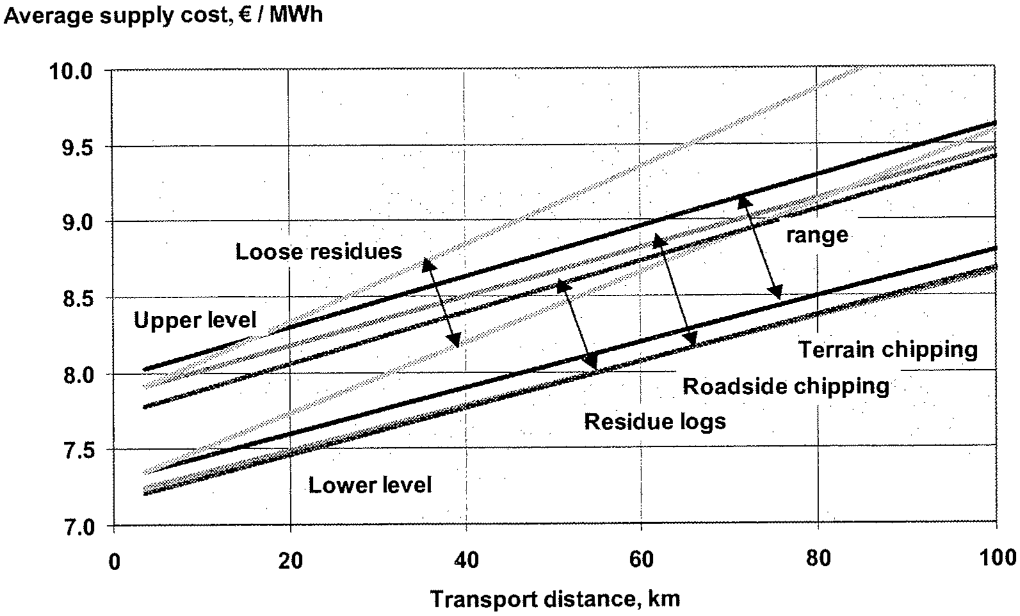


Fig. 35. Supply cost (average trendlines) range as a function of distance for green fresh logging residues. Hourly cost variation (± 5%) of machines that will give the range.

6.2 Logging residue potential at national level

The potential logging residue (green supply) reserve without any technical or economical limitations was 9.0 Mm^3, (18.2 TWh). According to the harvesting yield and different stand selection criteria, the potential decreased to 4.1 Mm^3 (8.2 TWh) (Fig. 36). The major part of this potential of regeneration fellings came from clear fellings, 91% and the rest from seed- and shelter wood fellings 9%. If the harvesting was limited only to spruce dominated stands, the potential was further reduced to 3.5 Mm^3 (7.1 TWh).

The share of logging residue potential from pine-dominant stands was 13% of the whole reserve, which was a potential addition to reserve, if the selection criterion of spruce-dominant was omitted (Fig. 37).

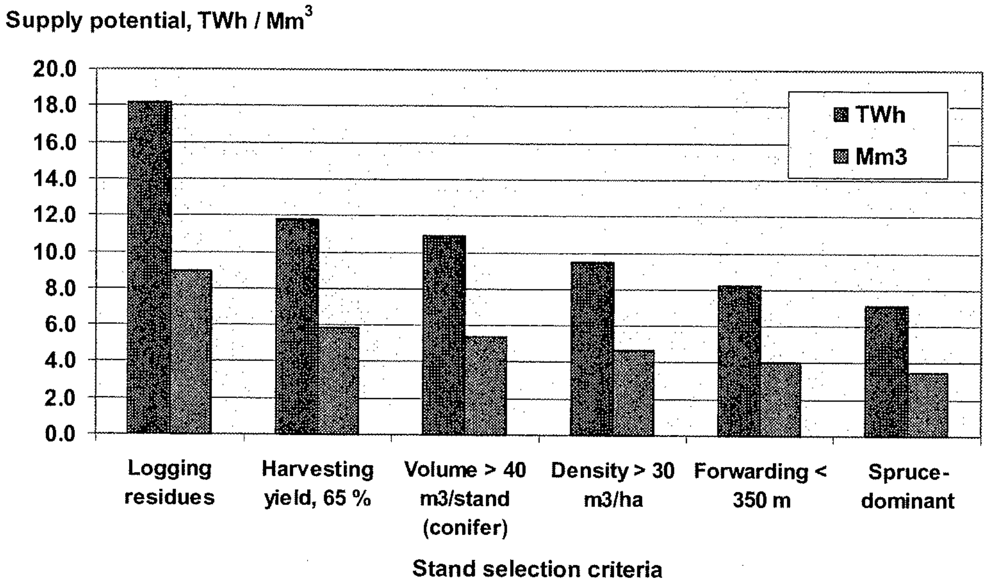


Fig. 36. Logging residue potential (green supply) from regeneration fellings according to stand selection criteria.

The potential reserve of seasoned, brown, logging residues (see initial calculation values from Table 3 and Table 4) was 7.8 Mm^3 (16.5 TWh). According to the harvesting yield and different stand selection criteria, the potential decreased to 3.3 Mm^3 (7.0 TWh). The spruce-dominant selection criterion was ignored in this case. Compared to green supply the potential (TWh) before stand selection criteria was 9% and after criteria 15% lower (Fig. 38).

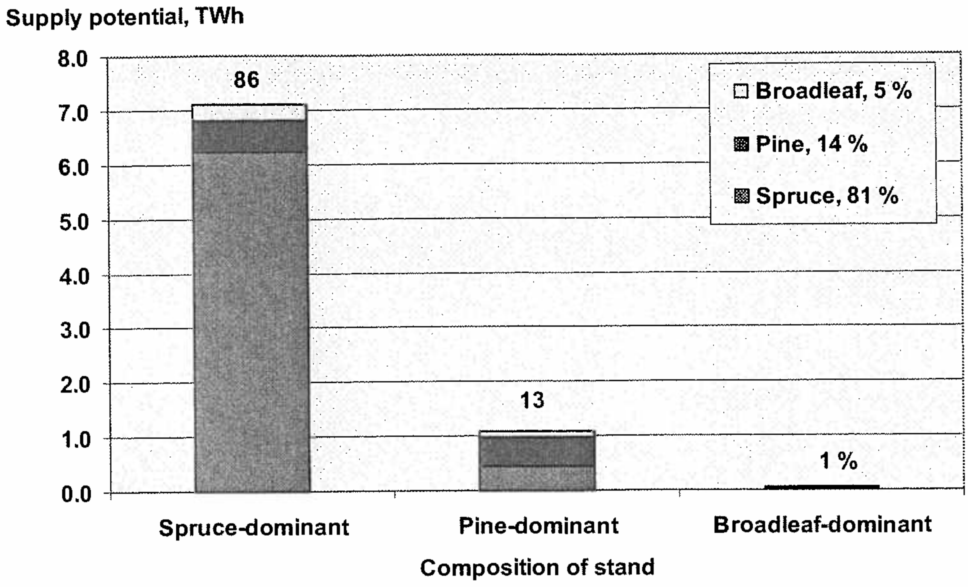


Fig. 37. Logging residue potential (after selection criteria) according to the composition of stands. The share of spruce (merchantable roundwood) must be highest to be classified as spruce-dominant and correspondingly with other wood species.

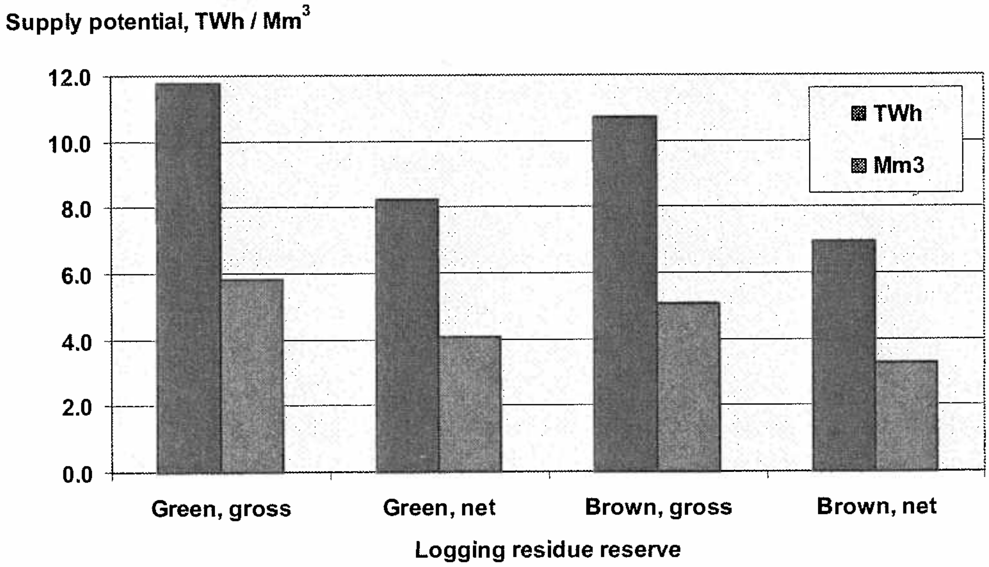


Fig. 38. Logging residue potential, green vs. brown supply. Gross reserve, technically available using a recovery rate of 65 %, net reserve economically available, using stand selection criteria.

“Volume” and “density” criteria limited the potential for brown supply policy more due to loss of material during seasoning. The net reserve was 30% lower for green supply and 35% for brown supply. Among the selecting criteria, the “density” criterion limited the reserve more than the “volume” or “forwarding distance” (Table 7). The ratio between recovered residue and merchantable wood volume was 26% for green and 22% for brown supply. “Density” criterion was important, since it took into consideration the ecological aspect. At low productive forest sites, where the logging residues were left at stands, also the density was lower in many cases. Also stricter limitations of density have used, like ≥ 35 m^3/ha, but it limited also many suitable pine-stands in the northern part of Finland. The distribution of reserve according to different stand selection criteria is illustrated in Appendix 4.

Table 7. The effects of single stand selection criteria to the logging residue reserve (see cumulative frequencies in Appendix 4). Starting level = 100 using a recovery rate of 65%.

Reserve	**Green supply**		**Brown supply**	
Selection criterion	**Individual**	**Cumulative**	**Individual**	**Cumulative**
Volume, ≥ 40 m^3	93	93	91	91
Density, ≥ 30 m^3/ha	83	80	78	75
Forwarding, ≤ 350 m	87	70	87	65
Spruce dominant	76	60	76	57
Residue / merch. wood, %		26		22

In this case the residue potential was allocated into periods on the grounds of the forwarding time of the timber. There was a distinct annual harvesting rhythm, with intensive timber felling during autumn (Fig. 39). In summertime the harvesting intensity was lowest. Typically also spring was one of the most difficult periods for wood supply because of the low bearing capacity of truck roads in many areas. Therefore weather conditions reduced the harvestable logging residue potential especially in spring due to trafficability of roads and stands. This harvesting rhythm meant, that there was an obvious need to store material over the winter period to meet quality requirements and to balance forest fuel production against the demand on a yearly basis.

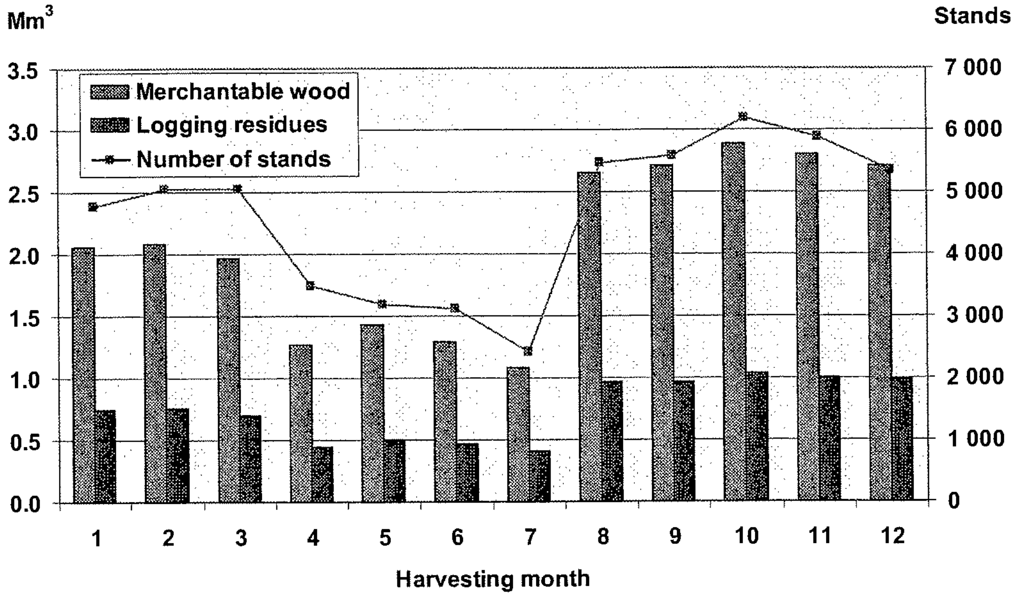


Fig. 39. Distribution of the harvestable logging residue potential for the year 2000.

Not all stands were accessible all year-round. Based on ground conditions, each stand was assigned advisable harvesting seasons. In principle, stands with good ground conditions, such as those permissible for harvest in spring or autumn, were cut in any season. Only 23% of the reserve was located in areas suitable for all year-round harvesting and 18% of the reserve was obligated to harvest during wintertime. The rest of the reserve, marked as summer-suitable, was harvested also at wintertime when needed. The distribution of felling suitability is illustrated in Appendix 4.

The potential logging residue reserve, using a harvesting yield of 65%, from regeneration fellings of the Finnish Forest and Park Service was 0.7 Mm^3 (green supply) and if Lapland was excluded, the potential decreased to 0.5 Mm^3 (Fig. 40). The available reserve was only 0.3 Mm^3 if the existing worksite factors followed the pattern of the stand data of this study (see Table 7).

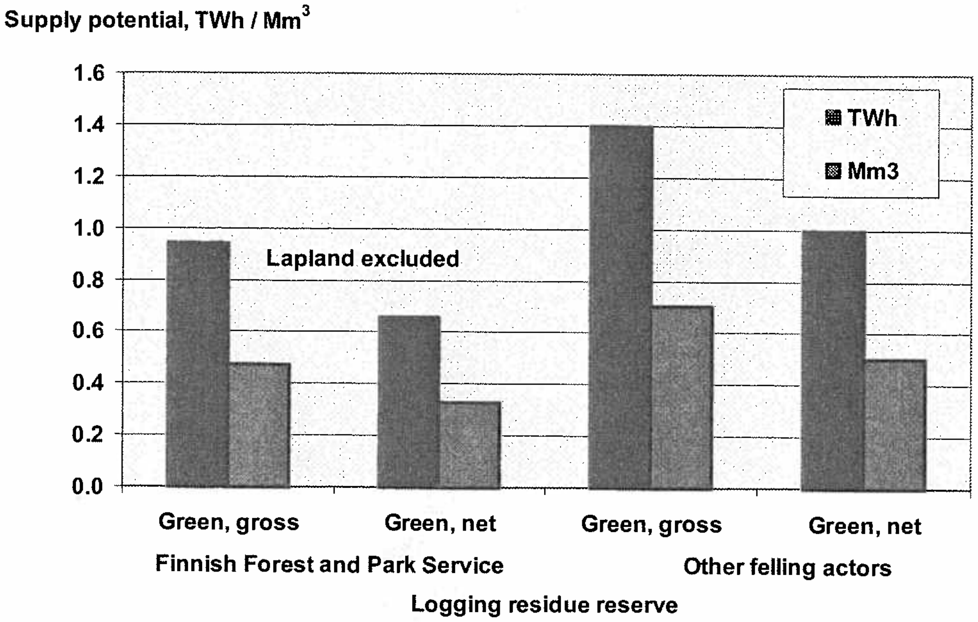


Fig. 40. Logging residue potential (green supply using a recovery rate of 65%) from regeneration fellings of other felling organizations.

According to statistics (Metsätilastotiedote 596, 2001) for the remaining regeneration felling areas, the contribution of other felling actors, like the members of the Association of the Finnish Sawmills and the Forest Management Associations, had in total some 0.7 Mm^3 potential residue reserve and after reduction of the worksite factors some 0.5 Mm^3. To sum up, the gross potential of other felling actors was 1.2 Mm^3 (2.3 TWh) and the net potential was 0.8 Mm^3 (1.7 TWh), which was 16% of the total values for all felling actors. Despite the contribution of other felling actors at national level being minor, it may regionally be of great significance to the potential of available residues.

6.3 Logging residue potential at regional level

The logging residue potential per unit area (km^2), i.e. regional potential map (m^3/km^2), had distinct regional variation according to the calculation procedure based on stand data aggregation and Voronoi diagram (Fig. 41). The largest potential was located in Central and Eastern Finland. Each class range had on average at one fifth of the area and the color gradation from darkest to brightest represented the decrease in potential from highest to lowest according to the selected range-division. Aggregation distance affected the regional potential pattern; the shorter the distance the more detailed the potential map, ending up to single stand locations. However, to illustrate the regional patterns, aggregation at some level was needed. In Fig. 41 the aggregation distance was 10 km and the logging residue reserve was calculated for the gross stand reserve, using a green supply policy and a recovery rate of 65%.

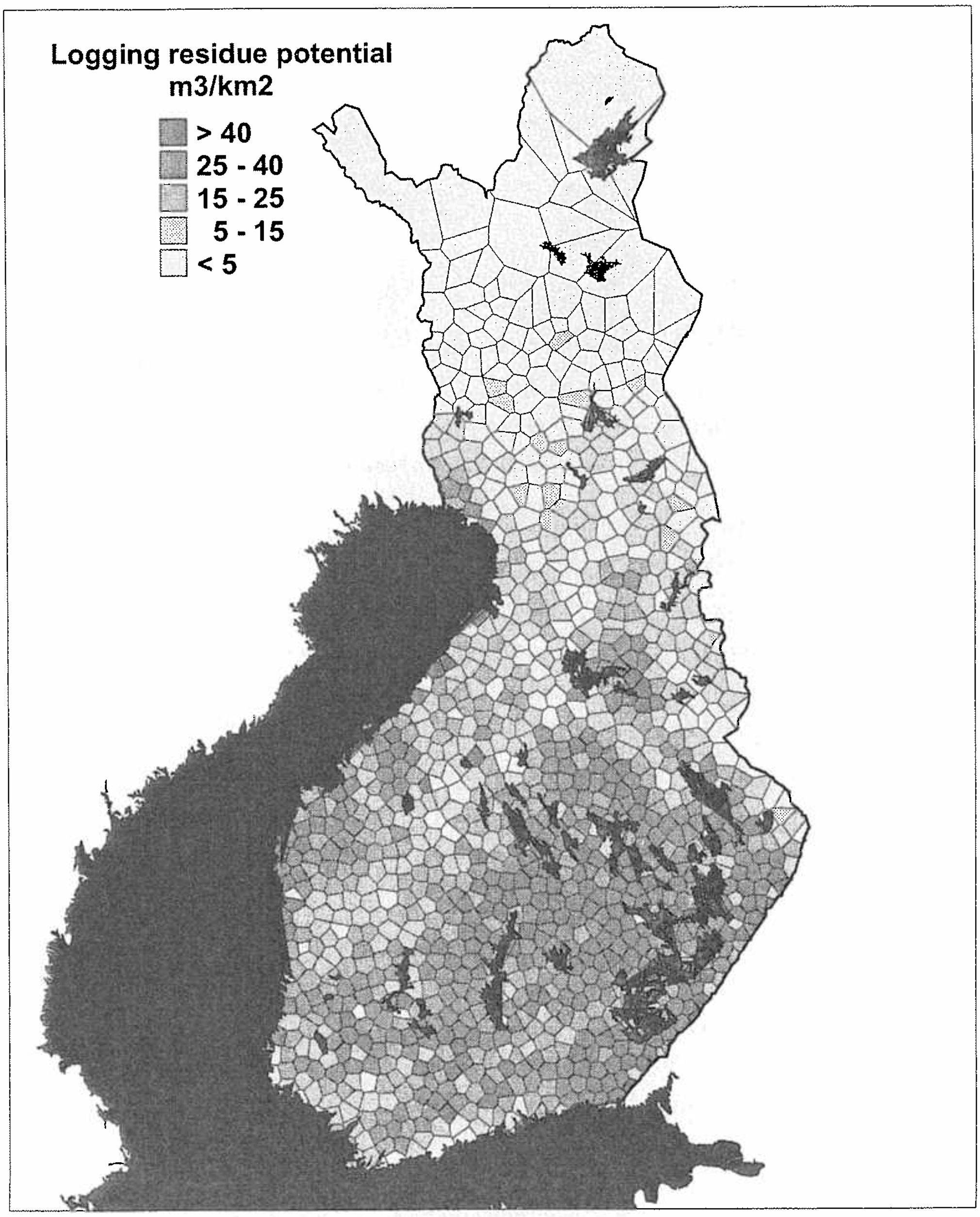


Fig. 41. Logging residue regional potential, m^3/km^2, green supply of gross stand reserve with a recovery rate of 65%, aggregation search radius of 10 km.

The regional variation of potential per area unit resulted from the regeneration felling activity and composition of stands. In practice the map showed the location of mature spruce-forests, which were also the most favorable areas for logging residue recovery. The maps from worksite related factors, like average forwarding distance (m), residue density (m^3/ha), residue volume, (m^3/stand) and composition of stand (share of spruce and pine of merchantable wood volume) were illustrated in Appendix 5. They were constructed in the same manner as Fig. 41 using a 10 km aggregation distance. Shorter aggregation distances would illustrate the same spatial phenomenon in more detail.

Residue density, m^3/ha, and composition of the stand were highly correlated factors, which was clearly illustrated by the map representations. Pine-dominated stands were located mostly in the northern part of Finland and Ostrobothnia, which was the reason for lower residue density in these areas. Residue volume per stand was highest in Kainuu and also in the northern Finland there were many districts, where larger stands, based on unit area and volume per stand, were felled than on average in Finland. The average forwarding distance was longer in the northern part of Finland and Ostrobothnia.

If the supply potential was defined as a net reserve, the worksite factors diminished the potential according to the regional variation of them. The variation was larger for gross reserves, since worksite factors like forwarding distance and residue density, was more unfavorable in areas where the potential was already lowest like in Ostrobothnia and Lapland. The effect of worksite factors to potential for the green and brown supply policy at different plant locations all around Finland was analyzed in more detail in section 6.4.

One method to analyze the felling activity was to construct the stand location density maps, which showed where most of regeneration fellings were located according to stand proximity with a different distance limit. The selected contour maps were constructed according to proximity calculations to 100, 500 or 1 000 nearest stands (see Appendix 6). The grid dimension was 5 * 5 km and the contour interval was based on percentile grid intervals, (10 - 25 - 50 - 75 - 100%), which were constructed in a cumulative manner, i.e. grids in a lower class were included in a upper one. The lowest class, 10%, included the grids having shortest distance to the nearest (100, 500 or 1 000) stands and it consisted of 10% of the whole grid population. The lower the calculation distance limit was the more detailed the regional pattern of stands average proximity was. Naturally the highest proximity, i.e. lowest distance, fell in areas having the largest logging residue potential (compare to Fig. 41).

The logging residue availability according to transport distance, in this case GWh at a transport distance of 100 km, were illustrated by availability maps in Appendix 7. The contour interval was based on predefined potential classes and the interpretation of maps was straightforward - what was the supply potential when the transport distance was at a maximum of 100 km along a road network? The aggregation distance limit had an effect on the contour map layout, since sparser initial data points led to coarser layout of contour maps. When the aggregation distance was larger, the variation of potential between aggregated points was larger too. For instance there was more grids classified to the highest class (> 800 GWh) for 20 km than for 10 km aggregation distance. With the brown supply policy the areas of highest classes were to some extent smaller because of the smaller potential of data points (see Appendix 7). The effect of selected grid-size was minor, for instance if the grid size had been 1*1 km or 10*10 km instead of 5*5 km. Availability maps illustrated the effect of regional geography to potential and showed the advantages of inland areas, which had larger supply areas compared to coastal or areas near the national frontier (see Fig. 42). The effect of waterways to the availability was taken into consideration through a winding coefficient. The effects of land use classes and road network characteristics inside supply areas and how supply areas varied regionally will be analyzed in detail in section 6.4.

The results from plant location analysis based on a location allocation algorithm were illustrated via selected map representations (demand levels 200-500-800 GWh) in Appendix 8. According to green net stand reserve, the plant locations were analyzed for the maximum transport distance of 100 km using different demand levels. For example if the demand level was 300 GWh, there were 19 potential plant locations (Fig. 42). With a higher demand level the number of potential plant locations decreased as follows; 200 GWh - 31 potential plant locations, 300 GWh - 19, 400 GWh - 14, 500 GWh - 8, 600 GWh - 7, 700 GWh - 6, 800 GWh - 5. The locations defined to higher demand levels were not optimally located at the same site as the smaller demand levels due to the allocation process. If the distance limit was longer the number of potential sites was higher due to a larger supply area. With the brown reserve the number of locations were to some extent smaller due to a lower potential. The most advantageous plant locations were inland areas due to better availability.

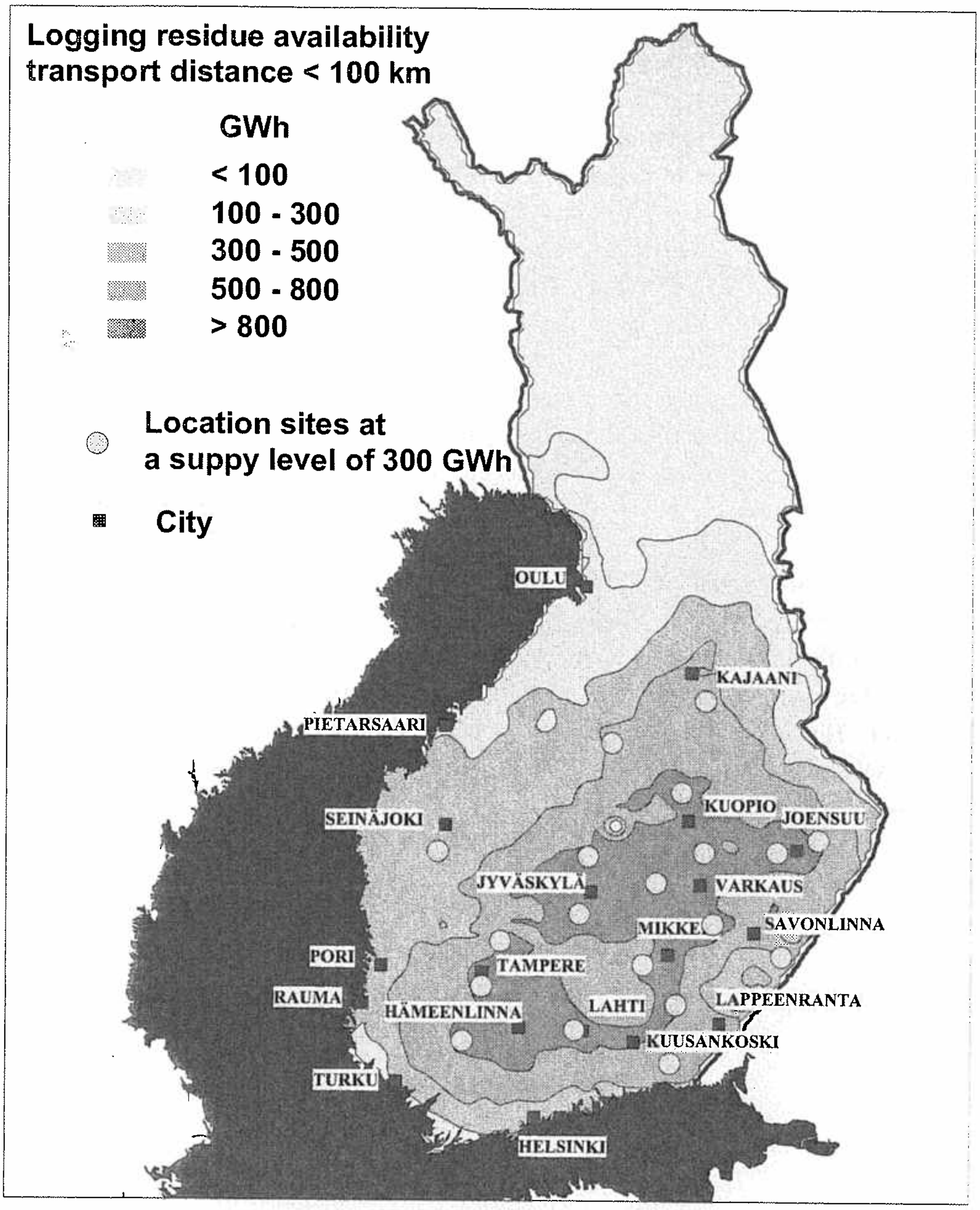


Fig. 42. Logging residue availability map as a function of distance and optimized facility locations at a supply level of 300 GWh, green supply policy, grid-size 5 x 5 km, aggregation distance of 10 km.

6.4 Logging residue potential at plant level

Logging residue potential calculations were conducted for the power plant population selected for this study. First there was a comparison between plant sites according to procurement area size and area-based potential inside procurement areas, which gave as a result the potential under different supply policy and reserve options. The potential was also calculated according to supply cost with alternative supply methods. After that a supply potential allocation was analyzed between power plants according to the transport LP-model under constraints for demand and supply.

The average value of the winding coefficient (w_j) inside procurement areas was 1.31 ± 0.06 (stdev), with range of 1.20-1.49. There was no difference between the weighted or non-weighted average value, since the variation of weights, i.e. residue volume per stand, was small. According to the regional variation in winding factor, the most advantageous areas were located at coastal areas in the southern and western part of Finland. In the northern part of the country, the road net was sparse, which produced higher values of the winding factor as did the river and lake systems in some inland areas (Fig. 43).

Besides the regional variation of the winding factor, it was also dependent on size of the procurement area, since the individual values (w_{ij}) varied significantly, but the cumulative effect moderated the variation. For example, according to the selected plant locations (Fig. 44) the variation of cumulative winding factors at a distance of 100 km was minor. However, with smaller distances the variation was larger and the rank between selected plants changed (Fig. 45). Therefore, this analysis is scale-dependent, i.e. the smaller the sample the larger the inter-plot variation.

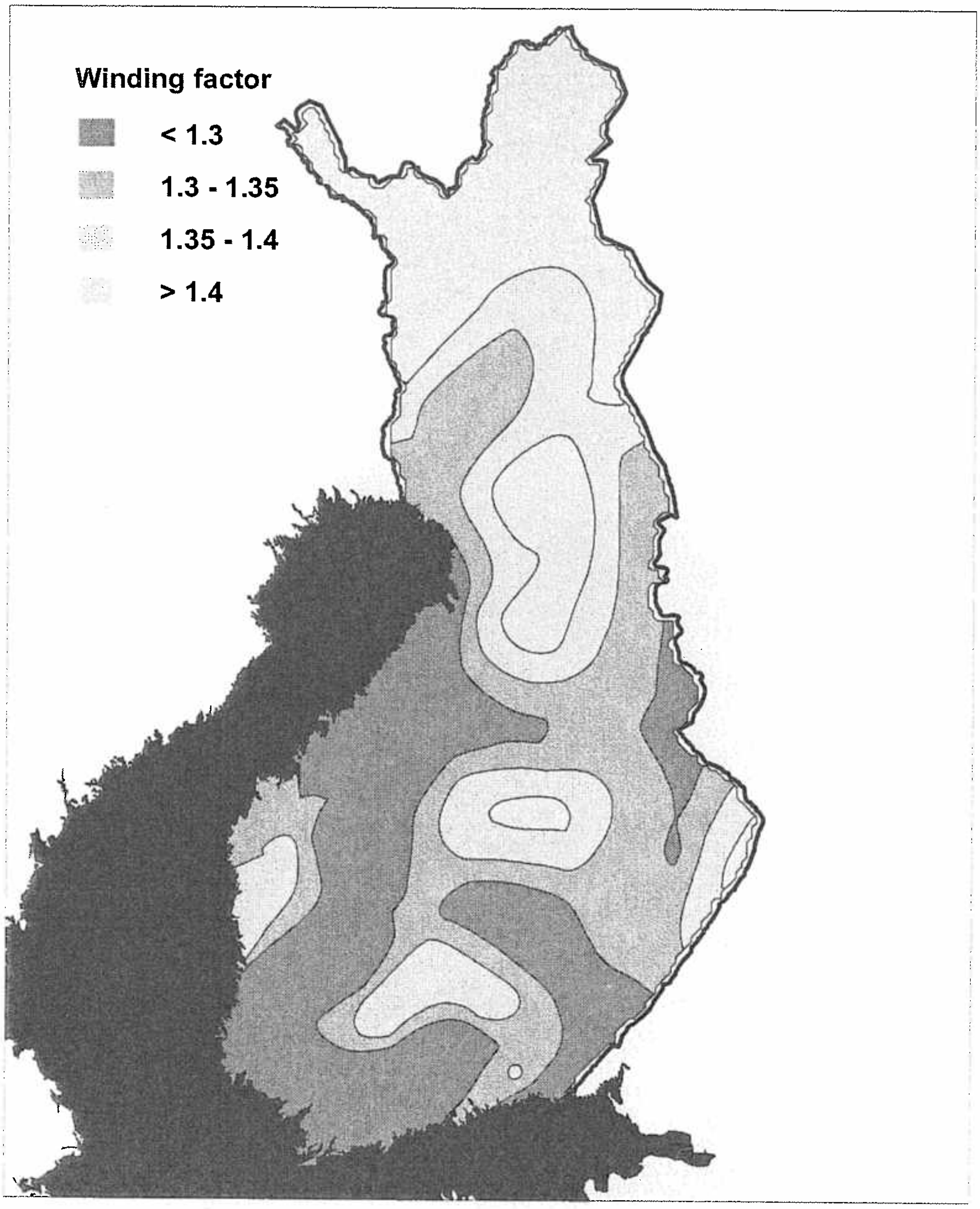


Fig. 43. Thematic map of the winding coefficient, procurement radius along a road net of 100 km, grid size 5 x 5 km

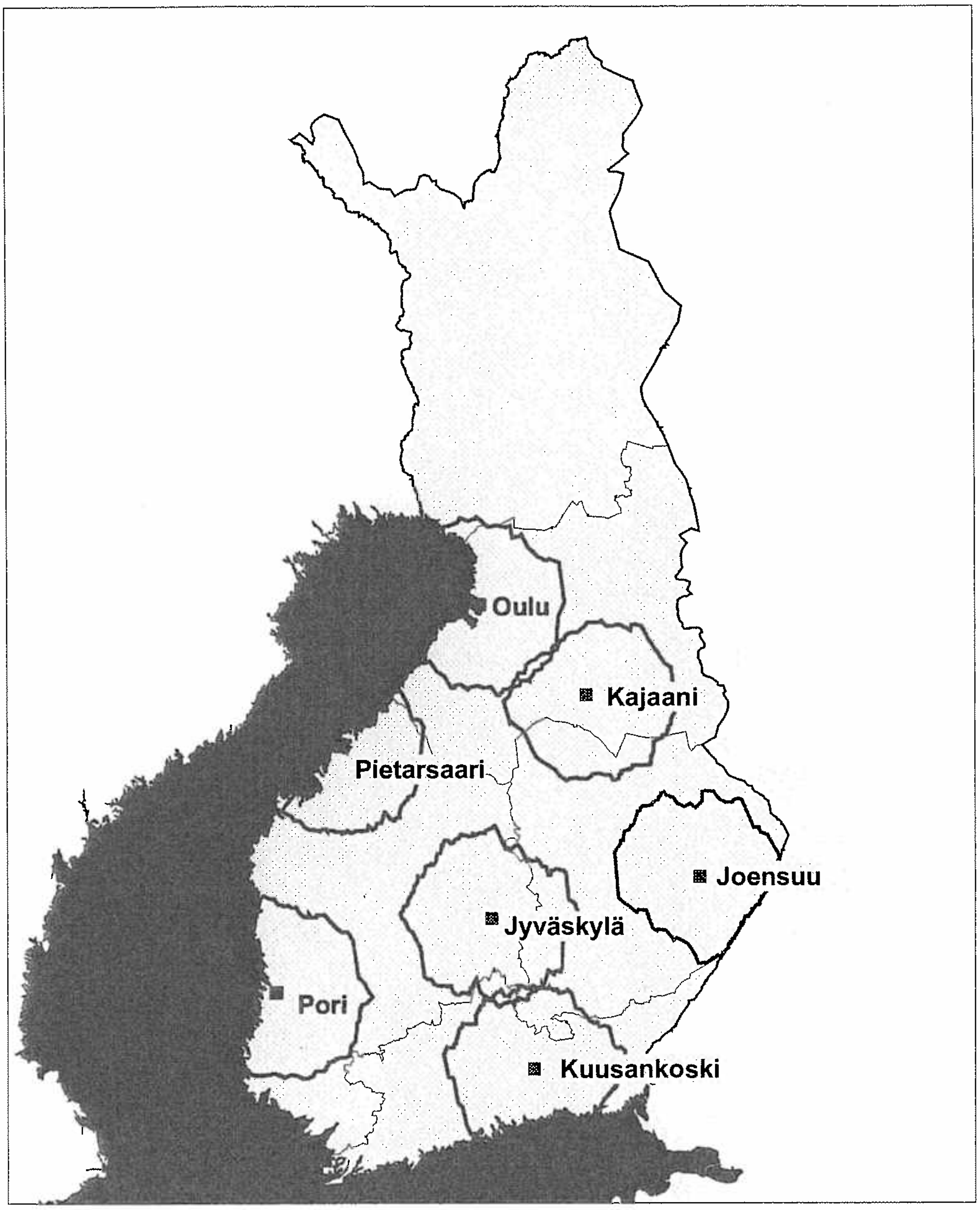


Fig. 44. Procurement areas (< 100 km), according to isodistance curves of 100 km around selected plant locations.

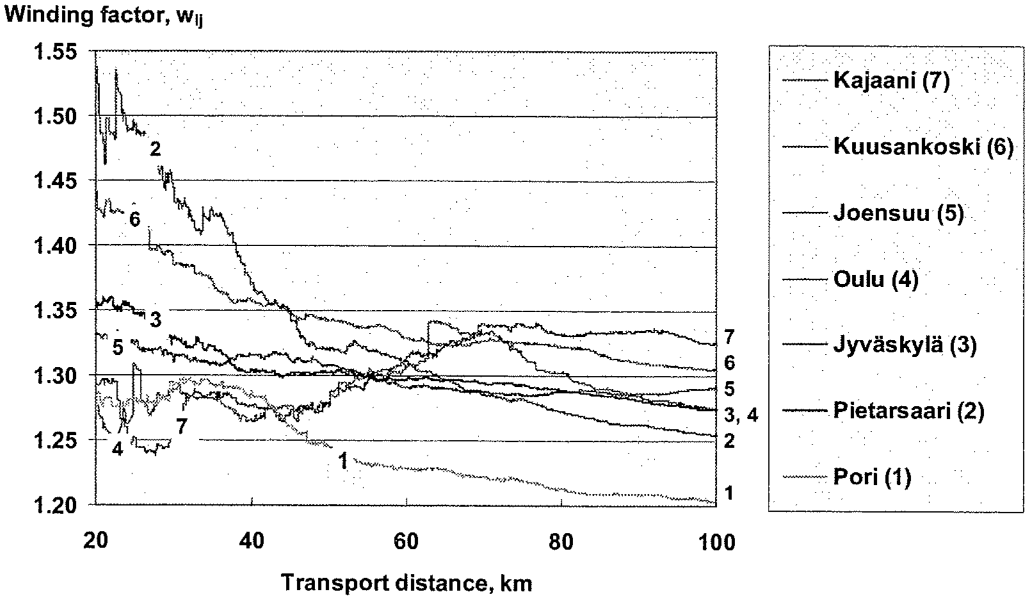


Fig. 45. Winding factors as a function of distance around selected plant locations.

When comparing the winding factors and procurement areas for inland plant sites, the area was in the outmost case one third larger, which resulted mainly from differences in winding factors (Table 8). The average procurement area was 63% from the theoretical area size of a circle. Other category included the procurement areas, which were restricted according to the coast or national frontier. In this category the winding factor seemed to be to some extent lower, which can be seen also in Fig. 43. However due to geographical restrictions the procurement area was in the outmost case only one third from the largest one in inland sites.

Table 8. Procurement areas and winding factors inland and in other regions around whole power plant population (transport distance 100 km).

	Procurement area, km^2	**Winding factor, w_j**
Inland, avg ± stdev	19 907 ± 1 481	1.33 ± 0.05
Inland, min - max	17 261 - 22 857	1.24 - 1.42
Other, avg ± stdev	14 798 ± 3 659	1.28 ± 0.05
Other, min-max	8 089 – 21 899	1.20 - 1.37

When comparing the procurement areas between selected plant locations, the difference between coastal and inland area was evident and became larger as the transport distance increased (Fig. 46). The differences between areas of inland site were caused by the winding factors.

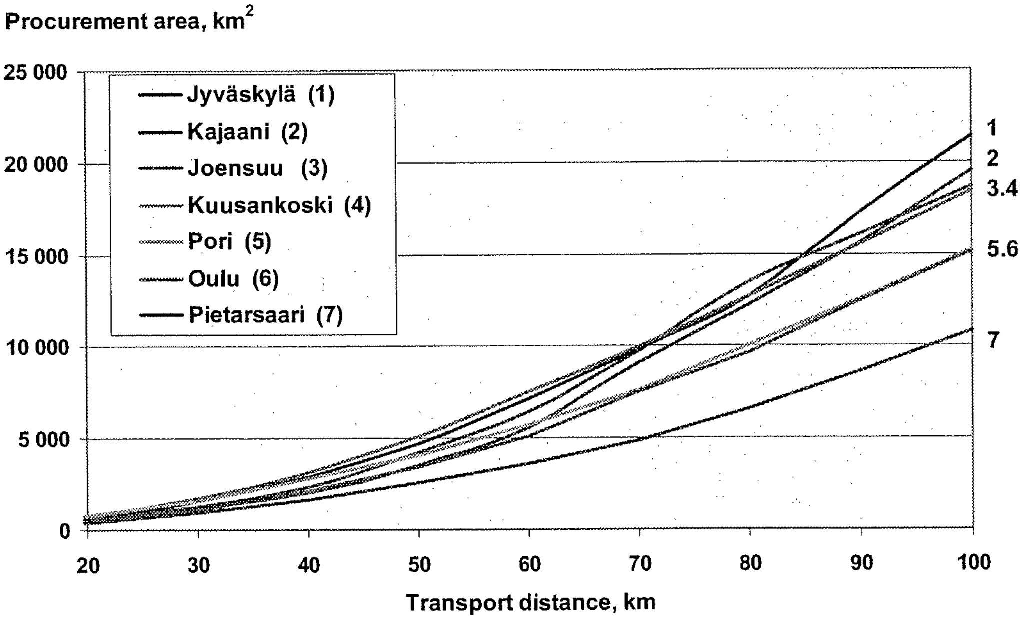


Fig. 46. Procurement areas, km², as a function of distance around selected plant locations.

The variation in the logging residue potential, MWh/km², inside procurement areas resulted from land-use patterns, regeneration felling activity and worksite factors. On average the share of forest land inside procurement areas was 72% with a range of 57-94%. The forest land share was the largest in the northern part of Finland, where the watercourses had a minor effect. Whereas the smallest values were in eastern part of Finland due to watercourses, like Saimaa, whereas the regeneration felling activity was the largest in the same area (see previous Fig. 41). The variation in potential was large (Table 9 and Fig. 41) and there was also variation as a function of distance, which is illustrated in Fig. 47 and Fig. 48 around selected plants. When the potential was calculated per inland area, the variation resulted from changes in land-use patterns, whereas per forest land area, the variation resulted from changes in regeneration felling activity or worksite factors when it was a question of net reserve. With the green supply the potential was at its highest (net-gross reserve) 69-90 MWh/km² per inland and 99-132 MWh/km² per forest land. With the brown supply the potential was at its highest 61-82 MWh/km² per inland and 89-120 MWh/km² per forest land. These values are valid for a procurement area of 100 km transport distance, for smaller areas they were higher being at the upmost case as a single stand potential like the average value of 99 MWh/ha for gross reserve or 138 MWh/ha for net reserve stand population. Listed in

Appendix 9 are plant-specific potential values for green and brown supply cases per inland and forest land area.

Table 9. Logging residue potential, (avg ± stdev) MWh/km², inside procurement area around the whole power plant population, transport distance 100 km.

	Green supply		Brown supply	
Potential, MWh/km²	**Inland**	**Forest land**	**Inland**	**Forest land**
Gross reserve	52 ± 22	73 ± 35	47 ± 20	66 ± 32
Net reserve	38 ± 18	53 ± 28	33 ± 16	45 ± 24

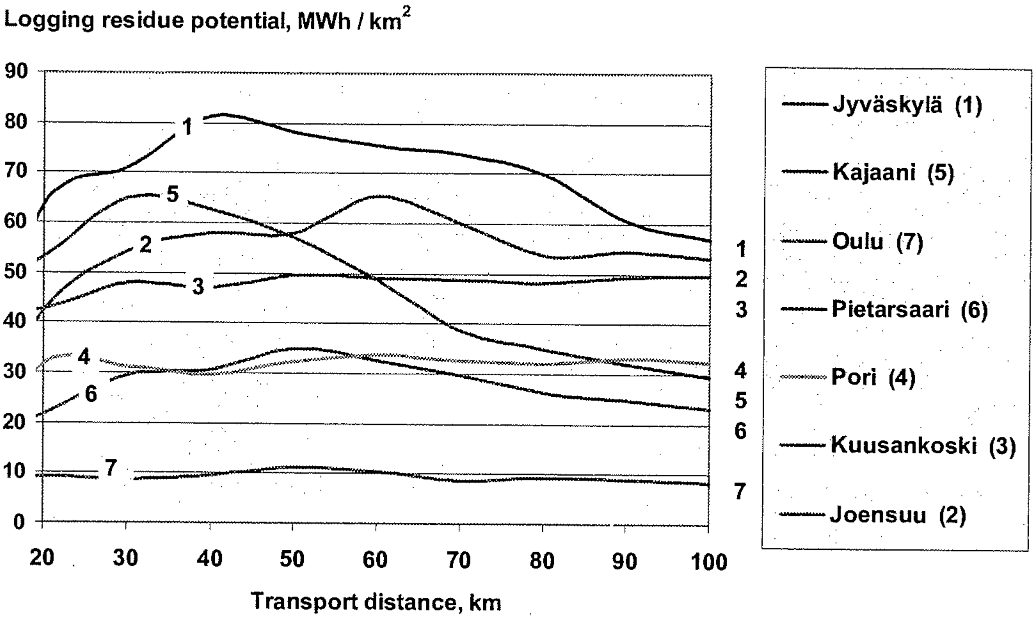


Fig. 47. Logging residue potential (net reserve) inside the procurement area, MWh/km², as a function of distance. The area includes total land area and inland watercourses.

As a combination of procurement area size and potential per area within procurement area, supply curves were formulated around selected sites, as in Fig. 49. The cumulative potential as a function of transport distance rose very rapidly at favorable inland sites whereas at coastal or northern located sites the rise was slower. The potential difference between best and worst sites was multifold, for example between the cities Jyväskylä and Pietarsaari the difference was almost fivefold.

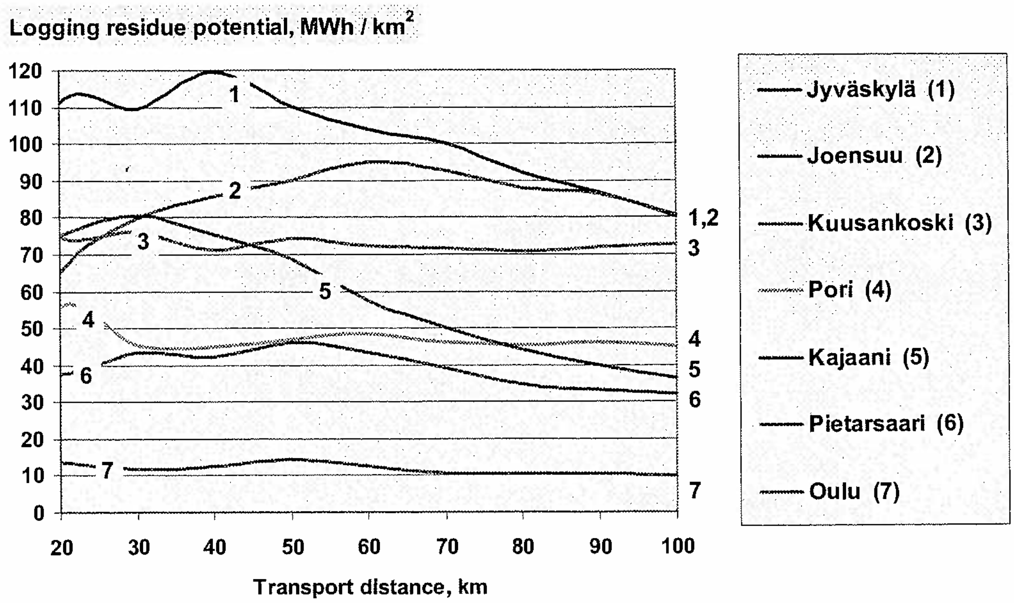


Fig. 48. Logging residue potential (net reserve) inside the procurement area, MWh/km², as a function of distance. The area includes forest land.

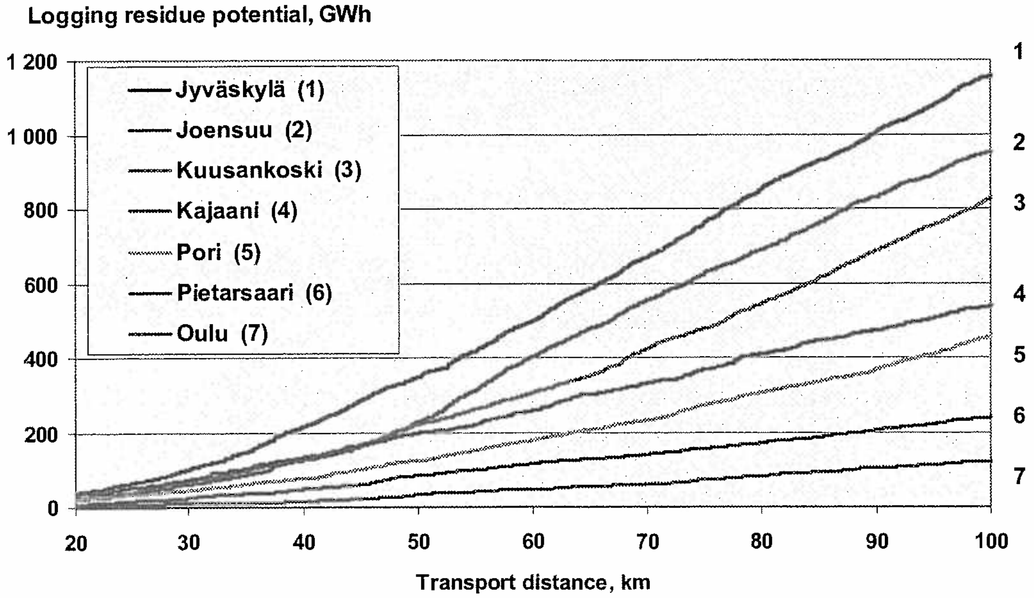


Fig. 49. Logging residue potential (net reserve), GWh, as a function of distance.

The potential at plant level was defined according to supply policy (green/brown) and reserve (gross/net) like at national level (see previous Fig. 38 and Table 7). In this case the cumulative potential was illustrated as a function of transport distance to a value of

100 km. As it has been pointed out earlier, the brown supply decreased to some extent the potential due to presumed material loss. Stand selection criteria reduced more potential for brown than green supply, since more stands were allocated out of the potential calculation for the brown supply as in the example around the city of Jyväskylä (Fig. 50). For practical reasons the potential availability lay between illustrated levels. For actual availability the procurement of other plants in the same area and market structure (forest company market shares and delivery contracts) had to be taken into account. Listed in Appendix 10 are plant-specific potentials at different levels which, can be compared to earlier map representations in Appendix 7. Among the highest potential sites were such inland plant locations, as the cities Pieksamäki (1 200-1 700 GWh, i.e. brown net-green gross, see Fig. 50), Varkaus (1 100-1 700 GWh), Jyväskylä and Mikkeli (1 000-1 600 GWh) and Kuopio (1 000 - 1 500 GWh). The decrease between different potential levels resulted from variation in worksite factors. Typically in the northern and western part (especially in Ostrobothnia) the decrease was higher than in other areas. Variation of worksite factors had been illustrated earlier in Appendix 5 via thematic map representations.

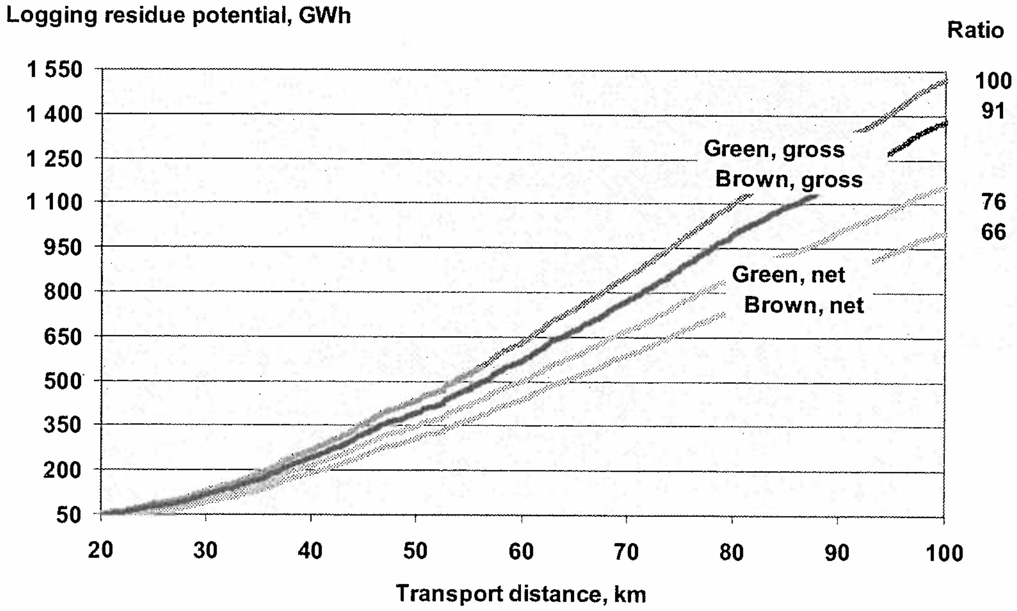


Fig. 50. Logging residue potential (green and brown) around the city of Jyväskylä. Gross volume using a recovery rate of 65% includes all stands and net volume stands, which were valid according to selection criteria.

Logging residue supply costs were also defined as a function of potential availability with different supply chains and supply policy options (green/brown). The supply chains were decentralized methods like terrain or roadside chipping or centralized methods like crushing loose residues or logging residue logs at the end-use facility. The supply cost parameters were defined earlier in section 5.1.8 and in Appendix 1. All availability calculations were based in this case on net reserve. Supply costs were calculated as marginal and average cost (Fig. 51). The marginal cost came from latest stand costs in a cumulative manner when the cost of stands were ranked in ascending order according to the supply cost. The weighted average of those stands gave the average cost, where the weight was energy content (MWh) of logging residues collected from stands. Marginal cost referred to the cost of individual stands, whereas average cost referred to the whole selected stand population.

The supply-cost curve (see Fig. 51-Fig. 53) for logging residues could be assumed to have different shapes, depending on the plant location, supply method and the mode in which material was transported (chips, loose, bundles, i.e. residue logs). According to the break-even point of supply cost it was possible to estimate the potential availability of logging residues. However, given the typically low energy density, and its low extent of value added, the transportability of logging residue-based material was limited, with rising costs at the point of delivery, as the area of supply was widened. Owing to high transport costs the supply-cost curves were upward sloping. Increased use involved declining competitiveness due to higher supply costs.

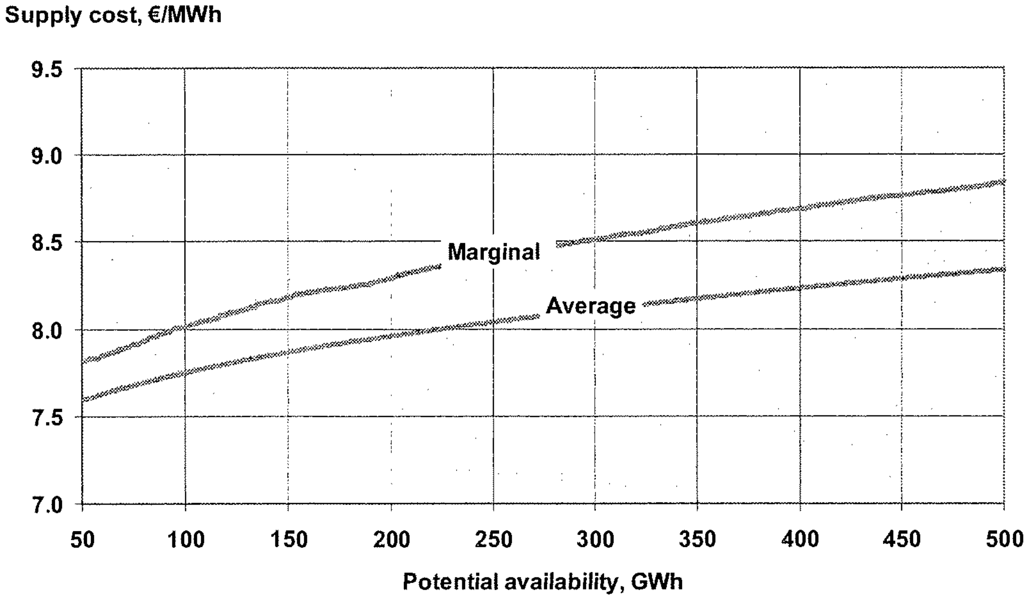


Fig. 51. Logging residue supply cost as a function of potential availability around the city of Jyväskylä. Green supply policy with roadside chipping method.

Typically there was a minor variation in supply-cost curves between supply methods except the loose residue-method due to lower transport economy like the city of Jyväskylä example illustrated (Fig. 52). With the brown supply policy, the competitiveness of loose residues became better. Also the rank between other methods changed, but the variation was still minor (Fig. 53). The availability as a function of supply cost was lower due to reasons listed in section 5.1.8, which resulted mainly from changes in productivity and moisture content and transport distance.

The decentralized chipping methods were sensitive to chipping productivity changes. The roadside chipping method was more sensitive due to the nature of hot-operation, where the chipping operations had a direct effect on transport effectiveness. The availability was compared with for example at a supply cost level of 8.5 €/MWh. In the case of the brown supply policy this meant on average a 44% lower availability for the roadside chipping-method compared to the situation of any productivity drop (Fig. 54). At the same time the average cost rose by 0.33 €/MWh for roadside chipping-method, i.e. 4%. The corresponding values for the terrain chipping-method were 37% and 0.31 €/MWh, i.e. 4 %. The supply-cost curves were also affected by moisture-content. The initial values of seasoned material, were 35% in summertime and 45% in wintertime. If the moisture-content was an average 5% higher, the availability was 27% lower at a supply cost level of 8.5 €/MWh for roadside chipping-method. At the same time the average cost rose by 0.21 €/MWh, i.e. 2%. These values were valid around the city of Jyväskylä when using the geography and stand features typical for that region.

The main part of supply cost resulted from transport cost and its share rose with transport distance. The effects of transport distance and roadside cost for different supply methods were analyzed in detail earlier in section 6.1 and Appendix 2. However the effect of transport distance varied between supply methods. Since the increase in transport distance influenced the procurement area according to the square-law dependence, the availability as a function of supply cost rose slowly upwards as is shown in Fig. 52-Fig. 54.

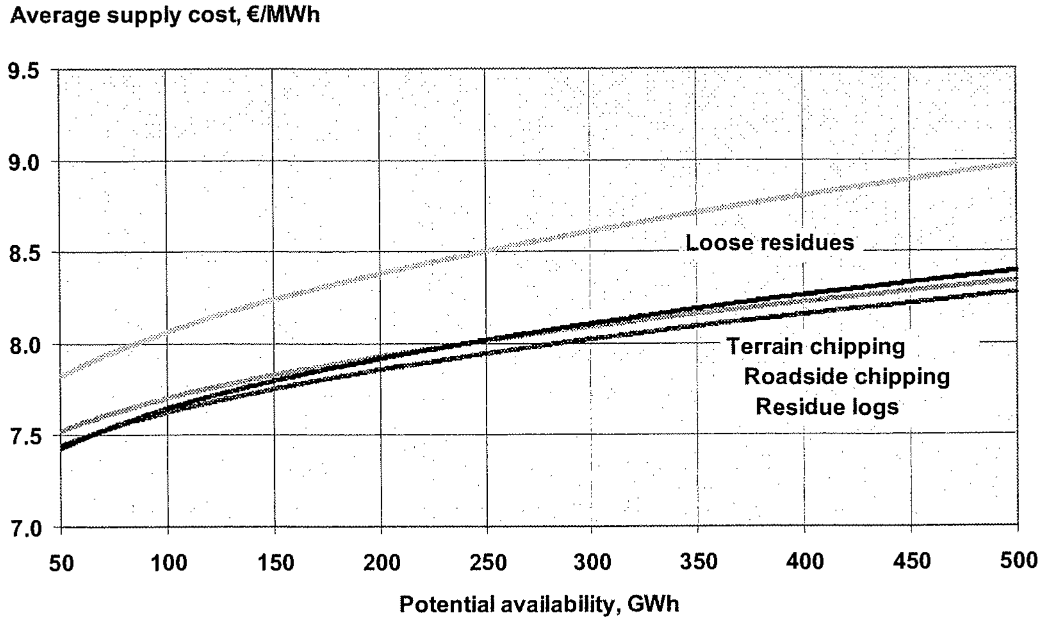


Fig. 52. Logging residue supply cost (average) as a function of potential availability around the city of Jyväskylä. Green supply policy for different supply method.

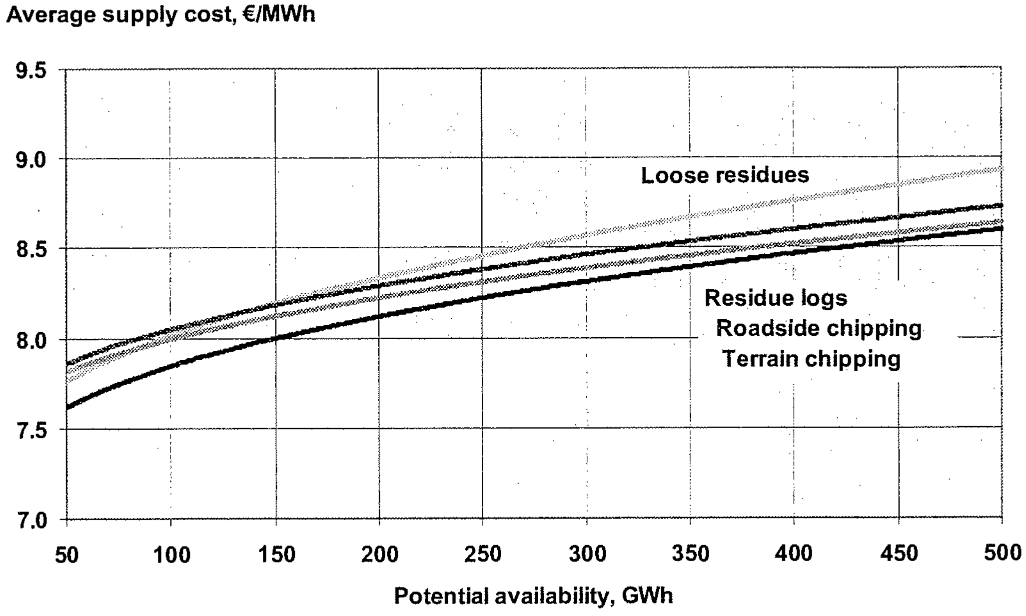


Fig. 53. Logging residue supply cost (average) as a function of potential availability around the city of Jyväskylä. Brown supply policy for different supply method.

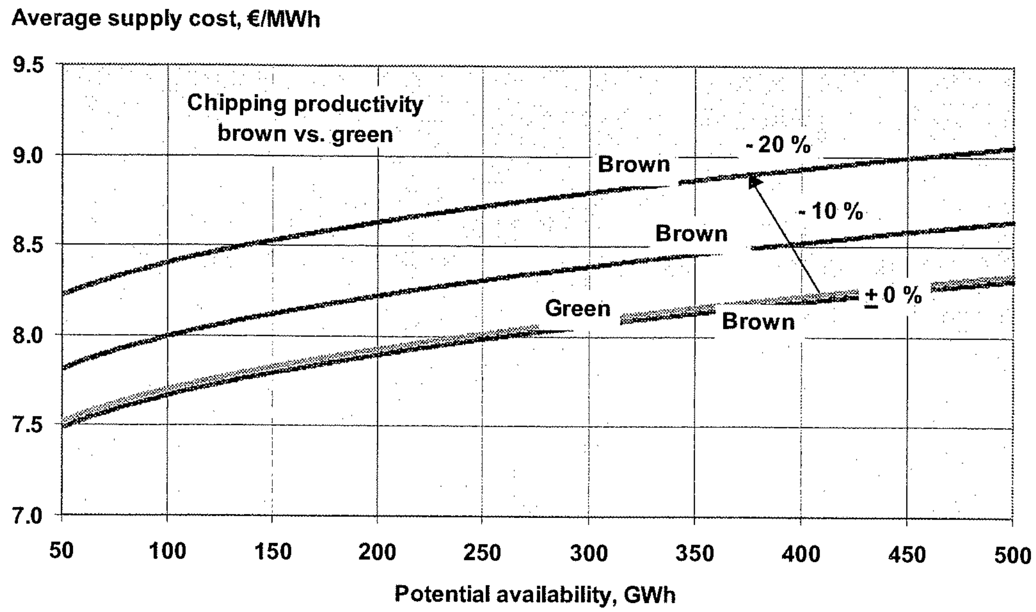


Fig. 54. The effect of roadside chipping productivity on logging residue supply cost (average) as a function of potential availability around the city of Jyväskylä.

When comparing the logging residue availability as a function of supply cost for different supply methods, it seemed that at a marginal cost of 8.41 €/MWh (50 FIM/MWh), one fifth and 9.25 €/MWh (55 FIM/MWh) half of the green potential it was economically available (Table 10). The corresponding average costs were 8.0 €/MWh and 8.6 €/MWh (Table 11). Values listed in Table 10 and Table 11 are an average of all procurement areas involved in this study (see previous Fig. 32). Owing to intersecting supply curves (see Fig. 52 and Fig. 53), the change in average cost was modest with methods competitive in short transport distances like the loose residue chain. However, the potential availability was very sensitive to supply cost parameters due to slowly upward shape supply-cost curves.

The results were dependent on power plant locations and they were valid under plant population selected in this study (see plant-specific values for different supply method for green and brown supply policy in Appendix 11). The competitiveness of different supply methods varied regionally i.e. the rank of procurement areas according to availability at certain supply costs varied between supply methods. For instance in areas, where the average forwarding distance was shorter or residue density higher at stand level, m^3/ha, were ranked higher with the terrain chipping method. Sites with smaller procurement areas alongside with shorter average transport distances were ranked higher for the loose-method and larger procurement areas with longer average transport distances were ranked higher for the roadside chipping and the residue bundle-method.

Table 10. Logging residue availability measured as a share of net potential inside procurement areas (< 100 km), for different supply methods.

Marginal cost class	**Share of net potential inside procurement areas at maximum marginal cost**			
€/MWh, (FIM/MWh)	**7.57** (45)	**8.41** (50)	**9.25** (55)	**10.09** (60)
Green supply				
Roadside chipping	2%	17%	53%	89%
Terrain chipping	3%	16%	43%	79%
Residue logs	3%	19%	52%	85%
Loose residues	1%	7%	22%	45%
Brown supply				
Roadside chipping	1%	12%	45%	86%
Terrain chipping	2%	13%	43%	78%
Residue logs	1%	10%	37%	80%
Loose residues	1%	9%	26%	53%

Table 11. Average supply cost vs. marginal cost with different supply methods

Marginal cost class	**Average cost, €/MWh, within each class**			
€/MWh, (FIM/MWh)	**7.57** (45)	**8.41** (50)	**9.25** (55)	**10.09** (60)
Green supply				
Roadside chipping	7.34	8.00	8.59	9.01
Terrain chipping	7.30	7.98	8.57	9.02
Residue logs	7.34	7.99	8.58	8.98
Loose residues	7.36	8.01	8.60	9.17
Brown supply				
Roadside chipping	7.43	8.09	8.69	9.14
Terrain chipping	7.34	8.01	8.62	9.08
Residue logs	7.44	8.10	8.72	9.23
Loose residues	7.35	7.99	8.58	9.15

Overlapping procurement areas were managed by allocating the reserve between power plants according to the transport LP-model. The reserve was first allocated without any specified target levels to assist finding feasible target levels of residue usage potential according to residue availability. Allocation was made both for stand-level data and aggregated data (10/20 km) for green and brown supplies with gross and net reserves. This result was optimal according to the supply side. The differences in allocation results between stand and aggregated data were minor in most cases except for locations with low potential. The transport distance limitation, maximum 100 km, reduced only 2-3% of the potential reserve, since the power plant geographical coverage was dense (see Appendix 12). According to the allocated potential, i.e. supply side and usage potentials of power plants, i.e. demand side, were set as the target potential levels for each plant. The maximum theoretical usage potential was based on procured solid fuel consumption, i.e. peat and wood-based by-products from the forest industry. Despite possible technical limitations, the usage potential was in most plants higher than the supply potential. The plant level supply potential figures are listed in Appendix 12.

In the transport LP-model the supply level was set by the brown net reserve, i.e. 7 TWh. Plant-specific demand targets were balanced according to the above supply potential and technical usage potential. This target was characterized as an ambitious and there was no need to use a higher one. Plant-specific demand potentials were classified using a class interval of 50 GWh with the exception of the lowest class 20 GWh. The highest class was 400 GWh, mode 50 GWh and median 100 GWh (see Appendix 13). Conflicting objectives between supply and demand side lessened the optimal result given in transport allocation. The transport model was run also with the supply potential for the gross brown reserve, 11 TWh, and gross green reserve, 12 TWh, and net green reserve, 8 TWh. The supply potential varied in this case 7-12 TWh and with a larger supply reserve the target was naturally achieved with shorter transport distances (Table 12). Plant-specific values are listed in Appendix 13. According to the target level of 7 TWh, the logging residue availability was 4.1-5.4 TWh (brown-green net reserve) within 60 km of the maximum transport distance, i.e. 59-77% of the target. The transport limit of 80 km rose the availability to 5.1-6.2 TWh correspondingly, i.e. 73-89% of the target. There were minor possibilities to change plant-specific targets to get higher supply potential in total for the whole plant population because of the usage side restrictions.

The transport LP-model result was illustrated using map representation (Fig. 55), where the reserve was classified according to transport distances. This analysis showed the areas, where the most favorite sites for extra usage potential were. For instance the reserve, which was located in areas over 100 km transport distance, should have additional usage sites in the vicinity to become more advantageous for recovery. The brown net reserve included 1.2 TWh in areas over a 100 km transport distance from power plant sites (see Table 12).

Table 12. Supply potential according to the transport LP-model, target in total 7 TWh.

Distance class, km	**40**	**60**	**80**	**100**
Reserve	**Supply potential, GWh, within each class**			
Brown, net	2 467	4 112	5 140	5 813
Brown, gross	3 972	6 179	6 864	6 974
Green, net	3 301	5 391	6 247	6 655
Green, gross	4 484	6 503	7 000	7 000

In the analysis, where the reserves and usage targets were allocated into forestry centers, the regional balance between usage and the supply side was defined. Via map (Fig. 56) and table illustration (Table 13) it was found that the most surplus areas were in forestry centers located in the counties Savo, North-Karelia and Häme-Uusimaa. Whereas the most deficit areas were in forestry centers located in the counties Kymi, Central-Finland, Pirkanmaa and Southwest-Finland. The arrows in the map representation illustrated the presumable residue flows from surplus to deficit areas. The differences between allocated and target potential in the bar diagram in Fig. 56 resulted from residue flows between forest centers. In some forest centers owing surplus potential like North Karelia and Kainuu, the possibilities to increase the usage of residue were restricted due to the limited usage side in the vicinity including surrounding forestry centers. The long transport distances (see Fig. 55) as a result from the transport LP-model, were the consequence of this phenomenon.

In Table 14 the supply potential is classified according to supply cost using the roadside chipping as a supply method. Due to the slowly upward sloping supply-cost curves, the availability was very sensitive to supply cost. When comparing the distance and the average supply cost classes with each other, 9.25 €/MWh correspond to 100 km, 8.83 €/MWh to 80 km and a cost class of 8.41 €/MWh to a distance class of nearly 60 km. With the brown supply policy the corresponding distance values were slightly lower due to higher roadside costs (see previous Table 6). The plant-specific values are listed in Appendix 14. The thematic map of supply cost according to predefined cost-classes was analogous like the map of transport distance (see Fig. 55).

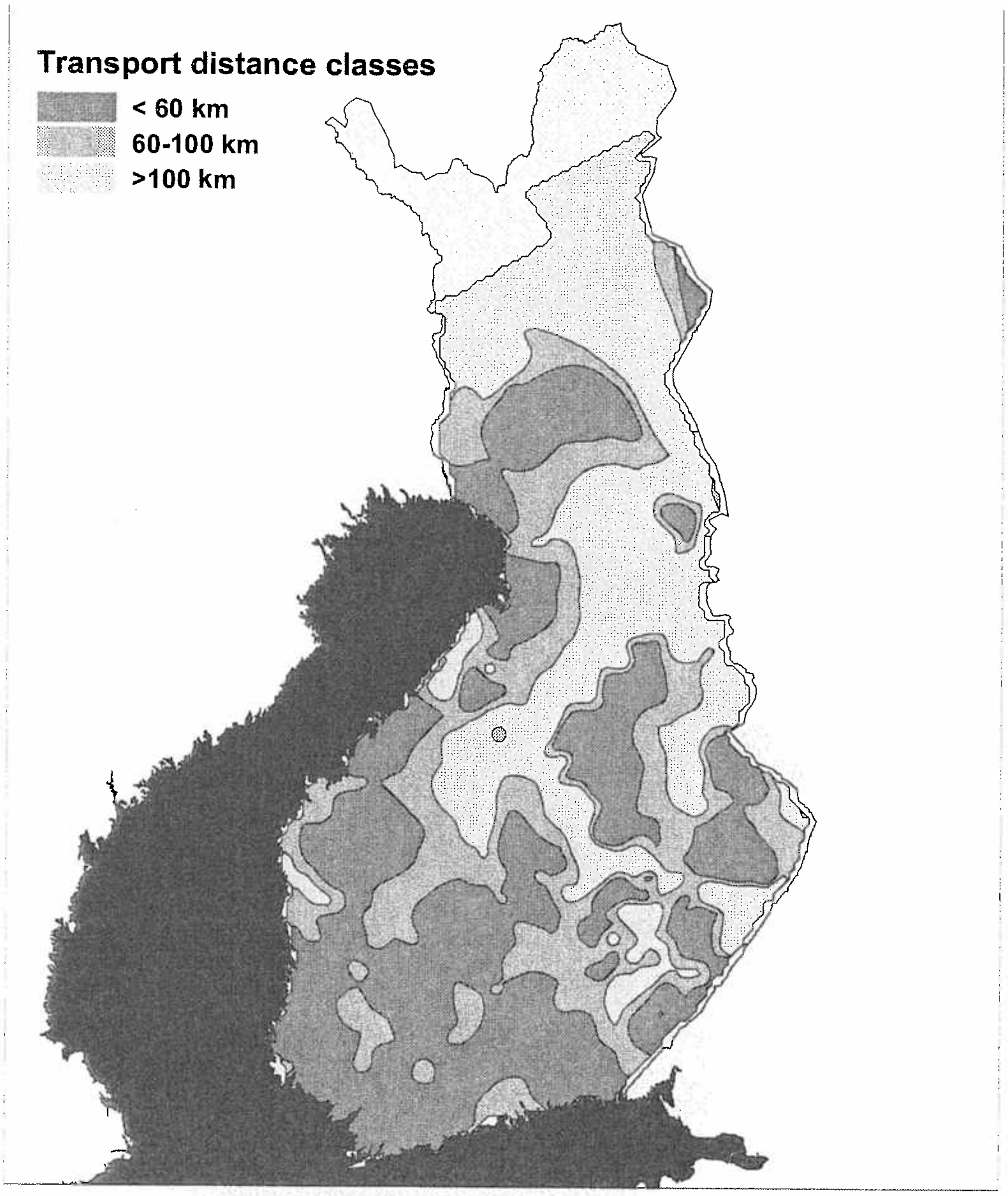


Fig. 55. Transport distances according to the transport LP-model, brown net logging residue reserve.

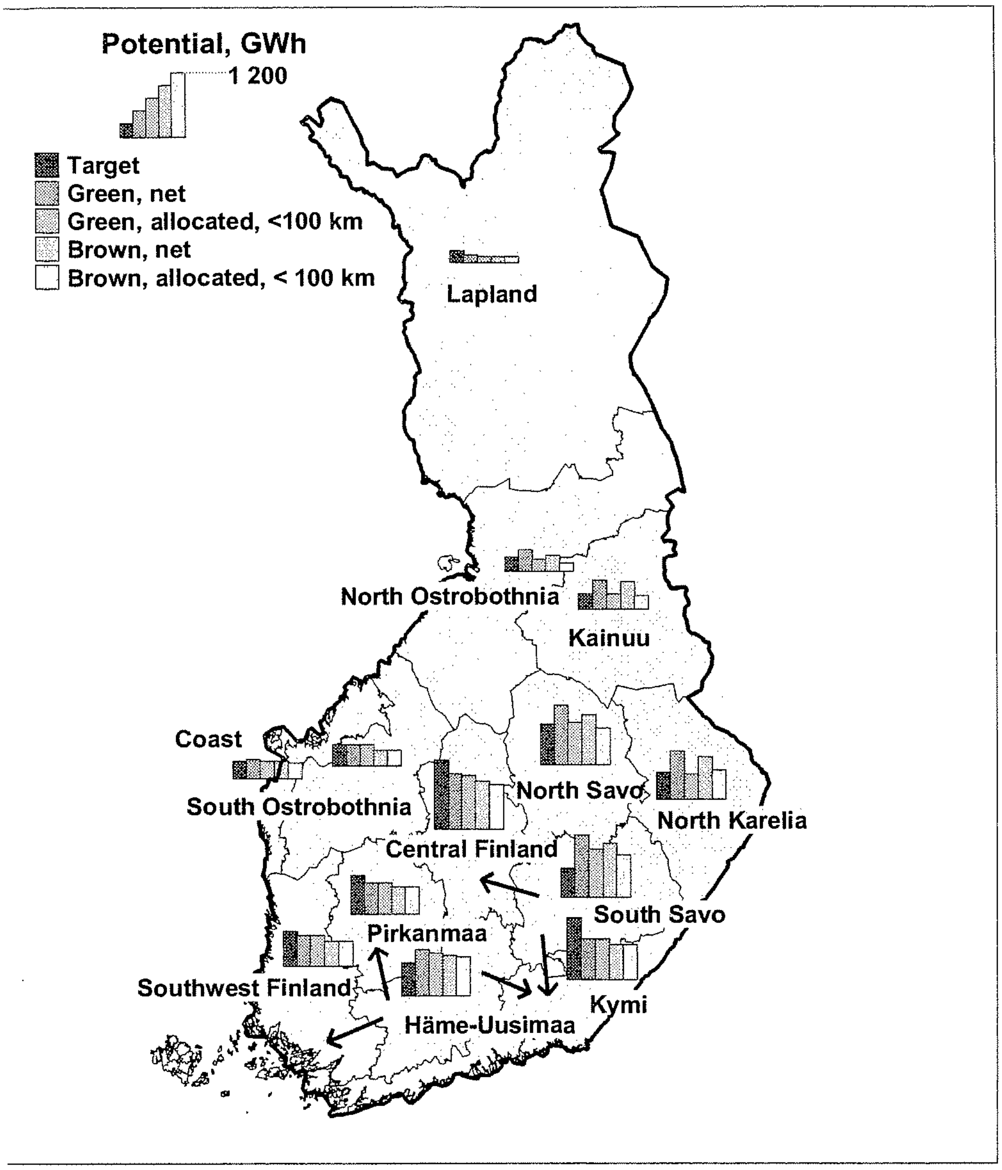


Fig. 56. Logging residue use and supply potentials in forestry centers.

Table 13. Supply potentials (GWh) at forestry centre levels.

		Green reserve		**Brown reserve**		
Forestry center	**Target**	**Net**	**≤100 km**	**Net**	**≤100 km**	**Balance**
Coast	300	338	286	289	265	deficit
Southwest Finland	590	523	519	446	435	deficit
Häme-Uusimaa	550	810	747	684	677	surplus
Kymi	1 050	697	694	589	587	deficit
Pirkanmaa	650	530	536	470	470	deficit
South Savo	500	1 058	825	940	729	surplus
South Ostrobothnia	350	372	362	283	262	deficit
Central Finland	1 200	962	928	820	767	deficit
North Savo	700	1 045	728	876	619	surplus
North Karelia	450	843	450	737	509	surplus
Kainuu	250	514	256	454	237	surplus
North Ostrobothnia	220	354	207	278	145	surplus
Lapland	190	128	103	106	99	deficit
In total	**7 000**	**8 175**	**6 640**	**6 973**	**5 802**	

Table 14. Supply potential according to the transport LP-model, target in total 7 TWh. The supply cost is based on the roadside-chipping method.

Cost class, €/MWh, (FIM/MWh)	**8.41** (50)	**8.83** (52.5)	**9.25** (55)
Reserve	**Supply potential, GWh, within each class**		
Brown, net, marginal	810	2 296	3 720
Brown, net, average	2 683	4 709	5 763
Green, net, marginal	2 017	3 954	5 566
Green net, average	4 848	6 228	6 703

7 DISCUSSION AND CONCLUSIONS

7.1 Assessment of the case study results of supply cost and availability

On the basis of monitoring surveys of alternative logging residue production chains, it is possible to assess the competitiveness of different methods in varying operating ranges. According to the GIS-analyses conducted in this study, the competitiveness of the chains will vary in Finland due to regional differences in relation to stands and according to the size of the procurement area. This is why the competitiveness of the chains must be defined as power plant-specific, paying attention to local conditions. Also other relevant aspects can be found, which have not been incorporated into the cost models such as service level issues in the form of security of supply and quality requirements of fuels.

When comparing the supply cost, the variation between supply chain options is minor with the exception of long-distance transportation of loose residues due to low transport economy. The same conclusion had been reached also in the study conducted by Hämäläinen (2000). In that study the seasoning effect had been analyzed around the city of Joensuu region using the same stand database as in this study. In practice the procurement radius and transport distance are clearly shorter, which reduces the effect of transport economy. However, there exists room for improvement within supply methods in the future. In particular the improvement of the transporting economy of loose residue and the development of the bundling stage of the logging residue logs by for instance integrating it more tightly to the harvesting stage are potential targets for development.

Seasoning will raise the supply cost to some extent, because of material loss during the storage period, which will reduce productivity at terrain operations as well as roadside chipping due to changes in material handling. Also transport distances will rise due to a larger procurement area. Storage costs will include covering costs of the piles and capital cost. However the quality needs, e.g. moisture content, possibly environmental, or sustainability-related needs, e.g. nutrient leaching or buffering storage needs may presuppose the storage period regardless of supply cost effect. The balance between changes of material loss and moisture content will provide the final result of the supply cost.

The supply cost results will keep changing over time because of technological and organizational development and cost progress. Economy of scale and scope are the most essential areas owing to developmental potential for cost reductions. Economy of scale implies reductions in average costs attributable to increases in scale. Increasing scale admits the efficient use of more large-scale equipment full time. An optimal situation as regards an individual harvesting and transportation chain is one where the chain operates near its full annual capacity. However, economy of scale is variable for the different parts making up the supply chain. It will thus be impossible to optimize the system by optimizing the individual parts separately. Optimization must be addressed at the system level (Andersson et al. 2002). Forest fuel production can take advantage of joint-production alongside commercial timber or peat production to decrease the forest fuel supply costs. The use of existing skills or infrastructures such as machines, storage sites and organizations are examples of integration. Besides inherent price competitiveness versus other fuels it will also result from tax-policy and other subsides for forest fuel.

In this study the gross, technically available, reserve of three main forest companies (with a recovery rate of 65%) varied between 10.7-11.8 TWh (brown vs. green supply) and the net, economical available, reserve varied between 7.0-8.2 TWh in 2000. Therefore, some 30-35% of the gross reserve is unavailable due to economical and also ecological reasons, since the restriction set for residue concentration per area excludes the major part of potential from most sensitive areas. In practice both supply policies are used and the residue potential will lie within the range defined according to pure policies. Also higher recovery rates may be used, which will rise the potential reserves. In this study prudence concept has used when selecting the recovery rate, since there existed some other limitations, which have not taken into account. Also other practices may be used when selecting stand selection criteria to evaluate the net reserve. In this study, the limiting values of criteria were based on used practices among forest industry companies.

The contribution of other felling actors, like the Finnish Forest and Park Service, the members of the Association of the Finnish Sawmills and the Forest Management Associations is minor at national level. The gross, technically available, reserve (green supply) of other felling actors is 2.3 TWh and net, economically available, reserve 1.6 TWh, which accounts for 16% of the total values of all felling actors in the year 2000. This will raise the gross reserve to 14.1 TWh and net reserve to 9.8 TWh. Regionally the contribution of other felling actors might be important. However so far this potential has been considered of minor importance due to organizational reasons. Forest companies have organized their forest fuel supply in a different way (see section 3.2) and prioritized forest fuel recovery from their own fellings. Also the total supply chain perspective, discussed in section 4.1, is more difficult to realize from external sources.

The technical potential, 14.1 TWh discussed earlier, is consistent with the study of Electrowatt-Ekono Ltd. (Puupolttoaineiden kysynnän..., 2000). According to actual regeneration felling area in 1997, the technical residue potential (with recovery rate of 65%) was estimated to be 13.1 TWh. The regeneration felling area has increased since 1997, which may explain the difference (see Fig. 28). However, the net, economically available, reserve was estimated as high as 11.8 TWh, where a 10% potential was reduced due to uneconomical logging sites. The potential on the market was estimated to be 9.5 TWh, where 20% of potential was reduced due to forest owners unwillingness to give permission for recovery. In 2010 the technical potential was estimated to rise to 14.0 TWh, economical potential 12.6 TWh and potential on the market 10.1 TWh. The difference between economical potentials arose from the source data, since in this study actual stand-data was used with worksite factors and Electrowatt-Ekono Ltd. had used felling area data at forestry-center level. Therefore, the regional differences among worksite factors had been omitted and a generic ratio-based reduction factor has used. On the other hand in this study no selling willingness reduction factor was used unlike in the study conducted by Electrowatt-Ekono Ltd.

Hakkila & Fredriksson (1996) ended up for their national logging residue reserve calculations values as high as 12.3-18.1 TWh (brown vs. green supply) despite the estimated reduction factors. The differences resulted from the broader felling reserve base used in this study. Helynen & Nousiainen (1996) estimated the logging residue (green) reserve to be 7.6-10.6 TWh, where the lower value resulted from spruce-dominated regeneration fellings and the upper value from all regeneration fellings. A recovery rate of 60% was assumed and the share of economically feasible potential was assumed to be 80%. These ratio-values have equal to the whole country. These calculations were based on private forest owners' wood harvesting plans distributed at municipal level. The potential from other owner groups was estimated accordingly to the municipal-specific share of ownership. The technical potential corresponding to this study, i.e. with a recovery rate 65%, was 10.2-14.3 TWh. The potential from all regeneration fellings was 14.3 TWh, which is consistent with the potential, 14.1 TWh, for all actor's fellings in this study.

The resource-focusing approach consisted of an estimation of a regional variation of logging residue potential per area and availability as a function of transport distance. According to potential per area maps, a distinct spatial variation of logging residue reserves was found. The largest potential was located in Central and Eastern Finland. The regional variation of potential per area unit resulted from the regeneration felling activity and composition of stands at different parts of the country. The stand proximity, i.e. location density maps, showed also the felling activity to be highest in the preceding areas. Worksite factors diminished the net reserve, most feasible potential, especially in northern and western parts of Finland and the pattern of regional variation become even clearer. For example, the average forwarding distance is longer in the northern part of Finland and Ostrobothnia, which was consistent with results by Uotila & Viitala (2000).

Uotila & Viitala (2000) analyzed the road density at forest land by the aid of roadmaps and forestry area at municipal and forestry centre level. The most sparse road network per forest land and equivalent calculated forwarding distance were in Ostrobothnia and North Finland. However, the calculatory forwarding distances were longer than distances based on empirical data in this study.

Logging residue potential at plant level was determined by the size of the procurement area and the logging residue area-based potential inside that area. The procurement areas were defined according to a 100 km maximum transport distance where the preceding values are valid. The shorter the transport distance limit is the larger the range of area-based potentials will be, because of aggregation effect. However, the variation of potential between sites is significant (see Table 9 in section 6.4) as in the study (Keskimölö 2000), where potentials were defined around peat production bogs. In the study by Keskimölö (2000) the variation was even larger due to smaller procurement areas and regional differences between selected peat production sites.

Besides the plant location in relation to national frontier and coast, also the road infrastructure and its straightness have an effect on the size of the procurement area. This straightness i.e. accessibility via road network to forest fuel sources, is estimated by aid of a winding coefficient. In this study the Finnish average value for the winding coefficient is 1.3, in the case of a 100 km procurement area radius. However there can be found a distinct spatial variation and the values are procurement radius- and region-specific, like the studies concerning Norwegian (Haartveit & Fjeld 2000) and Swedish (Börjesson & Gustavsson 1996) conditions will demonstrate.

In this study the lowest values of winding coefficient are in the southern and western parts of Finland due to differences in the road network and land use patterns. For instance watercourses in the eastern and central part of Finland give rise to the winding coefficient values in those areas. The average winding coefficient in inland areas means, that the average procurement area is some 63% of the theoretical circle area when the transport distance is 100 km. In the outmost cases the procurement area at coastal areas is only one third from the largest one at inland sites. Due to differences in potential per area and procurement area size within a given transport distance, the logging residue supply potential between power plant sites may be multifold. The cumulative supply potential as a function of transport distance rises very rapidly at favorable inland sites and the supply curves are upward sloping, whereas at coastal or northern located sites, the rise is slower and the slope of supply curves are moderate.

When the logging residue supply cost is defined as a function of residue availability or vice versa, the supply-cost curve can be assumed to have different shapes, depending on the regional geography, supply method and the mode in which material is transported.

Theoretically by using a resource focusing approach, it is possible to estimate how much potential on average is available at a different supply cost level to the power plant population used in this study without any allocation and optimization between sites. Typically, there is a minor variation in supply-cost curves between supply methods except in the loose residue-method due to lower transport economy. Since the supply-curves (supply cost as a function of availability) are slowly upward sloping, the availability is very sensitive to supply cost. Therefore, already minor changes in supply cost will increase or decrease the availability at certain cost-levels significantly. Regional worksite factors and geography, i.e. accessibility via a road network will have an influence on the competitiveness between different supply methods. For instance methods with better transport economy, as residue logs and full trailer loads of forest chips, will have an advantage in areas characterized with longer transport distances, since they do not react as strongly to the lengthening of transport distance as the methods for lower transport economy as with loose residues or different types of container solutions (chipper-truck) for forest chips. If the used procurement radius is shorter as the one in this study, the relative competitiveness of methods with low terminal time or costs as terrain chipping and loose residue method will be better. As the procurement radius grows the methods with higher terminal time or costs gain in competitiveness as roadside chipping and residue bundle-methods.

In order to manage the overlapped procurement areas, the residue potential is allocated between end-user sites according to the transport LP-model. Transport LP-modeling gives the possibility to evaluate the potential as a function of the transport distance or supply cost either at regional or whole plant population level, i.e. national level under user defined restrictions. Since forest fuel is a low-value commodity, optimizing forest-fuel production essentially means minimizing transportation cost (Eriksson & Björheden 1989). By means of a resource focusing approach the potential is first allocated without demand side constraints to assist the usage potential target setting of the demand side in the LP-model. This is the optimal solution based on the supply side. The power-plant coverage is dense, since only 2-3% of the potential reserves is excluded, if the maximum allowable transport distance is at 100 km. Despite possible technical limitations, in most plants the potential demand exceeds the possibly supply. For instance the brown net reserve makes up only some 20% of the whole usage potential among the power plant base. However there is large variations between plants and regions. As a consequence of this the contribution of forest fuel is only minor or at most of moderate importance among large-scale solid fuel users.

The selected target-level of demand, 7 TWh, for the whole power plant population is the same as been set for logging residues in the Action Plan for Renewable Energy Sources by the year 2010 (see section 2.3). Due to a regional imbalance between supply and demand, there is some 1.2-1.5 TWh (brown-green) of the net reserve unutilized in areas over 100 km of transport distance to power plant sites. Since the geographical coverage of the power plants is dense, the possible changes of plant population or plant-level targets between plants, will not dramatically change the final results of the LP-model (i.e. availability vs. transport distance or supply cost), if the total target level, 7 TWh, is kept unchanged. Also the potential of small-scale use can be merged to the usage potential of a large plant in proximity without changing the final result. Multi-level supply cost division is used to evaluate the sensitivity of the results. The available potential is dependent on reference fuel prices or plant readiness to pay for forest fuel. Owing to of possible changes in cost parameters some part of the potential may move between cost classes. Therefore results are also divided into transport distance classes, since the interpretation is straightforward and includes less speculative elements than the cost division (e.g. supply method, policy, organization). At the current fuel cost level, the feasible procurement area will typically lie within a procurement area outlined by a maximum transport distance of 60 km, i.e. 4-5 TWh. The possibility to use longer transport distances need some special arrangements as economy of joint production of merchantable wood and arrangements for back loads in long-distance transportation stage.

In this study the whole reserve has been treated as an integral entity despite organizational territories of supply side. In practice potential calculations have also been made separately as forest company-specific or among alliances. This will decrease the potential at plant level significantly and increase the supply cost, because of the need for a larger procurement area to satisfy the demand. Also the supply priority between plants will vary according to ownership. Naturally the power plants for forest industry will have higher priority within its own supply due to benefits related to joint production and economy of scale within raw-material supply.

7.2 Assessment of the analysis method

The definition of the procurement costs of forest fuel produced by logging residues is multifaceted because of the versatility of the logistics cost factors (see Fig. 22 and Fig. 23). Despite the calculation model used in this context, there are many speculative elements. The common problem of generalization of results from certain field-studies to a broader concept exists (e.g. Mitchell 2000) because of machine and organization-specific factors. Time consumption functions are strictly speaking only valid under the specific experimental conditions (worksite, weather, machine, and operator), which cannot be repeated. Therefore, the results of supply cost should be considered guiding and the measure of uncertainty must be taken into consideration. One common approach is to use work-difficulty factors for different terrain classes or seasons. They are included in time consumption functions of individual work elements (e.g. Kuitto et al.

1994, Asikainen et. al. 2002). It presupposes that besides work-site factors used in regression analysis (e.g. forwarding distance) also information and rating scale for work-difficulty factors (e.g. nature and slope of the terrain surface) is available. Only via long-time follow-up studies from different production sites can estimates of difficulty factors be produced.

The most speculative part of cost calculation is the component of other cost, which include stumpage price, piling compensation, organization cost and for seasoned material also storage cost. Different practices are found among supply organizations to value them and include them in calculations. Other sources of differences between supply costs are assessment of machine rates and cost of other production factors (labor, operating and capital cost). Also within each supply method a broad range of alternative machine options are found, whose productivity and cost structure may vary to some extent. For example in the study related to supply cost analysis of logging residues (Korpilahti & Suuriniemi 2001) the relative competitiveness of terrain chipping was lower and loose residues better than in this study due to the reasons mentioned above. The machine types were different and the lower productivity values of terrain chipping used may have resulted from field studies, which had been performed at unfavorable sites. However the average supply cost range between methods except for terrain chipping was in consistent with this study.

Geographic information systems (GIS) are useful tools for understanding the geographic context of a wide range of issues pertinent to bioenergy, especially energy demand and biomass supplies. The dispersed geographical distribution of biomass potential has risen the interest of researches in using GIS for the evaluation of the biomass supply and characteristics, the estimation of the transportation cost to existing power plants as well as the site selection for biomass-based fuel developments. The GIS-model allows users to test the effects of various decisions and scenarios on the economics and availability of the range of biomass fuels. The selected modeling system should estimate the costs and environmental implications of supplying specified volumes of biomass across a predefined region. According to Voivontas et al. (2001) the major advantage of using a GIS modeling biomass supply is that it allows one to explicitly and quantitatively account for variation in geographic factors that affect supply and the cost of biomass production, for example for logging residues. Many of the potential benefits related to GIS are in the area of geographical visualization. Displaying simple statistical summaries and plots of data in map format with location information illustrates the results better than traditional reporting, which also this study has demonstrated.

One of the most prominent barriers and a bottleneck to the efficient use of GIS relates to the availability of public or commercial digital geographical data. Both the hardware capabilities of GIS have been improved notably and the availability of primary geographical digital data (e.g. road network, boundaries) has become better, allowing better sophistication in analyses. Sometimes also the pricing policy of the organization responsible for maintenance will limit the potential use. Therefore GIS models are often limited by the lack of spatially explicit data and they are not aimed to handle uncertainty well. GIS are also scale-dependent, and it is necessary to consider the appropriate spatial scale for addressing the problem at hand (Graham et al. 2000).

In the energy sector the location problem can focus on selecting the best areas for power and heating plants or conversion plants for upgraded wood fuels using large volumes of biomass-based fuels. Typical location analysis problems are very complex and dataintensive. Complexity is a product of the number of locations multiplied by the alternative location sites multiplied by the supply strategies for each location. Location problems typically involve an exceedingly large number of network design configurations to be evaluated to manage the size of the problem. Data intensity is created because the analysis requires detailed demand and transportation information. For cogeneration facilities the existing heat demand locations within municipal and industrial plants will diminish the size of problem. However, it would be useful, for example, to ask how far away the current infrastructure and other features (e.g. electric and district heating network service territories, roads, railroads, land cover) is to form some sort of optimal configuration according to raw-material supply cost as in the study of Withrow & Wichert (1996). To obtain a solution, it is generally necessary to use aggregate data relationships when solving a practical location problem. However, for example power plant site selection analysis calls for methods using the nearest few data aggregation in order to differentiate regional geography.

In this study the original stand data is aggregated, to reduce the number of individual stands when calculating the logging residue potential at regional level. The original stand/parcel data are spatially grouped and statistically merged, if the locations are in close proximity. Area data are assigned to a set of points that corresponds to the centers of subregions. The reason for this procedure is to calculate stand-related values, that are representative of specific area criteria over the entire mapped area instead of single stand locations and features. In order for stand-based studies to be more widely applicable, there is a need to be able to extend the results of a single stand sample to a larger area, or to be able to fill in the spatial gaps between a set of spatially distributed stands. The risk of misinterpret of mapped output is related to used spatial scale, using too large areas to erase the regional details. Too small areas on the other hand do not take into consideration the spatial variation of stand locations from year to year. The spatial scaling used in this study (see Table 5) does not affect volume calculations, since the constructed Voronoi diagram is dense in procurement areas around power plants (maximum 100 km transport distance).

The logging residue volume calculation at stand level is estimated on a percentage basis for different mature tree species in this study. Different ratios are used for the southern and northern parts of Finland. It has been proved that the volume estimates based on stem-based equations instead of percentage ratios are more accurate at stand level (Harstela & Kiljunen 2001). However the difference between cumulative estimates will become smaller in larger procurement areas with numerous stands, due to the lower variance for large populations (Cochran 1977). The residue volume is also dependent on harvest methods, machinery used, harvesting season and additional losses in the system, which might have a more significant effect on the volume estimate. In addition the moisture content has had a major effect on energy content. Because of this variation calculations have been made for both green and brown supply either with a gross or net reserve to get a range of variation of possible residue potential. In practice the actual potential falls inside this range because of different supply practices used.

With respect to previous residue reserve surveys based on regionally forest management plans (see section 2.6), this study has been based on actual fellings at stand level for the calendar year in 2000. The sample consists of data from regeneration fellings from three major forest companies in Finland, which is made up of 84% of the total annual residue volume (see section 5.2.3). The supply potential is identified by coordinates to have exact spatial identity. This allows data transformation to draw on derived spatial aspects of the stand-data such as supply potential calculation and allocation to predefined sites through the road network. According to stand-level attributes as works-site factors, it has been possible to evaluate the potential via different stand selection criteria instead of average ratio-based estimates. Through exact spatial identity also the regional geography and its effect to transport distances can be taken into account instead of average winding factors or procurement areas. According to the worksite factors, the productivity and supply cost-calculations can be linked to stand level, and the regional characteristics of worksites can be taken into account more accurately. Despite annual fluctuations with felling activity, it can be assumed that the average regional characteristics of geography and worksite factors remain stable in proportion to each other. Potential procurement areas as a function of distance and average worksite factors inside procurement areas in question remains in the near future, only the number of felling sites according to felling activity changes.

There can be expect annual fluctuations in regeneration felling activity (see Fig. 28). The felling level was high in 2000, the reference year used in this study. These fluctuations may be leveled into smaller regions as forestry centre or municipality except for the situation, where felling activity between forest ownership categories (private, forest industries, state) change considerably due to spatial differences (see Fig. 29). Normally, it can be expected, that if harvesting activity will fluctuate from year to year at a larger area (for instance municipality), it will fluctuate alike also in these formed smaller areas (within this municipality), only single stand locations would vary within this smaller area from year to year. Also major changes (i.e. reinvestment or shutdown) at end user sites of merchantable wood or large storm-thrown areas may affect to the regional felling activity. The crucial question was to determine the method and accuracy of partitioning the areas into subregions. In the future the logging will be gradually increased according to Finland's National Forest Programme 2010. Despite this increase, the logging residue potential will decrease slowly from the current level due to changes in composition of stands (i.e. the share of pine will rise) according to the MELA-calculations (Metsätilastollinen vuosikirja 2001) carried out by the Finnish Forest Research Institute.

The constructed modeling environment enables also to the use of spatially coarser without geographically exact site-specific, resource data as used in this study. If the resource data of forest fuel is at forestry centre or municipality level without knowledge of the spatial variability inside the area, this resource should be located to the spatial center or distribute spatially into the area in question (e.g. Ranta 1999). Other sources of variation of spatial accuracy are related to the characteristics of road networks, e.g. road-classes such as forest roads and location accuracy of road segments. Demand points are typically easy to locate to have spatial identity according to the end-use facility address. The coarser resource data would illustrate the same spatial phenomenon in less detailed nuances. Also the possible absence of regional worksite factors presupposes to use more common supply cost functions (see Table 6 in section 6.1) as in this study.

The spatial variation of residue potential between each felling year may be interesting in future research topics. What will be the appropriate spatial scale for addressing the problem at hand, i.e. aggregation and spatial clustering of individual stands for further logistics analysis. By means of multi-year stand-data it might be possible to evaluate the spatial homogeneity by varying spatial scale. Also the residue amount at stand level calls for further analysis to achieve more accurate estimates without prior knowledge of external tree characteristics for planning purposes as in this study. One approach might be nonparametric-estimation via natural neighbor methods to evaluate the possible geographical variation between regions. This study has used distinct values for the southern and northern part of country, but other appropriate divisions may be found. Since also the recovery rate affects the residue volume, there is a need to estimate the variation of recovery rate between different supply methods and harvesting seasons to achieve more accurate estimates.

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Initial values of supply cost calculations in 2000 Appendix (1/2)

	Decentralized comminution		Centralized comminution	
Supply chains	**Terrain**	**Roadside**	**Loose residues**	**Residue logs**
Cost components				
Other				
Stumpage price	16.82 €/ha	16.82 €/ha	16.82 €/ha	16.82 €/ha
Piling	0.42 €/m^3	0.42 €/m^3	0.42 €/m^3	0.42 €/m^3
Organization	1.35 €/m^3	1.35 €/m^3	1.35 €/m^3	0.67 €/m^3
Storage				
Covering	0.08 €/m^3	0.08 €/m^3	0.08 €/m^3	—
Capital	6 %, 8 mo.	6 %, 8 mo.	6 %, 8 mo.	6 %, 8 mo.
Bundling				
Investment, VAT 0%				336 000
Hourly cost, E_{15}	—	—	—	67.3 €/h
Moving cost	—	—	—	63.9 €/move
Bundle size				
Spruce	—	—	—	0.59 m^3
Pine	—	—	—	0.44 m^3
Productivity, E_{15}				
Spruce	—	—	—	20 bundle/h
Pine	—	—	—	21 bundle/h
Forwarding				
Investment, VAT 0%	454 000	198 000	198 000	185 000
Hourly cost, E_{15}	87.6 €/h	52.6 €/h	52.6 €/h	51.3 €/h
Moving cost	63.9 €/move	63.9 €/move	63.9 €/move	63.9 €/move
Load size	6 m^3	8 m^3	8 m^3	25 residue logs
Productivity, E_{15}	Function	Function	Function	Function[a]
Transportation				
Investment, VAT 0%	213 000	220 000	269 000	220 000
Load size	42 m^3	44 m^3	27 m^3	70 residue logs
Loading time	0.8 h	1.6 h[b]	1.7 h[c]	0.75 h[e]
Unloadinng time	(0.5+0.3) h	(0.5+0.3) h	0.8 h[d]	(0.5+0.3) h
Hourly cost, E_{15}				
Driving time	75.6	76.5	75.4	70.0
Terminal time	53.0	53.8	52.6	47.3
Comminution				
Investment, VAT 0%	454 000	656 000	—	—
Hourly cost, E_{15}	87.6 €/h	122.1 €/h	2.2 €/m^3	2.2 €/m^3
Moving cost	63.9 €/move	47.1 €/move	—	—
Productivity, E_{15}	Function	28 m^3/h[f]	—	—

[a] = Loading and unloading 20 sec/residue log

[b] = Transportation load size per productivity of comminution

[c] = 3.83 min/m^3

[d] = 1.04 min/m^3 + 0.3 h (0.3 h = auxiliary time of transport cycle)

[e] = Average value of loading timber truck

[f] = Fresh green residue, seasoned - 10 %

Time study material of bundling

Raw material	Spruce, green	Spruce, brown	Pine, green
Number of logs	196	119	85
Moisture content, %	45 %	19 %	44 %
Moving distance, m/log	4 m	5 m	8 m
Length of log, m	3,0 m	3,1 m	3,1 m
Dry mass, kg/log	250 kg	217 kg	174 kg
Residue m^3/100 m strip road	14,7 m^3/100 m	9,3 m^3/100 m	5,5 m^3/100 m

Time study material of terrain chipping and logging residue forwarding

	Terrain chipping			Forwarding		
	Loads	Volume		Loads	Volume	
Raw material	Number	m^3	Dry ton	Number	m^3	Dry ton
Spruce, green	31	202	81.8	34	198	81.7
Spruce, brown	6	32	15.1	18	139	62.7
Pine, green	3	17	8.1	13	56	23.8
Total	40	251	105.0	65	393	168.2

Range of dependent variables in time study of terrain chipping

	Load size		Moisture	Forwarding	Residue m^3/100 m
Raw material	m^3	Dry ton	content , %	distance, m	strip road
Spruce, green	6.0 - 7.9	2.4 - 3.2	50 - 58	248 - 629	3.9 – 17.0
Spruce, brown	5.3 - 5.4	2.5	34 - 49	222 - 325	7.8 - 16.8
Pine, green	5.8	2.7	46	506	13.3

Range of dependent variables in time study of residue forwarding

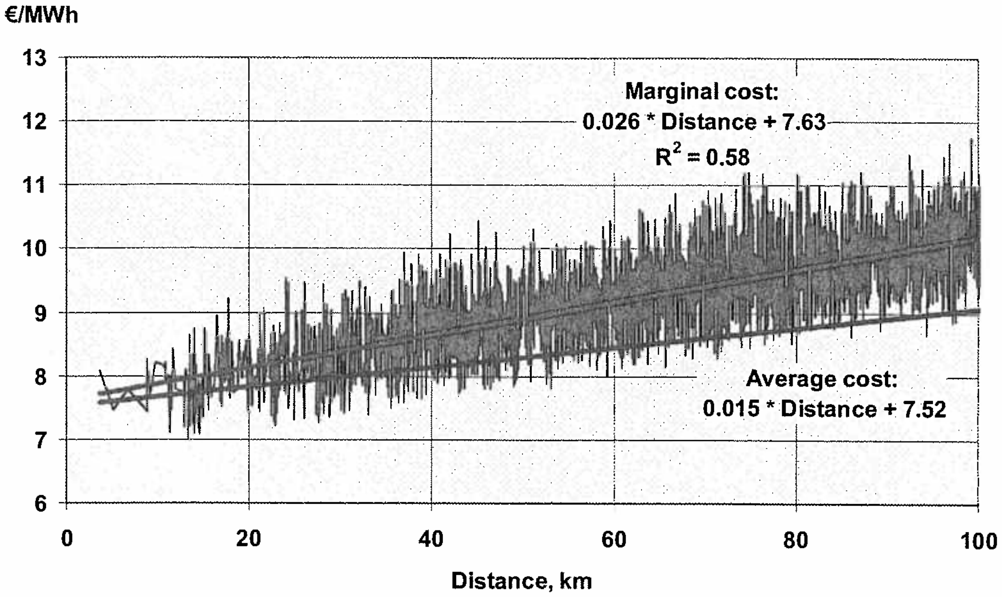
	Load size		Moisture	Forwarding	Residue m^3/100 m
Raw material	m^3	Dry ton	content , %	distance, m	strip road
Spruce, green	3.3 - 7.9	1.4 - 3.0	36 - 59	104 - 401	4.1 - 12.0
Spruce, brown	3.6 - 9.1	1.7 - 4.1	26 - 50	129 - 262	9.1 - 10.5
Pine, green	4.3 - 4.9	1.8 - 1.9	52 - 57	63 - 201	3.7 - 6.9

Time study material of roadside chipping

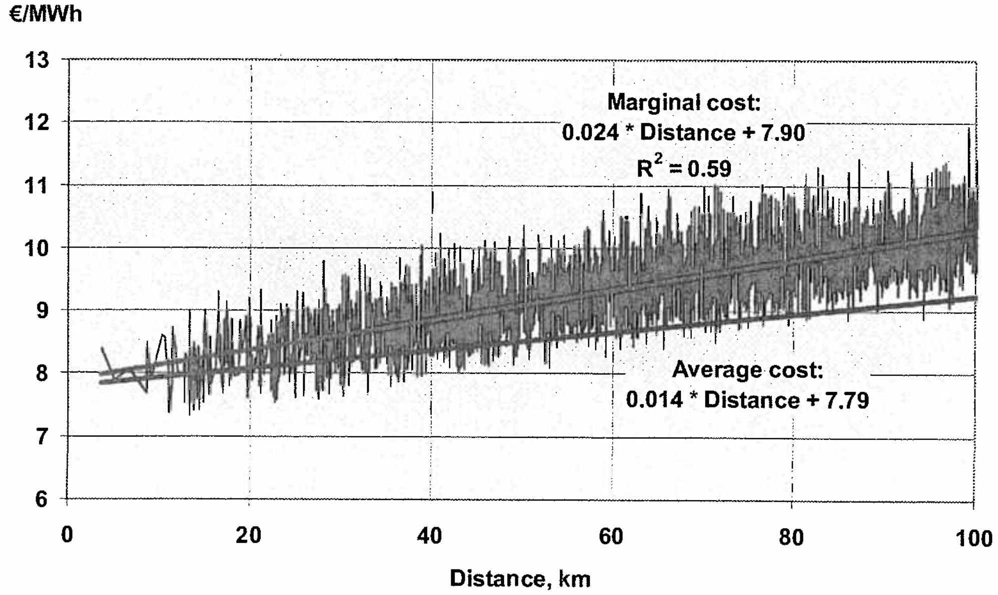
		Volume	Moisture	Productivity, E_{15}		Productivity, E_0		Grapple load size	
Machine no.	Raw material	Dry ton	content, %	m^3/h, loose	Dry ton / h	m^3/h, loose	Dry ton / h	m^3, loose	Dry kg
Chipper 1	Spruce, Brown, Summer	63	28	47.5	9.3	72.8	14.3	0.65	126
Chipper 1	Spruce, Green, Summer	9	59	108.3	16.8	108.0	16.08	0.81	126
Chipper 1	Pine, Green, Summer	25	57	53.1	8.3	99.1	15.4	0.85	133
Chipper 2	Spruce, Brown, Summer	na	51	57.5	na	57.5	na	0.25	38
Chipper 2	Spruce, Brown, Summer	na	49	58.7	na	58.7	na	0.23	38
Chipper 3	Spruce, Brown, Winter	58	45	52.4	9.7	60.9	11.3	0.3	56
Chipper 3	Spruce, Green, Winter	63	58	66.4	8	81.8	9.8	0.4	49
Chipper 3	Pine, Green, Summer	37	38	58.0	10.4	79.5	14.2	0.37	66
Chipper 3	Spruce, Brown, Summer	40	34	42.7	7.7	58.5	10.5	0.25	45
Chipper 3	Whole tree, Brown, Wint	38	31	61.4	10.7	83.9	14.7	0.5	119
Chipper 4	Pine, Green, Winter	15	56	58.7	na	74.1	na	0.38	64
Crusher 1	Spruce, Brown, Winter	na	55	77.7	na	77.7	na	0.73	127
Crusher 1	Spruce, Brown, Winter	na	53	75.4	na	75.4	na	0.73	123
Crusher 1	Spruce, Green, Summer	na	30	61.8	na	89.9	na	0.88	163
Crusher 2	Spruce, Green, Winter	166	56	61.8	9.6	83.7	12.9	0.47	75
Crusher 2	Spruce, Green, Summer	38	38	53.5	8.9	79.4	13.3	0.51	88
Crusher 2	Spruce, Brown, Summer	48	42	58.8	9.3	82.6	13.1	0.61	97

Supply cost analysis around the city of Jyväskylä region

Supply cost of logging residues as a function of distance
Roadside chipping of green fresh residues

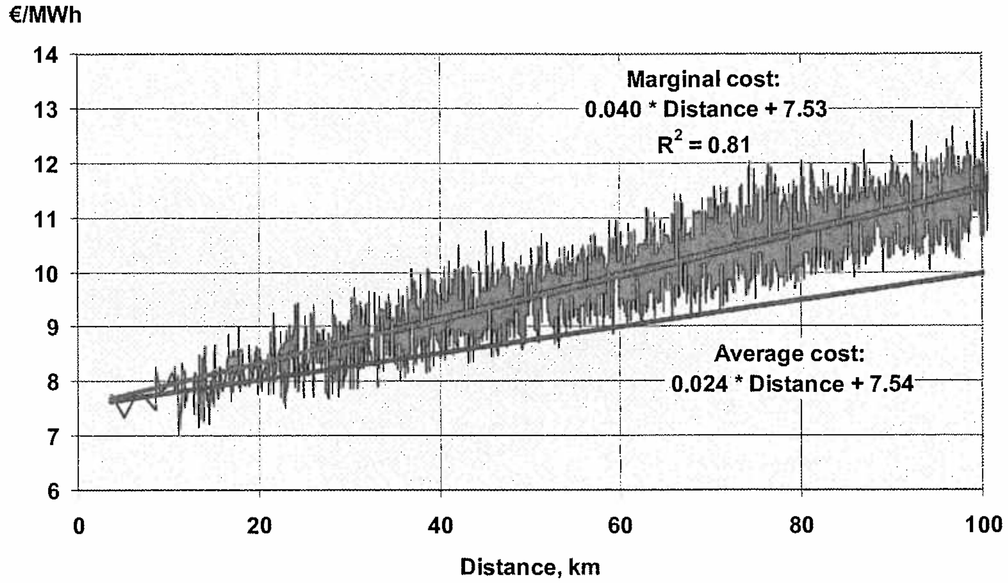


Supply cost of logging residues as a function of distance
Roadside chipping of brown seasoned residues

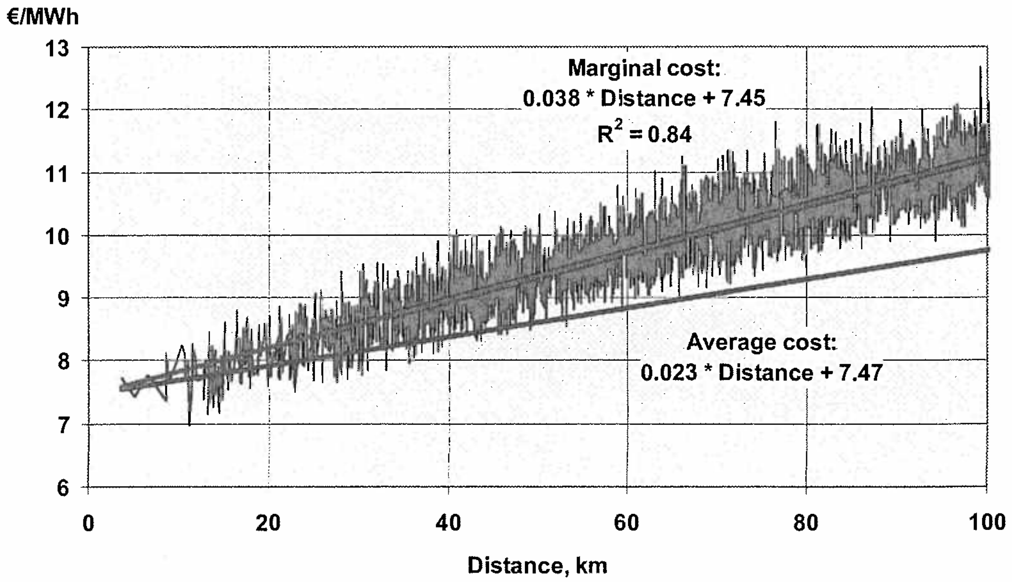


Supply cost analysis around the city of Jyväskylä region

Supply cost of logging residues as a function of distance
End-use facility crushing of green fresh loose residues

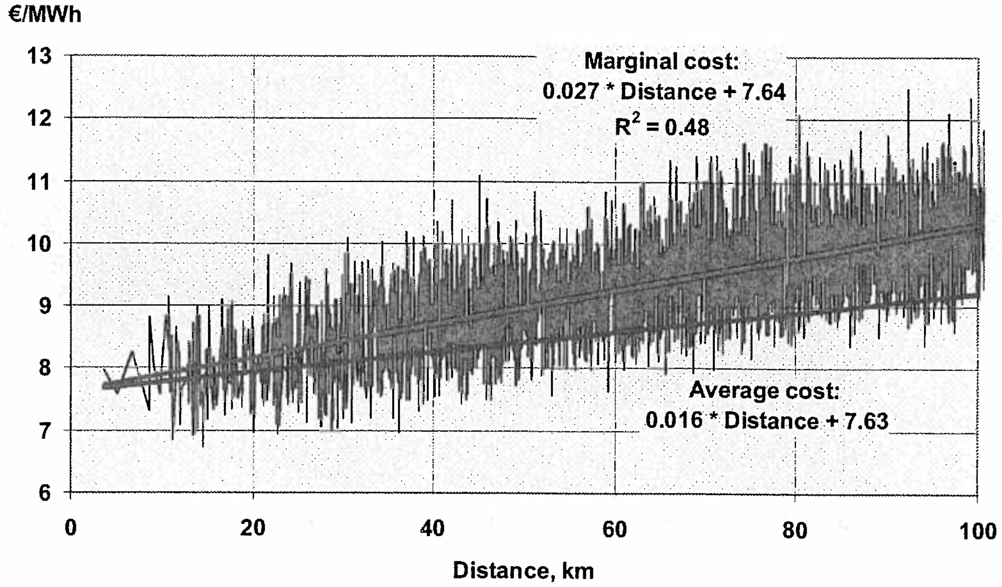


Supply cost of logging residues as a function of distance
End-use facility crushing of brown seasoned loose residues

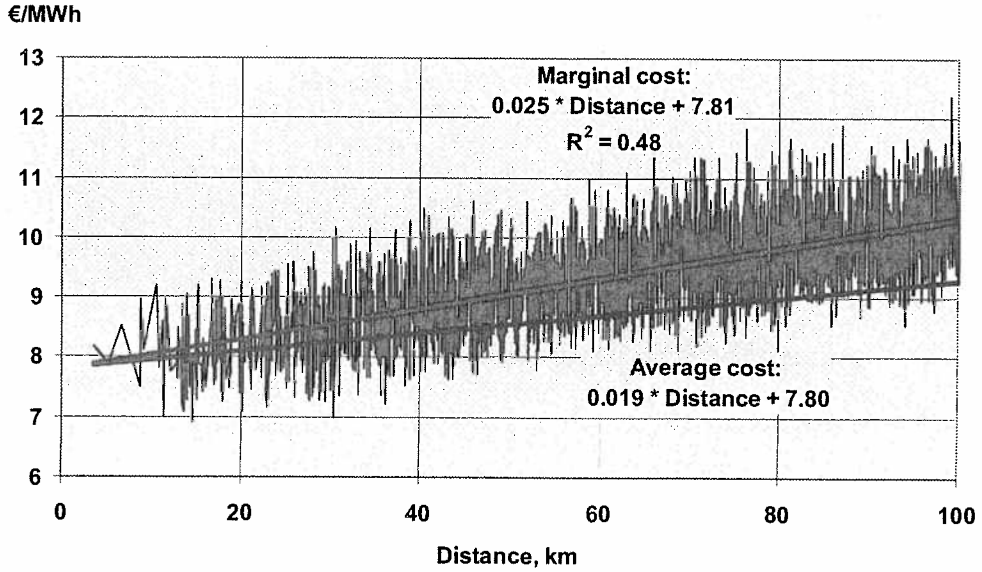


Supply cost analysis around the city of Jyväskylä region

Supply cost of logging residues as a function of distance
Terrain chipping of green fresh residues

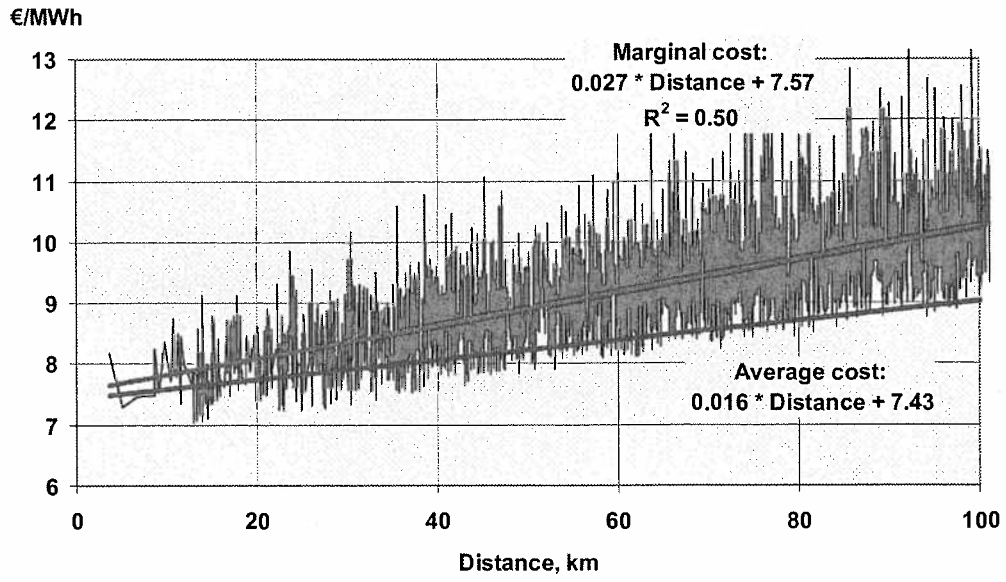


Supply cost of logging residues as a function of distance
Terrain chipping of brown seasoned residues

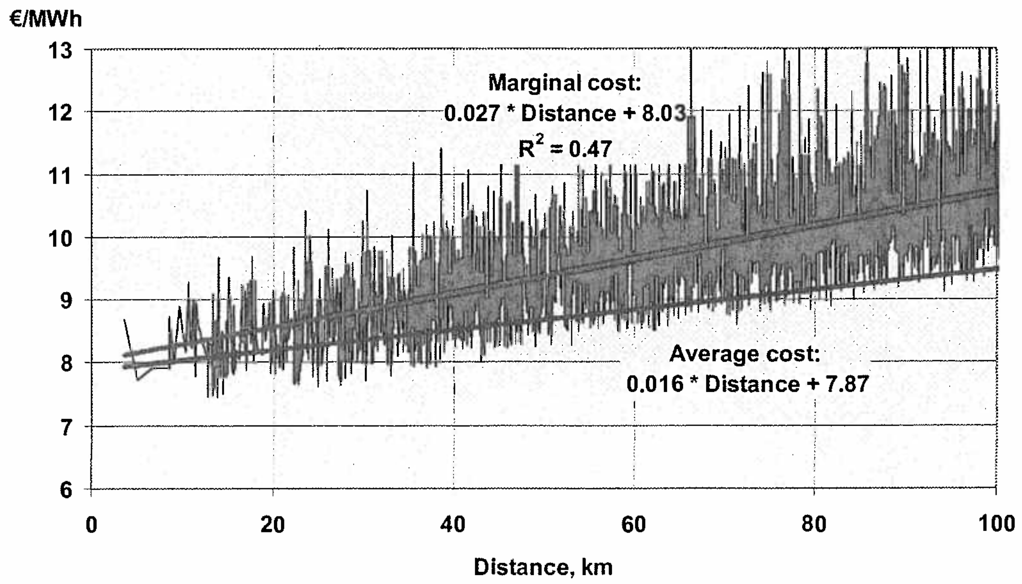


Supply cost analysis around the city of Jyväskylä region

Supply cost of logging residues as a function of distance
End-use facility crushing of green fresh residue logs

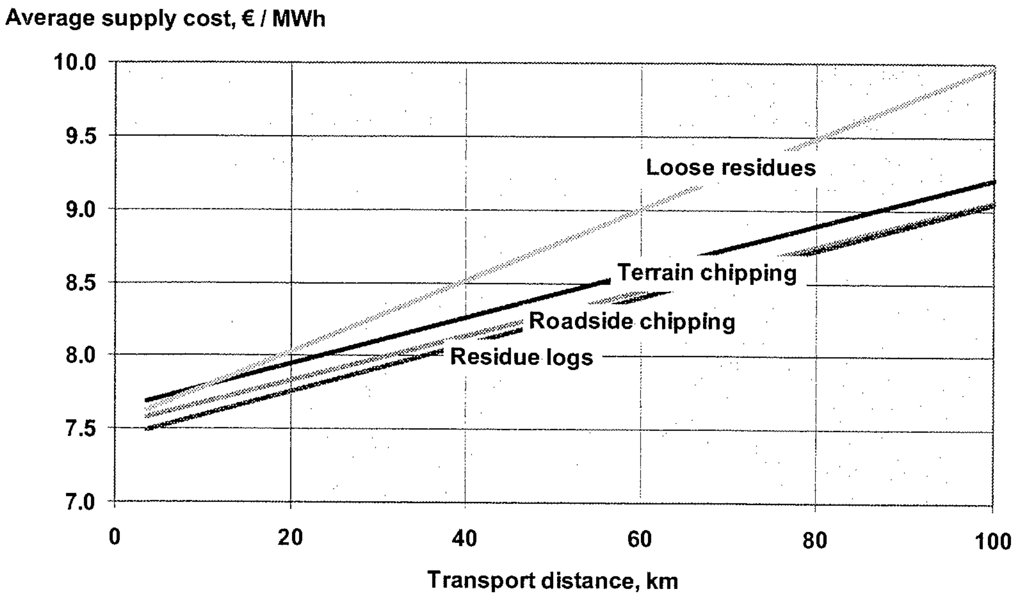


Supply cost of logging residues as a function of distance
End-use facility crushing of brown seasoned residue logs

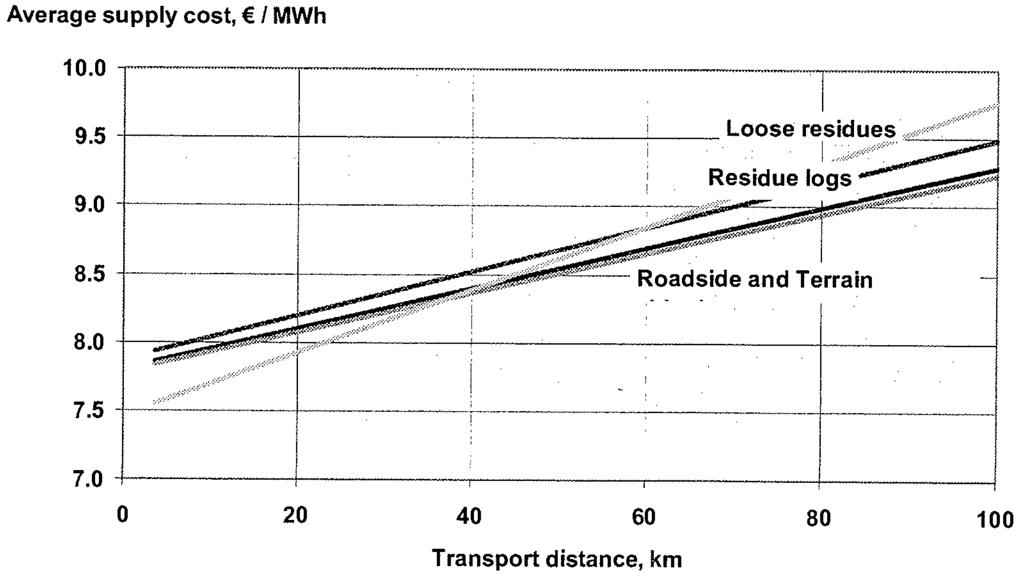


Supply cost analysis around the city of Jyväskylä region

Supply cost as a function of distance for green fresh logging residues using alternative supply chain options

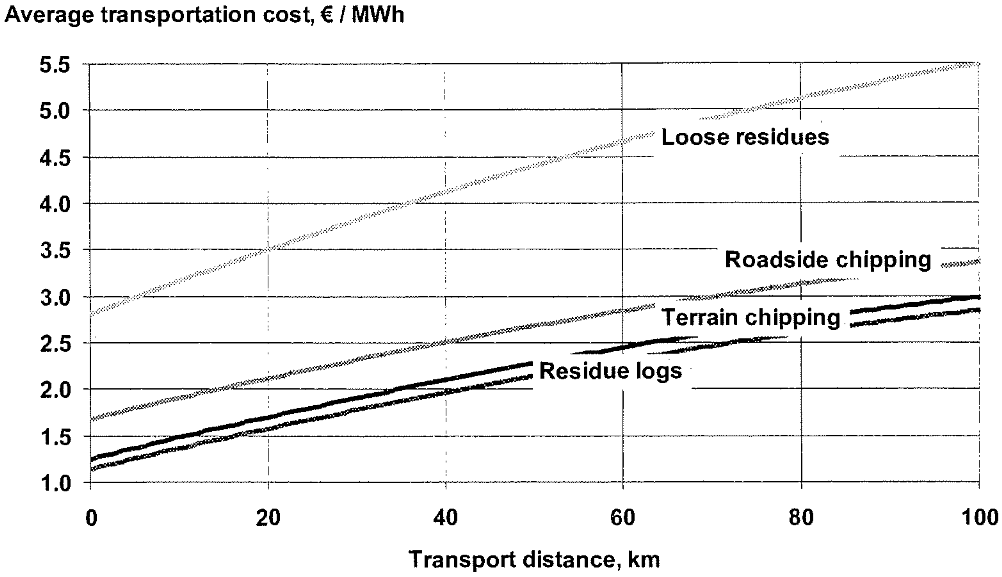


Supply cost as a function of distance for brown seasoned logging residues using alternative supply chain options

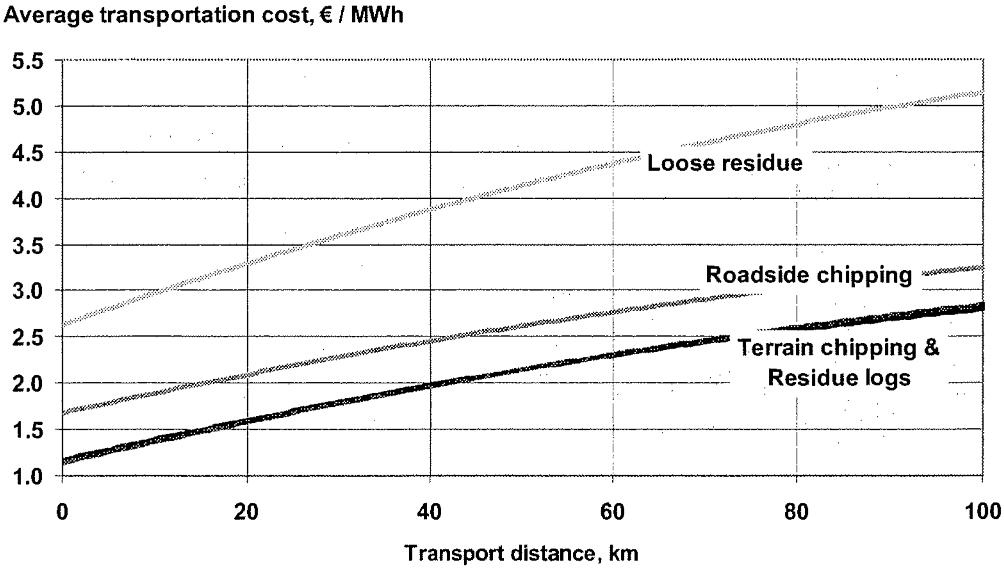


Transport cost analysis around the city of Jyväskylä region

Transportation cost as a function of distance for green fresh logging residues using alternative supply chain options



Transportation cost as a function of distance for brown seasoned logging residues using alternative supply chain options

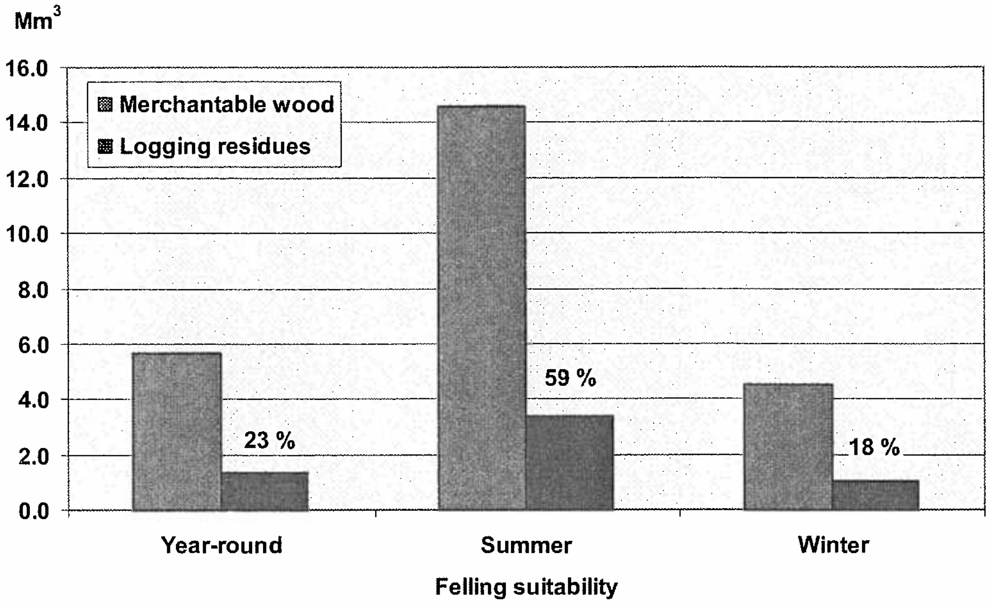


Basic information on power plants in 2000

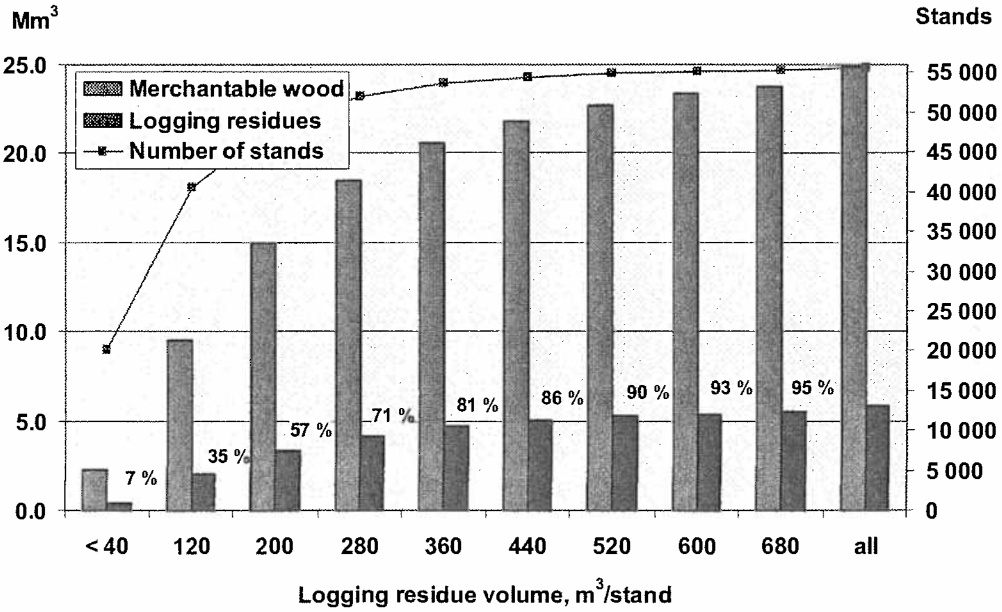
Appendix 3

Owner	Investment	Location	Municipality	Boiler	Main customer for heat	Combustion technology	Capacity MW
Vattenfall Oy (Myllykoski Paper Oy)	Under construction	Anjalankoski	Anjalankoski		Industry	fluidized bed	50-100
Stora Enso Oyj	In operation	Inkeroinen	Anjalankoski	K2	Industry	fluidized bed	200-300
Fortum Power and Heat Oy (Ahlström Kauttua Oy)	In operation	Kauttua	Eura	k1	Industry	fluidized bed	50-100
Vapo Oy	In operation	Forssa	Forssa		Municiplity	fluidized bed	50-100
Stora Enso Oyj	In operation	Heinola	Heinola	KII	Industry	fluidized bed	100-200
Fortum Power and Heat Oy	In operation	Vanaja	Hämeenlinna	K4	Municiplity	fluidized bed	50-100
Savon Voima Oyj	Under construction	Iisalmi	Iisalmi		Municiplity	fluidized bed	50-100
Salmi Voima Oy	In operation	Parkatti	Iisalmi	k1	Municiplity	fluidized bed	10-50
Primalco Oy	In operation	Koskenkorva	Ilmajoki	k1	Industry	fluidized bed	10-50
Stora Enso Oyj	In operation	Kaukopää	Imatra	KK2	Industry	fluidized bed	100-200
Fortum Power and Heat Oy	In operation	Joensuu	Joensuu		Municiplity	fluidized bed	200-300
Jyväskylän Energiantuotanto Oy	In operation	Rauhalahti	Jyväskylä	k1	Municiplity	fluidized bed	200-300
Jyväskylän Energiantuotanto Oy	In operation	Savela	Jyväskylä	k4	Municiplity	grate	10-50
UPM-Kymmene Oyj	In operation	Kaipola	Jämsä	K5	Industry	fluidized bed	100-200
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Under construction	Jämsänkoski	Jämsänkoski		Industry	fluidized bed	100-200
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	In operation	Jämsänkoski	Jämsänkoski	K1	Industry	fluidized bed	50-100
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	In operation	Jämsänkoski	Jämsänkoski	K2	Industry	fluidized bed	50-100
Kainuun Voima Oy	In operation	Kajaani	Kajaani	K1	Industry	fluidized bed	200-300
UPM-Kymmene Oyj	In operation	Kajaani	Kajaani	K5	Industry	grate	100-200
Vatajakosken Sähkö Oy	In operation	Kankaanpää	Kankaanpää	k3	Municiplity	fluidized bed	10-50
Metsä-Botnia Oy	In operation	Kemi	Kemi	K10	Industry	fluidized bed	100-200
Veitsiluodon Voima Oy (Stora Enso Oyj)	In operation	Veitsiluoto	Kemi	K7	Industry	fluidized bed	200-300
Kemijärven Kaukolämpö Oy	In operation	Kemijärvi	Kemijärvi	k1	Municiplity	fluidized bed	10-50
Fortum Power and Heat Oy	In operation	Kokkola	Kokkola	C5	Industry	fluidized bed	100-200
Kokkolan Voima Oy	Under construction	Kokkola	Kokkola		Municiplity	fluidized bed	50-100
Kuopion Energia	In operation	Haapaniemi	Kuopio	II	Municiplity	burner	200-300
Kuopion Energia	In operation	Haapaniemi	Kuopio	I	Municiplity	burner	100-200
Metsä-Serla Oyj	In operation	Kuopio	Kuopio	Pääk	Industry	grate	100-200
Fortum Power and Heat Oy	In operation	Kuusamo	Kuusamo		Municiplity	fluidized bed	10-50
Kymin Voima Oy (UPM-Kymmene Oyj)	Under construction	Kuusankoski	Kuusankoski		Industry	fluidized bed	200-300
UPM-Kymmene Oyj	In operation	Kuusankoski	Kuusankoski	K6	Industry	fluidized bed	100-200
Lahti Energia	In operation	Lahti	Lahti		Municiplity	burner, fluidized	300-400
Fortum Lämpö Oy (Valio Oy)	In operation	Lapinlahti	Lapinlahti	k4	Industry	fluidized bed	10-50
UPM-Kymmene Oyj, Kaukas	In operation	Lappeenranta	Lappeenranta	kk1	Industry	fluidized bed	100-200
UPM-Kymmene Oyj, Kaukas	In operation	Lappeenranta	Lappeenranta	kk2	Industry	grate	50-100
Vapo Oy	In operation	Lieksa	Lieksa		Industry	fluidized bed	10-50
Fortum Power and Heat Oy	In operation	Lohja	Lohja	k2	Industry	fluidized bed	50-100
Etelä-Savon Energia Oy	In operation	Pursiala	Mikkeli		Municiplity	fluidized bed	50-100
Mäntän Energia Oy (Metsä-Serla Oyj)	In operation	Mänttä	Mänttä	K4	Industry	fluidized bed	100-200
Fortum Power and Heat Oy	In operation	Naantali	Naantali	II	Municiplity	burner	300-400
Fortum Power and Heat Oy	In operation	Naantali	Naantali	III	Municiplity	burner	300-400
Oulun Voima Oy (Stora Enso Oyj)	In operation	Nuottasaari	Oulu	K3	Industry	fluidized bed	200-300
Kemira Chemicals Oy	In operation	Oulu	Oulu	k3	Industry	fluidized bed	50-100
Kemira Chemicals Oy	In operation	Oulu	Oulu	k1	Industry	fluidized bed	10-50
Oulun Energia	In operation	Toppila	Oulu	2	Municiplity	fluidized bed	300-400
Oulun Energia	In operation	Toppila	Oulu	1	Municiplity	fluidized bed	200-300
Pieksämäen Energia Oy	In operation	Pieksämäki	Pieksamäki	k2	Municiplity	fluidized bed	10-50
Alholmens Kraft Oy Ab (UPM-Kymmene Oyj)	Under construction	Pietarsaari	Pietarsaari		Industry	fluidized bed	500-600
Porin Lämpövoima Oy	In operation	Aittaluoto	Pori	RT	Municiplity	fluidized bed	100-200
Porin Lämpövoima Oy	In operation	Aittaluoto	Pori	R	Municiplity	fluidized bed	50-100
Porin Lämpövoima Oy	In operation	Pihlava	Pori	k1	Industry	fluidized bed	10-50
UPM-Kymmene Oyj	In operation	Rauma	Rauma	HK5	Industry	fluidized bed	100-200
UPM-Kymmene Oyj	In operation	Rauma	Rauma	SK 2	Industry	fluidized bed	50-100
Metsä-Serla Oyj	In operation	Simpele	Rautjärvi	K6	Industry	fluidized bed	100-200
Fortum Power and Heat Oy	In operation	Riihimäki	Riihimäki	k1	Industry	grate	10-50
Fortum Power and Heat Oy	In operation	Riihimäki	Riihimäki	k2	Industry	grate	10-50
UPM-Kymmene Oyj	Under construction	Ristiina	Ristiina		Industry	fluidized bed	50-100
Rovaniemen Energia	In operation	Suosiola	Rovaniemi		Municiplity	fluidized bed	100-200
Voimavasu Oy	Under construction	Salo	Salo		Municiplity	fluidized bed	10-50
Suur-Savon Sähkö Oy	In operation	Savonlinna	Savonlinna		Municiplity	grate	10-50
Vaskiluodon Voima Oy	In operation	Seinäjoki	Seinäjoki		Municiplity	fluidized bed	300-400
Lämpö Oy Juurakkoluli	In operation	Sodankylä	Sodankylä	k1	Municiplity	fluidized bed	10-50
Tampereen sähkölaitos	In operation	Naistenlahti	Tampere	2	Municiplity	fluidized bed	200-300
Turku Energia	Under construction	Turku	Turku		Municiplity	fluidized bed	10-50
UPM-Kymmene Oyj	In operation	Tervasaari	Valkeakoski	K2	Industry	fluidized bed	100-200
Fortum Power and Heat Oy (Säteri Oy)	In operation	Valkeakoski	Valkeakoski	k5	Industry	fluidized bed	50-100
Stora Enso Oyj	In operation	Varkaus	Varkaus	K6	Industry	fluidized bed	100-200
Stora Enso Oyj	In operation	Summa	Vehkalahti	K2	Industry	fluidized bed	100-200
Vieska Energia Oy	In operation	Ylivieska	Ylivieska	k3	Municiplity	fluidized bed	10-50
Metsä-Serla Oyj	Under construction	Äänekoski	Äänekoski		Industry	fluidized bed	100-200

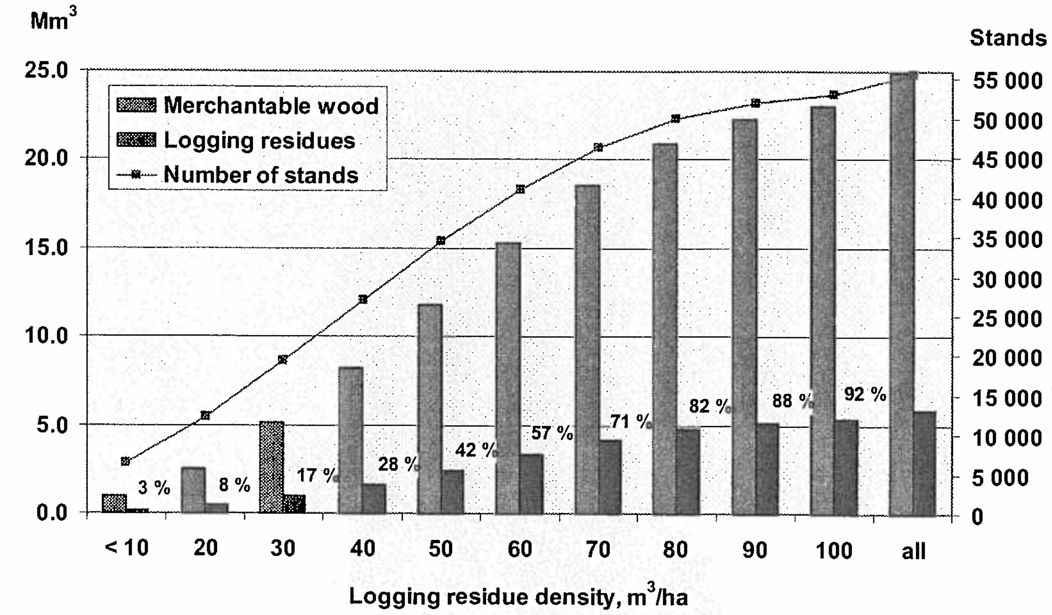
Distribution of reserve (green supply) according to the felling suitability



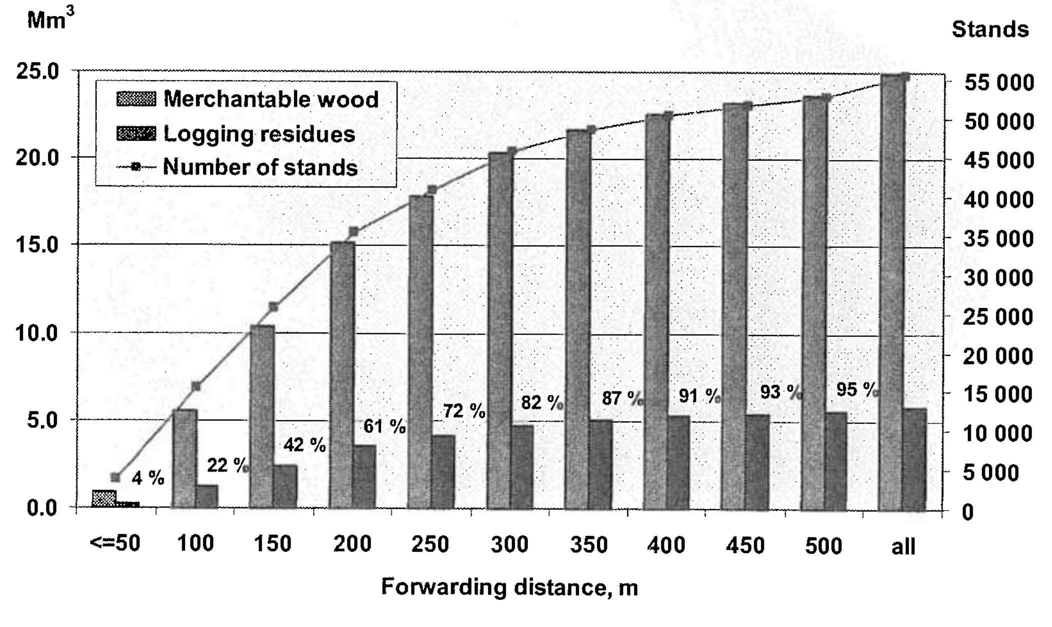
Accumulation of reserve (green supply) according to the logging residue volume, m³/stand



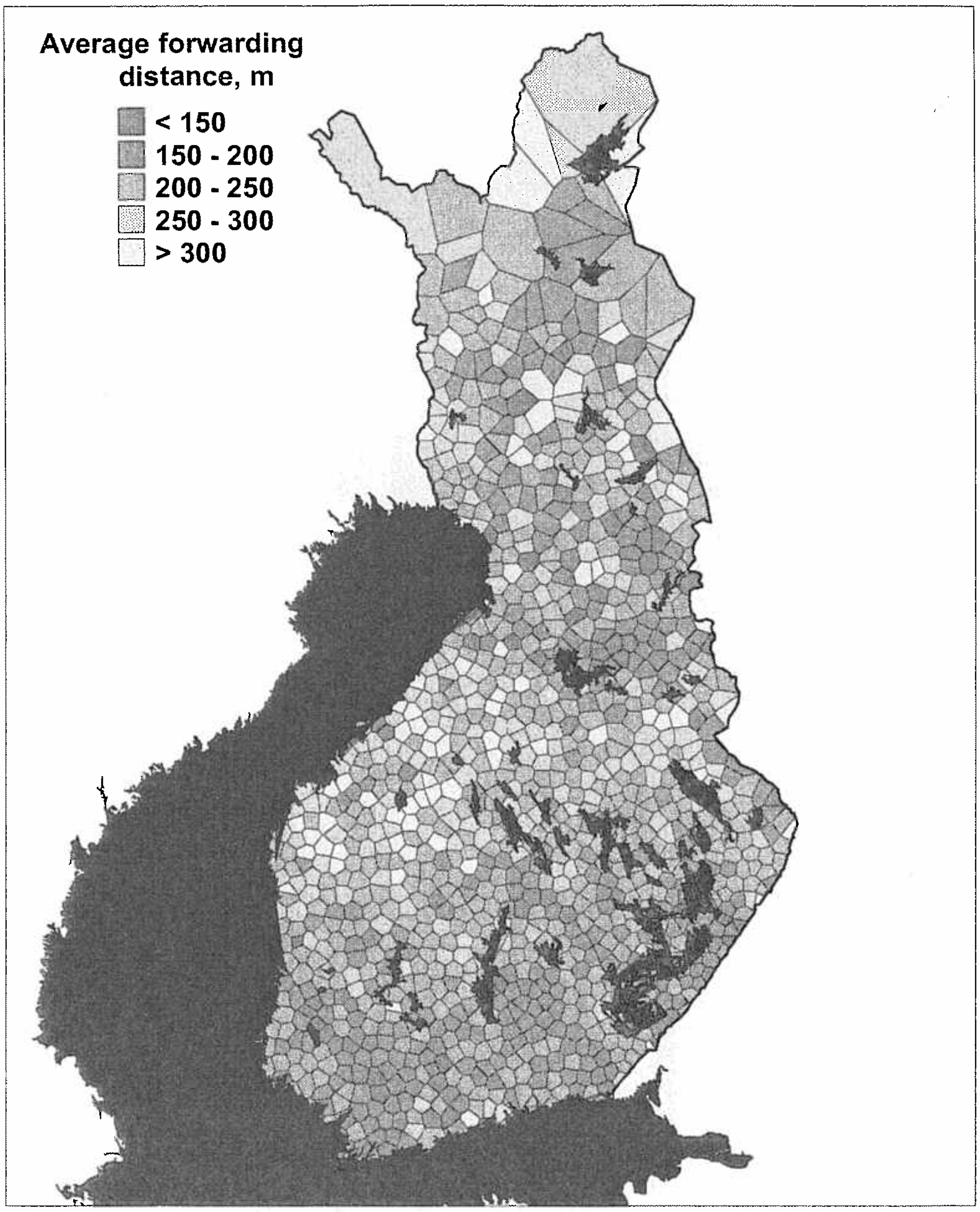
Accumulation of reserve (green supply) according to the logging residue density, m^3/ha



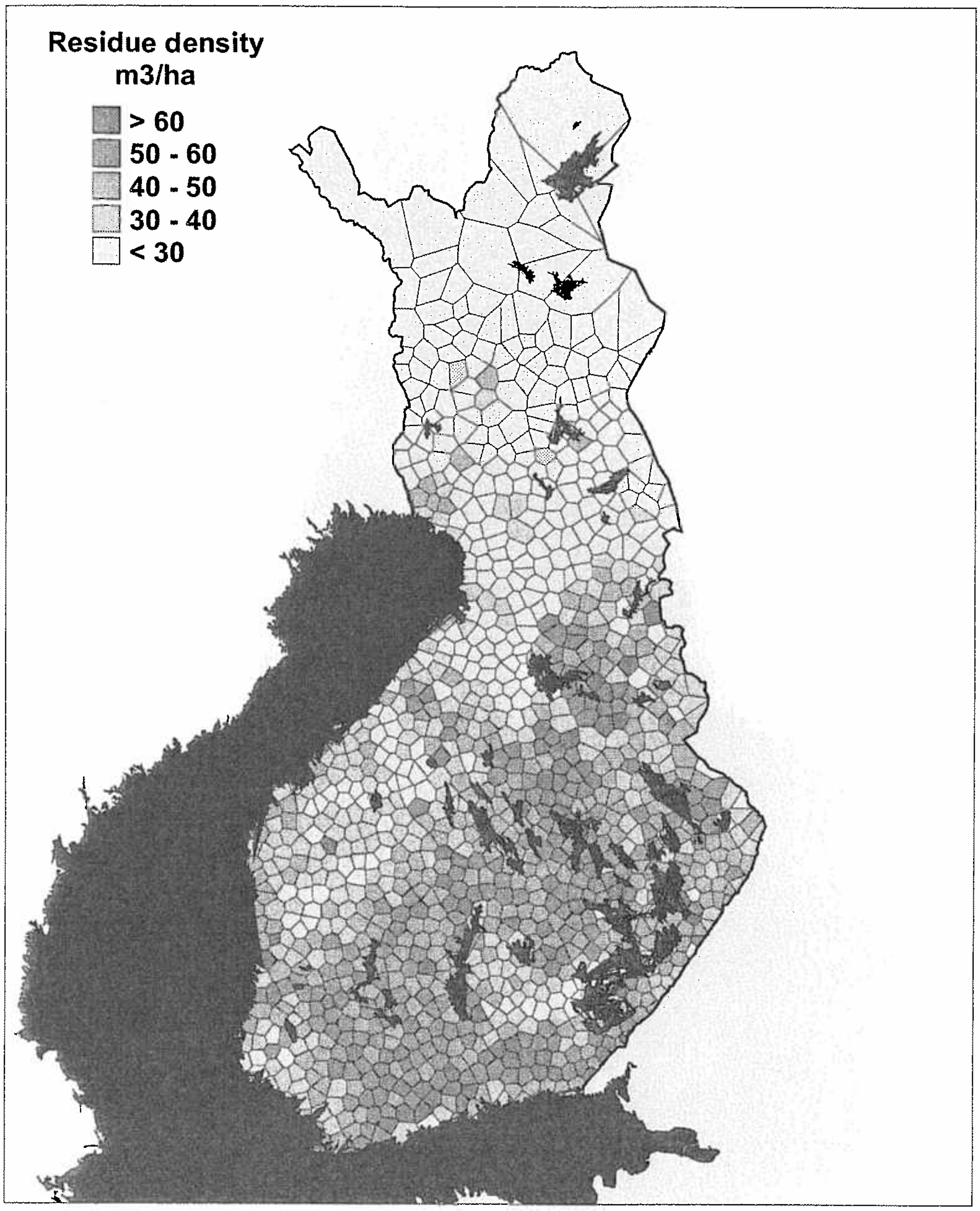
Accumulation of reserve (green supply) according to the forwarding distance, m



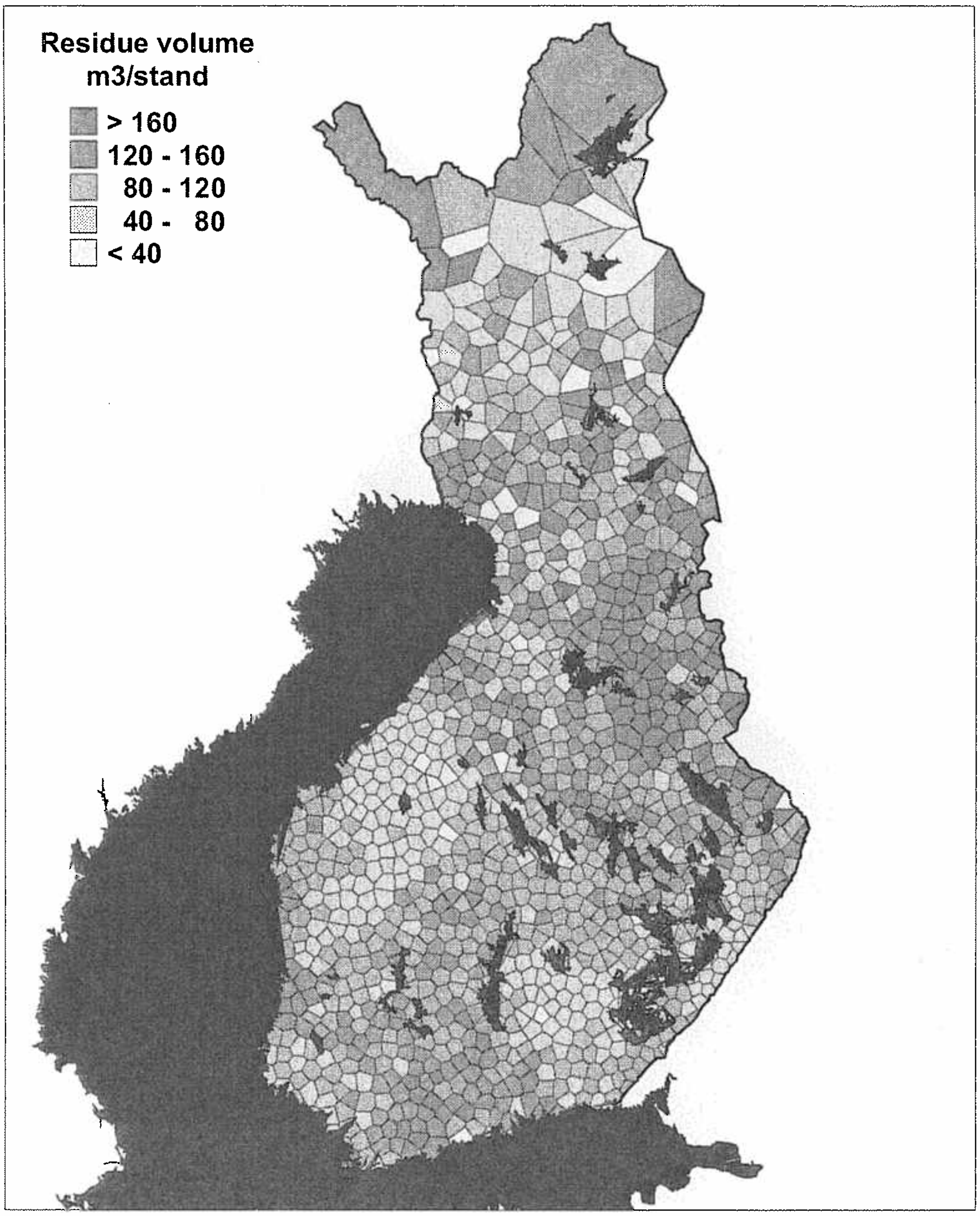
Average forwarding distance of gross stand reserve, aggregation search radius of 10 km



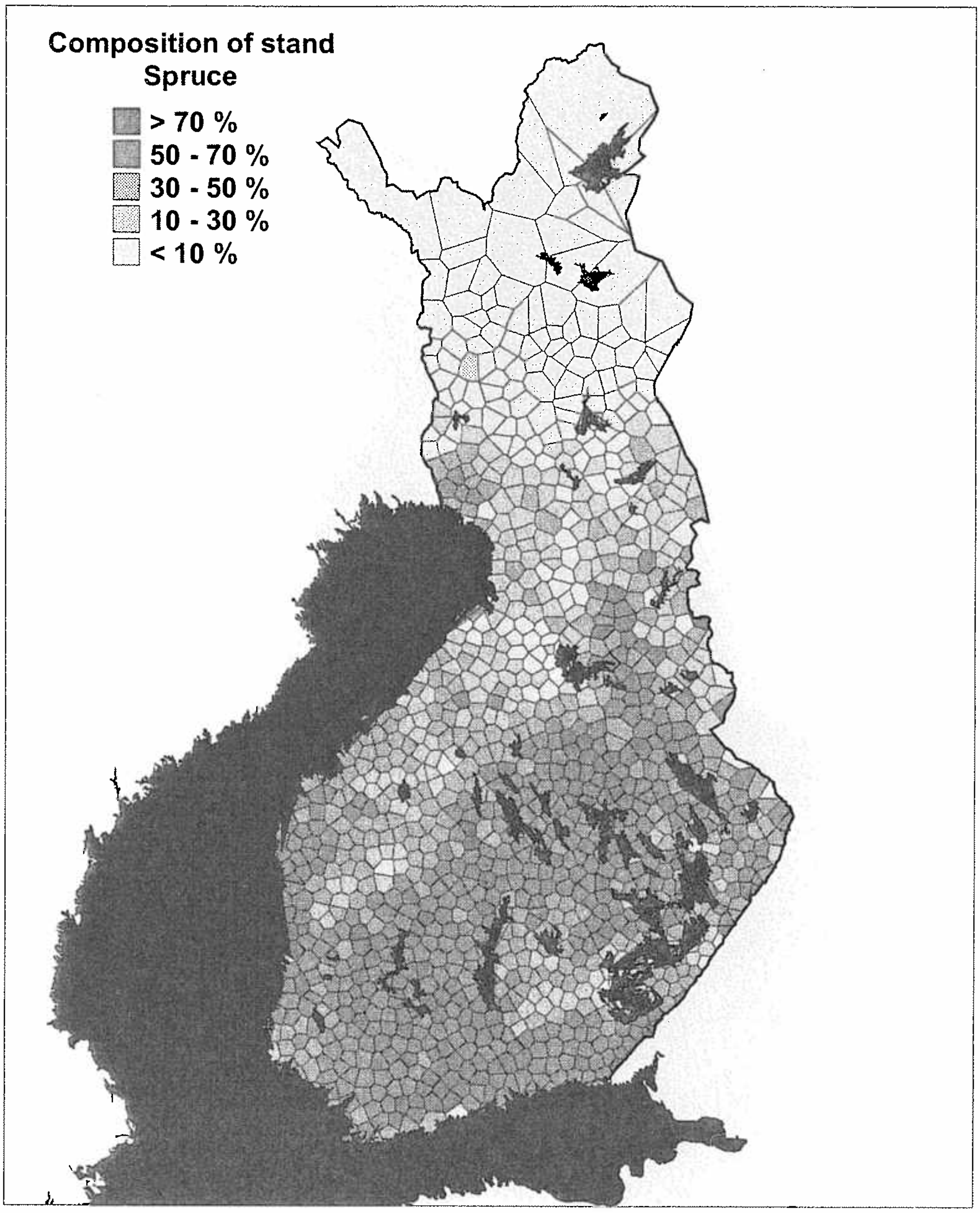
Average residue density, m^3/ha, recovery rate of 65%, green supply of gross stand reserve, aggregation search radius of 10 km



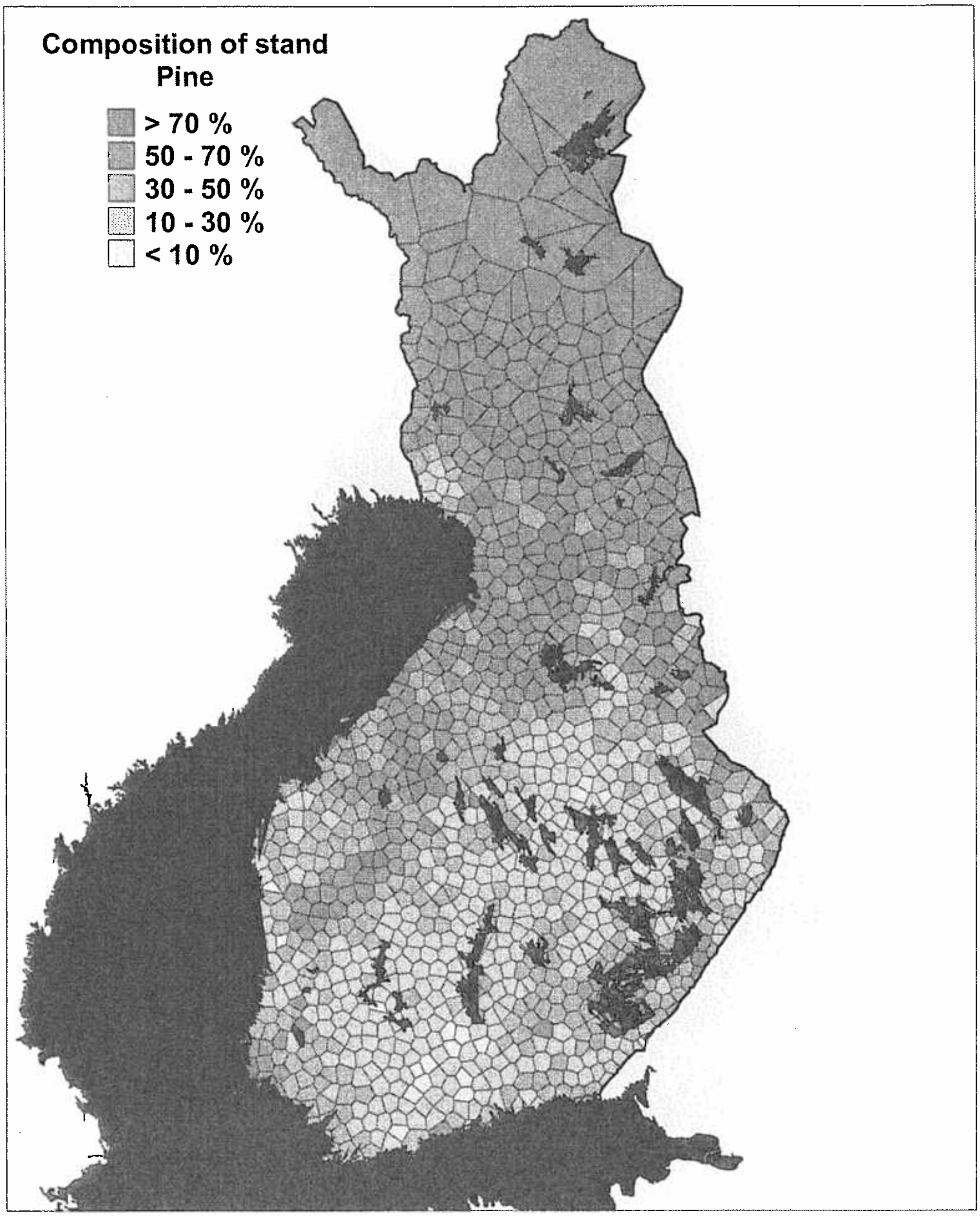
Logging residue volume, m^3/stand, recovery rate of 65%, green supply of gross stand reserve, aggregation search radius of 10 km



Composition of stand, share of spruce of merchantable wood volume, aggregation search radius of 10 km

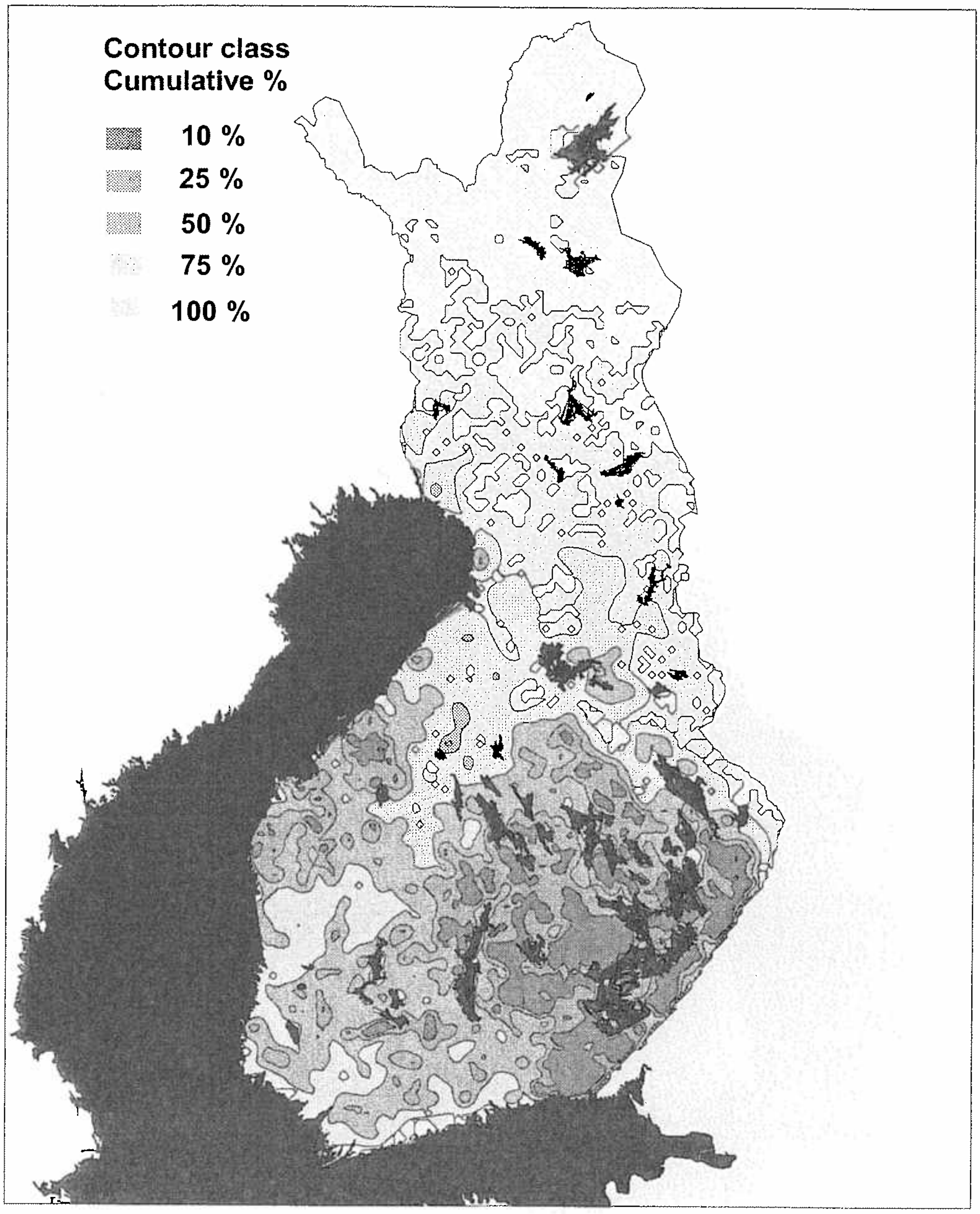


Composition of stand, share of pine of merchantable wood volume, aggregation search radius of 10 km

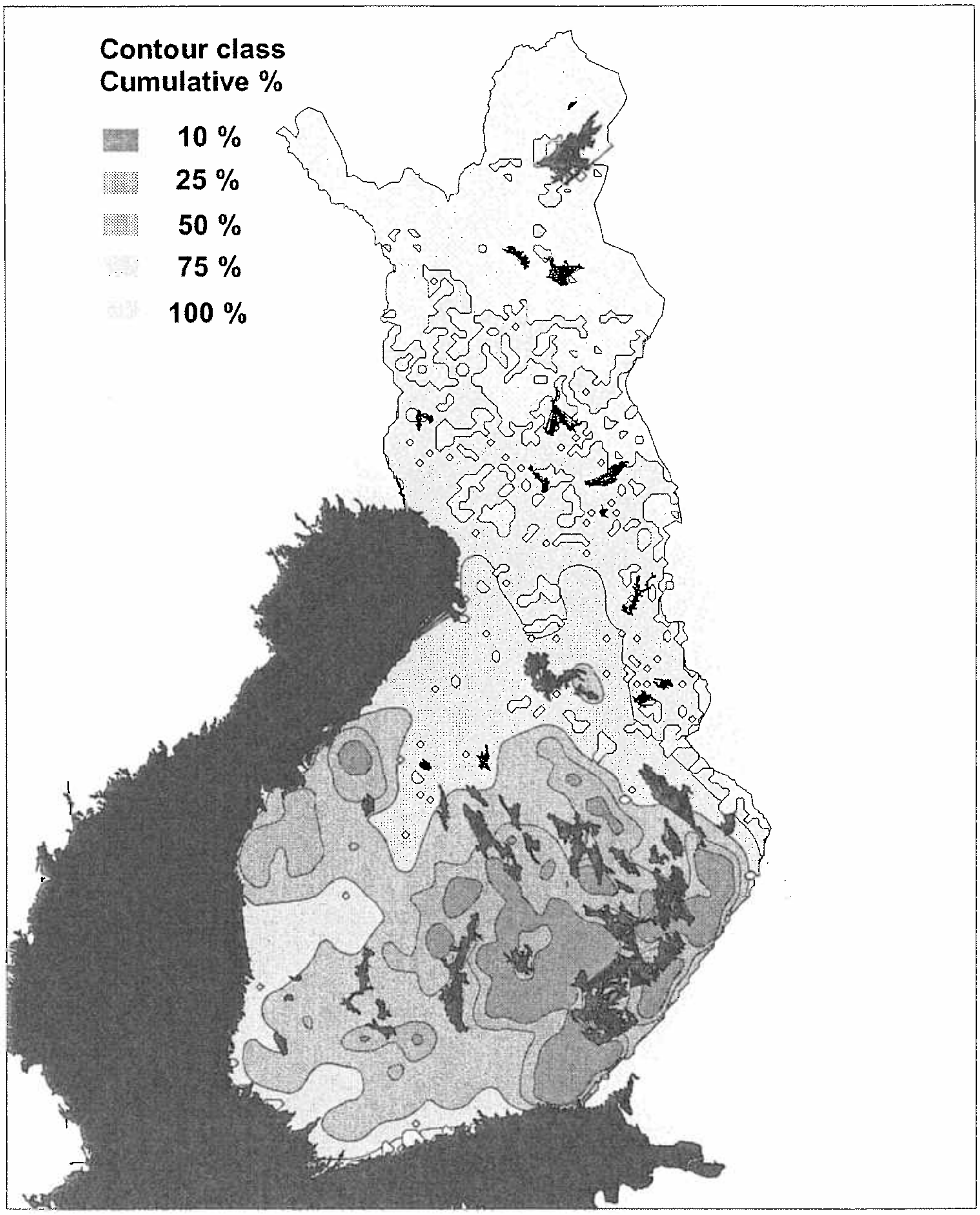


Appendix 6 (1/3)

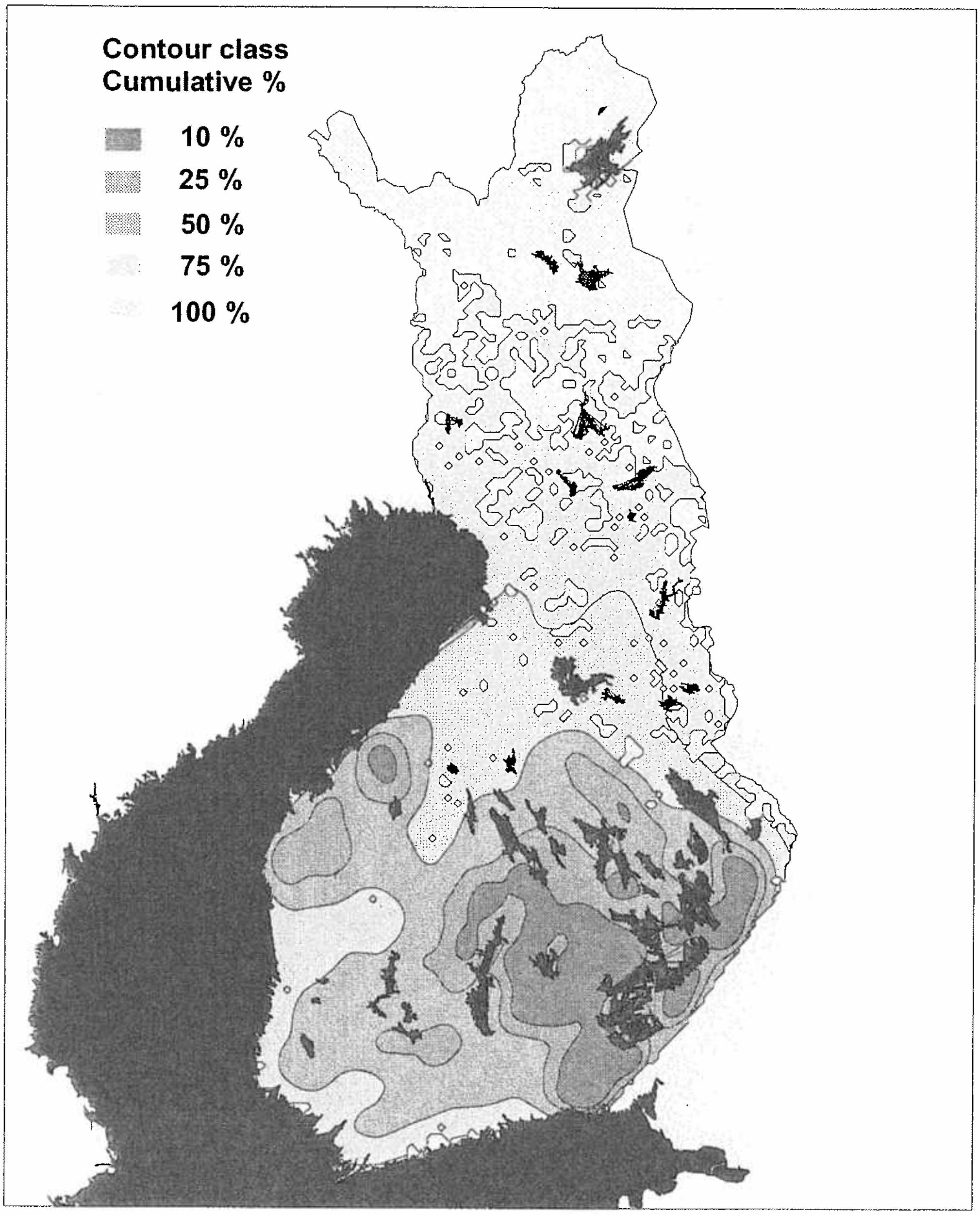
Stand location density map of gross stand reserve, grid-size 5 x 5 km, maximum search criterion: 100 nearest stands



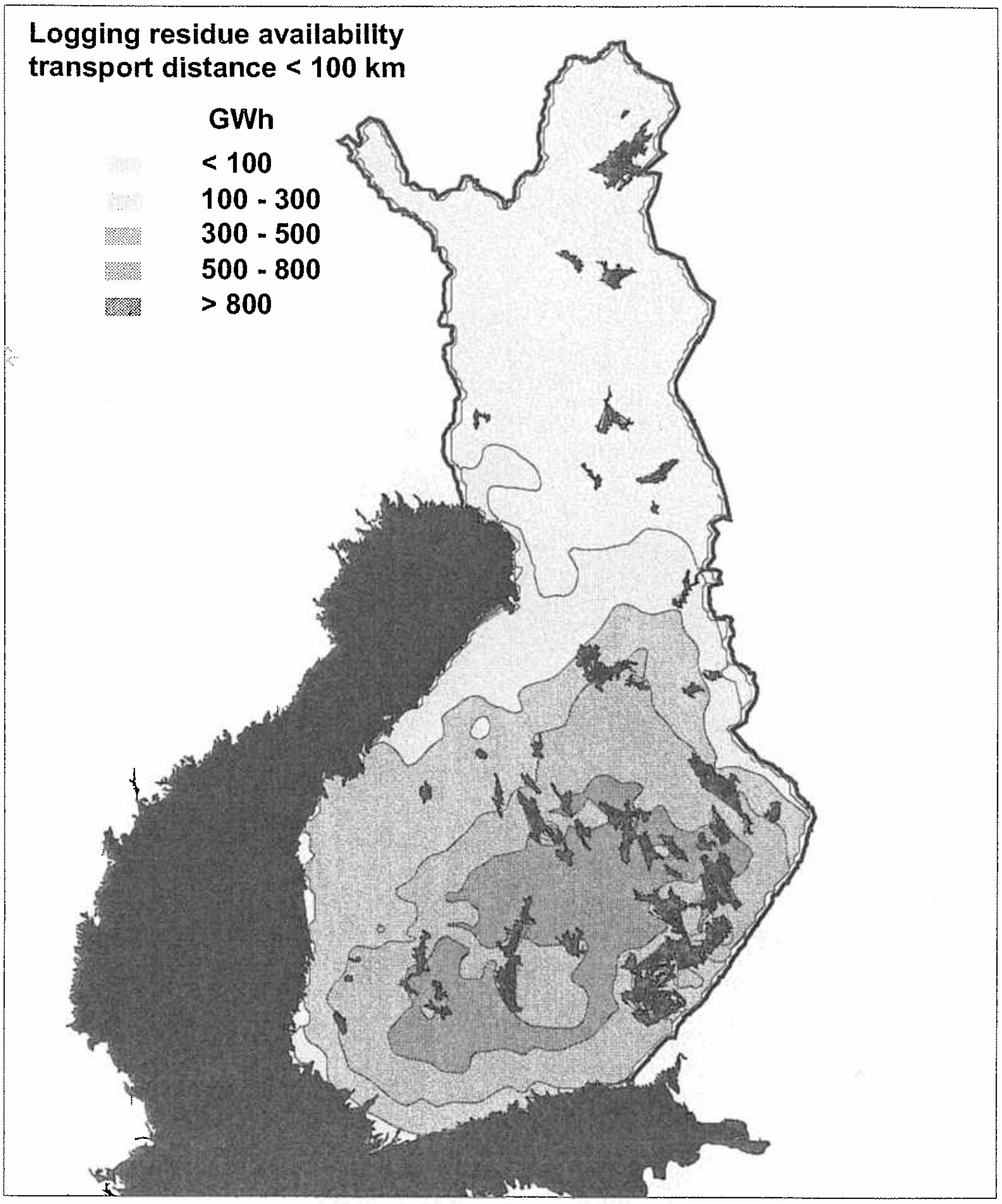
Stand location density map of gross stand reserve, grid-size 5 x 5 km, maximum search criterion: 500 nearest stands



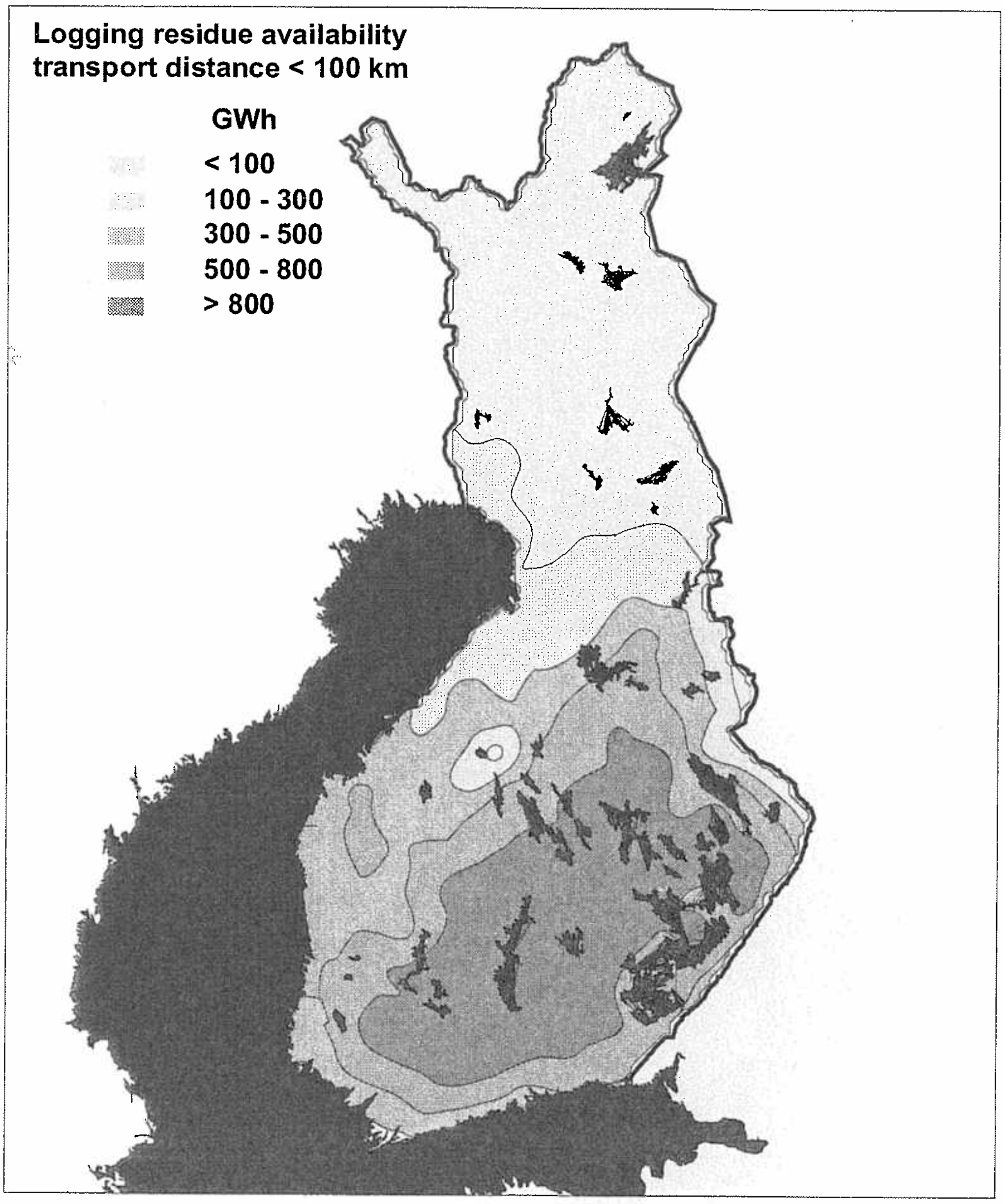
Stand location density map of gross stand reserve, grid-size 5 x 5 km, maximum search criterion: 1 000 nearest stands



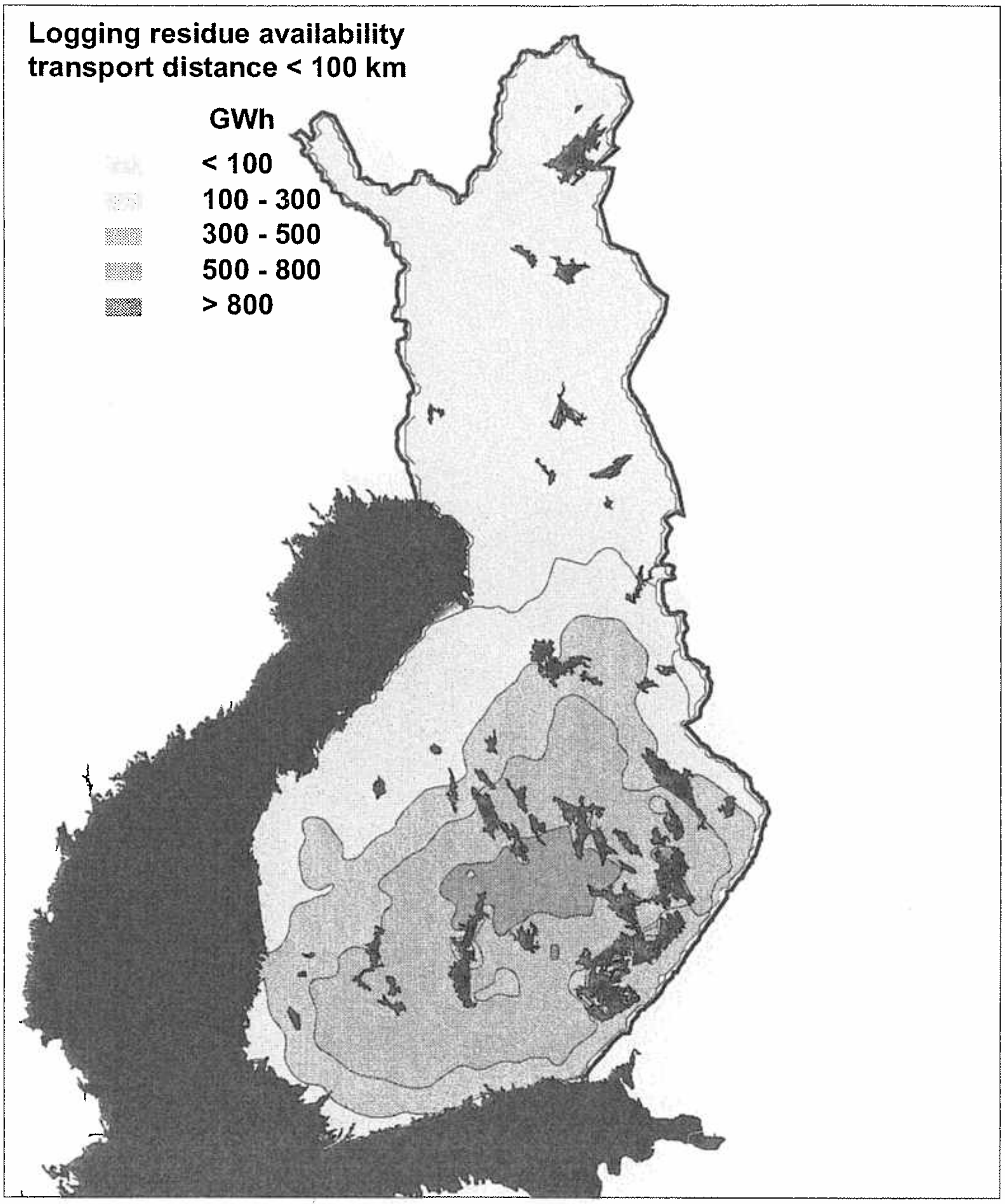
Logging residue availability map as a function of distance, green supply policy, grid-size 5 x 5 km, aggregation distance of 10 km



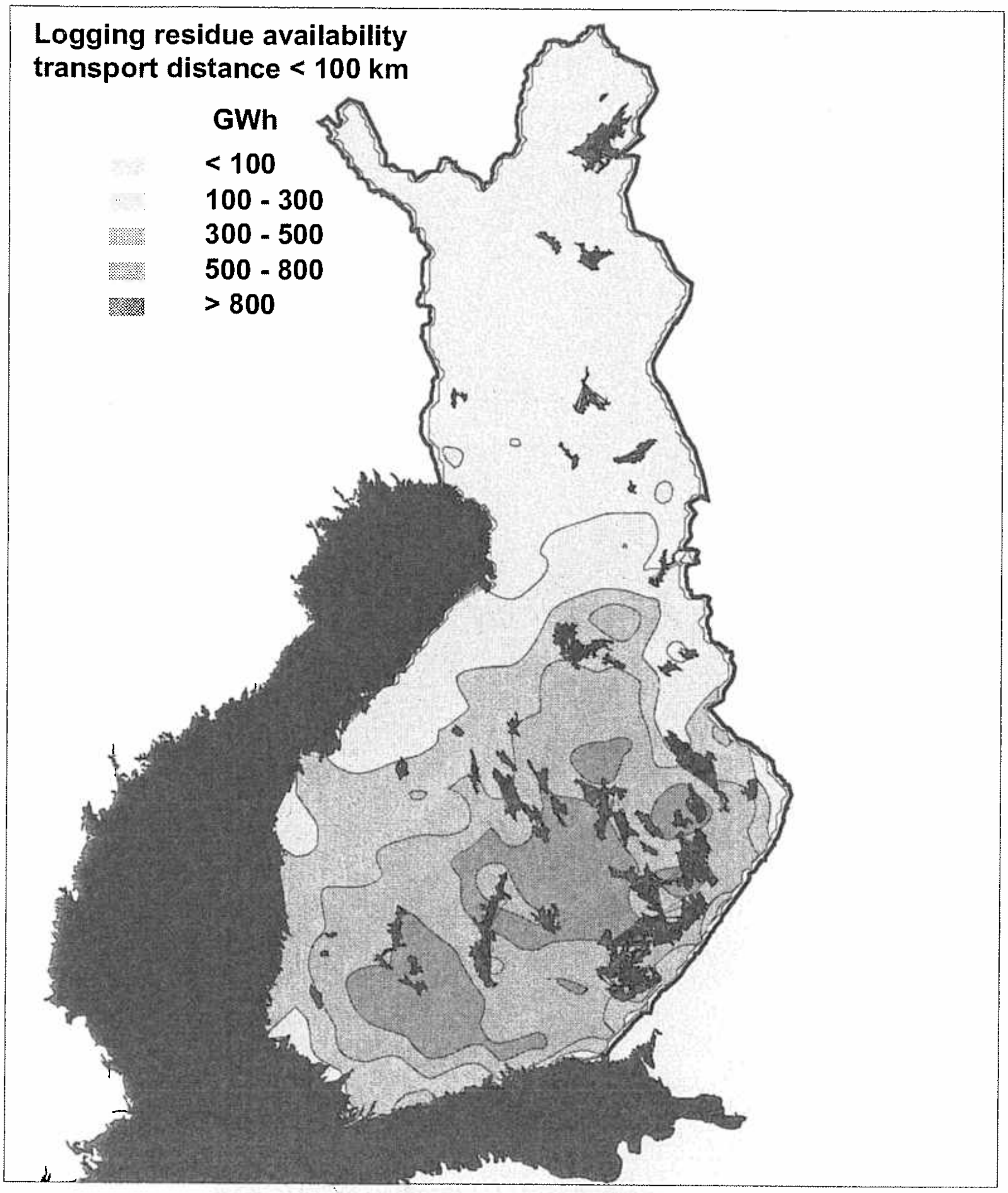
Logging residue availability map as a function of distance, green supply policy, grid-size 5 x 5 km, aggregation distance of 20 km



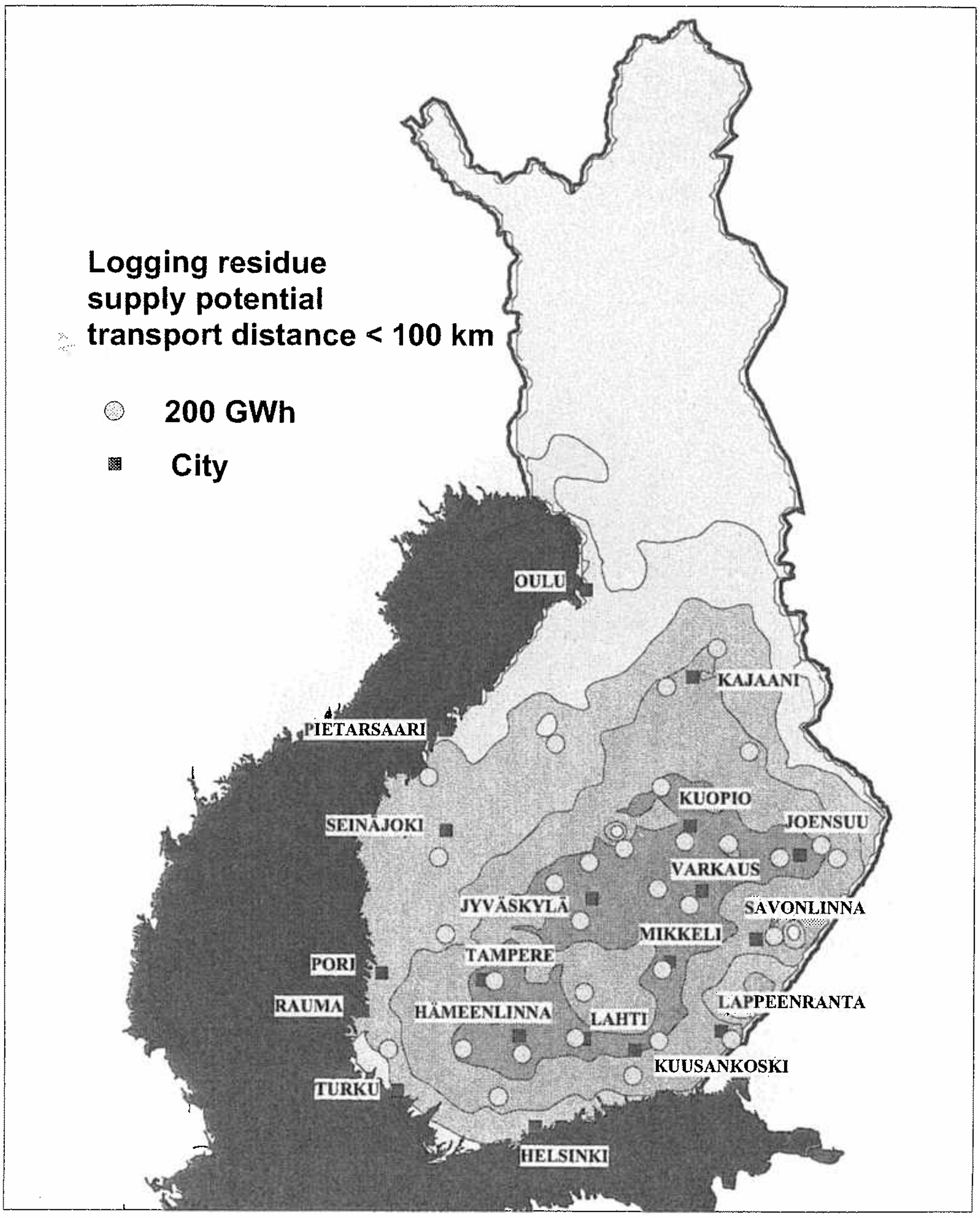
Logging residue availability map as a function of distance, brown supply policy, grid-size 5 x 5 km, aggregation distance of 10 km



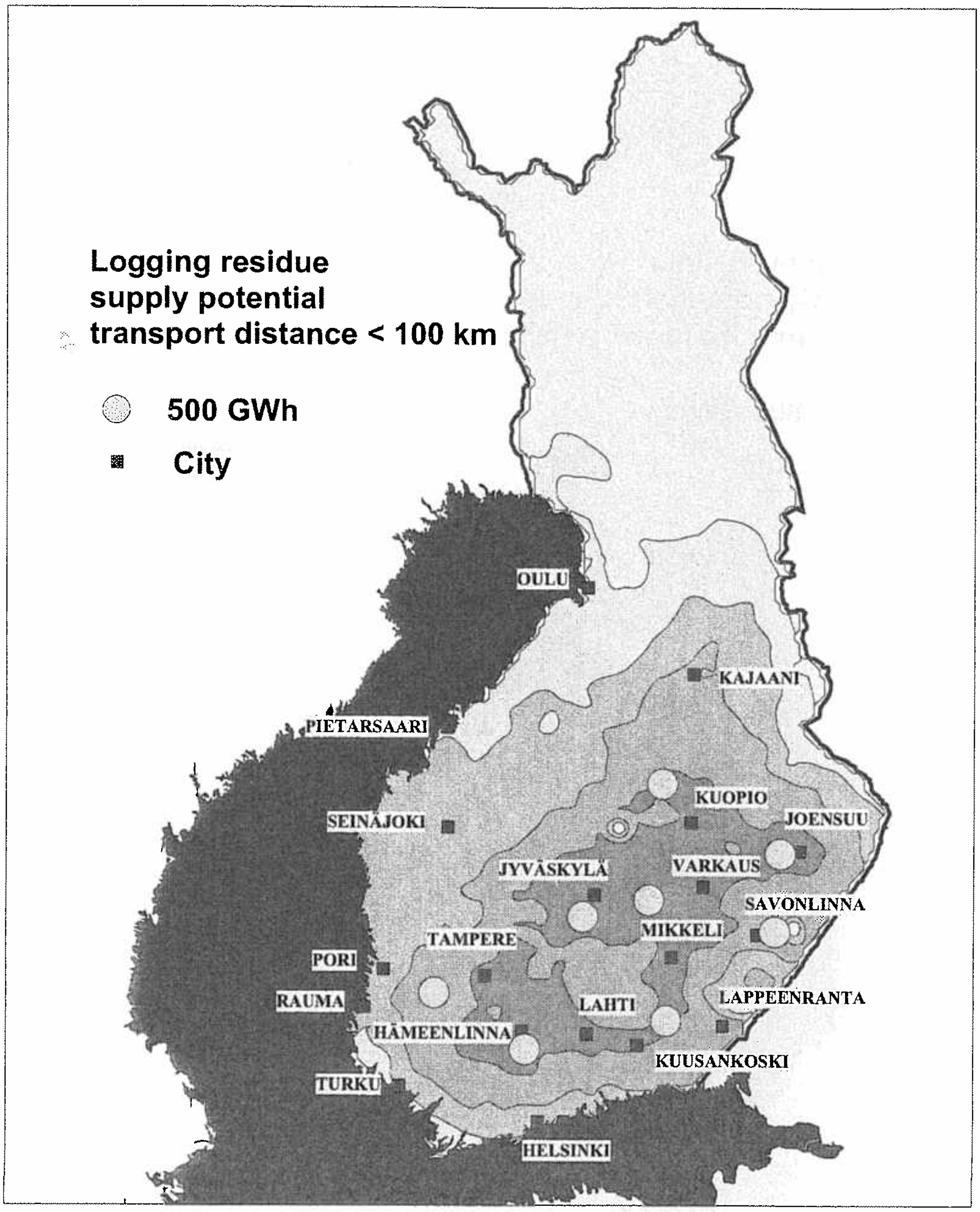
Logging residue availability map as a function of distance, brown supply policy, grid-size 5 x 5 km, aggregation distance of 20 km



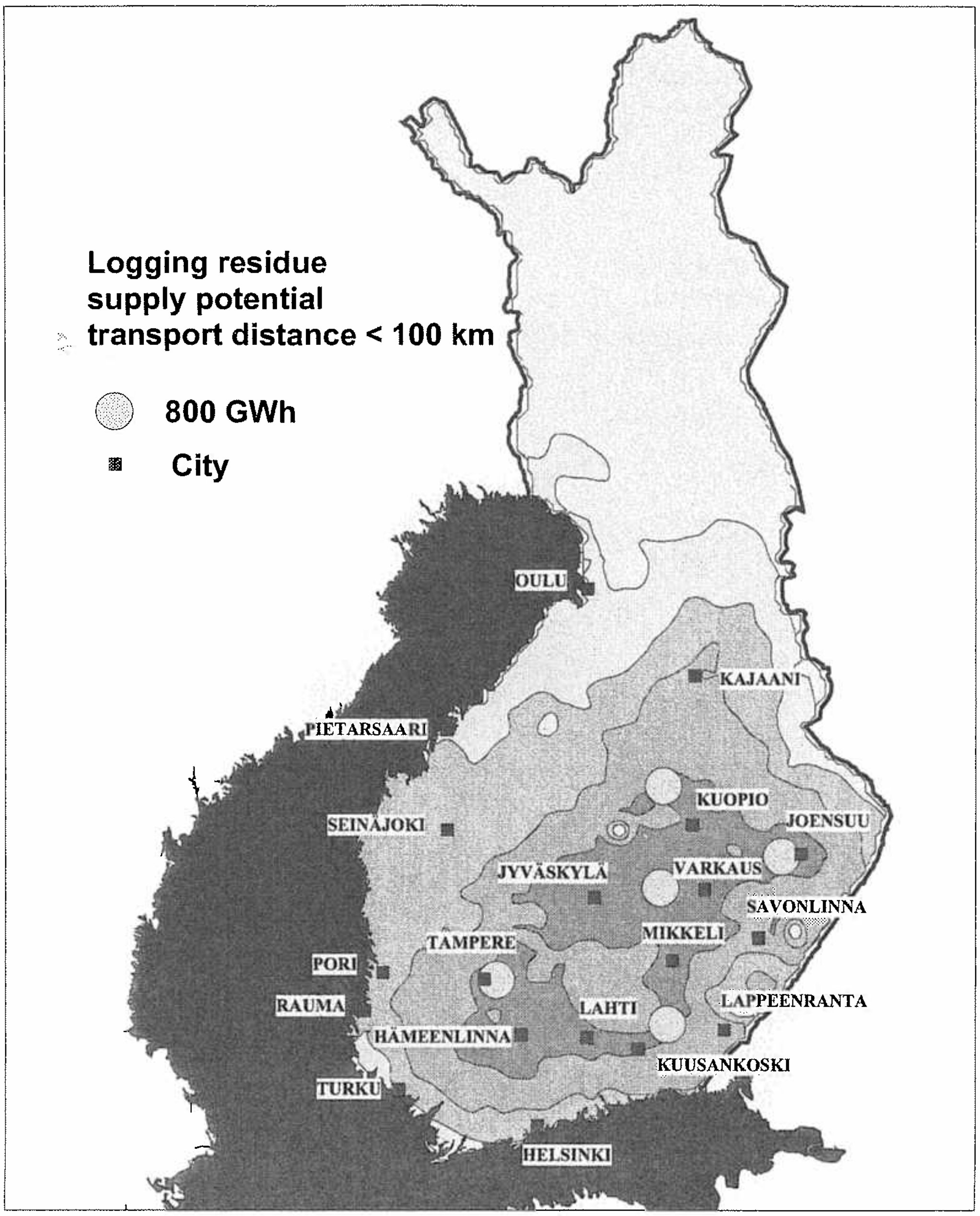
Logging residue supply potential, optimal facility locations at a supply level of 200 GWh, green supply policy, grid-size 5 x 5 km, aggregation distance of 10 km



Logging residue supply potential, optimal facility locations at a supply level of 500 GWh, green supply policy, grid-size 5 x 5 km, aggregation distance of 10 km



Logging residue supply potential, optimal facility locations at a supply level of 800 GWh, green supply policy, grid-size 5 x 5 km, aggregation distance of 10 km



Appendix 9

Procurement areas, share of forest land inside the procurement area, logging residue potential as green or brown net reserve per inland area (including watercourses) and per forest land, transport distance of 100 km

					Green net reserve		Brown net reserve	
Owner	Location	Municipality	Area, km^2	Forest land, %	Inland MWh/km^2	Forest land MWh/km^2	Inland MWh/km^2	Forest land MWh/km^2
Vattenfall Oy (Myllykoski Paper Oy)	Anjalankoski	Anjalankoski	15 852	68 %	49	72	42	62
Stora Enso Oyj	Inkeroinen	Anjalankoski	14 258	68 %	50	72	42	62
Fortum Power and Heat Oy (Ahlström Kauttua Oy)	Kauttua	Eura	17 568	60 %	31	51	26	44
Vapo Oy	Forssa	Forssa	21 899	61 %	43	72	37	62
Stora Enso Oyj	Heinola	Heinola	18 907	68 %	47	69	40	59
Fortum Power and Heat Oy	Vanaja	Hämeenlinna	21 714	62 %	48	77	41	66
Savon Voima Oyj	Iisalmi	Iisalmi	19 518	77 %	39	50	33	43
Salmi Voima Oy	Parkatti	Iisalmi	++++	++++	++++	++++	++++	++++
Primalco Oy	Koskenkorva	Ilmajoki	18 506	74 %	25	34	19	26
Stora Enso Oyj	Kaukopää	Imatra	11 409	61 %	46	76	39	64
Fortum Power and Heat Oy	Joensuu	Joensuu	18 539	68 %	53	81	46	70
Jyväskylän Energiantuotanto Oy	Rauhalahti	Jyväskylä	21 108	71 %	57	80	50	69
Jyväskylän Energiantuotanto Oy	Savela	Jyväskylä	21 188	72 %	56	76	48	67
UPM-Kymmene Oyj	Kaipola	Jämsä	17 758	71 %	54	77	47	67
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	18 685	72 %	54	75	46	65
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++
Kainuun Voima Oy	Kajaani	Kajaani	19 440	81 %	30	38	26	32
UPM-Kymmene Oyj	Kajaani	Kajaani	19 460	81 %	29	36	25	31
Vatajakosken Sähkö Oy	Kankaanpää	Kankaanpää	19 081	73 %	29	40	25	34
Metsä-Botnia Oy	Kemi	Kemi	9 565	83 %	13	15	10	12
Veitsiluodon Voima Oy (Stora Enso Oyj)	Veitsiluoto	Kemi	9 847	84 %	13	15	10	12
Kemijärven Kaukolämpö Oy	Kemijärvi	Kemijärvi	17 261	92 %	1	1	1	1
Fortum Power and Heat Oy	Kokkola	Kokkola	11 954	78 %	22	28	17	22
Kokkolan Voima Oy	Kokkola	Kokkola	11 621	78 %	23	29	18	23
Kuopion Energia	Haapaniemi	Kuopio	18 925	67 %	60	89	52	78
Kuopion Energia	Haapaniemi	Kuopio	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Kuopio	Kuopio	18 423	67 %	60	89	52	78
Fortum Power and Heat Oy	Kuusamo	Kuusamo	14 328	87 %	3	3	2	2
Kymin Voima Oy (UPM-Kymmene Oyj)	Kuusankoski	Kuusankoski	18 363	68 %	50	73	43	63
UPM-Kymmene Oyj	Kuusankoski	Kuusankoski	++++	++++	++++	++++	++++	++++
Lahti Energia	Lahti	Lahti	21 404	67 %	48	71	41	61
Fortum Lämpö Oy (Valio Oy)	Lapinlahti	Lapinlahti	18 882	73 %	43	59	37	51
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	10 443	74 %	62	84	53	71
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	++++	++++	++++	++++	++++	++++
Vapo Oy	Lieksa	Lieksa	15 041	78 %	28	36	24	31
Fortum Power and Heat Oy	Lohja	Lohja	13 827	63 %	37	58	32	50
Etelä-Savon Energia Oy	Pursiala	Mikkeli	21 783	65 %	55	85	43	67
Mäntän Energia Oy (Metsä-Serla Oyj)	Mänttä	Mänttä	19 550	72 %	45	62	39	54
Fortum Power and Heat Oy	Naantali	Naantali	12 051	57 %	24	41	20	34
Fortum Power and Heat Oy	Naantali	Naantali	++++	++++	++++	++++	++++	++++
Oulun Voima Oy (Stora Enso Oyj)	Nuottasaari	Oulu	18 425	89 %	7	8	5	6
Kemira Chemicals Oy	Oulu	Oulu	15 548	87 %	8	10	8	7
Kemira Chemicals Oy	Oulu	Oulu	++++	++++	++++	++++	++++	++++
Oulun Energia	Toppila	Oulu	15 085	87 %	8	10	6	7
Oulun Energia	Toppila	Oulu	++++	++++	++++	++++	++++	++++
Pieksämäen Energia Oy	Pieksämäki	Pieksamäki	19 286	69 %	69	99	61	89
Alholmens Kraft Oy Ab (UPM-Kymmene Oyj)	Pietarsaari	Pietarsaari	10 846	73 %	24	32	18	25
Porin Lämpövoima Oy	Aittaluoto	Pori	15 185	72 %	33	45	28	39
Porin Lämpövoima Oy	Aittaluoto	Pori	++++	++++	++++	++++	++++	++++
Porin Lämpövoima Oy	Pihlava	Pori	11 544	72 %	32	44	27	37
UPM-Kymmene Oyj	Rauma	Rauma	11 059	63 %	31	49	26	41
UPM-Kymmene Oyj	Rauma	Rauma	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Simpele	Rautjärvi	8 089	75 %	57	75	48	64
Fortum Power and Heat Oy	Riihimäki	Riihimäki	20 116	64 %	47	73	40	64
Fortum Power and Heat Oy	Riihimäki	Riihimäki	++++	++++	++++	++++	++++	++++
UPM-Kymmene Oyj	Ristiina	Ristiina	20 719	63 %	48	76	41	65
Rovaniemen Energia	Suosiola	Rovaniemi	19 781	89 %	4	4	3	3
Voimavasu Oy	Salo	Salo	17 019	60 %	32	53	27	45
Suur-Savon Sähkö Oy	Savonlinna	Savonlinna	18 649	58 %	52	89	44	76
Vaskiluodon Voima Oy	Seinäjoki	Seinäjoki	21 634	74 %	22	30	17	23
Lämpö Oy Juurakkotuli	Sodankylä	Sodankylä	18 234	94 %	0	0	0	0
Tampereen sähkölaitos	Naistenlahti	Tampere	22 857	67 %	44	65	38	56
Turku Energia	Turku	Turku	15 489	59 %	28	48	23	40
UPM-Kymmene Oyj	Tervasaari	Valkeakoski	20 741	65 %	49	74	42	64
Fortum Power and Heat Oy (Säteri Oy)	Valkeakoski	Valkeakoski	20 111	65 %	49	76	42	65
Stora Enso Oyj	Varkaus	Varkaus	22 547	58 %	57	99	50	86
Stora Enso Oyj	Summa	Vehkalahti	10 714	69 %	55	80	47	69
Vieska Energia Oy	Ylivieska	Ylivieska	17 172	81 %	17	21	14	17
Metsä-Serla Oyj	Äänekoski	Äänekoski	19 021	75 %	54	71	47	62

Appendix 10

Logging residue potentials around the power plants for green and brown supply policies, transport distance of 100 km, overlapping procurement areas

			Green supply			Brown supply				
			Gross	Net		Gross	Net			
Owner	Location	Municipality	GWh (1)	GWh (2)	(2) / (1)	GWh (3)	GWh (4)	(4) / (3)	(3) / (1)	(4) / (2)
Vattenfall Oy (Myllykoski Paper Oy)	Anjalankoski	Anjalankoski	1 071	777	73 %	971	668	69 %	91 %	86 %
Stora Enso Oyj	Inkeroinen	Anjalankoski	971	706	73 %	879	605	69 %	91 %	88 %
Fortum Power and Heat Oy (Ahlström Kauttua Oy)	Kauttua	Eura	702	545	78 %	634	461	73 %	90 %	85 %
Vapo Oy	Forssa	Forssa	1 172	952	81 %	1 056	818	77 %	90 %	86 %
Stora Enso Oyj	Heinola	Heinola	1 201	886	74 %	1 092	759	69 %	91 %	88 %
Fortum Power and Heat Oy	Vanaja	Hämeenlinna	1 275	1 039	81 %	1 147	898	78 %	90 %	86 %
Savon Voima Oyj	Iisalmi	Iisalmi	1 038	754	73 %	943	653	69 %	91 %	87 %
Salmi Voima Oy	Parkatti	Iisalmi	++++	++++	++++	++++	++++	++++	++++	++++
Primalco Oy	Koskenkorva	Ilmajoki	797	458	57 %	729	353	49 %	91 %	77 %
Stora Enso Oyj	Kaukopää	Imatra	793	526	66 %	728	445	61 %	92 %	85 %
Fortum Power and Heat Oy	Joensuu	Joensuu	1 325	987	74 %	1 209	852	70 %	91 %	88 %
Jyväskylän Energiantuotanto Oy	Rauhalahti	Jyväskylä	1 588	1 209	78 %	1 440	1 046	73 %	91 %	87 %
Jyväskylän Energiantuotanto Oy	Savela	Jyväskylä	1 560	1 180	76 %	1 414	1 018	72 %	91 %	88 %
UPM-Kymmene Oyj	Kaipola	Jämsä	1 245	964	77 %	1 125	834	74 %	90 %	87 %
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	1 296	1 001	77 %	1 172	867	74 %	90 %	87 %
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Kainuun Voima Oy	Kajaani	Kajaani	737	574	78 %	674	499	74 %	91 %	87 %
UPM-Kymmene Oyj	Kajaani	Kajaani	720	562	78 %	658	489	74 %	91 %	87 %
Vatajakosken Sähkö Oy	Kankaanpää	Kankaanpää	752	560	74 %	681	471	69 %	90 %	84 %
Metsä-Botnia Oy	Kemi	Kemi	197	121	61 %	183	96	52 %	93 %	79 %
Veitsiluodon Voima Oy (Stora Enso Oyj)	Veitsiluoto	Kemi	203	125	61 %	188	97	52 %	93 %	78 %
Kemijärven Kaukolämpö Oy	Kemijärvi	Kemijärvi	96	13	14 %	91	10	11 %	94 %	73 %
Fortum Power and Heat Oy	Kokkola	Kokkola	491	265	54 %	452	206	46 %	92 %	78 %
Kokkolan Voima Oy	Kokkola	Kokkola	484	262	54 %	446	204	46 %	92 %	78 %
Kuopion Energia	Haapaniemi	Kuopio	1 510	1 127	75 %	1 367	982	72 %	90 %	87 %
Kuopion Energia	Haapaniemi	Kuopio	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Kuopio	Kuopio	1 466	1 097	75 %	1 327	957	72 %	90 %	87 %
Fortum Power and Heat Oy	Kuusamo	Kuusamo	113	37	33 %	105	26	25 %	93 %	70 %
Kymin Voima Oy (UPM-Kymmene Oyj)	Kuusankoski	Kuusankoski	1 268	920	73 %	1 152	789	68 %	91 %	86 %
UPM-Kymmene Oyj	Kuusankoski	Kuusankoski	++++	++++	++++	++++	++++	++++	++++	++++
Lahti Energia	Lahti	Lahti	1 320	1 022	77 %	1 195	879	73 %	91 %	86 %
Fortum Lämpö Oy (Valio Oy)	Lapinlahti	Lapinlahti	1 114	811	73 %	1 008	702	70 %	91 %	87 %
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	922	651	71 %	840	553	66 %	91 %	85 %
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	++++	++++	++++	++++	++++	++++	++++	++++
Vapo Oy	Lieksa	Lieksa	598	420	70 %	545	360	66 %	91 %	86 %
Fortum Power and Heat Oy	Lohja	Lohja	616	506	82 %	555	437	79 %	90 %	86 %
Etelä-Savon Energia Oy	Pursiala	Mikkeli	1 577	1 203	76 %	1 443	946	66 %	92 %	79 %
Mäntän Energia Oy (Metsä-Serla Oyj)	Mänttä	Mänttä	1 158	882	76 %	1 044	761	73 %	90 %	86 %
Fortum Power and Heat Oy	Naantali	Naantali	385	287	75 %	348	238	68 %	91 %	83 %
Fortum Power and Heat Oy	Naantali	Naantali	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Voima Oy (Stora Enso Oyj)	Nuottasaari	Oulu	293	132	45 %	278	99	36 %	94 %	75 %
Kemira Chemicals Oy	Oulu	Oulu	287	129	45 %	271	97	36 %	94 %	75 %
Kemira Chemicals Oy	Oulu	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Energia	Toppila	Oulu	283	127	45 %	267	95	36 %	94 %	75 %
Oulun Energia	Toppila	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Pieksämäen Energia Oy	Pieksämäki	Pieksämäki	1 740	1 323	76 %	1 579	1 182	75 %	91 %	89 %
Alholmens Kraft Oy Ab (UPM-Kymmene Oyj)	Pietarsaari	Pietarsaari	479	256	53 %	441	197	45 %	92 %	77 %
Porin Lämpövoima Oy	Aittaluoto	Pori	641	496	77 %	579	422	73 %	90 %	85 %
Porin Lämpövoima Oy	Aittaluoto	Pori	++++	++++	++++	++++	++++	++++	++++	++++
Porin Lämpövoima Oy	Pihlava	Pori	469	364	78 %	424	309	73 %	90 %	85 %
UPM-Kymmene Oyj	Rauma	Rauma	445	344	77 %	402	290	72 %	90 %	84 %
UPM-Kymmene Oyj	Rauma	Rauma	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Simpele	Rautjärvi	680	457	67 %	626	386	62 %	92 %	84 %
Fortum Power and Heat Oy	Riihimäki	Riihimäki	1 143	936	82 %	1 029	812	79 %	90 %	87 %
Fortum Power and Heat Oy	Riihimäki	Riihimäki	++++	++++	++++	++++	++++	++++	++++	++++
UPM-Kymmene Oyj	Ristiina	Ristiina	1 437	1 002	70 %	1 314	853	65 %	91 %	85 %
Rovaniemen Energia	Suosiola	Rovaniemi	191	75	39 %	179	60	33 %	94 %	79 %
Voimavasu Oy	Salo	Salo	681	537	79 %	614	458	75 %	90 %	85 %
Suur-Savon Sähkö Oy	Savonlinna	Savonlinna	1 220	864	71 %	1 117	740	66 %	92 %	86 %
Vaskiluodon Voima Oy	Seinäjoki	Seinäjoki	853	482	57 %	780	374	48 %	91 %	78 %
Lämpö Oy Juurakkotuli	Sodankylä	Sodankylä	44	2	4 %	42	1	3 %	95 %	72 %
Tampereen sähkölaitos	Naistenlahti	Tampere	1 260	1 000	79 %	1 135	858	76 %	90 %	86 %
Turku Energia	Turku	Turku	560	433	77 %	506	363	72 %	90 %	84 %
UPM-Kymmene Oyj	Tervasaari	Valkeakoski	1 242	1 008	81 %	1 118	868	78 %	90 %	86 %
Fortum Power and Heat Oy (Säteri Oy)	Valkeakoski	Valkeakoski	1 213	986	81 %	1 092	849	78 %	90 %	86 %
Stora Enso Oyj	Varkaus	Varkaus	1 720	1 292	75 %	1 562	1 121	72 %	91 %	87 %
Stora Enso Oyj	Summa	Vehkalahti	794	587	74 %	718	506	70 %	90 %	86 %
Vieska Energia Oy	Ylivieska	Ylivieska	528	292	55 %	492	242	49 %	93 %	83 %
Metsä-Serla Oyj	Äänekoski	Äänekoski	1 336	1 025	77 %	1 210	891	74 %	91 %	87 %

Appendix 11 (1/8)

Logging residue potentials around the power plants, roadside chipping, green supply policy, overlapping procurement areas

			Marginal cost classes, €/MWh				Marginal cost classes, €/MWh			
			Logging residue potential, GWh				Average cost, €/MWh			
		FIM/MWh	45	50	55	60	45	50	55	60
Owner	Location	Municipality	7.57	8.41	9.25	10.09	7.57	8.41	9.25	10.09
Vattenfall Oy (Myllykoski Paper Oy)	Anjalankoski	Anjalankoski	20	153	412	681	7.32	7.99	8.54	8.97
Stora Enso Oyj	Inkeroinen	Anjalankoski	15	148	399	828	7.32	8.00	8.54	8.94
Fortum Power and Heat Oy (Ahlström Kauttua Oy)	Kauttua	Eura	14	111	315	488	7.30	8.02	8.55	8.93
Vapo Oy	Forssa	Forssa	17	153	519	853	7.40	8.02	8.83	9.01
Stora Enso Oyj	Heinola	Heinola	15	92	403	773	7.32	7.96	8.87	9.15
Fortum Power and Heat Oy	Vanaja	Hämeenlinna	38	238	595	930	7.40	7.96	8.50	8.91
Savon Voima Oyj	Iisalmi	Iisalmi	21	178	457	691	7.39	7.99	8.53	8.90
Salmi Voima Oy	Parkatti	Iisalmi	++++	++++	++++	++++	++++	++++	++++	++++
Primalco Oy	Koskenkorva	Ilmajoki	6	65	208	388	7.38	8.06	8.64	9.11
Stora Enso Oyj	Kaukopää	Imatra	18	106	276	461	7.29	7.95	8.51	8.98
Fortum Power and Heat Oy	Joensuu	Joensuu	10	154	587	923	7.35	8.04	8.65	9.00
Jyväskylän Energiantuotanto Oy	Rauhalahti	Jyväskylä	27	245	724	1 107	7.39	8.01	8.57	8.93
Jyväskylän Energiantuotanto Oy	Savela	Jyväskylä	35	260	725	1 082	7.33	7.99	8.55	8.90
UPM-Kymmene Oyj	Kaipola	Jämsä	28	185	488	856	7.38	7.98	8.53	9.00
Jämsänkoskan Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	30	212	557	909	7.35	7.96	8.53	8.96
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Kainuun Voima Oy	Kajaani	Kajaani	30	168	377	525	7.36	7.93	8.44	8.78
UPM-Kymmene Oyj	Kajaani	Kajaani	29	168	366	514	7.35	7.93	8.42	8.78
Vatajakosken Sähkö Oy	Kankaanpää	Kankaanpää	8	56	245	475	7.41	8.05	8.69	9.18
Metsä-Botnia Oy	Kemi	Kemi	5	41	79	114	7.39	7.98	8.37	8.78
Veitsiluodon Voima Oy (Stora Enso Oyj)	Veitsiluoto	Kemi	5	35	81	116	7.37	7.95	8.40	8.77
Kemijärven Kaukolämpö Oy	Kemijärvi	Kemijärvi	na	1	7	12	na	7.94	8.74	9.11
Fortum Power and Heat Oy	Kokkola	Kokkola	4	37	123	224	7.43	8.01	8.81	9.07
Kokkolan Voima Oy	Kokkola	Kokkola	3	37	117	221	7.41	8.03	8.81	9.08
Kuopion Energia	Haapaniemi	Kuopio	16	153	555	1 013	7.41	8.05	8.85	9.09
Kuopion Energia	Haapaniemi	Kuopio	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Kuopio	Kuopio	13	141	538	983	7.45	8.08	8.68	9.11
Fortum Power and Heat Oy	Kuusamo	Kuusamo	na	1	17	33	na	8.06	8.81	9.24
Kymin Voima Oy (UPM-Kymmana Oyj)	Kuusankoski	Kuusankoski	16	154	473	807	7.34	8.02	8.59	9.03
UPM-Kymmene Oyj	Kuusankoski	Kuusankoski	++++	++++	++++	++++	++++	++++	++++	++++
Lahti Energia	Lahti	Lahti	17	191	564	927	7.31	8.00	8.59	8.99
Fortum Lämpö Oy (Valio Oy)	Lapinlahti	Lapinlahti	23	177	468	747	7.36	8.00	8.55	8.95
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	26	146	380	591	7.30	7.90	8.49	8.89
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	++++	++++	++++	++++	++++	++++	++++	++++
Vapo Oy	Lieksa	Lieksa	11	83	208	387	7.39	7.95	8.82	9.08
Fortum Power and Heat Oy	Lohja	Lohja	14	118	314	471	7.29	7.96	8.52	8.89
Etelä-Savon Energia Oy	Pursiala	Mikkeli	21	184	564	1 034	7.40	8.00	8.61	9.08
Mäntän Energia Oy (Metsä-Serla Oyj)	Mänttä	Mänttä	30	202	514	814	7.43	8.00	8.51	8.92
Fortum Power and Heat Oy	Naantali	Naantali	1	20	109	254	7.54	8.11	8.78	9.29
Fortum Power and Heat Oy	Naantali	Naantali	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Voima Oy (Stora Enso Oyj)	Nuottasaari	Oulu	2	15	88	117	7.49	7.96	8.68	9.09
Kemira Chemicals Oy	Oulu	Oulu	4	19	65	114	7.45	8.00	8.62	9.05
Kemira Chemicals Oy	Oulu	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Energia	Toppila	Oulu	3	18	63	112	7.45	7.96	8.65	9.07
Oulun Energia	Toppila	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Pieksämäen Energia Oy	Pieksämäki	Pieksamäki	43	251	762	1 203	7.31	7.94	8.57	8.98
Alholmens Kraft Oy Ab (UPM-Kymmene Oyj)	Pietarsaari	Pietarsaari	1	32	117	210	7.45	8.09	8.85	9.10
Porin Lämpövoima Oy	Aittaluoto	Pori	13	87	247	442	7.36	7.99	8.56	9.04
Porin Lämpövoima Oy	Aittaluoto	Pori	++++	++++	++++	++++	++++	++++	++++	++++
Porin Lämpövoima Oy	Pihlava	Pori	2	38	170	309	7.50	8.03	8.89	9.13
UPM-Kymmene Oyj	Rauma	Rauma	3	54	164	305	7.48	8.05	8.60	9.08
UPM-Kymmene Oyj	Rauma	Rauma	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Simpele	Rautjärvi	18	112	253	408	7.23	7.89	8.44	8.89
Fortum Power and Heat Oy	Riihimäki	Riihimäki	37	245	621	889	7.34	7.95	8.51	8.84
Fortum Power and Heat Oy	Riihimäki	Riihimäki	++++	++++	++++	++++	++++	++++	++++	++++
UPM-Kymmene Oyj	Ristiina	Ristiina	9	113	447	871	7.41	8.07	8.69	9.15
Rovaniemen Energia	Suosiola	Rovaniemi	na	7	31	66	na	8.17	8.70	9.21
Voimavasu Oy	Salo	Salo	8	91	291	486	7.44	8.02	8.60	9.02
Suur-Savon Sähkö Oy	Savonlinna	Savonlinna	8	113	424	781	7.30	8.08	8.87	9.11
Vaskiluodon Voima Oy	Seinäjoki	Seinäjoki	4	59	196	393	7.42	8.06	8.64	9.18
Lampö Oy Juurakkotuli	Sodankylä	Sodankylä	na	na	1	1	na	na	8.82	9.05
Tampereen sähkölaitos	Naistenlahti	Tampere	8	151	518	908	7.39	8.07	8.64	9.07
Turku Energia	Turku	Turku	2	37	166	379	7.51	8.12	8.73	9.24
UPM-Kymmene Oyj	Tervasaari	Valkeakoski	24	181	510	867	7.42	7.99	8.60	9.04
Fortum Power and Heat Oy (Säten Oy)	Valkeakoski	Valkeakoski	16	148	490	868	7.39	7.99	8.62	9.08
Stora Enso Oyj	Varkaus	Varkaus	35	251	717	1 170	7.38	7.98	8.56	8.98
Stora Enso Oyj	Summa	Vehkalahti	21	138	371	539	7.38	8.01	8.54	8.88
Vieska Energia Oy	Ylivieska	Ylivieska	11	64	181	258	7.24	7.97	8.49	8.92
Metsä-Serla Oyj	Äänekoski	Äänekoski	19	210	559	917	7.37	8.00	8.55	8.98

Logging residue potentials around the power plants, roadside chipping, brown supply policy, overlapping procurement areas

			Marginal cost classes, €/MWh				Marginal cost classes, €/MWh			
			Logging residue potential, GWh				Average cost, €/MWh			
		FIM/MWh	45	50	55	60	45	50	55	60
Owner	Location	Municipality	7.57	8.41	9.25	10.09	7.57	8.41	9.25	10.09
Vattenfall Oy (Myllykoski Paper Oy)	Anjalankoski	Anjalankoski	6	84	297	558	7.36	8.06	8.63	9.11
Stora Enso Oyj	Inkeroinen	Anjalankoski	8	86	289	515	7.43	8.09	8.64	9.08
Fortum Power and Heat Oy (Ahlström Kauttua Oy)	Kauttua	Eura	8	54	230	403	7.44	8.04	8.66	9.09
Vapo Oy	Forssa	Forssa	2	91	401	726	7.35	8.07	8.71	9.11
Stora Enso Oyj	Heinola	Heinola	5	52	275	623	7.28	8.02	8.78	9.27
Fortum Power and Heat Oy	Vanaja	Hämeenlinna	9	150	440	766	7.50	8.05	8.59	9.04
Savon Voima Oyj	Iisalmi	Iisalmi	5	105	341	582	7.46	8.07	8.63	9.04
Salmi Voima Oy	Parkatti	Iisalmi	++++	++++	++++	++++	++++	++++	++++	++++
Primalco Oy	Koskenkorva	Ilmajoki	1	29	132	284	7.50	8.14	8.72	9.23
Stora Enso Oyj	Kaukopää	Imatra	8	60	200	375	7.37	8.02	8.81	9.11
Fortum Power and Heat Oy	Joensuu	Joensuu	3	84	420	774	7.46	8.12	8.74	9.14
Jyväskylän Energiantuotanto Oy	Rauhalahti	Jyväskylä	3	139	529	932	7.48	8.10	8.67	9.09
Jyväskylän Energiantuotanto Oy	Savela	Jyväskylä	16	142	535	909	7.46	8.05	8.66	9.06
UPM-Kymmene Oyj	Kaipola	Jämsä	9	104	351	703	7.45	8.05	8.82	9.14
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	9	129	404	755	7.43	8.05	8.82	9.10
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Kainuun Voima Oy	Kajaani	Kajaani	10	124	298	445	7.38	8.04	8.52	8.89
UPM-Kymmene Oyj	Kajaani	Kajaani	11	125	291	438	7.39	8.03	8.50	8.88
Vatajakosken Sähkö Oy	Kankaanpää	Kankaanpää	0	29	163	382	7.30	8.13	8.76	9.29
Metsä-Botnia Oy	Kemi	Kemi	2	28	83	89	7.51	8.06	8.49	8.84
Veitsiluodon Voima Oy (Stora Enso Oyj)	Veitsiluoto	Kemi	1	25	65	90	7.31	8.07	8.54	8.84
Kemijärven Kaukolämpö Oy	Kemijärvi	Kemijärvi	na	1	6	8	na	8.22	8.92	9.13
Fortum Power and Heat Oy	Kokkola	Kokkola	1	20	81	174	7.45	8.10	8.70	9.21
Kokkolan Voima Oy	Kokkola	Kokkola	1	20	79	169	7.51	8.12	8.71	9.21
Kuopion Energia	Haapaniemi	Kuopio	5	82	392	850	7.53	8.10	8.73	9.23
Kuopion Energia	Haapaniemi	Kuopio	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Kuopio	Kuopio	2	70	372	823	7.55	8.12	8.75	9.25
Fortum Power and Heat Oy	Kuusamo	Kuusamo	na	0	7	21	na	8.25	8.94	9.40
Kymin Voima Oy (UPM-Kymmene Oyj)	Kuusankoski	Kuusankoski	5	82	336	857	7.41	8.08	8.89	9.17
UPM-Kymmene Oyj	Kuusankoski	Kuusankoski	++++	++++	++++	++++	++++	++++	++++	++++
Lahti Energia	Lahti	Lahti	5	107	407	773	7.31	8.09	8.68	9.13
Fortum Lämpö Oy (Valio Oy)	Lapinlahti	Lapinlahti	6	103	347	629	7.45	8.09	8.65	9.09
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	9	88	275	487	7.38	7.98	8.60	9.05
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	++++	++++	++++	++++	++++	++++	++++	++++
Vapo Oy	Lieksa	Lieksa	4	43	145	303	7.45	8.05	8.87	9.18
Fortum Power and Heat Oy	Lohja	Lohja	8	69	236	394	7.46	8.03	8.62	9.03
Etelä-Savon Energia Oy	Pursiala	Mikkeli	4	104	390	814	7.46	8.06	8.89	9.20
Mäntän Energia Oy (Metsä-Serla Oyj)	Mänttä	Mänttä	3	114	379	878	7.51	8.08	8.82	9.07
Fortum Power and Heat Oy	Naantali	Naantali	na	9	67	198	na	8.20	8.84	9.42
Fortum Power and Heat Oy	Naantali	Naantali	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Voima Oy (Stora Enso Oyj)	Nuottasaari	Oulu	na	10	45	87	na	8.14	8.74	9.18
Kemira Chemicals Oy	Oulu	Oulu	0	10	48	84	7.42	8.08	8.72	9.14
Kemira Chemicals Oy	Oulu	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Energia	Toppila	Oulu	0	10	45	83	7.50	8.13	8.75	9.18
Oulun Energia	Toppila	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Pieksämäen Energia Oy	Pieksämäki	Pieksamaki	17	151	550	1 017	7.42	8.02	8.66	9.11
Alholmens Kraft Oy Ab (UPM-Kymmene Oyj)	Pietarsaari	Pietarsaari	na	15	78	158	na	8.19	8.75	9.21
Porin Lämpövoima Oy	Aittaluoto	Pori	6	49	175	360	7.46	8.06	8.65	9.18
Porin Lämpövoima Oy	Aittaluoto	Pori	++++	++++	++++	++++	++++	++++	++++	++++
Porin Lämpövoima Oy	Pihlava	Pori	0	21	109	249	7.55	8.10	8.74	9.28
UPM-Kymmene Oyj	Rauma	Rauma	na	29	113	246	na	8.17	8.69	9.22
UPM-Kymmene Oyj	Rauma	Rauma	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Simpele	Rautjärvi	5	51	151	305	7.38	8.06	8.57	9.13
Fortum Power and Heat Oy	Riihimäki	Riihimäki	13	149	460	752	7.40	8.02	8.60	8.99
Fortum Power and Heat Oy	Riihimäki	Riihimäki	++++	++++	++++	++++	++++	++++	++++	++++
UPM-Kymmene Oyj	Ristiina	Ristiina	1	56	292	698	7.41	8.13	8.76	9.28
Rovaniemen Energia	Suosiola	Rovaniemi	na	4	25	50	na	8.10	8.75	9.23
Voimavasu Oy	Salo	Salo	1	52	204	400	7.45	8.10	8.69	9.16
Suur-Savon Sähkö Oy	Savonlinna	Savonlinna	3	52	300	643	7.34	8.10	8.77	9.25
Vaskiluodon Voima Oy	Seinajoki	Seinajoki	na	30	128	289	na	8.13	8.71	9.26
Lämpö Oy Juurakkotuli	Sodankylä	Sodankylä	na	na	1	1	na	na	8.95	9.23
Tampereen sähkölaitos	Naistenlahti	Tampere	1	78	364	745	7.28	8.15	8.73	9.20
Turku Energia	Turku	Turku	na	18	104	299	na	8.20	8.81	9.37
UPM-Kymmene Oyj	Tervasaari	Valkeakoski	5	85	364	733	7.40	8.02	8.69	9.18
Fortum Power and Heat Oy (Säteri Oy)	Valkeakoski	Valkeakoski	5	79	348	717	7.44	8.04	8.71	9.20
Stora Enso Oyj	Varkaus	Varkaus	9	142	525	979	7.41	8.04	8.85	9.12
Stora Enso Oyj	Summa	Vehkalahti	6	69	274	450	7.44	8.05	8.66	9.04
Vieska Energia Oy	Ylivieska	Ylivieska	7	41	124	208	7.39	8.03	8.58	9.02
Metsä-Serla Oyj	Äänekoski	Äänekoski	5	122	401	758	7.37	8.10	8.63	9.11

Logging residue potentials around the power plants, terrain chipping, green supply policy, overlapping procurement areas

			Marginal cost classes, €/MWh				Marginal cost classes, €/MWh			
			Logging residue potential, GWh				Average cost, €/MWh			
		FIM/MWh	45	50	55	60	45	50	55	60
Owner	Location	Municipality	7.57	8.41	9.25	10.09	7.57	8.41	9.25	10.09
Vattenfall Oy (Myllykoski Paper Oy)	Anjalankoski	Anjalankoski	33	149	385	823	7.27	7.89	8.48	8.93
Stora Enso Oyj	Inkeroinen	Anjalankoski	36	182	389	588	7.27	7.91	8.46	8.86
Fortum Power and Heat Oy (Ahlström Kauttua Oy)	Kauttua	Eura	23	140	334	473	7.24	7.90	8.44	8.80
Vapo Oy	Forssa	Forssa	27	157	464	764	7.32	7.95	8.56	9.00
Stora Enso Oyj	Heinola	Heinola	17	100	383	883	7.24	7.95	8.64	9.12
Fortum Power and Heat Oy	Vanaja	Hämeenlinna	52	230	546	850	7.29	7.87	8.44	8.89
Savon Voima Oyj	Iisalmi	Iisalmi	28	150	389	819	7.31	7.92	8.50	8.93
Salmi Voima Oy	Parkatti	Iisalmi	++++	++++	++++	++++	++++	++++	++++	++++
Primalco Oy	Koskenkorva	Ilmajoki	7	45	155	303	7.45	8.01	8.62	9.14
Stora Enso Oyj	Kaukopää	Imatra	21	102	282	429	7.21	7.89	8.49	8.95
Fortum Power and Heat Oy	Joensuu	Joensuu	15	150	485	845	7.33	8.03	8.82	9.08
Jyväskylän Energiantuotanto Oy	Rauhalahti	Jyväskylä	37	227	630	1 017	7.34	7.97	8.55	8.96
Jyväskylän Energiantuotanto Oy	Savela	Jyväskylä	42	234	830	996	7.26	7.94	8.52	8.94
UPM-Kymmene Oyj	Kaipola	Jämsä	28	186	433	770	7.30	7.96	8.51	9.01
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	38	197	488	821	7.31	7.93	8.50	8.97
Jämsänkoskan Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Jämsänkoskan Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Kainuun Voima Oy	Kajaani	Kajaani	30	168	377	525	7.38	7.93	8.44	8.78
UPM-Kymmene Oyj	Kajaani	Kajaani	28	148	328	473	7.28	7.92	8.43	8.80
Vatajankosken Sähkö Oy	Kankaanpää	Kankaanpää	5	58	203	395	7.32	8.02	8.64	9.14
Metsä-Botnia Oy	Kemi	Kemi	8	32	70	101	7.28	7.90	8.39	8.78
Veitsiluodon Voima Oy (Stora Enso Oyj)	Veitsiluoto	Kemi	3	24	63	97	7.31	7.97	8.52	8.92
Kemijärven Kaukolämpö Oy	Kemijärvi	Kemijärvi	na	2	6	9	na	8.28	8.83	9.05
Fortum Power and Heat Oy	Kokkola	Kokkola	6	41	120	208	7.35	7.97	8.58	9.04
Kokkolan Voima Oy	Kokkola	Kokkola	3	34	96	188	7.41	8.06	8.81	9.12
Kuopion Energia	Haapaniemi	Kuopio	23	146	491	911	7.29	7.98	8.81	9.09
Kuopion Energia	Haapaniemi	Kuopio	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Kuopio	Kuopio	18	134	464	880	7.31	8.01	8.63	9.11
Fortum Power and Heat Oy	Kuusamo	Kuusamo	na	1	9	27	na	8.10	8.94	9.48
Kymin Voima Oy (UPM-Kymmene Oyj)	Kuusankoski	Kuusankoski	30	153	439	724	7.30	7.93	8.54	8.98
UPM-Kymmene Oyj	Kuusankoski	Kuusankoski	++++	++++	++++	++++	++++	++++	++++	++++
Lahti Energia	Lahti	Lahti	28	179	508	857	7.31	7.94	8.54	8.99
Fortum Lämpö Oy (Valio Oy)	Lapinlahti	Lapinlahti	28	160	399	872	7.28	7.96	8.51	8.97
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	39	151	360	549	7.24	7.84	8.44	8.86
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	++++	++++	++++	++++	++++	++++	++++	++++
Vapo Oy	Lieksa	Lieksa	11	50	155	322	7.36	7.95	8.58	9.13
Fortum Power and Heat Oy	Lohja	Lohja	20	112	289	441	7.26	7.89	8.48	8.88
Etelä-Savon Energia Oy	Pursiala	Mikkeli	29	171	502	910	7.29	7.93	8.56	9.05
Mäntän Energia Oy (Metsä-Serla Oyj)	Mänttä	Mänttä	29	182	482	731	7.34	7.96	8.50	8.92
Fortum Power and Heat Oy	Naantali	Naantali	na	17	90	203	na	8.08	8.75	9.28
Fortum Power and Heat Oy	Naantali	Naantali	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Voima Oy (Stora Enso Oyj)	Nuottasaari	Oulu	1	12	47	91	7.23	8.01	8.70	9.17
Kemira Chemicals Oy	Oulu	Oulu	1	14	49	89	7.00	8.01	8.68	9.13
Kemira Chemicals Oy	Oulu	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Energia	Toppila	Oulu	1	12	45	85	7.03	7.97	8.87	9.13
Oulun Energia	Toppila	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Pieksämäen Energia Oy	Pieksämäki	Pieksamäki	51	249	685	1 105	7.25	7.90	8.52	8.95
Alholmens Kraft Oy Ab (UPM-Kymmene Oyj)	Pietarsaari	Pietarsaari	2	27	94	177	7.49	8.06	8.84	9.13
Porin Lämpövoima Oy	Aittaluoto	Pori	15	80	211	364	7.36	7.97	8.52	9.03
Porin Lämpövoima Oy	Aittaluoto	Pori	++++	++++	++++	++++	++++	++++	++++	++++
Porin Lämpövoima Oy	Pihlava	Pori	2	37	145	287	7.42	8.03	8.87	9.13
UPM-Kymmene Oyj	Rauma	Rauma	3	44	143	267	7.45	8.06	8.81	9.10
UPM-Kymmene Oyj	Rauma	Rauma	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Simpele	Rautjärvi	15	80	200	349	7.24	7.89	8.46	8.98
Fortum Power and Heat Oy	Riihimäki	Riihimäki	53	237	554	833	7.26	7.86	8.44	8.64
Fortum Power and Heat Oy	Riihimäki	Riihimäki	++++	++++	++++	++++	++++	++++	++++	++++
UPM-Kymmene Oyj	Ristiina	Ristiina	14	109	412	791	7.31	8.01	8.68	9.13
Rovaniemen Energia	Suosiola	Rovaniemi	na	3	24	49	na	8.17	8.78	9.25
Voimavasu Oy	Salo	Salo	13	86	265	441	7.36	7.96	8.58	9.00
Suur-Savon Sähkö Oy	Savonlinna	Savonlinna	11	111	385	703	7.19	8.00	8.63	9.09
Vaskiluodon Voima Oy	Seinäjoki	Seinäjoki	10	87	177	348	7.38	8.01	8.55	9.10
Lämpö Oy Juurakkotuli	Sodankylä	Sodankylä	na	0	1	1	na	8.38	8.59	9.08
Tampereen sähkölaitos	Naistenlahti	Tampere	14	143	459	813	7.33	8.01	8.80	9.08
Turku Energia	Turku	Turku	3	32	152	331	7.45	8.10	8.73	9.28
UPM-Kymmene Oyj	Tervasaari	Valkeakoski	28	165	480	801	7.31	7.95	8.54	9.02
Fortum Power and Heat Oy (Säteri Oy)	Valkeakoski	Valkeakoski	24	151	447	780	7.33	7.96	8.57	9.04
Stora Enso Oyj	Varkaus	Varkaus	47	252	829	1 073	7.29	7.93	8.48	8.97
Stora Enso Oyj	Summa	Vehkalahti	28	138	349	513	7.25	7.92	8.50	8.88
Vieska Energia Oy	Ylivieska	Ylivieska	12	53	133	220	7.14	7.87	8.47	8.95
Metsä-Serla Oyj	Äänekoski	Äänekoski	23	185	488	829	7.30	7.97	8.52	8.99

Logging residue potentials around the power plants, terrain chipping, brown supply policy, overlapping procurement areas

			Marginal cost classes, €/MWh				Marginal cost classes, €/MWh			
			Logging residue potential, GWh				Avarage cost, €/MWh			
		FiM/MWh	45	50	55	60	45	50	55	60
Owner	Location	Municipality	7.57	8.41	9.25	10.09	7.57	8.41	9.25	10.09
Vattenfall Oy (Myllykoski Paper Oy)	Anjalankoski	Anjalankoski	19	110	320	527	7.30	7.93	8.56	9.00
Stora Enso Oyj	Inkeroinen	Anjalankoski	15	104	303	489	7.26	7.94	8.54	8.97
Fortum Power and Heat Oy (Ahlström Kauttua Oy)	Kauttua	Eura	9	85	223	378	7.33	8.00	8.81	9.04
Vapo Oy	Forssa	Forssa	17	125	407	694	7.41	8.00	8.81	9.04
Stora Enso Oyj	Heinola	Heinola	12	65	279	574	7.30	7.94	8.68	9.18
Fortum Power and Heat Oy	Vanaja	Hämeenlinna	29	179	449	730	7.34	7.93	8.51	8.96
Savon Voima Oyj	Iisalmi	Iisalmi	14	111	327	533	7.33	7.97	8.58	9.00
Salmi Voima Oy	Parkatti	Iisalmi	++++	++++	++++	++++	++++	++++	++++	++++
Primalco Oy	Koskenkorva	Ilmajoki	2	27	114	237	7.50	8.04	8.68	9.21
Stora Enso Oyj	Kaukopää	Imatra	14	71	206	360	7.30	7.92	8.53	9.02
Fortum Power and Heat Oy	Joensuu	Joensuu	8	101	386	720	7.39	8.07	8.87	9.12
Jyväskylän Energiantuotanto Oy	Rauhalahti	Jyväskylä	19	154	511	877	7.36	8.01	8.61	9.04
Jyväskylän Energiantuotanto Oy	Savela	Jyväskylä	25	182	516	858	7.30	7.98	8.60	9.02
UPM-Kymmene Oyj	Kaipola	Jämsä	17	117	351	655	7.34	8.00	8.57	9.08
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	22	142	395	699	7.35	7.98	8.56	9.04
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Jämsänkoskan Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Kainuun Voima Oy	Kajaani	Kajaani	15	119	288	418	7.22	7.95	8.48	8.84
UPM-Kymmene Oyj	Kajaani	Kajaani	15	119	278	412	7.22	7.94	8.45	8.83
Vatajakosken Sähkö Oy	Kankaanpää	Kankaanpää	3	40	159	330	7.29	8.06	8.69	9.21
Metsä-Botnia Oy	Kemi	Kemi	3	18	51	79	7.44	7.96	8.55	8.94
Veitsiluodon Voima Oy (Stora Enso Oyj)	Veitsiluoto	Kemi	3	17	51	82	7.38	8.00	8.58	8.98
Kemijärven Kaukolämpö Oy	Kemijärvi	Kemijärvi	na	1	5	6	na	8.32	8.92	8.96
Fortum Power and Heat Oy	Kokkola	Kokkola	1	24	78	152	7.38	8.10	8.66	9.18
Kokkolan Voima Oy	Kokkola	Kokkola	1	22	71	150	7.34	8.10	8.64	9.17
Kuopion Energia	Haapaniemi	Kuopio	15	110	395	779	7.33	8.03	8.66	9.15
Kuopion Energia	Haapaniemi	Kuopio	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Kuopio	Kuopio	12	95	373	758	7.35	8.04	8.87	9.18
Fortum Power and Heat Oy	Kuusamo	Kuusamo	na	1	2	18	na	8.10	8.71	9.61
Kymin Voima Oy (UPM-Kymmene Oyj)	Kuusankoski	Kuusankoski	17	111	348	611	7.33	7.97	8.58	9.05
UPM-Kymmene Oyj	Kuusankoski	Kuusankoski	++++	++++	++++	++++	++++	++++	++++	++++
Lahti Energia	Lahti	Lahti	13	129	414	734	7.31	8.00	8.59	9.06
Fortum Lämpö Oy (Valio Oy)	Lapinlahti	Lapinlahti	15	110	327	581	7.33	8.00	8.57	9.04
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	23	110	292	466	7.28	7.90	8.52	8.94
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	++++	++++	++++	++++	++++	++++	++++	++++
Vapo Oy	Lieksa	Lieksa	5	38	124	274	7.21	7.99	8.62	9.19
Fortum Power and Heat Oy	Lohja	Lohja	11	85	238	377	7.29	7.94	8.53	8.94
Etelä-Savon Energia Oy	Pursiala	Mikkeli	18	122	408	761	7.34	7.98	8.63	9.11
Mäntän Energia Oy (Metsä-Serla Oyj)	Mänttä	Mänttä	18	128	375	622	7.45	8.01	8.56	9.00
Fortum Power and Heat Oy	Naantali	Naantali	na	12	86	167	na	8.19	8.78	9.33
Fortum Power and Heat Oy	Naantali	Naantali	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Voima Oy (Stora Enso Oyj)	Nuottasaari	Oulu	1	9	35	72	7.33	8.05	8.69	9.20
Kemira Chemicals Oy	Oulu	Oulu	1	9	38	71	7.19	8.00	8.70	9.16
Kemira Chemicals Oy	Oulu	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Energia	Toppila	Oulu	1	9	33	69	7.24	8.04	8.89	9.18
Oulun Energia	Toppila	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Pieksämäen Energia Oy	Pieksämäki	Pieksamäki	30	177	557	962	7.27	7.94	8.57	9.03
Alholmens Kraft Oy Ab (UPM-Kymmene Oyj)	Pietarsaari	Pietarsaari	0	18	72	138	7.42	8.10	8.71	9.18
Porin Lämpövoima Oy	Aittaluoto	Pori	8	56	166	324	7.36	8.00	8.58	9.11
Porin Lämpövoima Oy	Aittaluoto	Pori	++++	++++	++++	++++	++++	++++	++++	++++
Porin Lämpövoima Oy	Pihlava	Pori	3	26	112	227	7.45	8.05	8.70	9.21
UPM-Kymmene Oyj	Rauma	Rauma	2	27	110	224	7.52	8.09	8.66	9.18
UPM-Kymmene Oyj	Rauma	Rauma	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Simpele	Rautjärvi	9	57	163	294	7.30	7.94	8.55	9.05
Fortum Power and Heat Oy	Riihimäki	Riihimäki	32	182	455	713	7.31	7.92	8.49	8.91
Fortum Power and Heat Oy	Riihimäki	Riihimäki	++++	++++	++++	++++	++++	++++	++++	++++
UPM-Kymmene Oyj	Ristiina	Ristiina	32	182	455	713	7.31	7.92	8.49	8.91
Rovaniemen Energia	Suosiola	Rovaniemi	na	2	21	43	na	8.03	8.77	9.25
Voimavasu Oy	Salo	Salo	8	63	209	374	7.41	8.00	8.82	9.07
Suur-Savon Sähkö Oy	Savonlinna	Savonlinna	8	81	304	600	7.24	8.05	8.67	9.15
Vaskiluodon Voima Oy	Seinäjoki	Seinäjoki	2	29	108	242	7.49	8.08	8.66	9.23
Lämpö Oy Juurakkotuli	Sodankylä	Sodankylä	na	na	1	1	na	na	8.82	9.00
Tampereen sähkölaitos	Naistenlahti	Tampere	8	98	383	690	7.31	8.06	8.66	9.13
Turku Energia	Turku	Turku	0	18	115	274	7.51	8.10	8.79	9.32
UPM-Kymmene Oyj	Tervasaari	Valkeakoski	15	114	380	682	7.33	7.99	8.82	9.08
Fortum Power and Heat Oy (Säteri Oy)	Valkeakoski	Valkeakoski	13	106	362	660	7.34	8.01	8.63	9.10
Stora Enso Oyj	Varkaus	Varkaus	25	182	513	921	7.30	7.96	8.54	9.03
Stora Enso Oyj	Summa	Vehkalahti	17	97	278	434	7.31	7.95	8.54	8.94
Vieska Energia Oy	Ylivieska	Ylivieska	9	43	110	184	7.21	7.93	8.51	8.99
Metsä-Serla Oyj	Äänekoski	Äänekoski	12	129	392	707	7.33	8.02	8.59	9.08

Logging residue potentials around the power plants, loose residues, green supply policy, overlapping procurement areas

			Marginal cost classes, €/MWh				Marginal cost classes, €/MWh			
			Logging residue potential, GWh				Average cost, €/MWh			
		FIM/MWh	45	50	55	60	45	50	55	60
Owner	Location	Municipality	7.57	8.41	9.25	10.09	7.57	8.41	9.25	10.09
Vattenfall Oy (Myllykoski Paper Oy)	Anjalankoski	Anjalankoski	9	55	168	313	7.25	7.94	8.58	9.08
Stora Enso Oyj	Inkeroinen	Anjalankoski	9	81	188	351	7.35	7.99	8.60	9.09
Fortum Power and Heat Oy (Ahlström Kauttua Oy)	Kauttua	Eura	7	41	143	294	7.34	7.93	8.63	9.17
Vapo Oy	Forssa	Forssa	4	49	183	373	7.31	8.03	8.64	9.25
Stora Enso Oyj	Heinola	Heinola	5	30	105	269	7.12	7.87	8.60	9.30
Fortum Power and Heat Oy	Vanaja	Hämeenlinna	6	99	275	499	7.38	8.00	8.54	9.06
Savon Voima Oyj	Iisalmi	Iisalmi	8	81	220	394	7.40	8.02	8.54	9.06
Salmi Voima Oy	Parkatti	Iisalmi	++++	++++	++++	++++	++++	++++	++++	++++
Primalco Oy	Koskenkorva	Ilmajoki	5	24	94	197	7.45	8.02	8.65	9.21
Stora Enso Oyj	Kaukopää	Imatra	9	54	139	253	7.31	7.94	8.52	9.05
Fortum Power and Heat Oy	Joensuu	Joensuu	5	47	200	505	7.42	8.07	8.89	9.31
Jyväskylän Energiantuotanto Oy	Rauhalahti	Jyväskylä	8	92	306	633	7.42	8.03	8.82	9.17
Jyväskylän Energiantuotanto Oy	Savela	Jyväskylä	20	100	312	838	7.38	7.93	8.57	9.15
UPM-Kymmene Oyj	Kaipola	Jämsä	12	85	214	412	7.39	8.00	8.53	9.09
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	15	93	251	472	7.36	7.98	8.51	9.08
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Kainuun Voima Oy	Kajaani	Kajaani	12	75	188	318	7.38	8.00	8.50	8.98
UPM-Kymmene Oyj	Kajaani	Kajaani	11	78	188	312	7.37	8.01	8.49	8.96
Vatajakosken Sähkö Oy	Kankaanpää	Kankaanpää	4	17	84	204	7.47	8.00	8.78	9.33
Metsä-Botnia Oy	Kemi	Kemi	1	18	48	75	7.28	8.07	8.53	8.93
Veitsiluodon Voima Oy (Stora Enso Oyj)	Veitsiluoto	Kemi	2	16	45	75	7.35	8.04	8.53	8.97
Kemijärven Kaukolämpö Oy	Kemijärvi	Kemijärvi	na	1	1	5	na	8.06	8.24	9.31
Fortum Power and Heat Oy	Kokkola	Kokkola	2	20	55	119	7.42	8.02	8.55	9.15
Kokkolan Voima Oy	Kokkola	Kokkola	2	20	56	114	7.48	8.05	8.58	9.15
Kuopion Energia	Haapaniemi	Kuopio	3	48	180	459	7.48	8.04	8.68	9.30
Kuopion Energia	Haapaniemi	Kuopio	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Kuopio	Kuopio	1	38	161	438	7.48	8.09	8.72	9.34
Fortum Power and Heat Oy	Kuusamo	Kuusamo	na	1	4	14	na	8.07	8.82	9.38
Kymin Voima Oy (UPM-Kymmene Oyj)	Kuusankoski	Kuusankoski	9	59	187	408	7.35	7.98	8.60	9.19
UPM-Kymmene Oyj	Kuusankoski	Kuusankoski	++++	++++	++++	++++	++++	++++	++++	++++
Lahti Energia	Lahti	Lahti	7	88	227	459	7.19	8.00	8.83	9.18
Fortum Lämpö Oy (Valio Oy)	Lapinlahti	Lapinlahti	14	68	213	405	7.38	7.94	8.57	9.10
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	17	94	193	348	7.31	7.92	8.41	8.98
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	++++	++++	++++	++++	++++	++++	++++	++++
Vapo Oy	Lieksa	Lieksa	4	29	81	164	7.50	7.95	8.52	9.14
Fortum Power and Heat Oy	Lohja	Lohja	8	49	143	271	7.36	7.95	8.58	9.09
Etelä-Savon Energia Oy	Pursiala	Mikkeli	11	64	232	472	7.40	7.97	8.55	9.15
Mäntän Energia Oy (Metsä-Serla Oyj)	Mänttä	Mänttä	4	82	209	405	7.42	8.01	8.81	9.12
Fortum Power and Heat Oy	Naantali	Naantali	na	3	32	90	na	7.97	8.80	9.38
Fortum Power and Heat Oy	Naantali	Naantali	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Voima Oy (Stora Enso Oyj)	Nuottasaari	Oulu	0	8	19	57	7.35	8.06	8.50	9.28
Kemira Chemicals Oy	Oulu	Oulu	2	9	20	57	7.44	7.97	8.47	9.23
Kemira Chemicals Oy	Oulu	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Energia	Toppila	Oulu	0	8	19	56	7.17	7.95	8.50	9.28
Oulun Energia	Toppila	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Pieksämäen Energia Oy	Pieksämäki	Pieksamäki	28	110	307	643	7.38	7.90	8.51	9.14
Alholmens Kraft Oy Ab (UPM-Kymmene Oyj)	Pietarsaari	Pietarsaari	1	12	56	118	7.49	8.11	8.73	9.24
Porin Lämpövoima Oy	Aittaluoto	Pori	5	41	104	218	7.45	7.99	8.55	9.14
Porin Lämpövoima Oy	Aittaluoto	Pori	++++	++++	++++	++++	++++	++++	++++	++++
Porin Lämpövoima Oy	Pihlava	Pori	0	14	51	132	7.51	8.15	8.69	9.32
UPM-Kymmene Oyj	Rauma	Rauma	0	25	89	141	7.32	8.15	8.63	9.18
UPM-Kymmene Oyj	Rauma	Rauma	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Simpele	Rautjärvi	8	43	116	184	7.25	7.92	8.48	8.93
Fortum Power and Heat Oy	Riihimäki	Riihimäki	18	108	291	525	7.31	7.98	8.55	9.07
Fortum Power and Heat Oy	Riihimäki	Riihimäki	++++	++++	++++	++++	++++	++++	++++	++++
UPM-Kymmene Oyj	Ristiina	Ristiina	4	40	152	359	7.37	8.04	8.68	9.28
Rovaniemen Energia	Suosiola	Rovaniemi	na	2	8	23	na	8.34	8.86	9.41
Voimavasu Oy	Salo	Salo	2	40	119	241	7.41	8.08	8.82	9.17
Suur-Savon Sähkö Oy	Savonlinna	Savonlinna	5	36	146	348	7.30	8.01	8.88	9.28
Vaskiluodon Voima Oy	Seinäjoki	Seinäjoki	3	24	88	184	7.49	8.05	8.68	9.22
Lämpö Oy Juurakkotuli	Sodankylä	Sodankylä	na	na	0	0	na	na	9.19	9.22
Tampereen sähkölaitos	Naistenlahti	Tampere	2	37	157	394	7.33	8.08	8.72	9.31
Turku Energia	Turku	Turku	na	11	54	136	na	8.05	8.73	9.35
UPM-Kymmene Oyj	Tervasaari	Valkeakoski	8	67	180	397	7.32	7.98	8.54	9.18
Fortum Power and Heat Oy (Säteri Oy)	Valkeakoski	Valkeakoski	4	84	169	380	7.33	8.02	8.57	9.21
Stora Enso Oyj	Varkaus	Varkaus	18	100	302	813	7.34	7.98	8.59	9.15
Stora Enso Oyj	Summa	Vehkalahti	5	48	155	289	7.34	7.94	8.60	9.10
Vieska Energia Oy	Ylivieska	Ylivieska	9	28	83	153	7.26	7.78	8.55	9.07
Metsä-Serla Oyj	Äänekoski	Äänekoski	8	84	282	474	7.33	8.03	6.60	9.08

Logging residue potentials around the power plants, loose residues, brown supply policy, overlapping procurement areas

			Marginal cost classes, €/MWh				Marginal cost classes, €/MWh			
			Logging residue potential, GWh				Average cost, €/MWh			
		FIM/MWh	45	50	55	60	45	50	55	60
Owner	Location	Municipality	7.57	8.41	9.25	10.09	7.57	8.41	9.25	10.09
Vattenfall Oy (Myllykoski Paper Oy)	Anjalankoski	Anjalankoski	11	64	195	357	7.25	7.93	8.56	9.07
Stora Enso Oyj	Inkeroinen	Anjalankoski	9	64	191	344	7.32	7.97	8.57	9.06
Fortum Power and Heat Oy (Ahlström Kauttua Oy)	Kauttua	Eura	9	43	150	278	7.34	7.92	8.83	9.10
Vapo Oy	Forssa	Forssa	6	61	208	471	7.36	8.00	8.82	9.23
Stora Enso Oyj	Heinola	Heinola	8	40	124	321	7.15	7.93	8.57	9.27
Fortum Power and Heat Oy	Vanaja	Hämeenlinna	11	118	274	507	7.42	8.00	8.49	9.06
Savon Voima Oyj	Iisalmi	Iisalmi	10	90	217	391	7.37	8.00	8.49	9.03
Salmi Voima Oy	Parkatti	Iisalmi	++++	++++	++++	++++	++++	++++	++++	++++
Primalco Oy	Koskenkorva	Ilmajoki	3	23	90	178	7.43	8.01	8.65	9.18
Stora Enso Oyj	Kaukopää	Imatra	10	55	137	240	7.31	7.93	8.49	9.01
Fortum Power and Heat Oy	Joensuu	Joensuu	8	56	230	522	7.42	8.06	8.71	9.27
Jyväskylän Energiantuotanto Oy	Rauhalahti	Jyväskylä	9	98	319	831	7.42	8.01	8.81	9.14
Jyväskylän Energiantuotanto Oy	Savela	Jyväskylä	22	109	321	642	7.35	7.94	8.56	9.13
UPM-Kymmene Oyj	Kaipola	Jämsä	14	85	213	409	7.39	7.95	8.50	9.08
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	14	102	241	472	7.34	7.95	8.48	9.07
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Kainuun Voima Oy	Kajaani	Kajaani	13	91	191	327	7.33	7.99	8.43	8.96
UPM-Kymmene Oyj	Kajaani	Kajaani	16	94	188	317	7.38	7.98	8.41	8.93
Vatajakosken Sähkö Oy	Kankaanpää	Kankaanpää	4	18	86	205	7.46	8.01	8.72	9.29
Metsä-Botnia Oy	Kemi	Kemi	2	20	45	87	7.33	8.04	8.44	8.80
Veitsiluodon Voima Oy (Stora Enso Oyj)	Veitsiluoto	Kemi	3	18	46	68	7.28	8.01	8.50	8.86
Kemijärven Kaukolämpö Oy	Kemijärvi	Kemijärvi	na	na	1	8	na	na	7.99	9.56
Fortum Power and Heat Oy	Kokkola	Kokkola	2	21	54	109	7.46	8.02	8.55	9.12
Kokkolan Voima Oy	Kokkola	Kokkola	2	21	53	107	7.42	8.03	8.56	9.13
Kuopion Energia	Haapaniemi	Kuopio	4	52	194	478	7.48	8.00	8.66	9.27
Kuopion Energia	Haapaniemi	Kuopio	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Kuopio	Kuopio	2	43	179	457	7.42	8.05	8.70	9.30
Fortum Power and Heat Oy	Kuusamo	Kuusamo	na	0	4	11	na	7.91	9.02	9.50
Kymin Voima Oy (UPM-Kymmene Oyj)	Kuusankoski	Kuusankoski	9	61	199	394	7.32	7.96	8.60	9.14
UPM-Kymmene Oyj	Kuusankoski	Kuusankoski	++++	++++	++++	++++	++++	++++	++++	++++
Lahti Energia	Lahti	Lahti	7	75	233	471	7.23	8.00	8.60	9.16
Fortum Lämpö Oy (Valio Oy)	Lapinlahti	Lapinlahti	13	82	218	413	7.33	7.99	8.54	9.09
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	17	87	181	335	7.31	7.90	8.41	9.01
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	++++	++++	++++	++++	++++	++++	++++	++++
Vapo Oy	Lieksa	Lieksa	8	35	81	178	7.37	7.95	8.47	9.16
Fortum Power and Heat Oy	Lohja	Lohja	9	56	151	283	7.37	7.96	8.55	9.04
Etelä-Savon Energia Oy	Pursiala	Mikkeli	12	88	225	466	7.38	7.95	8.51	9.14
Mäntän Energia Oy (Metsä-Serla Oyj)	Mänttä	Mänttä	8	81	253	453	7.45	8.02	8.81	9.08
Fortum Power and Heat Oy	Naantali	Naantali	1	4	34	87	7.54	8.09	8.81	9.35
Fortum Power and Heat Oy	Naantali	Naantali	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Voima Oy (Stora Enso Oyj)	Nuottasaari	Oulu	0	8	24	52	7.35	8.09	8.89	9.22
Kemira Chemicals Oy	Oulu	Oulu	0	8	25	53	7.04	7.98	8.64	9.19
Kemira Chemicals Oy	Oulu	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Energia	Toppila	Oulu	0	8	21	50	7.17	8.02	8.61	9.21
Oulun Energia	Toppila	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Pieksämäen Energia Oy	Pieksämäki	Pieksämäki	27	123	315	657	7.34	7.92	8.50	9.12
Alholmens Kraft Oy Ab (UPM-Kymmene Oyj)	Pietarsaari	Pietarsaari	1	13	55	108	7.51	8.11	8.70	9.18
Porin Lämpövoima Oy	Aittaluoto	Pori	9	38	111	212	7.44	7.91	8.57	9.11
Porin Lämpövoima Oy	Aittaluoto	Pori	++++	++++	++++	++++	++++	++++	++++	++++
Porin Lämpövoima Oy	Pihlava	Pori	0	16	52	135	7.49	8.09	8.64	9.29
UPM-Kymmene Oyj	Rauma	Rauma	0	23	71	132	7.36	8.10	8.82	9.10
UPM-Kymmene Oyj	Rauma	Rauma	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Simpele	Rautjärvi	9	47	114	174	7.30	7.96	8.47	8.91
Fortum Power and Heat Oy	Riihimäki	Riihimäki	19	119	292	523	7.31	7.97	8.50	9.04
Fortum Power and Heat Oy	Riihimäki	Riihimäki	++++	++++	++++	++++	++++	++++	++++	++++
UPM-Kymmene Oyj	Ristiina	Ristiina	4	45	163	361	7.38	8.06	8.87	9.25
Rovaniemen Energia	Suosiola	Rovaniemi	na	3	12	25	na	8.21	8.81	9.29
Voimavasu Oy	Salo	Salo	3	42	117	237	7.38	8.04	8.57	9.14
Suur-Savon Sähkö Oy	Savonlinna	Savonlinna	4	39	153	382	7.23	7.99	8.65	9.27
Vaskiluodon Voima Oy	Seinäjoki	Seinäjoki	3	26	83	188	7.42	8.04	8.81	9.18
Lämpö Oy Juurakkotuli	Sodankylä	Sodankylä	na	na	0	1	na	na	8.98	9.86
Tampereen sähkölaitos	Naistenlahti	Tampere	2	44	190	442	7.25	8.05	8.72	9.28
Turku Energia	Turku	Turku	na	11	53	132	na	8.07	8.70	9.32
UPM-Kymmene Oyj	Tervasaari	Valkeakoski	9	67	184	414	7.37	7.93	8.53	9.19
Fortum Power and Heat Oy (Säteri Oy)	Valkeakoski	Valkeakoski	7	81	169	387	7.37	7.96	8.54	9.19
Stora Enso Oyj	Varkaus	Varkaus	17	103	310	621	7.31	7.92	8.57	9.13
Stora Enso Oyj	Summa	Vehkalahti	8	57	178	318	7.38	7.94	8.58	9.06
Vieska Energia Oy	Ylivieska	Ylivieska	10	30	84	144	7.26	7.82	8.49	8.97
Metsä-Serla Oyj	Äänekoski	Äänekoski	12	89	272	471	7.36	8.02	8.58	9.06

Logging residue potentials around the power plants, residue bundles, green supply policy, overlapping procurement areas

			Marginal cost classes, €/MWh				Marginal cost classes, €/MWh			
			Logging residue potential, GWh				Avarage cost, €/MWh			
		FIM/MWh	45	50	55	60	45	50	55	60
Owner	Location	Municipality	7.57	8.41	9.25	10.09	7.57	8.41	9.25	10.09
Vattenfall Oy (Myllykoski Paper Oy)	Anjalankoski	Anjalankoski	22	157	423	670	7.34	7.98	8.54	8.94
Stora Enso Oyj	Inkeroinen	Anjalankoski	19	159	404	815	7.37	8.01	8.53	8.90
Fortum Power and Heat Oy (Ahlström Kauttua Oy)	Kauttua	Eura	15	118	328	491	7.37	8.00	8.53	8.89
Vapo Oy	Forssa	Forssa	18	174	555	862	7.40	8.02	8.60	8.96
Stora Enso Oyj	Heinola	Heinola	17	108	425	758	7.32	7.99	8.65	9.08
Fortum Power and Heat Oy	Vanaja	Hämeenlinna	41	271	647	948	7.38	7.96	8.48	8.84
Savon Voima Oyj	Iisalmi	Iisalmi	32	210	480	684	7.41	7.96	8.46	8.80
Salmi Voima Oy	Parkatti	Iisalmi	++++	++++	++++	++++	++++	++++	++++	++++
Primalco Oy	Koskenkorva	Ilmajoki	8	72	221	378	7.32	8.04	8.61	9.05
Stora Enso Oyj	Kaukopää	Imatra	18	99	254	414	7.27	7.94	8.50	8.93
Fortum Power and Heat Oy	Joensuu	Joensuu	8	178	598	897	7.35	8.07	8.82	8.95
Jyväskylän Energiantuotanto Oy	Rauhalahti	Jyväskylä	38	273	745	1 101	7.39	7.98	8.53	8.88
Jyväskylän Energiantuotanto Oy	Savela	Jyväskylä	48	287	743	1 078	7.33	7.98	8.51	8.85
UPM-Kymmene Oyj	Kaipola	Jämsä	36	202	530	866	7.38	7.95	8.52	8.95
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	39	232	585	908	7.35	7.94	8.49	8.89
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Kainuun Voima Oy	Kajaani	Kajaani	30	174	372	511	7.36	7.92	8.42	8.75
UPM-Kymmene Oyj	Kajaani	Kajaani	30	178	365	501	7.37	7.92	8.40	8.73
Vatajankosken Sähkö Oy	Kankaanpää	Kankaanpää	4	73	282	483	7.34	8.10	8.88	9.12
Metsä-Botnia Oy	Kemi	Kemi	8	52	82	102	7.39	7.95	8.27	8.53
Veitsiluodon Voima Oy (Stora Enso Oyj)	Veitsiluoto	Kemi	7	50	83	111	7.38	7.97	8.31	8.66
Kemijärven Kaukolämpö Oy	Kemijärvi	Kemijärvi	na	na	1	5	na	na	8.79	9.42
Fortum Power and Heat Oy	Kokkola	Kokkola	3	35	110	209	7.29	8.04	8.82	9.11
Kokkolan Voima Oy	Kokkola	Kokkola	4	32	107	205	7.38	8.01	8.83	9.12
Kuopion Energia	Haapaniemi	Kuopio	19	181	622	1 017	7.40	8.03	8.62	9.00
Kuopion Energia	Haapaniemi	Kuopio	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Kuopio	Kuopio	15	189	600	994	7.44	8.08	8.84	9.03
Fortum Power and Heat Oy	Kuusamo	Kuusamo	na	1	12	25	na	8.08	8.92	9.35
Kymin Voima Oy (UPM-Kymmene Oyj)	Kuusankoski	Kuusankoski	17	158	480	788	7.35	8.01	8.59	8.99
UPM-Kymmene Oyj	Kuusankoski	Kuusankoski	++++	++++	++++	++++	++++	++++	++++	++++
Lahti Energia	Lahti	Lahti	27	223	603	914	7.35	7.98	8.55	8.91
Fortum Lämpö Oy (Valio Oy)	Lapinlahti	Lapinlahti	32	208	511	747	7.35	7.96	8.49	8.84
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	30	149	364	552	7.31	7.89	8.47	8.86
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	++++	++++	++++	++++	++++	++++	++++	++++
Vapo Oy	Lieksa	Lieksa	11	75	214	375	7.40	8.00	8.58	9.04
Fortum Power and Heat Oy	Lohja	Lohja	20	131	325	471	7.33	7.95	8.49	8.83
Etelä-Savon Energia Oy	Pursiala	Mikkeli	26	160	550	970	7.42	7.98	8.60	9.04
Mäntän Energia Oy (Metsä-Serla Oyj)	Mänttä	Mänttä	27	232	557	810	7.38	8.01	8.51	8.85
Fortum Power and Heat Oy	Naantali	Naantali	na	20	107	245	na	8.12	8.75	9.25
Fortum Power and Heat Oy	Naantali	Naantali	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Voima Oy (Stora Enso Oyj)	Nuottasaari	Oulu	3	13	51	93	7.40	7.94	8.62	9.08
Kemira Chemicals Oy	Oulu	Oulu	3	18	51	92	7.25	7.95	8.58	9.05
Kemira Chemicals Oy	Oulu	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Energia	Toppila	Oulu	4	12	51	91	7.36	7.85	8.62	9.08
Oulun Energia	Toppila	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Pieksämäen Energia Oy	Pieksämäki	Pieksämäki	49	275	805	1 183	7.33	7.95	8.56	8.90
Alholmens Kraft Oy Ab (UPM-Kymmene Oyj)	Pietarsaari	Pietarsaari	1	30	104	200	7.51	8.11	8.65	9.13
Porin Lämpövoima Oy	Aittaluoto	Pori	18	91	254	445	7.38	7.95	8.54	9.00
Porin Lämpövoima Oy	Aittaluoto	Pori	++++	++++	++++	++++	++++	++++	++++	++++
Porin Lämpövoima Oy	Pihlava	Pori	5	49	169	311	7.48	8.03	8.63	9.10
UPM-Kymmene Oyj	Rauma	Rauma	5	57	170	300	7.42	8.03	8.58	9.03
UPM-Kymmene Oyj	Rauma	Rauma	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Simpele	Rautjärvi	12	75	199	352	7.25	7.94	8.54	9.03
Fortum Power and Heat Oy	Riihimäki	Riihimäki	45	283	858	890	7.33	7.94	8.48	8.75
Fortum Power and Heat Oy	Riihimäki	Riihimäki	++++	++++	++++	++++	++++	++++	++++	++++
UPM-Kymmene Oyj	Ristiina	Ristiina	7	108	442	826	7.33	8.08	8.70	9.14
Rovaniemen Energia	Suosiola	Rovaniemi	na	2	35	60	na	7.98	8.90	9.21
Voimavasu Oy	Salo	Salo	8	98	303	488	7.42	8.02	8.81	8.98
Suur-Savon Sähkö Oy	Savonlinna	Savonlinna	10	107	420	722	7.38	8.05	8.87	9.07
Vaskiluodon Voima Oy	Seinäjoki	Seinäjoki	7	82	202	382	7.46	8.05	8.83	9.12
Lämpö Oy Juurakkotuli	Sodankylä	Sodankylä	na	na	na	na	na	na	na	na
Tampereen sähkölaitos	Naistenlahti	Tampere	18	179	564	918	7.44	8.05	8.81	8.99
Turku Energia	Turku	Turku	1	38	178	375	7.42	8.09	8.78	9.22
UPM-Kymmene Oyj	Tervasaari	Valkeakoski	30	184	562	912	7.37	7.97	8.58	8.98
Fortum Power and Heat Oy (Säteri Oy)	Valkeakoski	Valkeakoski	27	173	540	889	7.39	7.99	8.80	9.00
Stora Enso Oyj	Varkaus	Varkaus	43	279	730	1 153	7.38	7.98	8.52	8.93
Stora Enso Oyj	Summa	Vehkalahti	17	142	372	531	7.31	8.01	8.53	8.88
Vieska Energia Oy	Ylivieska	Ylivieska	10	81	147	232	7.28	7.98	8.49	8.91
Metsä-Serla Oyj	Äänekoski	Äänekoski	29	230	586	913	7.41	7.97	8.52	8.92

Logging residue potentials around the power plants, residue bundles, brown supply policy, overlapping procurement areas

			Marginal cost classes, €/MWh				Marginal cost classes, €/MWh			
			Logging residue potential, GWh				Average cost, €/MWh			
		FIM/MWh	45	50	55	60	45	50	55	60
Owner	Location	Municipality	7.57	8.41	9.25	10.09	7.57	8.41	9.25	10.09
Vattenfall Oy (Myllykoski Paper Oy)	Anjalankoski	Anjalankoski	3	88	255	535	7.40	8.09	8.67	9.20
Stora Enso Oyj	Inkeroinen	Anjalankoski	2	83	255	497	7.44	8.10	8.69	9.17
Fortum Power and Heat Oy (Ahlström Kauttua Oy)	Kauttua	Eura	3	51	212	404	7.44	8.13	8.72	9.18
Vapo Oy	Forssa	Forssa	1	70	327	696	7.37	8.11	8.75	9.23
Stora Enso Oyj	Heinola	Heinola	5	42	225	579	7.34	8.04	8.78	9.32
Fortum Power and Heat Oy	Vanaja	Hämeenlinna	2	132	414	774	7.46	8.11	8.63	9.10
Savon Voima Oyj	Iisalmi	Iisalmi	2	93	317	568	7.44	8.09	8.63	9.08
Salmi Voima Oy	Parkatti	Iisalmi	++++	++++	++++	++++	++++	++++	++++	++++
Primalco Oy	Koskenkorva	Ilmajoki	na	28	121	280	na	8.13	8.73	9.27
Stora Enso Oyj	Kaukopää	Imatra	5	43	181	324	7.36	8.02	8.65	9.18
Fortum Power and Heat Oy	Joensuu	Joensuu	2	62	355	737	7.50	8.18	8.79	9.24
Jyväskylän Energiantuotanto Oy	Rauhalahti	Jyväskylä	6	124	484	952	7.50	8.10	8.68	9.18
Jyväskylän Energiantuotanto Oy	Savela	Jyväskylä	10	127	482	888	7.44	8.06	8.68	9.14
UPM-Kymmene Oyj	Kaipola	Jämsä	6	90	332	685	7.48	8.05	8.66	9.19
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	8	114	369	738	7.40	8.08	8.64	9.18
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Jämsänkosken Voima Oy (UPM-Kymmena Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++
Kainuun Voima Oy	Kajaani	Kajaani	8	90	252	426	7.48	8.08	8.58	9.02
UPM-Kymmena Oyj	Kajaani	Kajaani	4	93	248	419	7.42	8.08	8.58	9.00
Vatajakosken Sähkö Oy	Kankaanpää	Kankaanpää	1	19	142	360	7.53	8.17	8.81	9.35
Metsä-Botnia Oy	Kemi	Kemi	na	27	66	88	na	8.12	8.54	8.82
Veitsiluodon Voima Oy (Stora Enso Oyj)	Veitsiluoto	Kemi	1	22	85	92	7.39	8.09	8.56	8.89
Kemijärven Kaukolämpö Oy	Kemijärvi	Kemijärvi	na	na	0	4	na	na	9.17	9.73
Fortum Power and Heat Oy	Kokkola	Kokkola	1	12	59	155	7.57	8.08	8.75	9.34
Kokkolan Voima Oy	Kokkola	Kokkola	1	10	56	150	7.50	8.07	8.74	9.35
Kuopion Energia	Haapaniemi	Kuopio	2	70	357	818	7.49	8.14	8.78	9.28
Kuopion Energia	Haapaniemi	Kuopio	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Kuopio	Kuopio	0	61	340	789	7.52	8.17	8.78	9.29
Fortum Power and Heat Oy	Kuusamo	Kuusamo	na	na	4	16	na	na	9.09	9.55
Kymin Voima Oy (UPM-Kymmena Oyj)	Kuusankoski	Kuusankoski	3	65	282	618	7.40	8.12	8.73	9.25
UPM-Kymmena Oyj	Kuusankoski	Kuusankoski	++++	++++	++++	++++	++++	++++	++++	++++
Lahti Energia	Lahti	Lahti	6	99	356	742	7.36	8.09	8.66	9.18
Fortum Lämpö Oy (Valio Oy)	Lapinlahti	Lapinlahti	4	91	329	822	7.37	8.09	8.65	9.13
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	8	75	235	450	7.38	8.02	8.62	9.13
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	++++	++++	++++	++++	++++	++++	++++	++++
Vapo Oy	Lieksa	Lieksa	0	30	123	285	7.56	8.10	8.70	9.27
Fortum Power and Heat Oy	Lohja	Lohja	5	58	212	395	7.47	8.04	8.85	9.12
Etelä-Savon Energia Oy	Pursiala	Mikkeli	1	81	305	744	7.49	8.11	8.89	9.29
Mäntän Energia Oy (Metsä-Serla Oyj)	Mänttä	Mänttä	2	93	348	670	7.46	8.12	8.85	9.13
Fortum Power and Heat Oy	Naantali	Naantali	na	5	49	168	na	8.28	8.86	9.47
Fortum Power and Heat Oy	Naantali	Naantali	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Voima Oy (Stora Enso Oyj)	Nuottasaari	Oulu	na	8	29	69	na	8.01	8.78	9.30
Kemira Chemicals Oy	Oulu	Oulu	1	7	29	66	7.58	7.97	8.89	9.23
Kemira Chemicals Oy	Oulu	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Energia	Toppila	Oulu	na	6	28	65	na	7.95	8.71	9.26
Oulun Energia	Toppila	Oulu	++++	++++	++++	++++	++++	++++	++++	++++
Pieksämäen Energia Oy	Pieksämäki	Pieksämäki	9	119	475	969	7.43	8.03	8.68	9.18
Alholmens Kraft Oy Ab (UPM-Kymmena Oyj)	Pietarsaari	Pietarsaari	na	8	55	145	na	8.17	8.78	9.35
Porin Lämpövoima Oy	Aittaluoto	Pori	4	41	154	351	7.53	8.04	8.86	9.25
Porin Lämpövoima Oy	Aittaluoto	Pori	++++	++++	++++	++++	++++	++++	++++	++++
Porin Lämpövoima Oy	Pihlava	Pori	na	18	95	224	na	8.12	8.78	9.29
UPM-Kymmene Oyj	Rauma	Rauma	na	23	103	233	na	8.18	8.74	9.28
UPM-Kymmene Oyj	Rauma	Rauma	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Simpele	Rautjärvi	3	33	113	264	7.31	8.05	8.83	9.24
Fortum Power and Heat Oy	Riihimäki	Riihimäki	9	132	431	772	7.35	8.06	8.62	9.07
Fortum Power and Heat Oy	Riihimäki	Riihimäki	++++	++++	++++	++++	++++	++++	++++	++++
UPM-Kymmena Oyj	Ristiina	Ristiina	1	32	215	614	7.43	8.13	8.79	9.37
Rovaniemen Energia	Suosiola	Rovaniemi	na	1	14	46	na	8.24	9.00	9.47
Voimavasu Oy	Salo	Salo	1	42	174	392	7.47	8.18	8.73	9.28
Suur-Savon Sähkö Oy	Savonlinna	Savonlinna	2	36	221	555	7.39	8.14	8.78	9.32
Vaskiluodon Voima Oy	Seinäjoki	Seinäjoki	na	20	111	270	na	8.10	8.78	9.31
Lämpö Oy Juurakkotuli	Sodankylä	Sodankylä	na	na	na	na	na	na	na	na
Tampereen sähkölaitos	Naistenlahti	Tampere	1	63	329	735	7.37	8.15	8.75	9.28
Turku Energia	Turku	Turku	na	9	81	270	na	8.20	8.83	9.45
UPM-Kymmene Oyj	Tervasaari	Valkeakoski	4	77	328	732	7.45	8.05	8.70	9.24
Fortum Power and Heat Oy (Säteri Oy)	Valkeakoski	Valkeakoski	4	70	311	713	7.48	8.05	8.72	9.26
Stora Enso Oyj	Varkaus	Varkaus	5	118	459	930	7.42	8.07	8.67	9.19
Stora Enso Oyj	Summa	Vehkalahti	2	54	236	433	7.43	8.09	8.70	9.13
Vieska Energia Oy	Ylivieska	Ylivieska	2	24	95	183	7.36	8.02	8.66	9.15
Metsä-Serla Oyj	Äänekoski	Äänekoski	2	101	368	725	7.48	8.12	8.66	9.17

Appendix 12 (1/2)

Logging residue potentials around the power plants, green supply policy
Allocating rule: Minimizing transport distance without demand constraints

				Green supply, gross reserve				Green supply, net reserve			
				Without km-limit		< 100 km		Without km-limit		< 100 km	
			Potential	Stand	Agg10km	Stand	Agg10km	Stand	Agg10km	Stand	Agg10km
Owner	Location	Municipality	GWh[1]	GWh[2]	GWh[3]	GWh[2]	GWh[3]	GWh[2]	GWh[3]	GWh[2]	GWh[3]
Vattenfall Oy (Myllykoski Paper Oy)	Anjalankoski	Anjalankoski	650	60	35	60	35	43	42	43	42
Stora Enso Oyj	Inkeroinen	Anjalankoski	200	86	101	86	101	57	39	57	39
Fortum Power and Heat Oy (Ahlström Kauttua Oy)	Kauttua	Eura	70	185	181	185	181	144	139	144	139
Vapo Oy	Forssa	Forssa	200	170	179	170	179	136	136	136	136
Stora Enso Oyj	Heinola	Heinola	350	198	212	198	212	130	133	130	133
Fortum Power and Heat Oy	Vanaja	Hämeenlinna	80	213	203	213	203	173	199	173	199
Savon Voima Oyj	Iisalmi	Iisalmi	200	353	367	350	360	255	277	255	278
Salmi Voima Oy	Parkatti	Iisalmi	70	++++	++++	++++	++++	++++	++++	++++	++++
Primalco Oy	Koskenkorva	Ilmajoki	100	434	442	434	433	254	249	254	243
Stora Enso Oyj	Kaukopää	Imatra	1400	108	104	108	104	73	89	73	88
Fortum Power and Heat Oy	Joensuu	Joensuu	900	867	879	863	875	647	642	644	642
Jyväskylän Energiantuotanto Oy	Rauhalahti	Jyväskylä	1100	208	191	208	191	155	157	155	157
Jyväskylän Energiantuotanto Oy	Savela	Jyväskylä	100	180	212	180	212	137	172	137	172
UPM-Kymmene Oyj	Kaipola	Jämsä	250	185	175	185	175	128	123	128	123
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	250	114	108	114	108	87	87	87	87
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	200	++++	++++	++++	++++	++++	++++	++++	++++
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	1000	++++	++++	++++	++++	++++	++++	++++	++++
Kainuun Voima Oy	Kajaani	Kajaani	500	450	424	347	319	355	343	227	264
UPM-Kymmene Oyj	Kajaani	Kajaani	50	164	184	159	175	132	142	129	140
Vatajakosken Sähkö Oy	Kankaanpää	Kankaanpää	80	190	191	190	181	133	143	133	143
Veitsiluodon Voima Oy (Stora Enso Oyj)	Veitsiluoto	Kemi	1000	44	22	44	22	21	20	21	18
Metsä-Botnia Oy	Kemi	Kemi	200	102	113	98	108	73	68	72	68
Kemijärven Kaukolämpö Oy	Kemijärvi	Kemijärvi	70	74	73	67	66	8	8	7	8
Fortum Power and Heat Oy	Kokkola	Kokkola	250	153	143	149	137	78	74	77	74
Kokkolan Voima Oy	Kokkola	Kokkola	350	20	28	20	28	14	9	14	9
Kuopion Energia	Haapaniemi	Kuopio	1100	248	258	248	258	189	202	189	202
Kuopion Energia	Haapaniemi	Kuopio	300	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Kuopio	Kuopio	350	256	273	256	273	191	198	191	198
Fortum Power and Heat Oy	Kuusamo	Kuusamo	100	190	197	102	113	79	78	35	32
Kymin Voima Oy (UPM-Kymmene Oyj)	Kuusankoski	Kuusankoski	1900	172	190	172	190	132	168	132	168
UPM-Kymmene Oyj	Kuusankoski	Kuusankoski	70	++++	++++	++++	++++	++++	++++	++++	++++
Lahti Energia	Lahti	Lahti	2000	216	224	216	221	168	132	168	132
Fortum Lämpö Oy (Valio Oy)	Lapinlahti	Lapinlahti	150	338	306	338	306	231	210	231	210
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	700	273	286	273	286	195	189	195	189
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	200	++++	++++	++++	++++	++++	++++	++++	++++
Vapo Oy	Lieksa	Lieksa	80	314	336	296	325	212	214	201	201
Fortum Power and Heat Oy	Lohja	Lohja	200	151	132	151	132	120	90	120	90
Etelä-Savon Energia Oy	Pursiala	Mikkeli	300	329	358	329	358	228	241	226	241
Mäntän Energia Oy (Metsä-Serla Oyj)	Mänttä	Mänttä	400	327	328	327	328	250	251	250	251
Fortum Power and Heat Oy	Naantali	Naantali	1500	81	101	81	101	43	38	43	38
Fortum Power and Heat Oy	Naantali	Naantali	1500	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Voima Oy (Stora Enso Oyj)	Nuottasaari	Oulu	600	118	120	118	120	44	47	44	47
Kemira Chemicals Oy	Oulu	Oulu	250	123	148	86	112	51	41	40	34
Kemira Chemicals Oy	Oulu	Oulu	100	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Energia	Toppila	Oulu	1600	12	0	12	0	4	18	4	18
Oulun Energia	Toppila	Oulu	800	++++	++++	++++	++++	++++	++++	++++	++++
Pieksämäen Energia Oy	Pieksämäki	Pieksamäki	150	429	404	429	404	327	311	327	311
Alholmens Kraft Oy Ab (UPM-Kymmene Oyj)	Pietarsaari	Pietarsaari	3000	156	136	156	136	87	108	87	108
Porin Lämpövoima Oy	Aittaluoto	Pori	300	118	135	116	135	88	95	68	95
Porin Lämpövoima Oy	Aittaluoto	Pori	250	++++	++++	++++	++++	++++	++++	++++	++++
Porin Lämpövoima Oy	Pihlava	Pori	40	18	1	18	1	13	12	13	12
UPM-Kymmene Oyj	Rauma	Rauma	150	58	50	58	50	37	41	37	41
UPM-Kymmene Oyj	Rauma	Rauma	80	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Simpele	Rautjärvi	350	177	186	175	186	111	99	110	99
Fortum Power and Heat Oy	Riihimäki	Riihimäki	100	255	263	255	263	209	228	209	228
Fortum Power and Heat Oy	Riihimäki	Riihimäki	80	++++	++++	++++	++++	++++	++++	++++	++++
UPM-Kymmene Oyj	Ristiina	Ristiina	500	172	145	172	145	100	88	100	88
Rovaniemen Energia	Suosiola	Rovaniemi	500	140	138	103	106	40	44	31	36
Voimavasu Oy	Salo	Salo	250	136	130	136	129	100	107	100	107
Suur-Savon Sähkö Oy	Savonlinna	Savonlinna	200	368	337	366	337	243	261	243	252
Vaskiluodon Voima Oy	Seinäjoki	Seinäjoki	1400	292	305	292	305	155	137	155	137
Lämpö Oy Juurakkotuli	Sodankylä	Sodankylä	60	79	78	36	35	3	4	0	2
Tampereen sähkölaitos	Naistenlahti	Tampere	900	234	247	234	247	172	179	172	179
Turku Energia	Turku	Turku	250	78	73	78	73	52	49	52	49
UPM-Kymmene Oyj	Tervasaari	Valkeakoski	300	189	157	169	157	122	115	122	115
Fortum Power and Heat Oy (Säteri Oy)	Valkeakoski	Valkeakoski	200	++++	++++	++++	++++	++++	++++	++++	++++
Stora Enso Oyj	Varkaus	Varkaus	50	377	378	377	376	274	225	274	225
Stora Enso Oyj	Summa	Vehkalahti	600	179	163	179	163	132	127	132	127
Vieska Energia Oy	Ylivieska	Ylivieska	80	368	359	354	353	213	203	204	196
Metsä-Serla Oyj	Äänekoski	Äänekoski	1000	522	524	502	498	385	388	375	363
		In total		12 027	12 027	11 636	11 624	8 229	8 229	7 997	8 020
		Share				97 %	97 %			97 %	97 %

[1] Wood fuel usage potential, based on peat usage and with some plants also wood by-products and wastes without technical limitations

[2] Stand level allocation

[3] Aggregated, 10 km, supply point allocation

Logging residue potentials around the power plants, brown supply policy
Allocating rule: Minimizing transport distance without demand constraints

				Brown supply, gross reserve				Brown supply, net reserve			
				Without km-limit		< 100 km		Without km-limit		< 100 km	
			Potential	Stand	Agg10km	Stand	Agg10km	Stand	Agg10km	Stand	Agg10km
Owner	Location	Municipality	GWh[1]	GWh[2]	GWh[3]	GWh[2]	GWh[3]	GWh[2]	GWh[3]	GWh[2]	GWh[3]
Vattenfall Oy (Myllykoski Paper Oy)	Anjalankoski	Anjalankoski	650	54	31	54	31	38	51	38	51
Stora Enso Oyj	Inkeroinen	Anjalankoski	200	77	91	77	91	48	45	48	45
Fortum Power and Heat Oy (Ahlström Kauttua Oy)	Kauttua	Eura	70	167	164	167	164	125	117	125	117
Vapo Oy	Forssa	Forssa	200	153	161	153	161	116	134	116	134
Stora Enso Oyj	Heinola	Heinola	350	182	195	182	195	108	120	108	120
Fortum Power and Heat Oy	Vanaja	Hameenlinna	80	192	182	192	182	151	143	151	143
Savon Voima Oyj	Iisalmi	Iisalmi	200	321	333	318	327	219	207	217	207
Salmi Voima Oy	Parkatti	Iisalmi	70	++++	++++	++++	++++	++++	++++	++++	++++
Primalco Oy	Koskenkorva	Ilmajoki	100	394	401	394	393	193	193	193	188
Stora Enso Oyj	Kaukopää	Imatra	1400	100	98	100	98	61	69	61	69
Fortum Power and Heat Oy	Joensuu	Joensuu	900	790	801	786	797	557	546	555	546
Jyväskylän Energiantuotanto Oy	Rauhalahti	Jyväskylä	1100	190	173	190	173	135	149	135	149
Jyväskylän Energiantuotanto Oy	Savela	Jyväskylä	100	162	191	162	191	121	151	121	151
UPM-Kymmene Oyj	Kaipola	Jämsä	250	166	157	166	157	112	109	112	109
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	250	102	97	102	97	77	64	77	64
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jamsänkoski	Jämsänkoski	200	++++	++++	++++	++++	++++	++++	++++	++++
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	1000	++++	++++	++++	++++	++++	++++	++++	++++
Kainuun Voima Oy	Kajaani	Kajaani	500	412	388	317	292	310	307	245	241
UPM-Kymmene Oyj	Kajaani	Kajaani	50	149	167	144	159	116	120	113	118
Vatajakosken Sähkö Oy	Kankaanpää	Kankaanpää	80	173	173	173	164	112	124	112	124
Veitsiluodon Voima Oy (Stora Enso Oyj)	Veitsiluoto	Kemi	1000	41	20	41	20	16	13	16	13
Metsä-Botnia Oy	Kemi	Kemi	200	94	105	90	100	59	59	59	59
Kemijärven Kaukolämpö Oy	Kemijärvi	Kemijärvi	70	70	69	64	63	5	5	5	5
Fortum Power and Heat Oy	Kokkola	Kokkola	250	140	131	136	126	60	61	59	60
Kokkolan Voima Oy	Kokkola	Kokkola	350	19	25	19	25	11	7	11	7
Kuopion Energia	Haapaniemi	Kuopio	1100	224	233	224	233	165	156	165	156
Kuopion Energia	Haapaniemi	Kuopio	300	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Kuopio	Kuopio	350	232	247	232	247	166	180	166	180
Fortum Power and Heat Oy	Kuusamo	Kuusamo	100	176	182	95	105	58	58	24	22
Kymin Voima Oy (UPM-Kymmene Oyj)	Kuusankoski	Kuusankoski	1900	155	172	155	172	115	97	115	97
UPM-Kymmene Oyj	Kuusankoski	Kuusankoski	70	++++	++++	++++	++++	++++	++++	++++	++++
Lahti Energia	Lahti	Lahti	2000	194	201	194	198	148	139	148	139
Fortum Lämpö Oy (Valio Oy)	Lapinlahti	Lapinlahti	150	304	276	304	276	202	201	202	201
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	700	247	259	247	259	167	172	167	172
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	200	++++	++++	++++	++++	++++	++++	++++	++++
Vapo Oy	Lieksa	Lieksa	80	287	307	270	297	179	185	170	175
Fortum Power and Heat Oy	Lohja	Lohja	200	136	119	136	116	104	85	104	85
Etelä-Savon Energia Oy	Pursiala	Mikkeli	300	301	327	301	327	193	203	193	203
Mäntän Energia Oy (Metsä-Serla Oyj)	Mänttä	Mänttä	400	295	296	295	296	214	216	214	216
Fortum Power and Heat Oy	Naantali	Naantali	1500	74	92	74	92	34	34	34	34
Fortum Power and Heat Oy	Naantali	Naantali	1500	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Voima Oy (Stora Enso Oyj)	Nuottasaari	Oulu	600	112	114	112	114	35	39	35	39
Kemira Chemicals Oy	Oulu	Oulu	250	114	138	80	104	36	38	26	29
Kemira Chemicals Oy	Oulu	Oulu	100	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Energia	Toppila	Oulu	1600	11	0	11	0	3	3	3	3
Oulun Energia	Toppila	Oulu	800	++++	++++	++++	++++	++++	++++	++++	++++
Pieksämäen Energia Oy	Pieksämäki	Pieksamäki	150	386	366	388	366	282	269	282	269
Alholmens Kraft Oy Ab (UPM-Kymmene Oyj)	Pietarsaari	Pietarsaari	3000	143	124	143	124	66	74	66	74
Porin Lämpövoima Oy	Aittaluoto	Pori	300	105	122	105	122	77	64	77	84
Porin Lämpövoima Oy	Aittaluoto	Pori	250	++++	++++	++++	++++	++++	++++	++++	++++
Porin Lämpövoima Oy	Pihlava	Pori	40	16	1	16	1	11	10	11	10
UPM-Kymmene Oyj	Rauma	Rauma	150	52	45	52	45	31	34	31	34
UPM-Kymmene Oyj	Rauma	Rauma	80	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Simpele	Rautjärvi	350	165	173	163	173	92	100	92	100
Fortum Power and Heat Oy	Riihimäki	Riihimäki	100	229	237	229	237	185	201	185	201
Fortum Power and Heat Oy	Riihimäki	Riihimäki	80	++++	++++	++++	++++	++++	++++	++++	++++
UPM-Kymmene Oyj	Ristiina	Ristiina	500	159	135	159	135	84	85	84	85
Rovaniemen Energia	Suosiola	Rovaniemi	500	132	130	97	100	30	29	25	26
Voimavasu Oy	Salo	Salo	250	123	116	123	117	84	86	84	88
Suur-Savon Sähkö Oy	Savonlinna	Savonlinna	200	338	309	336	309	210	202	210	202
Vaskiluodon Voima Oy	Seinäjoki	Seinäjoki	1400	267	279	267	279	122	111	122	111
Lämpö Oy Juurakkotuli	Sodankylä	Sodankylä	60	75	74	34	33	2	2	0	0
Tampereen sähkölaitos	Naistenlahti	Tampere	900	210	222	210	222	152	147	152	147
Turku Energia	Turku	Turku	250	71	66	71	66	41	31	41	31
UPM-Kymmene Oyj	Tervasaari	Valkeakoski	300	152	141	152	141	106	92	106	92
Fortum Power and Heat Oy (Sateri Oy)	Valkeakoski	Valkeakoski	200	++++	++++	++++	++++	++++	++++	++++	++++
Stora Enso Oyj	Varkaus	Varkaus	50	341	339	341	339	241	231	241	231
Stora Enso Oyj	Summa	Vehkalahti	600	161	147	161	147	112	112	112	112
Vieska Energia Oy	Ylivieska	Ylivieska	80	342	334	313	327	179	168	171	166
Metsä-Serla Oyj	Äänekoski	Äänekoski	1000	473	474	455	451	333	345	325	337
		In total		10 950	10 950	10 571	10 577	7 012	7 012	6 864	6 872
		Share				97 %	97 %			98 %	98 %

[1] Wood fuel usage potential, based on peat usage and with some plants also wood by-products and wastes without technical limitations

[2] Stand level allocation

[3] Aggregated, 10 km, supply point allocation

Logging residue potentials around the power plants, green supply policy
Allocating rule: Optimization according to the transport LP-model

				Green supply, gross reserve				Green supply, net reserve			
				Transport distance limit				Transport distance limit			
			Potential	<40 km	<60km	<80km	<100 km	<40 km	<60km	<80km	<100 km
Owner	Location	Municipality	GWh[1]	GWh[2]	GWh[2]	GWh[2]	GWh[2]	GWh[2]	GWh[2]	GWh[2]	GWh[2]
Vattenfall Oy (Myllykoski Paper Oy)	Anjalankoski	Anjalankoski	100	77	90	100	100	71	71	76	76
Stora Enso Oyj	Inkeroinen	Anjalankoski	50	50	50	50	50	38	47	47	47
Fortum Power and Heat Oy (Ahlström Kauttua Oy)	Kauttua	Eura	50	37	50	50	50	38	50	50	50
Vapo Oy	Forssa	Forssa	50	50	50	50	50	50	50	50	50
Stora Enso Oyj	Heinola	Heinola	150	84	150	150	150	59	108	145	150
Fortum Power and Heat Oy	Vanaja	Hämeenlinna	50	50	50	50	50	50	50	50	50
Savon Voima Oyj	Iisalmi	Iisalmi	250	205	250	250	250	143	243	250	250
Salmi Voima Oy	Parkatti	Iisalmi	++++	++++	++++	++++	++++	++++	++++	++++	++++
Primalco Oy	Koskenkorva	Ilmajoki	100	100	100	100	100	35	73	100	100
Stora Enso Oyj	Kaukopää	Imatra	100	100	100	100	100	60	100	100	100
Fortum Power and Heat Oy	Joensuu	Joensuu	400	143	400	400	400	146	377	400	400
Jyväskylän Energiantuotanto Oy	Rauhalahti	Jyväskylä	250	138	242	250	250	83	131	205	250
Jyväskylän Energiantuotanto Oy	Savela	Jyväskylä	50	50	50	50	50	50	50	50	50
UPM-Kymmene Oyj	Kaipola	Jämsä	200	93	172	200	200	108	164	184	200
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	350	190	267	350	350	120	187	278	335
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++	++++
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++	++++
Kainuun Voima Oy	Kajaani	Kajaani	250	93	172	250	250	137	227	250	250
UPM-Kymmene Oyj	Kajaani	Kajaani	++++	++++	++++	++++	++++	++++	++++	++++	++++
Vatajakosken Sähkö Oy	Kankaanpää	Kankaanpää	50	48	50	50	50	38	50	50	50
Veitsiluodon Voima Oy (Stora Enso Oyj)	Veitsiluoto	Kemi	50	11	48	50	50	19	22	30	41
Metsä-Botnia Oy	Kemi	Kemi	50	39	48	50	50	31	41	50	50
Kemijärven Kaukolämpö Oy	Kemijärvi	Kemijärvi	20	20	20	20	20	1	1	3	3
Fortum Power and Heat Oy	Kokkola	Kokkola	50	32	50	50	50	13	14	21	32
Kokkolan Voima Oy	Kokkola	Kokkola	50	17	50	50	50	12	19	43	48
Kuopion Energia	Haapaniemi	Kuopio	200	100	200	200	200	81	200	200	200
Kuopion Energia	Haapaniemi	Kuopio	++++	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Kuopio	Kuopio	100	89	100	100	100	18	81	100	100
Fortum Power and Heat Oy	Kuusamo	Kuusamo	20	20	20	20	20	8	11	15	20
Kymin Voima Oy (UPM-Kymmene Oyj)	Kuusankoski	Kuusankoski	300	91	207	300	300	49	150	214	275
UPM-Kymmene Oyj	Kuusankoski	Kuusankoski	++++	++++	++++	++++	++++	++++	++++	++++	++++
Lahti Energia	Lahti	Lahti	150	124	150	150	150	41	142	150	150
Fortum Lämpö Oy (Valio Oy)	Lapinlahti	Lapinlahti	100	100	100	100	100	93	100	100	100
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	250	203	250	250	250	148	183	197	199
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	++++	++++	++++	++++	++++	++++	++++	++++	++++
Vapo Oy	Lieksa	Lieksa	50	50	50	50	50	50	50	50	50
Fortum Power and Heat Oy	Lohja	Lohja	50	50	50	50	50	50	50	50	50
Etelä-Savon Energia Oy	Pursiala	Mikkeli	200	200	200	200	200	107	189	200	200
Mäntän Energia Oy (Metsä-Serla Oyj)	Mänttä	Mänttä	150	115	150	150	150	70	128	150	150
Fortum Power and Heat Oy	Naantali	Naantali	20	19	20	20	20	17	17	17	20
Fortum Power and Heat Oy	Naantali	Naantali	++++	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Voima Oy (Stora Enso Oyj)	Nuottasaari	Oulu	50	8	27	50	50	3	18	32	38
Kemira Chemicals Oy	Oulu	Oulu	50	13	39	50	50	2	2	2	2
Kemira Chemicals Oy	Oulu	Oulu	++++	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Energia	Toppila	Oulu	100	30	60	100	100	18	33	33	53
Oulun Energia	Toppila	Oulu	++++	++++	++++	++++	++++	++++	++++	++++	++++
Pieksämäen Energia Oy	Pieksämäki	Pieksämäki	100	100	100	100	100	100	100	100	100
Alholmens Kraft Oy Ab (UPM-Kymmene Oyj)	Pietarsaari	Pietarsaari	200	78	153	200	200	45	83	141	186
Porin Lämpövoima Oy	Aittaluoto	Pori	200	86	168	200	200	57	145	162	176
Porin Lämpövoima Oy	Aittaluoto	Pori	++++	++++	++++	++++	++++	++++	++++	++++	++++
Porin Lämpövoima Oy	Pihlava	Pori	20	8	20	20	20	0	8	20	20
UPM-Kymmene Oyj	Rauma	Rauma	100	68	98	100	100	47	77	87	100
UPM-Kymmene Oyj	Rauma	Rauma	++++	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Simpele	Rautjärvi	50	50	50	50	50	34	50	50	50
Fortum Power and Heat Oy	Riihimäki	Riihimäki	100	100	100	100	100	100	100	100	100
Fortum Power and Heat Oy	Riihimäki	Riihimäki	++++	++++	++++	++++	++++	++++	++++	++++	++++
UPM-Kymmene Oyj	Ristiina	Ristiina	50	50	50	50	50	41	50	50	50
Rovaniemen Energia	Suosiola	Rovaniemi	50	28	50	50	50	3	13	21	32
Voimavesu Oy	Salo	Salo	100	85	100	100	100	77	100	100	100
Suur-Savon Sähkö Oy	Savonlinna	Savonlinna	150	150	150	150	150	79	150	150	150
Vaskiluodon Voima Oy	Seinäjoki	Seinäjoki	200	135	200	200	200	94	142	193	200
Lämpö Oy Juurakkotuli	Sodankylä	Sodankylä	20	14	20	20	20	0	0	0	2
Tampereen sähkölaitos	Naistenlahti	Tampere	250	109	250	250	250	104	207	243	250
Turku Energia	Turku	Turku	50	50	50	50	50	40	47	50	50
UPM-Kymmene Oyj	Tervasaari	Valkeakoski	200	114	200	200	200	78	136	189	200
Fortum Power and Heat Oy (Säteri Oy)	Valkeakoski	Valkeakoski	50	18	50	50	50	35	39	50	50
Stora Enso Oyj	Varkaus	Varkaus	50	50	50	50	50	50	50	50	50
Stora Enso Oyj	Summa	Vehkalahti	200	131	165	200	200	89	185	200	200
Vieska Energia Oy	Ylivieska	Ylivieska	50	50	50	50	50	42	50	50	50
Metsä-Serla Oyj	Äänekoski	Äänekoski	350	194	348	350	350	182	229	298	350
		In total	7 000	4 484	6 503	7 000	7 000	3 301	5 391	6 247	6 655
		Share		64 %	93 %	100 %	100 %	47 %	77 %	89 %	95 %

[1] Target for forest fuel usage

[2] Aggregated, 10 km, supply point allocation

Appendix 13 (2/2)

Logging residue potentials around the power plants, brown supply policy
Allocating rule: Optimization according to the transport LP-model

				Brown supply, gross reserve				Brown supply, net reserve			
				Transport distance limit				Transport distance limit			
			Potential	<40 km	<60km	<80km	<100 km	<40 km	<60km	<80km	<100 km
Owner	Location	Municipality	GWh[1]	GWh[2]	GWh[2]	GWh[2]	GWh[2]	GWh[2]	GWh[2]	GWh[2]	GWh[2]
Vattenfall Oy (Myllykoski Paper Oy)	Anjalankoski	Anjalankoski	100	65	82	93	93	44	58	68	92
Stora Enso Oyj	Inkeroinen	Anjalankoski	50	26	28	37	50	22	35	39	47
Fortum Power and Heat Oy (Ahlström Kauttua Oy)	Kauttua	Eura	50	32	50	50	50	27	42	50	50
Vapo Oy	Forssa	Forssa	50	50	50	50	50	40	50	50	50
Stora Enso Oyj	Heinola	Heinola	150	58	136	150	150	53	94	123	150
Fortum Power and Heat Oy	Vanaja	Hämeenlinna	50	50	50	50	50	50	50	50	50
Savon Voima Oyj	Iisalmi	Iisalmi	250	178	250	250	250	128	186	192	200
Salmi Voima Oy	Parkatti	Iisalmi	++++	++++	++++	++++	++++	++++	++++	++++	++++
Primalco Oy	Koskenkorva	Ilmajoki	100	78	100	100	100	41	67	100	100
Stora Enso Oyj	Kaukopää	Imatra	100	87	100	100	100	42	53	53	53
Fortum Power and Heat Oy	Joensuu	Joensuu	400	124	400	400	400	112	283	361	395
Jyväskylän Energiantuotanto Oy	Rauhalahti	Jyväskylä	250	110	188	250	250	32	100	148	174
Jyväskylän Energiantuotanto Oy	Savela	Jyväskylä	50	50	50	50	50	23	23	39	50
UPM-Kymmene Oyj	Kaipola	Jämsä	200	103	162	187	200	113	146	164	179
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	350	140	214	317	342	80	103	193	247
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++	++++
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++	++++
Kainuun Voima Oy	Kajaani	Kajaani	250	135	250	250	250	114	176	209	223
UPM-Kymmene Oyj	Kajaani	Kajaani	++++	++++	++++	++++	++++	++++	++++	++++	++++
Vatajakosken Sähkö Oy	Kankaanpää	Kankaanpää	50	38	50	50	50	30	42	45	50
Veitsiluodon Voima Oy (Stora Enso Oyj)	Veitsiluoto	Kemi	50	30	47	50	50	10	16	21	27
Metsä-Botnia Oy	Kemi	Kemi	50	30	37	50	50	30	39	44	50
Kemijärven Kaukolämpö Oy	Kemijärvi	Kemijärvi	20	18	20	20	20	1	1	4	4
Fortum Power and Heat Oy	Kokkola	Kokkola	50	9	43	50	50	4	5	10	24
Kokkolan Voima Oy	Kokkola	Kokkola	50	31	49	50	50	13	20	26	29
Kuopion Energia	Haapaniemi	Kuopio	200	86	200	200	200	47	110	178	191
Kuopion Energia	Haapaniemi	Kuopio	++++	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Kuopio	Kuopio	100	59	100	100	100	28	44	44	86
Fortum Power and Heat Oy	Kuusamo	Kuusamo	20	20	20	20	20	2	8	7	11
Kymin Voima Oy (UPM-Kymmene Oyj)	Kuusankoski	Kuusankoski	300	79	173	247	289	71	136	149	183
UPM-Kymmene Oyj	Kuusankoski	Kuusankoski	++++	++++	++++	++++	++++	++++	++++	++++	++++
Lahti Energia	Lahti	Lahti	150	84	150	150	150	78	135	150	150
Fortum Lämpö Oy (Valio Oy)	Lapinlahti	Lapinlahti	100	98	100	100	100	65	86	88	100
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	250	179	250	250	250	75	90	104	134
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	++++	++++	++++	++++	++++	++++	++++	++++	++++
Vapo Oy	Lieksa	Lieksa	50	50	50	50	50	45	50	50	50
Fortum Power and Heat Oy	Lohja	Lohja	50	50	50	50	50	49	50	50	50
Etelä-Savon Energia Oy	Pursiala	Mikkeli	200	152	200	200	200	38	101	162	179
Mäntän Energia Oy (Metsä-Serla Oyj)	Mänttä	Mänttä	150	98	126	150	150	62	113	126	150
Fortum Power and Heat Oy	Naantali	Naantali	20	17	20	20	20	5	13	18	20
Fortum Power and Heat Oy	Naantali	Naantali	++++	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Voima Oy (Stora Enso Oyj)	Nuottasaari	Oulu	50	7	23	50	50	0	0	3	3
Kemira Chemicals Oy	Oulu	Oulu	50	15	33	50	50	2	8	21	21
Kemira Chemicals Oy	Oulu	Oulu	++++	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Energia	Toppila	Oulu	100	27	55	83	100	11	22	30	31
Oulun Energia	Toppila	Oulu	++++	++++	++++	++++	++++	++++	++++	++++	++++
Pieksämäen Energia Oy	Pieksämäki	Pieksamäki	100	100	100	100	100	56	89	89	93
Alholmens Kraft Oy Ab (UPM-Kymmene Oyj)	Pietarsaari	Pietarsaari	200	68	136	200	200	37	69	104	128
Porin Lämpövoima Oy	Aittaluoto	Pori	200	64	133	200	200	41	103	154	185
Porin Lämpövoima Oy	Aittaluoto	Pori	++++	++++	++++	++++	++++	++++	++++	++++	++++
Porin Lämpövoima Oy	Pihlava	Pori	20	10	20	20	20	6	14	20	20
UPM-Kymmene Oyj	Rauma	Rauma	100	66	93	100	100	48	64	65	89
UPM-Kymmene Oyj	Rauma	Rauma	++++	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Simpele	Rautjärvi	50	50	50	50	50	8	19	27	27
Fortum Power and Heat Oy	Riihimäki	Riihimäki	100	100	100	100	100	56	100	100	100
Fortum Power and Heat Oy	Riihimäki	Riihimäki	++++	++++	++++	++++	++++	++++	++++	++++	++++
UPM-Kymmene Oyj	Ristiina	Ristiina	50	50	50	50	50	17	46	50	50
Rovaniemen Energia	Suosiola	Rovaniemi	50	25	46	50	50	6	17	23	29
Voimavasu Oy	Salo	Salo	100	73	100	100	100	66	99	100	100
Suur-Savon Sähkö Oy	Savonlinna	Savonlinna	150	132	150	150	150	50	67	132	150
Vaskiluodon Voima Oy	Seinäjoki	Seinäjoki	200	116	200	200	200	54	99	147	174
Lämpö Oy Juurakkotuli	Sodankylä	Sodankylä	20	13	20	20	20	0	0	0	1
Tampereen sähkölaitos	Naistenlahti	Tampere	250	93	231	250	250	96	209	233	250
Turku Energia	Turku	Turku	50	43	50	50	50	28	48	50	50
UPM-Kymmene Oyj	Tervasaari	Valkeakoski	200	93	179	200	200	81	128	200	200
Fortum Power and Heat Oy (Sälen Oy)	Valkeakoski	Valkeakoski	50	20	50	50	50	0	36	36	50
Stora Enso Oyj	Varkaus	Varkaus	50	50	50	50	50	38	42	50	50
Stora Enso Oyj	Summa	Vehkalahti	200	131	188	200	200	91	137	162	200
Vieska Energia Oy	Ylivieska	Ylivieska	50	50	50	50	50	18	21	38	46
Metsä-Serla Oyj	Äänekoski	Äänekoski	350	167	299	350	350	94	154	173	239
		In total	7 000	3 972	6 179	6 864	8 974	2 467	4 112	5 140	5 813
		Share		57 %	88 %	98 %	100 %	35 %	59 %	73 %	83 %

[1] Target for forest fuel usage

[2] Aggregated, 10 km, supply point allocation

Appendix 14 (1/2)

Logging residue potentials around the power plants, green supply policy
Allocating rule: Optimization according to the transport LP-model

				Green supply, net reserve							
				Marginal cost classes,€/MWh				Average cost classes, €/MWh			
			Potential	Logging residue potential GWh[2]				Logging residue potential GWh[3]			Cost[4]
			FIM/MWh	50	52.5	55	Cost[3]	50	52.5	55	
Owner	Location	Municipality	GWh[1]	8.41	8.83	9.25	€/MWh	8.41	8.83	9.25	€/MWh
Vattenfall Oy (Myllykoski Paper Oy)	Anjalankoski	Anjalankoski	100	48	71	76	11.14	71	76	90	9.65
Stora Enso Oyj	Inkeroinen	Anjalankoski	50	32	45	47	10.88	47	47	47	9.42
Fortum Power and Heat Oy (Ahlström Kauttua Oy)	Kauttua	Eura	50	14	32	50	9.49	50	50	50	8.62
Vapo Oy	Forssa	Forssa	50	38	50	50	8.61	50	50	50	8.12
Stora Enso Oyj	Heinola	Heinola	150	16	74	121	9.68	106	137	150	8.88
Fortum Power and Heat Oy	Vanaja	Hämeenlinna	50	50	50	50	8.09	50	50	50	7.78
Savon Voima Oyj	Iisalmi	Iisalmi	250	120	184	250	9.18	250	250	250	8.40
Salmi Voima Oy	Parkatti	Iisalmi	++++	++++	++++	++++	++++	++++	++++	++++	++++
Primalco Oy	Koskenkorva	Ilmajoki	100	12	20	50	9.70	35	80	100	8.89
Stora Enso Oyj	Kaukopää	Imatra	100	50	72	100	9.20	72	100	100	8.62
Fortum Power and Heat Oy	Joensuu	Joensuu	400	35	169	400	9.24	309	400	400	8.59
Jyväskylän Energiantuotanto Oy	Rauhalahti	Jyväskylä	250	30	63	131	9.85	131	234	250	8.86
Jyväskylän Energiantuotanto Oy	Savela	Jyväskylä	50	50	50	50	8.38	50	50	50	7.92
UPM-Kymmene Oyj	Kaipola	Jämsä	200	91	118	164	9.71	164	200	200	8.77
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	350	70	143	187	10.20	187	306	350	9.06
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++	++++
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++	++++
Kainuun Voima Oy	Kajaani	Kajaani	250	112	221	250	9.14	250	250	250	8.30
UPM-Kymmene Oyj	Kajaani	Kajaani	++++	++++	++++	++++	++++	++++	++++	++++	++++
Vatajakosken Sähkö Oy	Kankaanpää	Kankaanpää	50	13	38	50	9.19	42	50	50	8.58
Veitsiluodon Voima Oy (Stora Enso Oyj)	Veitsiluoto	Kemi	50	19	20	26	12.28	28	40	42	9.93
Metsä-Botnia Oy	Kemi	Kemi	50	8	41	48	9.32	50	50	50	8.41
Kemijärven Kaukolämpö Oy	Kemijärvi	Kemijärvi	20	1	1	1	13.84	1	3	3	11.21
Fortum Power and Heat Oy	Kokkola	Kokkola	50	13	13	14	10.64	13	17	32	9.47
Kokkolan Voima Oy	Kokkola	Kokkola	50	3	12	19	10.42	17	35	48	9.35
Kuopion Energia	Haapaniemi	Kuopio	200	83	170	200	9.05	83	200	200	8.43
Kuopion Energia	Haapaniemi	Kuopio	++++	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Kuopio	Kuopio	100	9	58	100	9.14	58	100	100	8.53
Fortum Power and Heat Oy	Kuusamo	Kuusamo	20	na	6	11	9.96	na	11	20	9.21
Kymin Voima Oy (UPM-Kymmene Oyj)	Kuusankoski	Kuusankoski	300	33	82	159	10.80	123	214	287	9.53
UPM-Kymmene Oyj	Kuusankoski	Kuusankoski	++++	++++	++++	++++	++++	++++	++++	++++	++++
Lahti Energia	Lahti	Lahti	150	30	109	150	9.14	142	150	150	8.43
Fortum Lämpö Oy (Valio Oy)	Lapinlahti	Lapinlahti	100	75	100	100	8.76	100	100	100	8.16
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	250	95	157	189	10.86	183	197	210	9.44
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	++++	++++	++++	++++	++++	++++	++++	++++	++++
Vapo Oy	Lieksa	Lieksa	50	40	50	50	8.53	50	50	50	8.01
Fortum Power and Heat Oy	Lohja	Lohja	50	50	50	50	8.29	50	50	50	7.85
Etelä-Savon Energia Oy	Pursiala	Mikkeli	200	49	107	184	9.41	152	200	200	8.65
Mäntän Energia Oy (Metsä-Serla Oyj)	Mänttä	Mänttä	150	35	93	128	9.56	124	150	150	8.65
Fortum Power and Heat Oy	Naantali	Naantali	20	na	6	17	9.86	8	17	20	9.19
Fortum Power and Heat Oy	Naantali	Naantali	++++	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Voima Oy (Stora Enso Oyj)	Nuottasaari	Oulu	50	na	3	17	11.16	8	25	38	9.96
Kemira Chemicals Oy	Oulu	Oulu	50	1	1	2	11.24	2	2	2	9.99
Kemira Chemicals Oy	Oulu	Oulu	++++	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Energia	Toppila	Oulu	100	6	16	33	11.10	26	33	53	9.91
Oulun Energia	Toppila	Oulu	++++	++++	++++	++++	++++	++++	++++	++++	++++
Pieksämäen Energia Oy	Pieksämäki	Pieksamäki	100	100	100	100	8.41	100	100	100	7.90
Alholmens Kraft Oy Ab (UPM-Kymmene Oyj)	Pietarsaari	Pietarsaari	200	7	35	79	11.03	35	113	183	9.64
Porin Lämpövoima Oy	Aittaluoto	Pori	200	50	73	145	10.40	131	162	176	9.28
Porin Lämpövoima Oy	Aittaluoto	Pori	++++	++++	++++	++++	++++	++++	++++	++++	++++
Porin Lämpövoima Oy	Pihlava	Pori	20	na	8	20	9.24	8	20	20	8.59
UPM-Kymmene Oyj	Rauma	Rauma	100	26	62	77	9.84	70	78	100	8.93
UPM-Kymmene Oyj	Rauma	Rauma	++++	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Simpele	Rautjärvi	50	31	46	50	8.84	50	50	50	8.12
Fortum Power and Heat Oy	Riihimäki	Riihimäki	100	45	100	100	8.76	100	100	100	8.12
Fortum Power and Heat Oy	Riihimäki	Riihimäki	++++	++++	++++	++++	++++	++++	++++	++++	++++
UPM-Kymmene Oyj	Ristiina	Ristiina	50	25	41	50	9.09	41	50	50	8.51
Rovaniemen Energia	Suosiola	Rovaniemi	50	2	10	20	12.61	10	21	32	10.98
Voimavasu Oy	Salo	Salo	100	22	86	100	8.98	100	100	100	8.37
Suur-Savon Sähkö Oy	Savonlinna	Savonlinna	150	43	112	150	9.08	131	150	150	8.49
Vaskiluodon Voima Oy	Seinäjoki	Seinäjoki	200	21	90	125	10.09	94	153	200	9.17
Lämpö Oy Juurakkotuli	Sodankylä	Sodankylä	20	na	0	0	13.49	na	0	0	11.30
Tampereen sähkölaitos	Naistenlahti	Tampere	250	49	127	228	9.91	191	243	250	9.02
Turku Energia	Turku	Turku	50	8	40	47	9.50	40	47	50	8.87
UPM-Kymmene Oyj	Tervasaari	Valkeakoski	200	58	111	164	9.68	136	200	200	8.79
Fortum Power and Heat Oy (Säteri Oy)	Valkeakoski	Valkeakoski	50	17	39	50	9.26	39	50	50	8.53
Stora Enso Oyj	Varkaus	Varkaus	50	50	50	50	8.14	50	50	50	7.73
Stora Enso Oyj	Summa	Vehkalahti	200	61	108	185	9.33	185	200	200	8.54
Vieska Energia Oy	Ylivieska	Ylivieska	50	31	42	50	8.89	50	50	50	8.22
Metsä-Serla Oyj	Äänekoski	Äänekoski	350	87	180	249	9.96	229	316	350	8.92
		In total	7 000	2 017	3 954	5 566		4 848	6 228	6 703	
		Share		29 %	56 %	80 %		69 %	89 %	96 %	

[1] Target for forest fuel usage

[2] Aggregated, 10 km, supply point allocation

[3] Marginal cost for supply of target level

[4] Average cost for supply of target level

Logging residue potentials around the power plants, brown supply policy
Allocating rule: Optimization according to the transport LP-model

				Brown supply, net reserve							
				Marginal cost classes, €/MWh				Average cost classes, €/MWh			
			Potential	Logging residue potential GWh[2]			Cost[3]	Logging residue potential GWh[3]			Cost[4]
			FIM/MWh	50	52.5	55		50	52.5	55	
Owner	Location	Municipality	GWh[1]	8.41	8.83	9.25	€/MWh	8.41	8.83	9.25	€/MWh
Vattenfall Oy (Myllykoski Paper Oy)	Anjalankoski	Anjalankoski	100	19	44	58	12.74	50	59	92	10.76
Stora Enso Oyj	Inkeroinen	Anjalankoski	50	10	22	35	10.59	35	39	50	9.36
Fortum Power and Heat Oy (Ahlström Kauttua Oy)	Kauttua	Eura	50	7	16	27	9.71	27	42	50	8.86
Vapo Oy	Forssa	Forssa	50	25	40	50	8.98	40	50	50	8.45
Stora Enso Oyj	Heinola	Heinola	150	18	53	91	10.03	59	123	150	9.23
Fortum Power and Heat Oy	Vanaja	Hämeenlinna	50	27	50	50	8.48	50	50	50	8.09
Savon Voima Oyj	Iisalmi	Iisalmi	250	31	128	186	11.28	181	192	233	9.68
Salmi Voima Oy	Parkatti	Iisalmi	++++	++++	++++	++++	++++	++++	++++	++++	++++
Primalco Oy	Koskenkorva	Ilmajoki	100	na	25	48	9.95	25	67	100	9.14
Stora Enso Oyj	Kaukopää	Imatra	100	9	42	53	11.69	42	53	53	10.15
Fortum Power and Heat Oy	Joensuu	Joensuu	400	8	93	230	10.50	97	350	395	9.50
Jyväskylän Energiantuotanto Oy	Rauhalahti	Jyväskylä	250	12	32	83	11.90	32	144	174	10.20
Jyväskylän Energiantuotanto Oy	Savela	Jyväskylä	50	23	23	23	9.90	23	39	50	8.97
UPM-Kymmene Oyj	Kaipola	Jämsä	200	42	100	141	11.89	123	159	179	10.40
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	350	32	60	103	12.85	103	182	247	10.90
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++	++++
Jämsänkosken Voima Oy (UPM-Kymmene Oyj)	Jämsänkoski	Jämsänkoski	++++	++++	++++	++++	++++	++++	++++	++++	++++
Kainuun Voima Oy	Kajaani	Kajaani	250	77	141	186	11.78	178	214	230	9.71
UPM-Kymmene Oyj	Kajaani	Kajaani	++++	++++	++++	++++	++++	++++	++++	++++	++++
Vatajakosken Sähkö Oy	Kankaanpää	Kankaanpää	50	5	25	33	9.89	25	42	50	9.12
Veitsiluodon Voima Oy (Stora Enso Oyj)	Veitsiluoto	Kemi	50	10	18	18	13.44	18	26	28	10.50
Metsä-Botnia Oy	Kemi	Kemi	50	11	30	39	10.11	39	48	50	8.86
Kemijärven Kaukolämpö Oy	Kemijärvi	Kemijärvi	20	1	1	1	14.42	1	1	4	11.20
Fortum Power and Heat Oy	Kokkola	Kokkola	50	na	4	4	11.99	4	5	10	10.48
Kokkolan Voima Oy	Kokkola	Kokkola	50	3	13	19	11.98	13	20	28	10.42
Kuopion Energia	Haapaniemi	Kuopio	200	10	47	92	10.66	47	122	191	9.68
Kuopion Energia	Haapaniemi	Kuopio	++++	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Kuopio	Kuopio	100	8	28	44	10.91	28	44	81	9.84
Fortum Power and Heat Oy	Kuusamo	Kuusamo	20	na	2	3	11.15	na	2	6	10.01
Kymin Voima Oy (UPM-Kymmene Oyj)	Kuusankoski	Kuusankoski	300	24	71	128	12.32	73	149	183	10.63
UPM-Kymmene Oyj	Kuusankoski	Kuusankoski	++++	++++	++++	++++	++++	++++	++++	++++	++++
Lahti Energia	Lahti	Lahti	150	29	93	135	9.74	121	148	150	8.93
Fortum Lämpö Oy (Valio Oy)	Lapinlahti	Lapinlahti	100	35	65	78	9.81	65	88	100	8.93
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	250	46	75	75	13.30	75	95	143	11.08
UPM-Kymmene Oyj, Kaukas	Lappeenranta	Lappeenranta	++++	++++	++++	++++	++++	++++	++++	++++	++++
Vapo Oy	Lieksa	Lieksa	50	28	45	50	9.16	50	50	50	8.53
Fortum Power and Heat Oy	Lohja	Lohja	50	39	50	50	8.79	50	50	50	8.27
Etelä-Savon Energia Oy	Pursiala	Mikkeli	200	na	36	73	11.17	36	121	179	9.97
Mäntän Energia Oy (Metsä-Serla Oyj)	Mänttä	Mänttä	150	9	41	99	10.12	73	119	150	9.09
Fortum Power and Heat Oy	Naantali	Naantali	20	na	2	5	10.13	1	5	18	9.48
Fortum Power and Heat Oy	Naantali	Naantali	++++	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Voima Oy (Stora Enso Oyj)	Nuottasaari	Oulu	50	na	na	na	13.06	na	na	3	11.18
Kemira Chemicals Oy	Oulu	Oulu	50	1	2	8	13.50	2	17	21	11.42
Kemira Chemicals Oy	Oulu	Oulu	++++	++++	++++	++++	++++	++++	++++	++++	++++
Oulun Energia	Toppila	Oulu	100	2	11	21	13.19	11	23	31	11.23
Oulun Energia	Toppila	Oulu	++++	++++	++++	++++	++++	++++	++++	++++	++++
Pieksämäen Energia Oy	Pieksämäki	Pieksamäki	100	28	56	72	10.83	56	89	93	9.60
Alholmens Kraft Oy Ab (UPM-Kymmene Oyj)	Pietarsaari	Pietarsaari	200	na	21	61	13.28	5	83	111	10.93
Porin Lämpövoima Oy	Aittaluoto	Pori	200	13	41	88	10.94	63	134	165	9.74
Porin Lämpövoima Oy	Aittaluoto	Pori	++++	++++	++++	++++	++++	++++	++++	++++	++++
Porin Lämpövoima Oy	Pihlava	Pori	20	na	8	14	9.66	6	18	20	8.96
UPM-Kymmene Oyj	Rauma	Rauma	100	11	38	55	10.58	38	64	89	9.48
UPM-Kymmene Oyj	Rauma	Rauma	++++	++++	++++	++++	++++	++++	++++	++++	++++
Metsä-Serla Oyj	Simpele	Rautjärvi	50	na	8	19	10.69	17	27	27	9.50
Fortum Power and Heat Oy	Riihimäki	Riihimäki	100	24	93	100	9.11	93	100	100	8.43
Fortum Power and Heat Oy	Riihimäki	Riihimäki	++++	++++	++++	++++	++++	++++	++++	++++	++++
UPM-Kymmene Oyj	Ristiina	Ristiina	50	na	17	31	9.87	12	48	50	9.01
Rovaniemen Energia	Suosiola	Rovaniemi	50	na	8	17	13.70	8	17	28	11.91
Voimavasu Oy	Salo	Salo	100	10	66	99	9.75	68	99	100	8.95
Suur-Savon Sähkö Oy	Savonlinna	Savonlinna	150	12	31	58	10.18	50	101	132	9.34
Vaskiluodon Voima Oy	Seinäjoki	Seinäjoki	200	4	31	72	11.38	37	99	158	10.10
Lämpö Oy Juurakkotuli	Sodankylä	Sodankylä	20	na	na	0	14.45	na	na	0	11.78
Tampereen sähkölaitos	Naistenlahti	Tampere	250	2	70	175	10.03	70	225	250	9.18
Turku Energia	Turku	Turku	50	na	12	42	9.76	8	42	50	9.15
UPM-Kymmene Oyj	Tervasaari	Valkeakoski	200	27	81	125	9.67	114	198	200	8.88
Fortum Power and Heat Oy (Säteri Oy)	Valkeakoski	Valkeakoski	50	na	na	36	10.02	na	36	50	9.14
Stora Enso Oyj	Varkaus	Varkaus	50	18	36	42	9.41	36	50	50	8.67
Stora Enso Oyj	Summa	Vehkalahti	200	30	58	112	10.09	112	182	200	9.08
Vieska Energia Oy	Ylivieska	Ylivieska	50	12	18	18	10.51	18	35	48	9.27
Metsä-Serla Oyj	Äänekoski	Äänekoski	350	22	88	154	11.47	106	165	239	9.96
		In total	7 000	810	2 296	3 720		2 683	4 709	5 763	
		Share		12 %	33 %	53 %		38 %	67 %	82 %	

1) Target for forest fuel usage

2) Aggregated, 10 km, supply point allocation

3) Marginal cost for supply of target level

4) Average cost for supply of target level

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