Estimation of Estonian Wood Fuel Resources

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Abstract

To collect background information for *the Long-term Development Programme of Promotion of Biomass and Bioenergy year 2007 – 2013* several studies financed by the Rural Development Foundation were carried out. The objective of this study was to investigate the potential yield of wood fuel. Conclusions about the potential yield of woody biomass were drawn up based on the results of the field experiments, modelling of forestry data and analysis of digital map layers. According to the calculations the total theoretical annual yield of Estonian forests is 8 406 thousand m^3 and the share of traditional fuel wood is 963 thousand m^3 (7 223 TJ). The theoretical yield of harvesting residues can be up to 1 504 thousand m^3 (9 775 TJ) and the quantity of stumps up to 778 thousand m^3 (5 059 TJ), incl. 480 thousand m^3 of stumps from coniferous trees. The results can be used for developing measures for promoting biofuels and for spatial analysis of the future scenarios of utilization of biofuels.

Key words: biomass resources, harvesting residues, alternative resources

Introduction

The dispersed geographical distribution of biomass potential has increased the interest of researchers in using GIS for evaluation of the biomass supply and characteristics, estimation of the transportation cost to existing power plants as well as site selection for biomass-based fuel developments (Ranta 2005). The general goals for the promotion of bioenergy are pointed out in Estonian forestry and energy sector development programmes - the share of renewables in electricity production should be increased to 5.1% by the year 2012 and the share of electricity produced from biomass in heat and power production plants should make up 20% of the total electricity production by the year 2020. In practice, the possibilities of additional use of forest industry by-products for energy production are very restricted and therefore most of the increase will be based on forest chips (Ranta *et al.* 2007). To collect background information for *the Long-term Development Programme of Promotion of Biomass and Bioenergy in 2007 – 2013* several studies financed by the Rural Development Foundation were carried out. The objective of one of the studies was to investigate the potential yield of wood fuel. The results of this study are presented in the following paper.

Material and methods
GIS-analysis
For calculating the amount of forest biomass, different parameters of forests are needed – forest area,

forest site type or type of the soil, quality class *etc*. For estimation of the potential resources of forest biomass in Estonia 4 map layers were used (Figure 1):
1) Estonian Base Map;
2) Estonian Digital Soil Map;
3) The digital forest maps from the State Registry of Forest Data;
4) Area maps of rural municipalities.

In addition, the forest inventory data from the State Registry of Forest Data and data on soil quality were used for analysis.
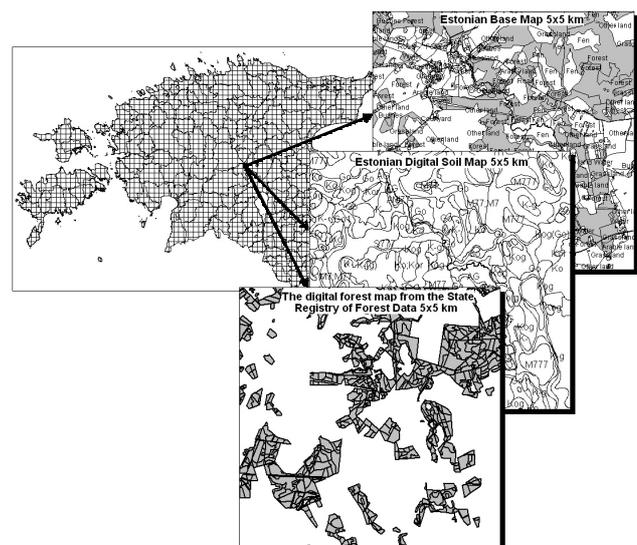

Figure 1. Estonian digital base map and map layers for analysis

At first the forest areas were calculated. As the map layers were not complete the following steps of calculation were used:

1) At first three map layers (Figure 1) were joined together and then split by borders into pieces for analysis. By combining these maps 6.5 million polygons were received. They cover the area of 18,070 km^2. Forest area was determined to be 16,211 km^2. An example can be seen on the top left corner of Figure 2, which presents the area of 5x5 km in Estonia.

2) After that the analyzed areas were subtracted from the layers of Base Map and are presented on top right corner of Figure 2. The remaining areas were integrated with map layers of Base Map and soil map. The combination of these maps gave 4.5 million polygons which cover the area of 24,378 km^2. Forest area was determined to be 7,740 km^2. An example of it can be seen on the bottom left corner of Figure 2.

3) Then the areas and characteristics of forests not covered by the forest inventory data were subtracted from the layers of Base Map, and, as a result, the areas of Base Map not covered by the polygons of soil map were determined – 1,039 km^2 including 110 km^2 of forest area, which is presented in the bottom right corner of Figure 2.

4) 509 km^2 of Estonian territory was not analyzed due to the absence of Base Map data. The data are missing as until now the Russian authorities have not given a permission to take aerial photographs from the Estonian-Russian border area. These areas cover only 1.2% of the total Estonian land area and therefore they were excluded from the calculations.

As a result of the analysis the area of forests was determined to be 24,061 km^2.

Based on calculated forest areas, the analysis of forest properties followed. For the modelling the forests growth and long-term production the best characteristics are site type (giving information about composition of tree species and moisture regime of the soil) and quality class (describing the rate of trees growth). Unfortunately only 16,211 km^2 of forests are described by reliable forest inventory data in the State Registry of Forest Data. The forest inventory data concerning 7,740 km^2 (32.6% of forest land) was missing and therefore the necessary data had to be created via modelling by using the databases of State Registry of Forest Data and Digital Soil Maps.

Calculation of forest data by soil characteristics

To get characteristics of 32.6% of forest lands not covered by the forestry data, the models had to be created based on the data of State Registry of Forest Data and Digital Soil Maps. At first, the indicators to describe moisture regime, soil pH and soil nutrient content were found for every site type by using the ordination scheme of forest site types (Lõhmus 1974, 2004). The results are presented in Table 1.

As a next step, the data from Table 1 were assigned to every subcompartment presented in State Registry of Forest Data and covered by layers of Base Map, Digital Soil Map and the maps of State Registry of Forest Data (ca 6.5 million records, 18,070 km^2). As a result of inquiry from the table of data a new table was compiled. This table included the following columns:

1) land category – land category from the Base Map;

2) soil – type of the soil from the Digital Soil Map (114 different types);

3) forest site type – the site type according to the data of the State Registry of Forest Data (31 different types, see Table 1);

4) type of the holding – the land category according to the State Registry of Forest Data;

5) area – sum of areas of consolidated map layers, km^2;

6) average quality class – the weighted average quality class calculated by the data of the State Registry of Forest Data;

7) class of humidity – the weighted average of classes of humidity calculated by the data of Table 1;

8) class of soil pH and soil nutrient content – the weighted average of classes of soil pH and soil nutrient content according to the data of Table 1.
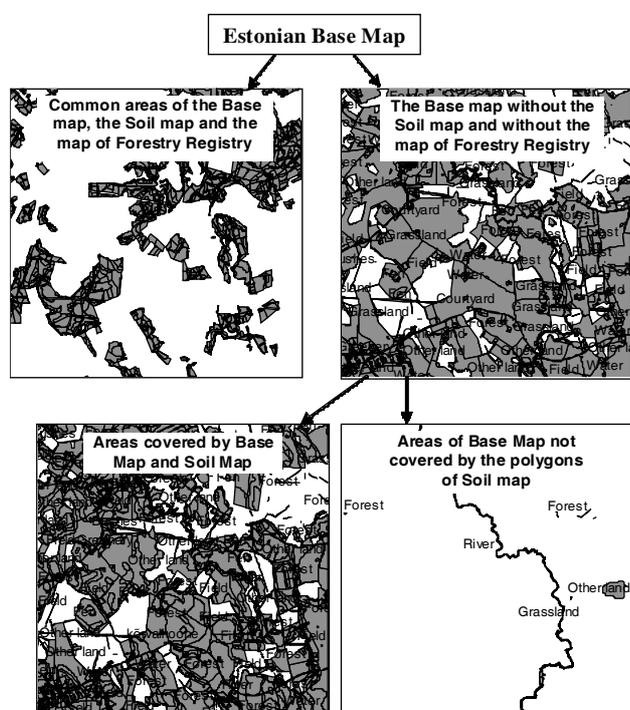

Figure 2. Example of analyses of map layers

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Table 1. Average characteristics of forests of different forest site types according to the ordination scheme of forest site types (Lõhmus, 1974, 2004)

Site type	Thickness of organogenic layer of soil (OHOR), cm	Moisture regime of soil	Soil pH and soil nutrient content
Alder fen	50	9.0	7.0
Bearberry alvar	2	0.5	8.0
Bilberry	10	6.0	3.0
Bilberry fulldrained swamp	50	7.5	3.0
Birch fen	50	9.5	5.0
Blue moor grass alvar	2	7.0	8.0
Bog	50	9.0	1.0
Bog whortleberry	20	6.0	1.0
Clay dump	1	7.5	4.0
Cowberry	4	2.5	3.0
Fern	15	7.0	7.0
Full-drained swamp	50	7.5	4.0
Goutweed	1	5.0	7.0
Hair moss	20	7.5	2.0
Hair moss - bilberry	13	7.0	2.5
Heather	5	2.0	1.0
Hepatica	1	3.5	7.0
Horsetail	20	8.0	4.0
Lichen	4	0.5	2.0
Meadowsweet	10	7.0	5.5
Peaty dump	50	8.0	3.0
Sandy dump	1	1.0	2.0
Sedge	20	8.0	4.0
Sedge - meadowsweet	15	7.5	5.0
Small reed alvar	1	2.0	8.0
Stony dump	1	1.0	8.0
Transition bog	50	9.0	3.0
Wood sorrel	4	4.5	4.5
Wood sorrel bilberry	6	5.0	3.5
Wood sorrel cowberry	4	3.5	3.5
Wood sorrel fulldrained swamp	50	7.5	5.0

As the definitions of the State Forest Registry of Forest Data and the Estonian Base Map are not concurrent, the corresponding models were calculated for all types of nature areas. The following specifiers were calculated:

1) the type of nature areas (fen, abandoned peatland, forest, brushland, bog) according to the Base Map;

2) type of the soil from the Digital Soil Map;

3) average quality class of the stands;

4) forest site type;

5) share of forest land – indicates the share of forests of the areas of a certain type of land category and soil type according to the data of the State Forest Registry of Forest Data;

6) share of shrubs – indicates the share of shrubs of the areas of a certain type of land category and soil type according to the data of the State Forest Registry of Forest Data;

7) share of bogs – indicates the share of bogs of the areas of a certain type of land category and soil type according to the data of the State Forest Registry of Forest Data;

8) share of other lands – indicates the share of bogs of the areas of a certain type of land category and soil type according to the data of the State Forest Registry of Forest Data.

Based on these models, the forest data were generated for the areas not covered by the data of the State Forest Registry of Forest Data – in total 7 740 km². There were still data missing for areas of Base Map not covered by the polygons of soil map. For these 110 km² of forests average forest data were used.

The data about the quality classes and site types enabled to calculate the average yield of the forests. For this models were created.

Determination of the theoretical potential of fuel wood and harvesting residues via calculation of the long-term yield of forests

To determine the theoretical long-term yield of forests, the average annual production of assortments by site types and quality classes were calculated. This method has been used previously by Padari and Muiste (2003). The calculations were the following:

1) The initial data of young forests (age, height, diameter, the number of trees and volume) were calculated for different tree species (8 varieties), OHOR (10 different options of the thickness of organogenic layer of the soil from Table 1) and quality classes (6 classes: Ia, I, II, III, IV and V or H_{100} equal to 33.5 m, 29.5 m, 25.5 m, 21.5 m, 17.5 m and 13.5 m):

• At first the stand age, diameter and height were calculated. For that the height at the age 50 and the diameter at the age 50 (correspondingly H_{50} and D_{50}) for 480 different combinations were found. Difference models by A. Kiviste (1997, 1999 and 2006) were used for calculation of H_{50} and empiric formula by A. Kiviste (1997) for calculation of D_{50}. As a next step the initial stand diameter and age was created for all 480 combinations of data by using specifier D_{50}, when the average diameter was 7.5 cm. The average height of the stand at the same age was calculated based on specifier H_{50}. For this the model by A. Kiviste (1997, 2006) was used.

• To determine the stand volume (Eq. 1) from stand height, it was presumed that the density is 0.8 and then the data from the standard yield table (Metsa korraldamise juhend 1999) were used:

$$M = 0.8 \cdot (a_1 + a_2 \cdot H + a_3 \cdot H^2), \qquad (1)$$

where: M – average volume of the stand, m³/ha; H – average height of the stand, m; a_1, a_2, a_3 – constants,

determined by the tree species (Metsa korraldamise juhend 1999).

• The basal area (Eq. 2) was calculated via the average volume of the stand, calculated by equation 1

$$G = \frac{M}{H \cdot F} \quad , \tag{2}$$

where: G – basal area of the stand, m²/ha; M – volume of the stand m³/ha; H – average height of the stand, m; F – specifier describing the form factor of the stand (Eq. 3).

Specifier F was calculated by the following equation (Metsa korraldamise juhend 1999):

$$F = b_1 + \frac{b_2}{H} + b_3 \cdot \sqrt{H} + b_4 \cdot Ln(H), \tag{3}$$

where: F – specifier describing the form factor of the stand; H – average height of the stand, m; b_1, b_2, b_3, b_4 – constants, determined by the tree species (Metsa korraldamise juhend 1999).

• To find number of trees per ha basal area and the average diameter of the stand were used.

2) During the next stage of calculation the initial data found during the previous stage of calculation were used to simulate the growth of forests. At first the sparsity of forest (average distance between trees, Eq. 4) was calculated:

$$L = \frac{10000}{\sqrt{N}}, \tag{4}$$

where: L – sparsity of forest, cm; N – number of trees per ha.

During simulation of the forest growth diameter dependency on sparsity of forest as an indicator was used. These models (created by Artur Nilson and Allar Padari, Eq. 5, 6 and 7) have not been published until now but they have been used in the infosystem of Estonian State Forest Mangement Center:

$$L_{mood} = a_L + b_L \cdot \frac{D^2}{H}, \tag{5}$$

$$L_{piir} = \frac{L_{mood}}{1,34}, \tag{6}$$

$$kD = 2 - 2 \cdot \frac{\left(\frac{L_{mood}}{L}\right)^6}{\left(\frac{L_{mood}}{L}\right)^6 + 1}, \tag{7}$$

where: kD – coefficient of the increment of the diameter; L_{mood} – mood sparsity of forest, cm; L – sparsity of forest, cm (Eq. 4); L_{piir} – limit of the sparsity of

forest, cm; D – average diameter of the stand, cm; H – average height of the stand, m; a_L, b_L – constants, determined by the tree species (Table 2).

Coefficient of the increment of diameter kD (Eq. 8) was then used for simulation of forest growth by the difference models by A. Kiviste (1997, 1999 and 2006). The growth of height and diameter of stands was simulated by models year by year until the age of final felling. Also the natural fellout was simulated to determine a decrease in the number of trees. For that several models created by Artur Nilson and Allar Padari were used:

• At first specifier L_{vahe} (Eq. 8) was found to characterize the difference between actual sparsity and the limit of the sparsity:

$$L_{vahe} = L - L_{piir}, \tag{8}$$

where: L – sparsity of the forest (Eq. 4), cm; L_{piir} – limit of the sparsity of forest (Eq. 6), cm.

• Then specifier K (Eq. 9) was found:

$$K = \sqrt{\left(1 - \frac{8 \cdot L_{vahe}}{3 \cdot L_{piir}}\right) \cdot \frac{b_L}{1,34}} \quad , \tag{9}$$

where: L_{vahe} – difference between actual sparsity and the limit of the sparsity (Eq. 8), cm; L_{piir} – limit of the sparsity of forest (Eq. 6), cm; b_L – constant determined by tree species (Table 2).

• Next the sparsity of forest after growth (Eq. 10) was calculated:

$$L_{A+1} = L + K \cdot \left[\frac{(D + zD)^2}{H + zH} - \frac{D^2}{H}\right], \tag{10}$$

where: L_{A+1} – sparsity of forest after growth of forest during 1 year, cm; L – sparsity of the forest (Eq. 4), cm; K – constant (Eq. 9); D – average diameter of the stand, cm; H – average height of the stand, m; zD – increment of the average diameter using KD with equation 7 and forest growth by the difference models by A. Kiviste (1997, 1999, and 2006) cm; zH – increment of the average height of the stand (Kiviste 1997, 1999, 2006), m.

• Next the limit of the sparsity of the forest after growth (Eq. 11) was found:

$$L_{piir,A+1} = a_L + b_L \cdot \frac{(D + zD)^2}{H \cdot 1,34}, \tag{11}$$

where: $L_{piir,A+1}$ – limit of the sparsity of forest after growth during 1 year, cm;; D – average diameter of the stand, cm; zD – increment of the average diameter using KD with equation 7 and forest growth by the difference models by A. Kiviste (1997, 1999, 2006) cm; H – average height of the stand, m; a_L, b_L – constants, determined by the tree species (Table 2).

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• If the sparsity calculated after growth of forest (L_{A+1}, Eq. 10) was less than limit of the sparsity ($L_{piir,A+1}$, Eq. 11), the sparsity was taken equal to the limit of the sparsity ($L_{A+1}=L_{piir,A+1}$).

• The number of trees after simulation of growth (Eq. 12) was calculated by equation:

$$N_{A+1} = \frac{100000000}{L_{A+1}^2},$$ (12)

where: N_{A+1} – number of trees after growth per ha; L_{A+1} – sparsity calculated after growth of forest, cm.

The results of the simulation of the growth were used as the initial data for calculation of all other parameters of forest.

3) The simulation programs checked the forests were fit (according to the official norms) for thinning by density by using the models by H. Korjus (Korjus 1994, 1999). Since in real life it is difficult to organize and carry out thinning in optimal time, the norm of sparsity for pre commercial thinning was decreased by 5 %. (L_{re} was multiplied by 0.95). During simulation of thinning, preference was given to cutting trees of smaller diameter, so the mean diameter of the trees thinned, was less than the initial one of the stand.

4) After simulation of thinning or final felling the quantities of different assortments were calculated by using the following models:

• Trees were divided into diameter classes by the distribution of (Padari 1999) where the relative diameter class was calculated as a ratio of diameter class and the average diameters of the stand (d/D), (Figure 3);
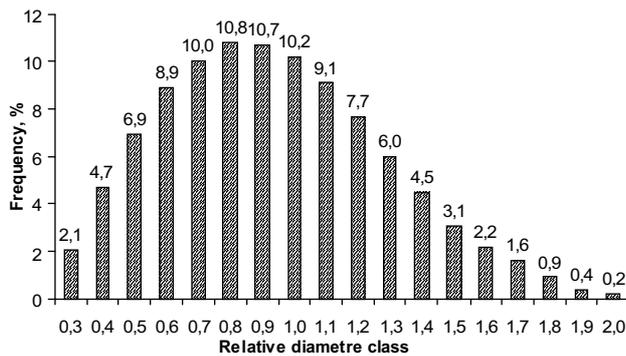

Figure 3. Division of diameters by relative diameter classes

• Height for every diameter class was calculated according to the height curve (Eq. 13). For that the equation by M. Prodan (Prodan 1965) was used:

$$h = H \cdot \left(\frac{d \cdot (D+b)}{D \cdot (d+b)} \right)^c,$$ (13)

where: h – height of the tree, m; H – average height of the stand, m; D – average diameter of the stand, cm; d – diameter of the tree, cm; b, c – constants (Padari 1999, 2004).

In the original formula constant b was equated with 1. However, as a result of additional analysis by A. Nilson and A. Padari (Padari 1999, 2004), the value of the constants was adjusted to the Estonian conditions.

• Volumes of different assortments were calculated by diameter and height, using the equation of taper curve equation by R. Ozolins (Standard of Forest Inventory 1988). This equation (Eq. 14) is widely used in calculation of volumes of Estonian forests:

$$d_l = d \cdot \frac{\left(1 + \left(\left(\frac{l}{h}\right)^2 - 0.01\right) \cdot (p \cdot (h - 1.0) + q \cdot (d - d0))\right)\left(a_0 + \left(q + \left(a_2 + \left(a_3 + \left(a_4 + \left(a_5 + a_6 \cdot \frac{l}{h}\right)\frac{l}{h}\right)\frac{l}{h}\right)\frac{l}{h}\right)\frac{l}{h}\right)\frac{l}{h}\right)}{\left(1 + \left(\left(\frac{1.3}{h}\right)^2 - 0.01\right) \cdot (p \cdot (h - 1.0) + q \cdot (d - d0))\right)\left(a_0 + \left(a_1 + \left(a_2 + \left(a_3 + \left(a_4 + \left(a_5 + a_6 \cdot \frac{1.3}{h}\right)\frac{1.3}{h}\right)\frac{1.3}{h}\right)\frac{1.3}{h}\right)\frac{1.3}{h}\right)\frac{1.3}{h}\right)};$$ (14)

where: d_l – diameter of the stem at the height of l, cm; d – breast height diameter, cm; l – height from the bottom, where the diameter is calculated, m; h – height of the stem, m; a_0, a_1, a_2, a_3, a_4, a_5, a_6, $h0$, $d0$, p, q – constants.

The lengths of the assortments that were used were 3.1 m for logs, 3.0 m for pulpwood and firewood. Assortments were divided into different groups by top diameter which was calculated by the taper curve formula of R. Ozolins. As that formula gives the diameter over bark, the thickness of the bark had to be substracted from the result. For that the equation of the bark (Eq. 15) was used:

$$bark = \frac{a_1 \cdot \left(\frac{d + a_2}{d + a_2 + 1}\right)^{a_3}}{100},$$ (15)

where: $bark$ – share of the bark of the stem; d – diameter of the tree, cm; a_1, a_2, a_3 – constants (Table 2).

The diameter of the stem under the bark (Eq. 16) was finally calculated as follows:

$$d_{k-ta} = \frac{d_{k-ga}}{\sqrt{1 + bark}},$$ (16)

where: d_{k-ga} – diameter of the stem over the bark calculated by the taper *curve, cm; bark* – share of the bark (Eq. 15).

The minimal top diameter of the log was estimated to be the following – for saw logs 18 cm, for small dimension coniferous logs 12 cm, for small dimension soft wood logs 14 cm, for pulpwood 7 cm and for firewood 5 cm. The volume of top was added to the volume of branches. The volumes of the assortments (Eq.

17) were calculated by the formula (Ozoliņš 2002, Standard of Forest Inventory 1988) which was adjusted to Estonian conditions by A. Padari (2004):

$$v = \frac{\pi}{40000} \cdot \int_{l=h_1}^{h_2} (d_l)^2 \, dl \ , \qquad (17)$$

where: v – volume of the stem, m³; l – distance from the butt, m; h_1 – beginning of the certain assortment from the butt, m; h_2 – end of the certain assortment from the butt, m; d_l – diameter of the tree at the height l (by the taper curve equation), cm.

• The volumes of branches were estimated roughly as a specific percentage of the volume of the stem – 7% in pines, 6% in birch and 8% in other tree species (Krigul 1971).

• The calculated volumes of assortments were corrected according to the percentage of damages and defects (Eq. 18), which depends on the tree species and their age:

$$K = \left(\frac{A}{A+1} \right)^{\left(\left(\frac{b}{A} \right)^c \right)} \ , \qquad (18)$$

where: K – share of damaged trees; A – age of the trees, years; b, c – constants (Table 2).

Table 2. Constants, determined by the tree species

Tree species	Constants in equation 5, 9 and 11		Constants in equation of the bark (Eq. 15)			Constants in equation of the share of the damaged trees (Eq. 18)	
	a_L	b_L	a_1	a_2	a_3	b	c
Pine	42.8	14.23	6.0	10	-17.5	9 000 000	0.5
Spruce	56.2	14.51	8.0	2	-4.9	1 300 000	0.5
Birch	117.0	14.15	11.1	3	-4.9	700	2.0
Aspen	106.8	12.67	12.0	2	-3.2	145	3.5
Black alder	95.5	14.21	10.8	2	-4	250	3.0
Grey alder	84.2	14.85	10.8	2	-4	60	6.0
Oak, ash	117.0	14.15	12.0	2	-3.2	10 000 000	0.5

50% of the damaged wood of all assortments of the merchantable wood was estimated to be fuel wood. The rest of the damaged wood was estimated to be as follows – 50% of damaged sawlogs of pine, oak and ash, 75% of spruce and 100% of other tree species was considered to be pulpwood.

• After that the effect of crook was taken into account - 5% of pine, spruce, oak and ash, 10% of aspen, 25% of birch and black alder and 50% of grey alder stems were considered to be either pulpwood or fuelwood (instead of logs).

• The volumes of saw logs, small dimension logs and pulpwood (Eq. 19) were calculated by equation:

$$v_{k-ta} = \frac{v_{k-ga}}{1 + bark} \ , \qquad (19)$$

where: v_{k-ta} – volume (under the bark) of the assortment, m³; v_{k-ga} – volume (over the bark) of the assortment, m³; bark – share of the bark of the stem (Eq. 15).

The volumes of fuel wood, tops and branches were left to be the volumes over the bark.

5) Next the volumes of calculated assortments from thinning and final felling were compiled. These sums were divided by length of rotation period. As a result the average annual production of assortments of every site class, site type and every tree species was retrieved.

6) Next, the average composition of tree species for every sites type and for every site index class was found by using the data of the State Registry of Forest Data. Then the production of different assortments was calculated by site classes and tree species.

Finally, based on the data about the yield of forests and the distribution of forest area by different site quality classes and site types, the total annual yield of Estonian forests was calculated.

Results

Based on calculated forest areas, the analysis of forest properties was made. Since only 16,211 km² of forests are described by reliable forest inventory data in the State Registry of Forest Data, the missing data concerning 7,740 km² (32.6% of forest land) was created via modelling by using the databases of State Registry of Forest Data and Digital Soil Maps. Combining this data gave the specific forestry data in correlation with the soil type. In case of the areas not covered by the polygons of soil map, the average forest data were used. Results of the analysis of map layers are presented in Table 3.

As a result of the analysis of areas covered by Base, Digital Soil and the maps of State Registry of Forest Data the distribution of forests by protection categories was determined (Table 4, II column).

Table 3. Results of the analysis of map layers

Stage of calculation	Area, km²	Forest land, km²
Areas covered by Base, Digital Soil and the maps of State Registry of Forest Data	18 070	16 211
Areas covered by Base and Digital Soil Maps	24 378	7 740
Areas of Base Map not covered by the polygons of soil map	1 039	110
Total	43 487	24 061

Table 4. Distribution of forests by protection categories (SP – strictly protected forest, P – protected forest, C – commercial forest)

Protection category of forest	Forest areas covered by Base, Digital Soil and the maps of State Registry of Forest Data , ha	Share of protected forests, %	Distribution of protected forests not covered by the State Registry of Forest data, 10³ ha	Areas of Base Map not covered by the polygons of soil map, 10³ ha	Total, 10³ ha
SP	140.08	8.6	65.74	1.04	206.87
P	261.26	16.1	130.98	1.82	394.05
C	1222.27	75.3	574.78	8.16	1805.21
Total	1623.61	100.0	771.50	11.01	2406.13

As to the rest of the forests it was presumed that in all the counties the distribution by categories is similar to the forests reflected in the State Registry of Forest Data (Table 4, columns IV and V). The results of the analysis indicate that the area of strictly protected forests is 206.9 thousand ha. In these forests the forest management is completely prohibited and they cannot be considered as a source of biomass. Total area of protected forests is 394.1 thousand ha. The protection regime in these forests can vary – in some cases it is possible to manage the forests as normal commercial forests and in some cases the protection regime is similar to strictly protected forests. The area of commercial forests is 1,805.2 thousand ha and it is the main source of wood base fuels.

The calculated annual yield of the biomass from Estonian forests regarding the regimes of protection is presented in Table 5. Due to the certain limitations of forest management for the calculation, 50 % of the potential of protected forests was taken into account. The volume of stumps was estimated to be 12% of the stem volume for coniferous trees (pine, spruce), 10% for soft deciduous trees (aspen, birch, black alder, grey alder) and 20% for hard deciduous trees (ash, oak) (Krigul 1971).

Table 5. Long-term average annual yield of forests regarding restrictions, Mm³ (TH – thinning, CC – clear cut)

Tree species	Felling system	Merchant-able wood	Fire-wood	Total	Harvest-ing residues	Stumps
Conife-rous	TH	1.463	0.011	1.474	0.318	
	CC	3.090	0.180	3.271	0.393	0.480
Deci-duous	TH	1.085	0.302	1.387	0.495	
	CC	1.805	0.470	2.274	0.298	0.298
Total		7.443	0.963	8.406	1.504	0.778

The data presented in Table 5 indicate that the total annual yield of Estonian forests is 8,406 thousand m³ including the yield of traditional firewood 963 thousand m³ (7,223 TJ). In comparison to Lithuania, according to Kairiūkštis *et al.* (2003) the Lithuanian annual yield of forests is estimated to be 10,480 thousand m³ including fuel wood 3,380 thousand m³. As a rule the traditional firewood is harvested and used.

About 60% of the total harvested trees is left in the forest and non-commercial species are often felled and left at site to rot or to make logging easier (Parikka 2004). However, the unused resource is harvesting residues, mainly tops and branches. Theoretically the amount that is available is 1 504 thousand m³ (9,775 TJ), in Lithuania 1,430 thousand m³ (Kairiūkštis *et al.* 2003). In addition to that, the potential of stumps has not been used up to now either. For calculations, only the resource of stumps from the final felling was taken into account as the collection of stumps after thinning will cause damage to the remaining trees. The results of the calculations indicate that the total volume of stumps from final felling is 778 thousand m³ (5,059 TJ). Based on the experience of Finland it can be said that only harvesting stumps of coniferous trees is feasible. The total amount of stumps of coniferous trees is 480 thousand m³ (3,123 TJ) but due to the environmental restrictions the volumes that are available in reality are smaller.

As a result of the calculations also the theoretical yield of Estonian forests was found - in this case the environmental restrictions were not taken into account (Table 6). According to the calculations the total theoretical annual yield of Estonian forests is 9,844 thousand m³ and the share of traditional firewood is 1,318 thousand m³ (9,884 TJ). The theoretical yield of harvesting residues can be up to 1,764 thousand m³ (11,463 TJ) and the quantity of stumps up to 913 thousand m³ (5,938 TJ), incl. 568 thousand m³ of stumps from coniferous trees.

Table 6. Theoretical long-term average annual yield of forests, Mm³ (TH – thinning, CC – clear cut)

Tree species	Felling system	Merchant-able wood	Fire-wood	Total	Harvest-ing residues	Stumps
Conife-rous	TH	1.208	0.395	1.603	0.573	
	CC	1.943	0.697	2.639	0.347	0.346
Deci-duous	TH	1.726	0.013	1.739	0.378	
	CC	3.648	0.214	3.862	0.465	0.568
Total		8.525	1.319	9.843	1.763	0.914

Discussion and conclusions

The results of the analysis indicate that the total annual yield of Estonian forests is 8,406 thousand m³. The area of commercial forests is 1,805.2 thousand ha and it is the main source of wood based fuels in Estonia. The total area of protected forests is 394.1 thousand ha (incl. strictly protected forests 206.9 thousand ha) and due to the different protection regimes, forest management of these forests is limited. Therefore only very small addition to wood fuel resources can be obtained from these forests. The annual yield of traditional firewood can be estimated to be 963 thou-

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sand m³, the resource of harvesting residues, mainly tops and branches, can be up to 1,503 thousand m³, and the total volume of stumps from final felling is 778 thousand m³ (incl. the volume of stumps of coniferous trees is 480 thousand m³).

We can draw the conclusion that due to environmental restrictions the loss of merchantable wood in Estonian forests is 1,437 thousand m³ (incl. 355 thousand m³ of traditional firewood), 260 thousand m³ of harvesting residues and 135 thousand m³ of stumps (incl. 87 thousand m³ of stumps from coniferous trees).

Acknowledgements

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ОПРЕДЕЛЕНИЕ ЭНЕРГЕТИЧЕСКОГО ПОТЕНЦИАЛА ЛЕСОВ ЭСТОНИИ

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Резюме

С целью набора исходных данных для программы „Программа развития биомассы и биоэнергии на период с 2007 по 2013 год“ Фонд развития агрокультуры финансировал ряд исследований. В данной статье представлены результаты исследования, целью которого было определение энергетического потенциала лесов Эстонии. Исходя из данных таксации, моделирования лесных ресурсов и анализа дигитальных карт был определен ежегодный энергетический ресурс. Также было выявлено уменьшение доступного ресурса с учетом ограничений для охраны окружающей среды. Ежегодный сбор лесоматериала из эстонских лесов составляет 8 406 тысяч кубометров, содержание сортимента для заготовки дров 963 тысячи кубометров (7 223 TJ). Теоретический ежегодный сбор отходов рубки 1 504 тысячи кубометров (9 775 TJ) и объем пней от сплошных рубок 778 тысяч кубометров (5 059 TJ) включая объем хвойных пней 480 тысяч кубометров. Полученные результаты могут быть полезны для пространственного анализа использования биологического топлива.

Ключевые слова: ресурс биомассы, отходы рубки, альтернативные ресурсы