Austro2007/FORMEC´07: Meeting the Needs of Tomorrows´ Forests – New Developments in Forest Engineering, October 7 – 11, 2007, Vienna and Heiligenkreuz – Austria

REGIONAL WOOD ENRGY LOGISTICS – ESTIMATION OF ENERGY WOOD RESOURCES BASED ON INVENTORY DATA

Christian Kanzian[1]; Georg Kindermann[2]
[1]University of Natural Resources and Applied Life Sciences; Vienna; Austria;
christian.kanzian@boku.ac.at;
[2]Bundesamt und Forschungszentrum Wald; georg.kindermann@bfw.gv.at

Keywords: Energy Wood Potential, Forest Inventory, Fuel Wood Resources

Abstract*:* *A renaissance of fuel wood has caught the Austrian forestry. The climate change forces the politics to subsidize renewable energy. 48% of Austria area is covered by forest. The utilization of the annual wood growth, especially in small scale forests, is low and we have a backlog of thinnings. Decision makers see a high potential of fuel wood out in the forest, but can all this considerate as energy wood? In terms of planning new biomass plants as well as the design of supply chains and calculation of supply costs, the availability of fuel wood is of great importance. The production of merchantable roundwood is still one of the primary targets of Austrian forestry. To get an idea of the amount of useable fuel wood, the Austrian forest inventory is used to estimate the potential annual "fuel wood" increment.*

The Austrian forest inventory, from the research area, was analyzed and all compartments of "non-merchantable" wood, tops and branches have been identified as energy wood. Using a taper curve and several biomass functions the volume of this compartments were calculated. At sensitive locations, were nutrient removal causes degradation, the use of branches was excluded. To predict the development of usable fuel wood for the next 20 years a tree growth model was applied. Different utilization periods for reducing the backlog of thinnings were assumed and the respective theoretically usable volume of energy wood was estimated. The ratio of technical and economical available energy wood is based on expert estimation.

The theoretically-ecological available amount of all defined fuel wood assortments (e.g. poor quality wood, tops and branches) is in the range of 330.000 m³ per year for the whole area and 2.3 m³ per year per hectare respectively. Maybe 60% of that amount is technical and economical usable for forest fuel production. A usage of the thinning backlog within the next 10 years will increase the amount of energy wood for 30% within this time period. A time period of 20 years will not gain any additional energy wood. If the utilization rate will remain the same as in the past, the stand volume per hectare will increase from 321 m³ up to 416 m³ within the next 20 years.

1. Introduction

By signing the Kyoto-protocol Austria has agreed to reduce the CO2 emissions by 13% in the time period 2008 till 2012 compared to the year 1990 (Schneider and Proidl, 2003). To reach the target, different strategies are required e.g. subsidizing of green energy production. More precisely electricity produced by burning forest chips in combined heating power plants (CHP) is especially promoted by a subsidized supply with current rate. The boost is such attractive that many power suppliers start to build CHP across the whole country. Assumptions about future fuel wood demand predict an increase from 1.6 to 5.0 mil. m³ solid fuel wood needed by CHP till 2007. The demand of solid fuel wood in total, including house heating and so on, was 10 mil. m³ in 2000. Referring to the forecast in total this will double till 2010 (Katzensteiner and Nemestothy , 2006).

In the past mainly saw by-products and bark was used as solid fuels in heating plants. Forest chips did not play an important role, as the supply costs and the fuel quality were not acceptable (Stockinger and Obernberger, 1998; Kanzian et al., 2006). Through the renaissance of wood as solid fuel new questions came up regarding supply logistics and costs. The availability and the allocation of the resources has a great impact on the design of supply chains and the costs (Asikainen et al., 2001; Nord-Larsen and Talbot, 2004; Ranta, 2005; Kanzian et al., 2006). Different studies about fuel wood potential in Austria are published, but all of them take the top-down-principle to estimate the amount. The calculations are based on addition and deduction rates applied on the results of the national forest inventory (Lechner et al., 2003; Haas and Kranzl, 2002; Jonas, 2003; Hirschberger, 2006). This study results differ in a wide range and do not allow any forecasts and ecological, economical and technical barriers are neglected.

This preliminary study tries to use the bottom-up principle, which means the calculation of volume for different fuel wood assortments for each individual tree in the forest inventory and the summarization by different categories. A drawback is, that the raw data of the national inventory is not free available and has to be purchased. In the study three different harvesting strategies and different development of stocking and growth, caused by these three different harvesting strategies, have been examined for the next 20 years.

2. Material and methods

2.1. Study area and data

Beside the political districts, Austria is also divided in forestry districts. The study area involves the three forestry districts “Friesach, Feldkirchen and St. Veit” in southern Austria with a total forest land of 139,300 ha. Compared to the share of forest land in Austria, which is around 48%, these districts are rich in forest. The district “Friesach” has a forest share of 74%. The annual wood increment varies between 10.0 and 11.0 m³/ha/year. The annual harvest is in the range of 4.2 to 8.0 m³/ha/year. So the utilization rate is between 41% and 73%. In the region 94% are conifers trees, mostly spruce followed by fire, larch and pine.The remaining species belong to hardwood trees.

The Austrian forest inventory has a nation wide raster of grouped sample plots, which means that every 3.89 km a survey unit is located with four independent plots arranged in a square with a side length of 200 meters (Schieler and Hauk, 2001). This results in 375 sample plots inside the study area. At each plot the angle-count method is applied to trees with a diameter at breast high (DBH) greater than 105 mm. Trees with a DBH less than 105 mm are observed on a circular sample with a radius of 9.77 meters. The analysis in this study is based on the raw data of this area.

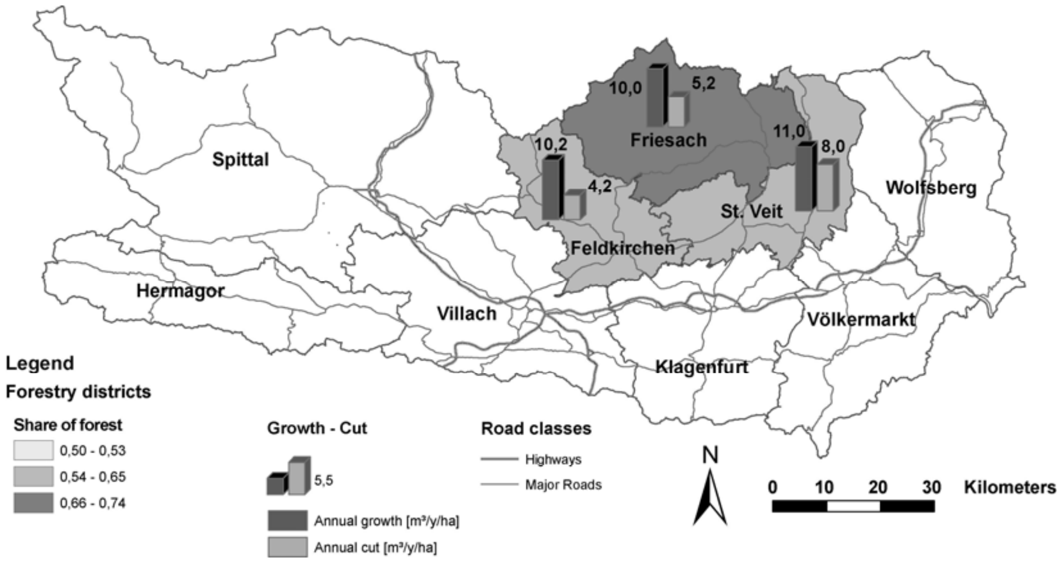

Figure 1: The study area in the southern part of Austria includes three different forestry districts shown in grey colours. The bars symbolise the annual growth and cut in these areas.

2.2. Potential of forest fuel and restrictions

Smeets and Faaij (2007) distinguish between five types of potential which are the theoretical, technical, economical, ecological-economical and ecological. The theoretical potential includes all others, because it represents the maximum wood production. Per definition this must have the highest value compared to the others. If technical barriers applied to the theoretical fuel wood potential, the result will be the technical potential. The economical potential is defined as that part of the technical that can be produced at a profitable level. By adding some ecological limits to the economical restriction, a further decrease in the amount of fuel wood potential can be expected and leads to the economical-ecological potential. Applying only ecological barriers to the theoretical fuel wood potential will give some kind of ecological potential.

The evaluation of a technical or economical amount needs the prediction of harvesting technologies, productivities and in the end the profit margin. A lot of data, with a high quality and resolution (e.g. terrain models from laser scanning, stand data) will be required, which are actually not available. Even though having this data doesn't guaranty a proper result as there are still a bunch of unknown facts.

However this study focuses on the calculation of an ecological potential, where some assumptions on the harvestable potential will be made. In consideration of the ecological potential the following restrictions were defined. At sides where nutrient removal is an issue, the green parts should be left, so the use of tops and branches must be excluded. These sensitive sites have soils with deepness less than 30 cm, or belong to one of the following soil types: skeletal, rendzina and podsol soils. From this sides only poor quality wood will be harvested.

2.3. Assortments of forest fuel

In connection with forest fuel the term biomass is used very often, but per definition biomass includes all living substances above and below ground (Kramer, 1988). In Central Europe the use of wood for energy purposes is limited to the above ground vegetable biomass. That comprises assortments like poor quality round wood, crones and branches. Collecting stumps would be an additional option like it is done in Finland (Hakkila, 2004), but there are various restrictions especially in mountainous regions (soil erosion, forestry regulations and laws).

To estimate the volume of wood with is useable as fuel wood, from the inventory data, several assumptions have to be done. The Austrian timber trade regulations distinguish between soft- and hardwood. According to this different bucking diameters where chosen (Table 1). For merchantable softwood the common minimum diameter is 8 cm including bark. Together with the brown branches this will give an additional volume with is not utilized now. Also trees with a DBH less than 10 cm are possible resources of forest fuel. An option to gain more fuel would be a change in the bucking strategy as an increase of the last cross cut diameter from 8 to 15 cm. Poor quality wood includes parts of the stem affected by root rot for example. To determine weather a standing tree is affected and if yes, how much of the stem is rotten, is a basically problem of forest inventories. There are significant correlations between sample trees of inventories and commercial assortments concerning quality, however there is a great variance between different regions and enterprises (Sterba et al., 2003). Nevertheless the national inventory defines several kinds of damages (harvesting, rock fall, deer bark stripping) and the presumption is that the first 2 meters of an affected stem are poor quality (Table 1).

Because of the low share of hardwood trees species in the study area, it makes no senses to define more than two assortments of hardwood. So for the species beech, oak, ash and Sycamore/Maple all compartments with a diameter less than 25 cm are treated as energy wood. For all other species the whole amount of stem and crone wood will be assigned to fuel wood.

Table 1: Definitions of compartments and assortments which can be used as forest fuel.

Softwood	Parts of the stem with a diameter less than 8 cm with bark (top)
	Branches without needles (brown)
	poor quality wood (first 2 meters of damaged stems)
	Trees with a DBH less than 10 cm
	Optional: assortments with a mid diameter less than 15 cm down to 8 cm top diameter
Hardwood	Crone and branches below a diameter of 25 cm with bark for the species beech, oak, ash and Sycamore/Maple
	Total amount of stem and crone wood for all other species

2.4. Volume calculations

The volumes in solid cubic meter of the defined assortments are calculated for each stem in the inventory database separately. For softwood the taper curve from Pöytäniemi (1981) was applied. The stump high (high of felling cut from ground) was set to 30 cm. To calculate the dry mass of softwood branches the biomass functions from Cerny (1990) were used (1, 2). The functions take the DBH (d) in centimeters and the tree high (h) in meters as input parameters. The dry mass was converted by the factor 0.43 g/cm³ to volume.

$$dry\_mass\_living\_branches[kg] = 0.00045394 * (d^2 * h)^{1.1262} \quad (1)$$

$$dry\_mass\_dead\_branches[kg] = 0.021705 * (d^2 * h)^{0.60715} \quad (2)$$

The volume calculation of the hardwood is based on two functions. For the parts of the stem with a diameter larger than 7 cm the formula after Kennel (1972) und for the parts with a diameter less than 7 cm the equation from Pellinen (1986) was used (3, 4). Both require the DBH (d) in cm and tree high (h) in m to calculate the volume in solid cubic meter. The calculated volume includes the stump. Therefore the volume was reduced by the volume of a cylinder with the high of 30 cm – same stump high as for softwood – and the diameter of the stump at the felling cut.

$$V_d = \frac{d^2\pi}{40000} h(0.444907 - \frac{107.345}{d^3} + 0.00000610582 d^2 + \frac{0.467061}{h} + 0.00126815h) \quad (3)$$

$$V_r = 0.01664061 + 0.00000072179 dh^2 + 0.00000252 d^3 \quad (4)$$

2.5. Utilization and harvesting scenarios

The growth simulation for the next 10 and 20 years respectively requires the prediction of trees to be removed. Trees which could be cut because of tending are marked in the database, but the final felling of trees is unknown. Because of the inventory design – using fixed plots with repeated surveys - the database contains information about already removed trees. Trees, which are cut or removed at final, are grouped into following classes:

- clear cut with an area greater than 500 m²,
- single tree selection and
- salvage cut (wind throw, wind- and snow break).

For each group a model was developed to predict the removal of a tree. The models (5, 6, 7) calculate the possibility of cutting within the next five years on the parameters: basal area in m^2ha^{-1} (gha), DBH in cm (d), soft- or hardwood (duba), land owner category (duea), inclination (neig), HD-value (hd) and meters above sea level (duseeh).

$$\rho_{Kahlhieb} = \frac{1}{1 + e^{-(-3.708 + 0.01247 gha + 0.01315 d + 0.3089 duba - 0.8887 duea - 0.1249 neig)}} \quad (5)$$

$$\rho_{Einzel} = 0.01073 \quad (6)$$

$$\rho_{Zufall} = \frac{1}{1 + e^{-(-7.159 - 0.8647 duba - 0.02295 d + 0.0181 hd + 2.035 duseeh)}} \quad (7)$$

Three different scenarios of cutting strategies were developed to show the possible effects of increasing tending operations. The first one represents the actual state of utilization, which means that the same amount of timber will be cut as during the last inventory period from 1996 to 2002. The forest growth simulation model Prognaus and the listed prediction models above were use to calculate the development of the stocking volume for the next 10 and 20 years respectively. Scenario two and three presume different time periods of harvesting the trees which have been selected by the inventory as backlog of tending. For the scenario two a period of 10 years is assumed to harvest the backlog, whereas 50% of the marked stems in the database are removed at the begin of the simulation and the rest 5 years later. In the scenario three the harvest is done during a time period of 20 years, whereas 25% of the marked stems are removed at the beginning, 33% after 5 years, 50% of the still standing trees after 10 years and finally the rest of them after 15 years.

The amounts of fuel wood were calculated for each single tree and have been summed up by different categories like forest district, terrain slope higher than 30%, terrain slope less than or equal to 30% and type of land owner e.g. state forest, private owner up to 200 ha and ownership larger than 200 ha. To give some information about the data quality the standard error for each category was computed.

3. Results

Looking at scenario 1, which reflects the actual state, the sum of all defined assortments gives an amount of energy wood of 2.3 m³ solid per year and hectare ($m^3a^{-1}ha^{-1}$) in average. The highest percentage of the potential is covered by the assortment softwood tops and branches with 39% followed by softwood 8 – 15 cm with 30%. Softwood of poor quality shows with 8% a low proportion. Compared to the distribution of tree species hardwood has an importance as fuel wood with a share of 23% (Figure 2).

If the backlog of omitted tendings and thinnings will be harvested within the next 10 years, the average potential will raise by 30% up to 3.0 $m^3a^{-1}ha^{-1}$. In this case especially a higher proportion of softwood tops and branches as well as the assortment 8 – 15 cm can be expected. At scenario 3 the total amount of fuel wood will be the same as for scenario 1. The slightly different harvesting strategy causes a change of the distribution of fuel wood assortments. The percentage of hardwood increases for the benefit of softwood (Figure 2). It can be assumed that the backlog of tending and thinning effects mostly softwood stands.

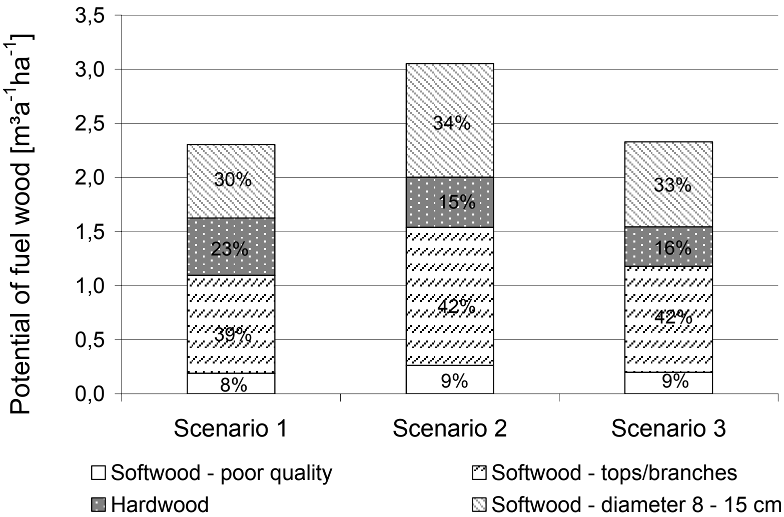

Figure 2: Potential of fuel wood by three different utilization scenarios and aggregated assortments.

A classification and a calculation respectively for each forestry district can be made, but it is afflicted by a high standard error. The total amount of fuel wood has a standard error of 17.6% for the district “Friesach”, 20.6% for “St. Veit” and 39.4% for “Feldkirchen”.

Additional some information regarding the land ownership and an idea of what is technical-economical harvestable is needed. A limit for wheeled forest machinery is the gradient. Slopes up to an inclination of 30% are treated as accessible terrain for harvesters, forwarders and skidders. On steeper slopes the extraction by cable yarders is preferable. In Austria the type of land owner ship or more precisely the size of property owned by one person, has an influence on the annual cut to growth ratio (utilization rate). The Austrian forest inventory distinguishes between different categories of land owner ship. An ownership with less than 200 ha is assigned as small scale land owner. The category of land owners with more than 200 ha has a utilization rate closely to one, but small scale land owners harvest approximately 50% of the annual growth.

In total a potential of 326,000 m^3a^{-1} of fuel wood is available in the three districts. Most of the forest land in the examined region belongs to the category small scale, which is reflected by the amount of potential usable fuel wood. For example tops and branches in the category land owner ship ≤200 ha and slope gradient ≤30% does have a potential of 51,000 m^3a^{-1}. At the category >200 ha there is only a fifth of that, 10,000 m^3a^{-1} of fuel wood, available (Table 2).

In the defined scenarios 2 and 3 the ecological potential of fuel wood changes a long the categories in reference to scenario 1 remarkable. In the category slope gradient ≤30% the potential is in scenario 1 193,000 m^3a^{-1}. Surprisingly the amount decreases in scenario 2 to 114,000 m^3a^{-1} or 59% and the potential increases by more than two times. One reason for that is that the prediction of harvesting is mainly based on tree dimensions. A second cause is that the model does not take into account how much is harvested in total and also does not try to balance the amount over the time.

Table 2: Fuel wood potential at scenario 1 in the study area categorized by land owner ship and slope gradient.

Category		Softwood [m^3y^{-1}]			Hardwood	in total
land owner ship	slope gradient	poor quality	branches/ tops	8 - 15 cm	[m^3y^{-1}]	[m^3y^{-1}]
≤200 ha	>30%	7000	44000	24000	12000	87000
	≤30%	9000	51000	52000	63000	175000
>200 ha	>30%	9000	23000	14000	0	46000
	≤30%	1000	10000	7000	0	18000
sum		**26000**	**128000**	**97000**	**75000**	**326000**

Table 3: Ecological potential of fuel wood compute by biomass functions with inventory data as base.

Category		Scenario 1		Scenario 2		Scenario 2	
		[m³y-1]	[%]	[m³y-1]	[%]	[m³y-1]	[%]
land owner ship	≤200 ha	263000	100%	343000	130%	259000	98%
	>200 ha	64000	100%	90000	141%	71000	111%
slope gradient	>30%	134000	100%	319000	238%	240000	179%
	≤30%	193000	100%	114000	59%	91000	47%
total		327000	100%	433000	132%	330000	101%

Sustainability is one guiding idea of typical forest management plans in Central Europe. The measurement of sustainability is difficult. Traditional forest management plans try to have a sustainable stock, which can be calculated by various formulas which are based on yield tables. The change in growing stock could indicate whether the defined scenario is sustainable or not. If the harvesting behavior does not change, the growing stock will increase from 321 m^3ha^{-1} in 2002 to 369 m^3ha^{-1} in 2012 and finally to 416 m^3ha^{-1} in 2022. Scenario 2, where the annual cut increases by more than 30%, keeps the growing stock at the same level. Compared to scenario 1 the growing stock will increase a bit slower within the next 20 years (Figure 3).

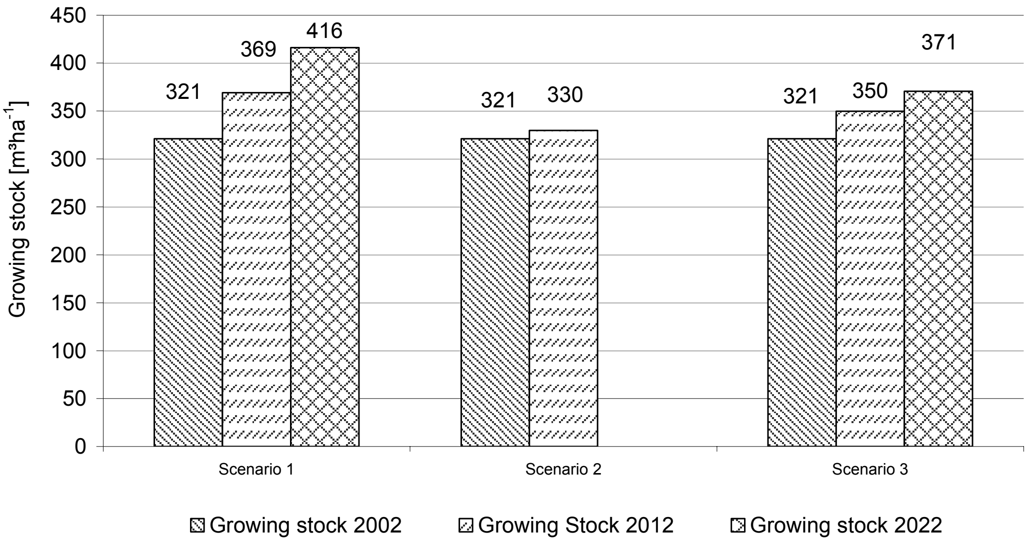

Figure 3: Changes in growing stock along the defined scenarios.

4. Discussion and conclusions

The ecological potential shows the amount of fuel wood at the site. How much of this potential is harvestable in steep terrain is unknown. For the flat terrain different experiences are available (Hakkila, 2004). Nevertheless collecting slash with forwarders like in Finland e.g. will not be introduced in Austria in the next decades because of various reasons like nutrient removal and costs properly. In steep terrain, the use of high mechanized harvesting systems, is common, especially in forest enterprises. The whole tree harvesting system, where the trees processed at the landing, offers the possibility to utilize the harvesting residuals for energy purposes afterwards. Lick (1989) investigated the proportion of dry and green branches which remains in the stand. Therefore he weighted 36 spruce trees before and after logging. The results show that 25% of dry and green branches lost during logging.

Beside ecological also the economical impacts of nutrient removal must be taken in consideration. In experimental stands of spruce after tending and consequent removal of all green material a decrease in growth of 20% was proven (Sterba, 2003 A reduction of growth of 5 till 18% in precommercial thinnings was measured by Nord-Larsen (2002) within the first four years after thinning. Jacobsen et al. (2000) verified a growth reduction of 5 till 6% in spruce and pine stands after thinning. However, the impacts of real harvests, where the whole tree system was used, had not been investigated (Sterba, 2003).

To get an idea how much of the ecological potential is technical-economical harvestable, several assumption can be made. In cable yarding terrain half of the harvest will be done by the whole tree system, whereas 25% of the branches will remain in the stand. This will reduce the potential of 128,000 m^3a^{-1} from scenario 1 to 26,000 m^3a^{-1} technical-economical harvestable wood. The statistics of the annual cut show that conventional fuel wood has a high proportion in the land owner category ≤200 ha, so this amount will not reach the market (Table 4).

The assortment softwood 8-15 cm represents an area of conflict between pulp and board industry and heating plants. How much of the material will be delivered to one of this competitors is influenced by the market price (Thess et al., 2004). Without that volume a technical-economical-ecological fuel wood potential of 111,000 m^3a^{-1} can be expected in the study area.

The study shows that inventory data can be used to estimate fuel wood potential. Nevertheless there is a lack of knowledge in this study field, which has to be closed in the near future. Anyway the results give a first estimation of the regional fuel wood potential and can be used as a reference for further calculations.

Table 4: Technical-economical potential of fuel wood taking ecological restrictions into account.

Category		Softwood [m^3y^{-1}]			Hardwood	in total
land owner ship	slope gradient	low quality	branches/ tops	8 - 15 cm	[m^3y^{-1}]	[m^3y^{-1}]
≤200 ha	>30%	-	17000	24000	12000	53000
	≤30%	-	-	52000	63000	115000
>200 ha	>30%	9000	9000	14000	-	32000
	≤30%	1000	-	7000	-	8000
sum		**10000**	**26000**	**97000**	**75000**	**208000**

5. References

Asikainen, A.; Ranta, T. & Laitila, J. (2001),Large-scale forest fuel procurement, *in* P Pelkonen; P Hakkila; T Karjalainen & B Schlamadinger, ed.,'Woody Biomass as an Energy Source – Challenges in Europe', European Forest Institute (EFI), , pp. 73-78.

Cerny, M. (1990), 'Biomass of Picea abies (L.) Karst. in Midwestern Bohemia', *Scandinavian journal of forest Research*, 83--95.

Haas, R. & Kranzl, L. (2002),'Bioenergie und Gesamtwirtschaft - Analyse der volkswirtschaftlichen Bedeutung der energeitischen Nutzung von Biomasse für Heizzwecke und Entwicklung von effizienten Förderstrategien für Österreich', Technical report, Technische Universität Wien, Institut für elektrische Anlagen und Energiewirtschaft, 239.

Hakkila, P. (2004),'Developing technology for large-scale production of forest chips - Wood Energy Technology Programme 1999 - 2003', Technical report, VTT Processes, 99.

Hirschberger, P. (2006),'Potenziale der Biomassenutzung aus dem Österreichischen Wald unter Berücksichtigung der Biodiversität - Naturverträgliche Nutzung forstlicher Biomasse zur Wärme- undStromgewinnung unter besonderer Berücksichtigung der Flächen der Österreichischen Bundesforste', Technical report, WWF Österreich, 60.

Jacobson, S.; Kukkola, M.; Mälkönen, E. & Tveite, B. (2000), 'Impact of whole-tree harvesting and compensatory fertilization on growth of coniferous thinning stands', *Forest Ecology and Management* **129**(1-3), 41--51.

Jonas, A. (2003), *Potentiale für biogene Rohstoffe zur energetischen Nutzung*, Agrar Plus GmbH, chapter Potentialabschätzung Waldhackgut, pp. 58 - 136.

Kanzian, C.; Holzleitner, F.; Kindermann, G. & Stampfer, K. (2006),'Regionale Energieholzlogistik Mittelkärnten', Technical report, Insitut für Forsttechnik, Department für Wald- und Bodenwissenschaften, Universität für Bodenkultur, 133.

Katzensteiner, K. & Nemestothy, K. P. (2006), 'Energetische Nutung von Biomasse aus dem Wald und Bodenschutz - ein Widerspruch?', *Mitteilungen der Österreichischen Bodenkundlichen Gesellschaft* **74**, 1-10.

Kennel, R. (1972), *Forschungsberichte: Die Buchendurchforstungsversuche in Bayern von 1810-1910 mit dem Modell einer Strukturertragstafel für die Buche*, Forstliche Forschungsanstalt München - Institut für Ertragskunde.

Kramer, H. (1988), *Waldwachstumslehre*, Parey, Hamburg [u.a.].

Lechner, H.; Lackner, M.; Nemestothy, K.; Ritter, H.; Simader, G.; Starzer, O. & Veigl, A. (2003),'Machbarkeitsstudie 4 % Ökostrom bis 2008', Technical report, Energieverwertungsagentur - the Austrian Energy Agency (E.V.A.), 432.

Lick, E. (1989),'Untersuchungen zur Problematik des Biomassen- und Nährelemententzuges bei der Erstdurchforstung ein', PhD thesis, Univ. für Bodenkultur.

Nord-Larsen, T. & Talbot, B. (2004), 'Assessment of forest-fuel resources in Denmark: Technical and economic availability', *Biomass and Bioenergy* **27**(2), 97--109.

Nord-Larsen, T. (2002), 'Stand and site productivity response following whole-tree harvesting in early thinnings of Norway spruce (Picea abies (L.) Karst.)', *Biomass and Bioenergy* **23**(1), 1--12.

Pellinen, P. (1986),'Biomasseuntersuchungen im Kalkbuchenwald', PhD thesis, Georg-Augustus-Universität Göttingen.

Pöytäniemi, A. (1981),'Schaftkurvensystem für die Fichte zur Anwendung bei der Österreichischen Forstinventur', PhD thesis, Universität für Bodenkultur in Wien.

Ranta, T. (2005), 'Logging residues from regeneration fellings for biofuel production - a GIS-based availability analysis in Finland', *Biomass-and-Bioenergy* **28(2)**, 171-182.

Schneider, F. & Proidl, H. M. (2003),'Österreich und die Kyoto-Ziel-Erreichung'.

Smeets, E. & Faaij, A. (2007), 'Bioenergy potentials from forestry in 2050: An assessment of the drivers that determine the potentials', *Climatic Change* **81**(3-4), 353--390.

Sterba, H. (2003),Growth after biomass removal during precommercial thinning., *in* B. Limbeck-Lilineau; Th. Steinmüller & K. Stampfer, ed.,'Austro2003: High Tech Forest Operations for Mountainous Terrain', Institute of Forest Engineering, , pp. 9.

Sterba, H.; Vospernik, S. & Ledermann, T. (2003),'Stem quality predictions and assortments from real harvests', *in* H. Vacik.; M.J. Lexer; M.H. Rauscher; K.M. Reynolds & R.T. Brooks, ed.,'Decision support for multiple purpose forestry. A transdisciplinary conference on the development and application of decision support tools for forest management', University of Natural Resources and Applied Life Sciences, Vienna, CD-Rom proceedings, 10.

Stockinger, H. & Obernberger, I. (1998),Life Cycle Analysis of District Heating with Biomass, *in* '10. Eurpean Bioenergy Conference', pp. 1-4.

Thees, O.; Frutig, F. & Kaufmann, E. (2004), 'Energiepotenzial im Schweizer Wald', *Informationsblatt Forschungsbereich - Eidg. Forschungsanstalt WSL* **18**, 1-3.