PRODUCTIVITY AND COSTS OF STUMP HARVESTING FOR BIOENERGY PRODUCTION IN LATVIAN CONDITIONS

Andis Lazdiņš [1], Henrik Von Hofsten[2], Dagnija Lazdiņa[1], Valentīns Lazdāns [1]
[1]Latvian State Forestry Research Institute "Silava" (LSFRI Silava), [2]SKOGFORSK, The Forestry Research Institute of Sweden (Skogforsk)
andis.lazdins@silava.lv

Abstract. The aim of this paper is to summarize results of two research projects implemented as collaborative actions of Joint stock company "Latvijas Valsts meži" (LVM), SKOGFORSK, The Forestry Research Institute of Sweden (Skogforsk), Latvian State Forestry Research Institute "Silava" (Silava) and State limited company VSIA "Vides projekti" (Vides projekti). The first project, "Forest energy from small-dimension stands, infrastructure objects and stumps" (LVM, Skogforsk and Silava), has the aim to estimate productivity and prime costs of stump extraction in Latvian conditions; the second project, "Biomasas izmantošanas ilgtspējības kritēriju pielietošana un pasākumu izstrāde" (Application of sustainability criteria of utilization of biofuels and elaboration of preventive actions to secure sustainable use of biofuels, Silava and Vides projekti), besides other tasks has targeted to estimate environmentally sustainable resources of stumps for biofuel in Latvian forests. The results of the first project demonstrated, that harvestable amount of stumps in calculation to dry tons is 12% of harvested volume of roundwood in cubic meters under bark. This assumption corresponds to average Swedish and Finnish conditions, but it should be evaluated further in Latvia, taking in account different dimensions of trees and composition of forest stands. The productivity of two key elements of stump harvesting, extraction and forwarding is, respectively, 5.2 and 5.1 t_{dry} E_0-h (dry tons per efficient hour) with one way terrain transport distance 500 m. The total time consumption to produce and supply 1 LVm^3 (LV – loose volume) of stump chips is about 12 minutes in calculation to E_0-h, if one way terrain transport distance is 500 m, road transport distance of stumps – 7 km and road transport distance of chips – 50 km. The prime cost of stump biofuel production under the same conditions is 4.89 LVL LVm^3 in calculation to current fuel price. This cost includes soil preparation for forest regeneration. The total potential of stumps in clear-cuts according to the Forest inventory data about harvesting in 2007 was 1350 th.t_{dry}. A part of those stumps are located in poor forest types on sandy soils, where stump extraction is not recommended, therefore, from environmental point of view the available resources are about 1228 th.t_{dry}. Taking in account technological losses, technically available resources reduce to 737 th.t_{dry} yearly corresponding to about 3903 th.MWh of net energy. It should be taken in account, that no technical or economical limitations are included in this estimation. The total carbon (C) emissions during harvesting and supply of stump biofuel as well as utilization of wood ash as a compensatory fertilizer corresponds to 5.6 % of carbon content in biofuel.

Keywords: stumps, forest, biofuel, extraction, productivity.

Introduction

Logging slash from clear-cuts for biofuel production becomes a widely accepted technology in state and private forests in Latvia. The demand for forest fuel is expected to grow, in spite in 2008 export of wood chips decreased by 11 % in comparison to 2007 [1]. Besides, harvesting of slash from clear-cuts, a variety of other forest residues can be utilized for biofuel production. Extraction of stumps have been started in Finland and in some extend – in Sweden [2]. If cost efficiency is used to evaluate the potential of the potential resources, stumps are located in the next position after slash from clear-cuts, both, in terms of available resources and harvesting costs in Latvian conditions [3].

Stumps consist of all wood and bark of a tree below the stump cross-section. Recovery is performed with heavy machines after harvesting and removal of roundwood. Excavators equipped with special stump lifting heads, that split the stumps into smaller pieces are usually used for recovery. The harvestable dry mass of a stump-root system is 23-25 % of the stem wood mass, for both spruce and pine [2, 4]. As a comparison, the crown mass and stem ratio is typically 40-60 % for spruce and 20-30 % for pine in Finnish and Swedish studies [4]. Information about extractable biomass of stumps of deciduous trees is limited [3]. To recover stumps, the excavator first gets the main teeth of the head below a stump and using it as a lever tries to lift the stump up. Then it squashes the stump between the main teeth and opposite splitting knife and moves to the pile. If the stump is too big, the operator splits it into two to four pieces so that every piece has long enough root for easy handling during forwarding and loading into the crusher. If the stump is too big to extract it at once, the operator cuts some main roots at the sides of the stump and then tries to lift it up again. Usually it is enough to extract stumps with diameter less than 60 cm [3]. The excavator puts stumps in small piles along strip roads and then the roundwood forwarder with extended loading space transports the stumps to the road-side, where they stay for several months to get clean and dry. The next step depends on organization of production – it can be transport of stumps to a larger terminal or an end-use place, or comminuting at the road-side using mobile crushers [3].

Stumps are utilized as solid biofuel in Finland and are becoming economically interesting for energy generation in Latvia, too. The energy content of stumps varies in different references. According to [4] about 140-160 MWh ha^{-1} can be harvested; in other publications 170 MWh ha^{-1} are mentioned [5]; Tekes [6] reported 200 MWh ha^{-1}. Stump recovery can also reduce the cost of site preparation for replanting [2]. It may also inhibit damage caused by pine weevils and the spreading of root rot disease [4].

Materials and methods

The field study of harvesting productivity consisted of detailed time studies of extraction and terrain transport, where separate working elements were evaluated, and less intense time studies of stump road transport, comminuting and wood chip transport, where working elements were not divided, but time consumption was estimated for the process as such, for instance – the total time consumption to fill a container with stumps.

Machines used in the study were a Hyundai LB21Lc crawler excavator with specialized CBI head for lifting operation, a John Deere 1110D prolonged forwarder with slash grapple, a specialized lorry for stump transport with 2 containers (35 m^3 each) and a slash grapple on 7 m long crane and a mobile CBI Magnum Force 6800 P 12 crusher. Additionally, a front loader was used to support stump transport and feeding of the crusher. The CBI stump lifting head had a shear blade to split stumps. The forwarder was equipped with scales to measure the actual loaded and unloaded weight. Both operators of the excavator were experienced with their machines but inexperienced with stump extraction. They had a training period of 2...3 days before the time studies. The operator of the forwarder was experienced with the machine, but inexperienced with stump forwarding. He had a training period of 2 loads before the time studies. The operators of the lorry and the front loader had some experience with stumps and all their working time was included into the time studies.

The site included into the study was a 4.2 ha clear felling, which was harvested in November, 2006 (Table 1). Characteristics of the study plots are shown in Table 2.

Table 1

Stand characteristics before clear cutting

Parameter	Characteristics
Forest site	Zemgale forestry, Garozas forest district, block No. 177, parcel No. 1 (2.7 ha) and No. 5 (1.4 ha)
No. of stems per ha (in average)	500
Tree species	parcel No. 5: 5B1P1S[1] (82 years old) 3P (120 years old) + S (65 years old) in second floor parcel No. 1: 7S2P1B (102 years old) + A, O (102 years old) + S in second floor
Harvested stock	parcel No. 5 – 279 m^3 ha^{-1} parcel No. 1 – 348 m^3 ha^{-1}
Average diameter of trees at breast height	parcel No. 5 – 28 cm parcel No. 1 – 35 cm

[1]B – birch, P – pine, S – spruce, A – aspen, O – oak.

All stumps were measured (average height and diameter) and marked with numbers to accumulate productivity data of harvesting for individual stumps according to harvesting conditions and tree specie. The amount of the material lifted and forwarded was estimated theoretically before calculations of productivity. Equations published in [7] were used to calculate the amount of dry weight of stumps of pine and spruce.

Table 2

Characteristics of study plots before the stump lifting

	Plot 1	Plot 2	Plot 3
Soil type	Sand (ridge)	Sand (low land)	Peat (40 cm)
Plot area, m^2	2,000	1,950	1,250
Species, % (P:S:B,A,O)	28:59:13	12:53:35	31:52:17
Average diameter of stumps (cm)	36	34	35
Gross weight of stumps, t_{dry}	8.6	8.4	3.9

For birch stumps and other deciduous formulas from [8] were used (Table 3). In contrast to the original report [3], biomass functions of the whole underground biomass were applied. The diameter at breast height was calculated using equations of relations of stump diameter and diameter at breast height published in [9]: for spruce 0.7+0.74*D0; for pine –1.89+0.87*D0; for deciduous – 6.7+0.916*D0+50.5/D0, where D0 is the diameter at stump level. The volume of stumps is calculated using assumption that density of stump biomass of spruce is 410 kg m^{-3}, pine – 450 kg m^{-3} and birch – 510 kg m^{-3} [5].

Table 3

Formulas used to estimate the amount of dry weight per stump

Species	Formula for calculation biomass of stump and roots[1]	Source
Pine	EXP(a+b·(D/(D+14)), where constant a = -2.4447 and b = 10.5381	7
Spruce	EXP(a+b·(D/(D+12)), where constant a = -3.3913 and b = 11.1106	7
Birch and other deciduous	EXP(a+b*(2+1,25*D)/((2+1,25*D)+26)+(c+d)/2), where constant a = -3.677, b = 11.537, c = 0.021 and d = 0.046	8

[1]D – diameter at breast height in cm; H – tree height in m.

The total weight achieved in that way included soil and moisture. To adjust for calculations the gross weight was corrected, first with a factor 0.5 [3] to adjust for moisture then with a factor 0.7 [10] to adjust for impurities. Allegro field computers with SDI software were used for time studies.

The structure of the prime cost model (spreadsheet) has been elaborated earlier in other research work in Latvia [11]. When calculating transport costs, the Transam model [12] could preferably be used, since Transam is better suited for transportation analyses. However, in this study simplified vehicle calculation is used. Table 4 shows the cost assumptions, that were used in calculations of investments. Salaries are overall assumed at the level 4.5 LVL E_{15}-h (working hour). Two shifts of 8 + 2 hours are assumed for all type of machines.

Table 4

Assumptions of machine investment costs

Operation and machine	Assumed machine investment cost, LVL, excluding VAT
Excavator for stump lifting with the head	105000
Stump forwarder	143000
Stump crusher + truck for moving	420000
Front loader	40000
Chip truck with 2 containers	70000

The same model of the prime costs was used to calculate carbon emissions during the stump harvesting by adding several rows calculating carbon emissions on the base of fuel consumption. Experimental data from the field studies were used as input values for carbon content and bulk density of stump biofuel [3]. This means, that in other conditions the results might be different, especially according to the bulk density, because it depends from comminuting equipment [13].

The total and technically available potential of stumps in Latvia was estimated on the base of the assumption, that technically available stump biomass in dry tons (t_{dry}) is about 12 % of under-bark volume of harvested roundwood and technological losses are about 40 % of stump and root biomass [3]. The state forest inventory data about harvesting in 2007 were used to estimate the area of clear-cuts and harvested stock. No distinguishing was done according to the specie or type of the stand, because the available scientific data are insufficient for more detailed assumptions [3]. The results of the field study, that is described in this article, were used to estimate development potential of stump extraction in Latvia as additional working places, machine hours and incomes. The fuel cost, machine costs and the cost of wood chips are actualized in comparison to the original material presented in [14].

Results and discussion

The average biomass of stumps in the sample plots No. 1, 2 and 3 was 80.9, 83.9 and 85.4 kg_{dry}, if compensation for the height of stumps is not taken in account. This means, that all plots in spite of different growing conditions represent similar dimensions of stumps. All stumps of deciduous trees due to limited number in productivity calculations are merged into one group.

Table 5

Time consumption and productivity in stump lifting (cmin/t_{dry})

Specie	Data	Plot No. 1	Plot No. 2	Plot No. 3
Deciduous	Total observation time, cmin	3050	2957	1562
	Stump and root biomass, t_{dry}	1.47	1.47	0.53
	Productivity, t_{dry} E_0-h^{-1}	2.9	3.0	2.0
Spruce	Total observation time, cmin	3902	6001	2447
	Stump and root biomass, t_{dry}	4.70	5.52	2.74
	Productivity, t_{dry} E_0-h^{-1}	7.2	5.5	6.7
Pine	Total observation time, cmin	923	1992	972
	Stump and root biomass, t_{dry}	0.79	0.72	0.57
	Productivity, t_{dry} E_0-h^{-1}	5.1	2.2	3.5
All species	Total observation time, cmin	7875	10950	4981
	Stump and root biomass, t_{dry}	6.96	7.72	3.84
	Productivity, t_{dry} E_0-h^{-1}	5.3	4.2	4.6

The productivity in the stump extraction in different plots ranged between 4.5 and 6.5 per productive (E_0) hour, if compensation for the stump height was used, as in the original report [3], with average 5.2 t_{dry} E_0-h^{-1}. Without compensation (Table 5) the productivity in different plots ranges from 4.2 to 5.3 with average 4.7 t_{dry} E_0-h^{-1}. The highest productivity can be reached with the spruce stumps on moist mineral soils, the smallest productivity is characteristic for the pine stumps on dry mineral soils and deciduous on peat soils.

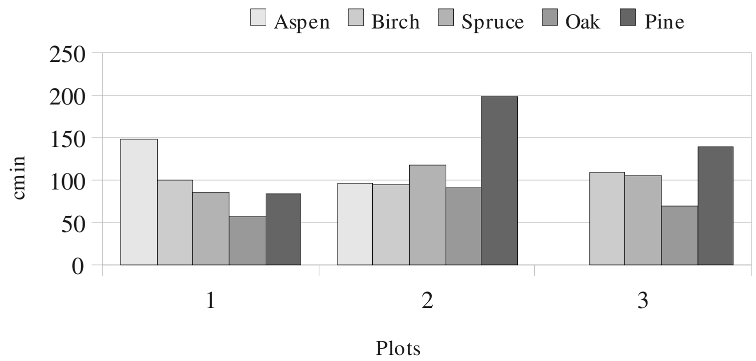

Fig. 1. **Average time consumption per stump**

Extraction of deciduous takes about twice more time than extraction of coniferous in calculation to biomass in all plots, but it may be also a wrong assumption of stump biomass of deciduous trees, because the equation used in calculations is not evaluated in Latvia. The time consumption calculated to a number of stumps (Fig. 1) confirms this conclusion.

The total volume of roundwood assortments produced in this stand were 1131 m^3 under bark or 269 m^3 ha^{-1}. An alternative way of calculating the output of stump volume is from the amount of roundwood, by mass or by volume, according to simple rules of thumb. The actual volume of stump biomass after comminuting was 698 LVm^3 or 166 LVm^3 ha^{-1} (Table 6). The estimated stump mass from functions was 38 t_{dry} ha^{-1}, whereas the actual measured mass was 32 t_{dry} ha^{-1}. This result means, that the equations and methodology of calculation of biomass published in [3] can be utilized in estimation of stump biomass in spruce dominant coniferous stands.

Table 6

Some calculations of the volume of stumps

Volume of stumps calculated according to volume of roundwood[1]	m^3	226
Theoretical output of stumps	LVm^3	678
Calculated volume of stump storage	LVm^3	1194
Volume of transported stumps	LVm^3	1505
Calculated comminuted volume	LVm^3	631
Actual volume and calculated mass of chips in a lorry	LVm^3	698
	LVm^3 ha^{-1}	166
	t_{dry} ha^{-1}	32

[1]20 % by volume or 12 % by mass.

To test for differences of time consumption with increasing size of the individual stump, the total time was plotted against the stump dry-weight (Fig. 2 to 4). The charts show, that no significant correlation between stump dimensions and the time consumption exists. At the same time, when the plot No. 1 was evaluated separately (Fig. 5) significant linear correlation (R^2 = 0,62) was found between the stump size and extraction time for pine.

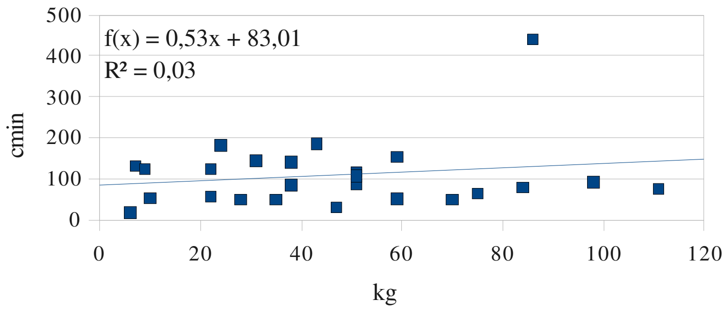

Fig. 2. **Time consumption over stump dry-weight for pine stumps, all plots**

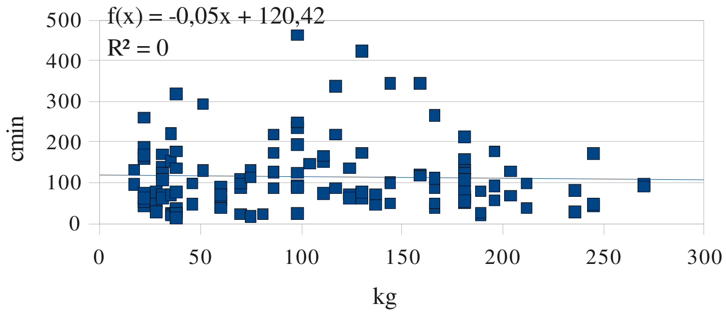

Fig. 3. **Time consumption over stump dry-weight for spruce stumps, all plots**

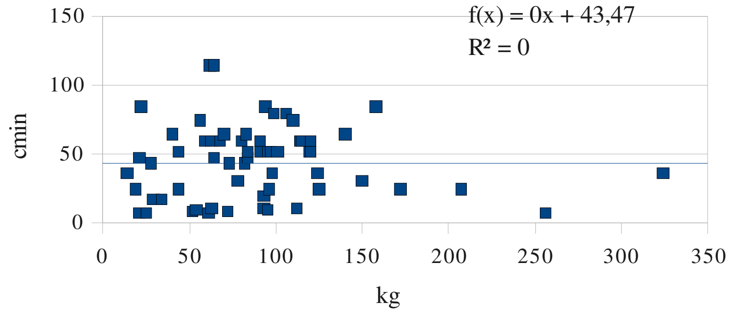

Fig. 4. **Time consumption over stump dry-weight for birch stumps, all plots**

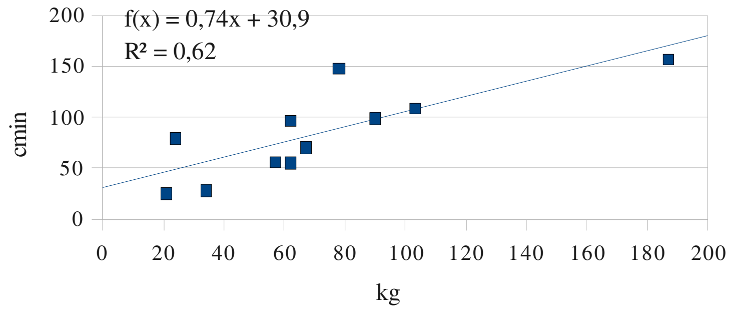

Fig. 5. **Time consumption over stump dry-weight for pine stumps, plot No 1**

The time consumption for the 6 forwarded loads resulted in productivity figures of 5.6...7.7 t_{dry} E_0-h^{-1} depending on the estimation of amount of impurities in the material. In Table 6 70 % wood material has been assumed of the total weight, mainly based on old Swedish studies [10]. To get dry mass, another 50 % has been drawn off (moisture of wood chips of stumps according to the results of the study was 50 %).

Table 7

Time consumption and productivity of forwarding in cmin t_{dry}^{-1}, 6 loads

Operation	Forwarding
Crane out	91.8
Gripping	112.5
Crane in	109.8
Drop	75.2
Arrange (on load)	7.7
Move to next stop	36.7
Reload	15.6
Other work time	3.5
Driving empty	71.5
Driving loaded	82.6
Unloading	294.3
Total forwarded, t_{dry}	16.0
Total cmin t_{dry}^{-1}	901.1
T_{dry} E_0-h^{-1}	6.7

Productivity of the stump road transport in the study was 3.5 t_{dry} E_0-h^{-1} with one way distance to the terminal 7 km. Productivity of the comminution was 10 t_{dry} E_0-h^{-1}. Productivity of road transport of chips was 4.2 t_{dry} E_0-h^{-1}.

The total cost of extraction, processing and supply of stump biofuel to 50 km distance in calculation to the current fuel price is 4.89 LVL LVm^{-3} (Table 8). With harvestable biomass of 32 t_{dry} this cost corresponds to 783 LVL ha^{-1}. According to the time studies soil scarification took 13 % of the working time of the excavator, which means that soil preparation costs 102 LVL ha^{-1}. This is comparable with the soil preparation cost, using ordinary forwarder mounted trenchers (90...120 LVL ha^{-1}) [15].

Table 8

Prime cost calculation of stump extraction

	Excavator	Forwarder	Stump truck	Chipper	Loader	Chip truck	Total
Investments, LVL per year							
Investment	29914	5983	14583	49582	4223	14583	118868
Staff	25329	25329	25329	25329	25329	25329	151976
Operating	51839	44202	32856	201299	47785	32856	410837
Total, Ls/year	107082	75514	72768	276211	77337	72768	681681
Productivity							
LVm^3 E_{15}-h^{-1}	26.00	25.59	18.84	60.00	250.00	20.79	
LVm^3 per year	389376	528307	64552	194832	912600	71259	
Prime costs							
LVL LVm^{-3}	1.43	0.75	1.17	1.46	0.09	1.06	4.89

Carbon emissions calculated on the base of fuel consumption during harvesting, processing and supply of stump biofuel were 3.34 kg LVm^{-3} or 535 kg ha^{-1} with growing stock 160 LVm^3 ha-1 (Table 9). Amount of carbon in biofuel under the same conditions is 86 kg LVm^{-3} or 13.8 th.kg ha^{-1}.

Table 9

Prime cost calculation of stump extraction

	Excavator	Forwarder	Stump truck	Chipper	Loader	Chip truck	Totals
Carbon emissions							
kg LVm^{-3}	0.45	0.25	0.67	1.34	0.04	0.61	3.34
kg ha^{-1}	71	39	107	214	6	97	535

Evaluation of stump resources in Latvian forests shows, that the total technically available amount of the stump biofuel, excluding technological losses, is 737 th.t_{dry} (26.4 t_{dry} ha^{-1}) or 3904 mill.MWh of net energy yearly according to harvesting stock in 2007 and under assumption, that the harvestable amount of stumps in dry tons is 12 % of harvested roundwood under-bark volume. The total resources of stumps according to the previously mentioned assumptions is 1350 th.t_{dry}. If forest stands on poor sandy soils are excluded from the calculation, available resources reduce to about 1228 th.t_{dry} yearly. At the maximum technically reasonable stump biofuel production level (737 th.t_{dry}) the yearly turnover of forest industry would increase by about 31 mill.LVL, excluding administrative costs, taxes and profit from selling biofuel. The production of the stump biofuel would also provide up to 850 working places for machine operators. Taking in account that in 'real world' conditions the machines will not be loaded fully as in field studies, the actual numbers will be higher.

Conclusions

1. The average biomass of stumps including compensation for the height of stump in the field trials was 80.9...85.4 kg_{dry}. The average harvestable biomass of stumps in the trial plots in calculation to dry tons was 12 % of the roundwood under-bark volume.
2. The productivity in the stump extraction in different plots ranged between 4.5 and 6.5 per productive (E_0) hour with average 5.2 t_{dry} E_0-h^{-1}, if compensation according to the stump height is used in calculation. The highest productivity can be reached with spruce stumps on moist mineral soils, the smallest productivity is characteristic for pine stumps on dry mineral soils.
3. No significant difference in productivity of extraction depending on the weight of the stump or specie of trees was found in the study, except for pine on dry mineral soil, where the time consumption to extract larger stumps was significantly higher.
4. The productivity of forwarding was 5.6...7.7 t_{dry} E_0-h^{-1} depending on the estimation of the amount of impurities in the material. Significantly higher productivity can by reached by more efficient utilization of the forwarder loading capacity.

5. The productivity of the stump road transport in the study was 3.5 t_{dry} E_0-h^{-1} with one way distance to the terminal 7 km. The productivity of the comminution was 10 t_{dry} E_0-h^{-1}. The productivity of road transport of chips was 4.2 t_{dry} E_0-h^{-1}. The road transport of stumps was a less efficient step of stump biofuel production, which should be avoided, if possible, in industrial scale production by utilization of smaller mobile crushers, which can work at roadside.
6. The total cost of extraction, processing and supply of stump biofuel to 50 km distance in calculation to the current fuel price was 4.89 LVL LVm^{-3}. The cost in calculation to the area corresponds to 783 LVL ha^{-1}.The soil scarification took 13 % of the working time of the excavator, which means, that soil preparation, if it is done simultaneously with stump extraction, costs 102 LVL ha^{-1}. Carbon emissions to harvest, process and supply stump biofuel were 3.34 kg LVm^{-3} or 535 kg ha^{-1} under the field study conditions.
7. The total technically available amount of the stump biofuel in Latvian forests is 737 th.t_{dry} (26.4 t_{dry} ha^{-1}) yearly according to the harvesting stock in 2007 and under assumption that a harvestable amount of stumps in dry tons is 12 % of harvested roundwood under-bark volume. The production of stump biofuel at the maximum technically reasonable scale would provide up to 850 working places for machine operators.

References

1. Ministry of Agriculture of Republic of Latvia, Meža nozares produkcijas izvedums no Latvijas (Export of wood industry products from Latvia), 2008, http://www.zm.gov.lv/doc_upl/2007_2008.pdf
2. Eriksson L.N. and Gustavsson L., Biofuels from stumps and small roundwood - Costs and CO2 benefits, 2008, Vol. 32, 897-902 pp.
3. Thor M., Nordén B., Iwarsson-Wide M., von Hofsten H., Lazdāns V., Lazdiņš A., Zimelis A., Forest energy from small-dimension stands, "infra-structure objects" and stumps (research report), SKOGFORSK, The Forestry Research Institute of Sweden, 2008, 75 p.
4. Hakkila P., Developing technology for large-scale production of forest chips. Wood Energy Technology Programme 1999-2003, National Technology Agency, 2004, 99 p.
5. Nylinder M., Relationstal, träbränslen – olja, Rapport nr 110, Swedish University of Agricultural Sciences, Department of Forest Products, 1979, p. (In Swedish)
6. TEKES, Stumps - an unutilised reserve, 2004
7. Marklund L.G. , Biomassafunktioner för tall, gran och björk i Sverige, Biomass Functions for Pine, Spruce and Birch in Sweden Rep. No 45, Department of Forest Survey. Swedish University of Agricultural Sciences, 1988, 73 p. (in Swedish)
8. Repola J., Ojansuu R., Kukkola M., Biomass functions for Scots pine, Norway spruce and birch in Finland, 2007, Vol. 53, 1-28 pp.
9. Семенюта Ф.И. , Лесая таксация (Forest inventory), Ленинград, 1961, 337p. (in Russian)
10. Jonsson Y., Teknik för tillvaratagande av stubbved (Techniquesfor recovering stump wood), 1985, Vol. 3, 33 pp.
11. Thor M., von Hofsten H., Lundström H., Lazdāns V., Lazdiņš A., Extraction of logging residues at LVM (research report), SKOGFORSK, The Forestry Research Institute of Sweden, 2006, 38 p.
12. Skogforsk, Transam model, 2006, http://www.google.com/url?sa=t&source=web&ct=res&cd=2&url=http%3A%2F%2Fwww.skogforsk.se%2Fupload%2F37688%2Ftransam_sv2.xls&ei=0yHGSbDQBI-TsAaAtOndCw&usg=AFQjCNHRfl1zMNBgilI4naqZxWC2nQpLaA&sig2=K_lgC4K5jlWEzk3Ie8-H7w
13. Van Loo S. and Koppejan J., 2008, 442p.
14. Lazdiņš A, Biomasas izmantošanas ilgtspējības kritēriju pielietošana un pasākumu izstrāde (Application of sustainability criteria of utilization of biofuels and elaboration of preventive actions to secure sustainable use of biofuels, research report) , LVMI "Silava", 2008, 37 p.
15. Lazdiņa D., Liepa J., Liepiņš J., Lazdiņš A., Mehanizētās ietvarstādu stādīšanas tehnoloģiju mežsaimnieciskais novērtējums (Silvicultural evaluation of mechanized container seedling planting technologies, research report), LVMI "Silava", 2008, 63 p.