PRELIMINARY RESULTS OF ESTIMATION OF FOREST BIOMASS FOR ENERGY POTENTIALS IN FINAL FELLING USING A SYSTEM ANALYSIS MODEL

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Abstract
Forests in Latvia have the highest potential to increase sustainable deliveries of biomass to secure implementation of the National and the Community targets in reduction of the greenhouse gas (GHG) emissions and increase of the share of renewables in the energy sector. According to the study, the final felling is the most significant source of forest biomass for energy in Latvia being able to provide additionally about 8.6 mill. MWh of primary energy annually (excluding the firewood assortment and potential production losses) without increase of the harvesting rate.

The scope of the study is to adapt results of the productivity studies and harvesting cost calculation models to the biomass production system analysis and to estimate resources of the biomass in the final felling on the base of the current harvesting rate and production costs. Harvesting slash (tops and branches) and stumps are considered in the study, taking into account the impact of technical (losses) and site specific limitations of the biomass production. Additionally, machinery and labour necessary for the full scale production as well as the GHG emissions from additional fuel consumption and amounts and characteristics of wood ash to be managed after the full scale implementation were evaluated.

The study demonstrates that the technological potential of biomass for energy in final felling, keeping the harvesting rate at the level of 10 mill. m^3 annually, is 2.1 mill. tons, including firewood. The full scale production would require about 1.3 mill. of working hours, at least 400 units of different machinery and more than 1000 of qualified operators. The prime cost of production at full load of the machinery and the full scale production would be about LVL 45 mill.; however, this figure is higher now due to growth of fuel cost. The additional emissions would be equal to about 36 thousand tons of carbon.

Key words: forest biomass, final felling, bioenergy, system analysis.

Introduction

Forest biomass is already making a substantial contribution to meeting global energy demand. This contribution can be expanded significantly in the future, providing greenhouse gas savings and other environmental benefits, as well as improving trade balances, providing opportunities for social and economic development in rural areas, and improving the management of resources and wastes (Bauen, Berndes, Junginger, et al., 2009).

Bioenergy could sustainably contribute between a quarter and a third of global primary energy supply in 2050. It is the only renewable source that can replace fossil fuels in all energy markets – in the production of heat, electricity, and fuels for transport (Lysen and van Egmond, 2008). However, expansion of bioenergy also poses some challenges. The potential competition for land and for raw material with other biomass uses must be managed. The productivity of forest biomass needs to be increased by improved forestry practices. Bioenergy must become increasingly competitive with other energy sources. Logistics and infrastructure issues must be addressed to continuously harmonize and to reach maximum synergy of forest management and solid biofuel production (Schmidt, Gass, and Schmid, 2011).

At present, forestry is the main feedstock for the generation of electricity and heat from biomass. Today, biomass supplies some 50 EJ globally, which represents 10 % of global annual primary energy consumption. This is mostly traditional biomass used for cooking and heating (Bauen, Berndes, Junginger, Londo, and Vuille, 2009). There is significant potential to expand biomass use by tapping the large volumes of unused harvesting residues, stumps and small trees not used in other industries. Based on this diverse range of feedstock, the technical potential for biomass, including forest resources, is estimated in the literature to be possibly as high as 1500 EJ annually by 2050, although most biomass supply scenarios that take into account sustainability constraints, indicate an annual potential of 200...500 EJ annually. Forestry and agricultural residues (including municipal solid waste) would provide between 50 and 150 EJ annually (Schmidt, Gass, and Schmid, 2011; de Wit and Faaij, 2010).

Projected world primary energy demand by 2050 is expected to be in the range of 600...1000 EJ (compared with about 500 EJ in 2008). Scenarios looking at the penetration of different low carbon energy sources indicate that future demand for bioenergy could be up to 250 EJ annually. Growth in the use of biomass resources in the mid-term period to 2030 will depend on different demand and supply side factors. Strong renewable energy targets being set at regional and national level (e.g. the European Renewable Energy Directive) will lead to a significant increase in demand (de Wit and Faaij, 2010). This demand is likely to be met through increased use of forest resources. Estimates of the potential increase in production do vary widely, just like prognosis for potential deliveries of solid biofuel. For example, the biomass potential from residues and energy crops in the EU to 2030 is estimated to range between 4.4 and 24 EJ (de Wit and Faaij, 2010).

The scope of the study is to evaluate availability and cost of forest biomass resources for bioenergy needs in final felling in Latvia using a system analysis approach for the machine cost and productivity estimates. Final felling stock and distribution by stand types and dominant tree species is borrowed from harvesting reports in 2007 by the State Forest Service, because production in this year was not affected by the economic crisis.

Materials and methods

The study involves estimates of the biomass resources in final felling including harvesting residues, stumps and firewood, but excluding wood processing residues, which are already fully utilized and, therefore, will not contribute in future to increase of solid biofuel deliveries from forest. Felling sites are merged into groups according to growing conditions. All forest types are considered in estimation of potential resources; however, technically available resources of harvesting residues are estimated only for mezotrophic and fertile stand types with good soil bearing capacity (*Vacciniosa, Myrtillosa, Hylocomiosa, Oxalidosa, Aegipodiosa, Myrtillosa mel. and Mercurialosa mel.*). Technically available resources of stumps are not estimated in *Cladinoso-callunosa*. Potential resources of forest biomass in final felling are estimated by multiplication of harvested stock and biomass expansion factors (Table 1) obtained in studies implemented in Latvia in cooperation with the Joint stock company "Latvia State Forests" (Lazdāns, Lazdiņš, and Graudums, 2005; Thor, Von Hofsten, Lundström, et al., 2006; Lazdāns and

Table 1

Relation between roundwood and biomass for energy

Type of solid biofuel	Spruce dominant stands	Deciduous trees stands	Pine dominant stands
Harvesting residues, tons per m^{-3} of roundwood		20 %	15 %
Stumps and coarse roots, tons per m^{-3} of roundwood	20 %	20 %	20 %

Source: calculation of the authors

Table 2

Input data used for system analysis

Type of resource	Harvesting	Forwarding	Road transport to temporary terminal	Comminution	Loading	Road transport to end use place
Time consumption in scheduled working hours, tons per hour						
Firewood	13.1	8.6				16
Harvesting residues		5.7		7		3.3
Stumps	5.2	4.3	18.8	12	50	4.2
Prime cost of working hour, LVL per hour excluding administration and profit						
Firewood	47.3	30.7				23.8
Harvesting residues		30.7		58.3		23.8
Stumps	37.9	28.8	25.1	88.7	25.9	23.1
GHG emissions in the production and delivery process, kg C per ton of biomass						
Firewood	0.4	0.8				0.7
Harvesting residues		1.1		3.6		3.3
Stumps	1.9	1.8	3.4	6.7	0.2	3

Source: calculation of the authors

Table 3

Assumptions for solid biofuel quality

Parameter	Firewood		Harvesting residues and stumps	
	Coniferous stands	**Deciduous stands**	**Coniferous stands**	**Deciduous stands**
Ash content, %	0.3 %	0.3 %	2 %	2 %
Higher heat value, kWh kg^{-1}	5.69	5.61	5.83	5.56
Lower heat value, kWh kg^{-1}	5.33	5.28	5.56	5.28

Source: Thor, Iwarsson-Wide, Von Hofsten, Nordén, et al., 2008; Thor, von Hofsten, Lundström, Lazdāns, and Lazdiņš, 2006

Lazdiņš, 2006; Thor, Berndt, Von Hofsten, Lazdāns, et al., 2008).

The share of technologically available resources (for firewood 5 %, for harvesting residues and for stumps 40 % of the technically available resources) are estimated using research data and expert judgements proposed in the studies implemented in Latvia earlier (Thor, von Hofsten, Lundström, Lazdāns, and Lazdiņš 2006; Thor, Berndt, von Hofsten, Lazdāns, et al. 2008; Lazdāns and Lazdiņš 2006).

Production costs, labour intensity, utilization of machinery and emissions of greenhouses gases (GHG) during the production and delivery are calculated using a tool for system analysis of production costs derived from Swedish model Flis (von Hofsten 2005). Input data for the model are taken from the studies implemented in Latvia earlier (Thor, Von Hofsten, Lundström, Lazdāns, and Lazdiņš 2006; Thor, Berndt, von Hofsten, Lazdāns, et al. 2008; Lazdiņš, Zariņš, Daugaviete, et al. 2007). Fuel costs and salaries are updated according to a nowadays situation. An average distance for fuel delivery is assumed 40 km, an average forwarding distance – 0.3 km, an average number of relocations of forest machinery – 60, an average load of chip truck – 70 m3. Carbon content in biofuel and fossil fuel for calculations of the GHG emissions is assumed 67 kg m-3 (LV – loose volume) and 0.87 kg kg^{-1} (0.72 kg L^{-1}). The assumed bulk density of wood chips is 5 (Andis Lazdiņš, Daugaviete, Bārdulis, et al. 2008). The summary of input data used for system analysis is provided in Table 2.

Assumptions on heat value and ash content of forest biofuel (Table 3) are taken from relevant studies (Thor, Iwarsson-Wide, Von Hofsten, Nordén, et al., 2008; Thor, von Hofsten, Lundström, Lazdāns, and Lazdiņš, 2006) and biofuel standards (Alakangas, 2011). The same values are used for stumps and harvesting residues.

Results and discussion

The total potential biofuel resources in final felling according to the harvesting stock distribution in 2007 is 3 412.7 ktons, including 2 142.8 ktons of technologically available resources annually (Table 4). Nearly half of the potential could be provided by stump extraction and 29 % – harvesting residues (Figure 1). Both resources are not sufficiently utilized nowadays. The biggest technologically available harvesting stock of solid biofuel per area unit (26.7 tons ha^{-1}) is also characteristic for stumps.

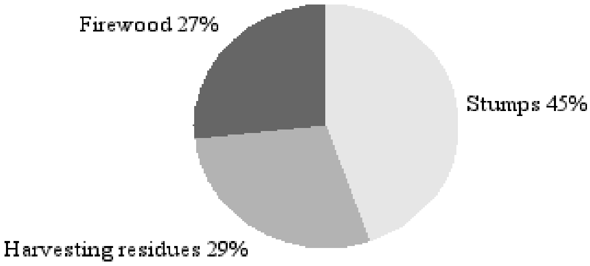
Full scale production of solid biofuel in final felling would fully utilize about 400 units of different kind of machinery, starting from excavators for stump extraction and finalizing with chip trucks (Table 5). The most of the investments relates to stump extraction, where 53 excavators can be fully utilized during the whole year in 2 shifts. This would require about LVL 7 mill. investments. In real world conditions, the machinery will not be utilized to a full extent; therefore, the necessary amount of the machinery can be safely increased by 30...40 %. Full scale production of solid biofuel in final felling would require about 1200 employees working on forest machines (Table 3), excluding administrative and service staff, which is necessary to manage the process. Like in the case with the machines, the number of operators can be increased by 30...40 % to get real world figures on necessary staff. The most of the employees will

Table 4

Resources of forest biomass in final felling

Operation	Firewood	Harvesting residues	Stumps	Total
Potential resources, ktons	600.6	1 205.5	1 606.6	**3 412.7**
Technically accessible resources, ktons	600.6	1 023.1	1 597.2	**3 320.9**
Technologically available resources, ktons	570.6	613.9	958.3	**2 142.8**
Technologically available resources, tons ha^{-1}	5.3	21.5	26.7	**-**

Source: calculation of the authors



Source: calculation of the authors

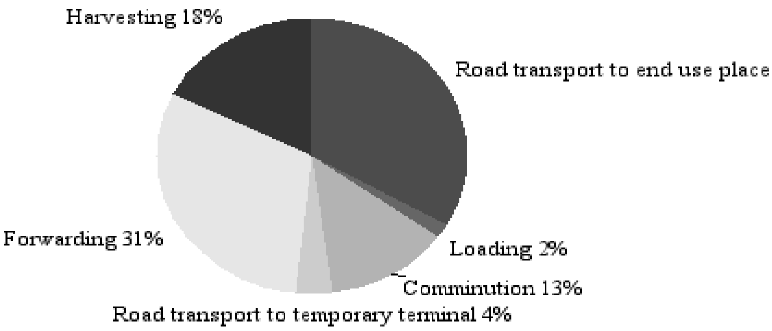
Figure 1. **Distribution of technologically available resources**

Table 5

Necessary labour and machinery resources

Operation	Firewood	Harvesting residues	Stumps	Total
Machinery				
Harvesting	17		53	**70**
Forwarding	22	35	64	**121**
Road transport to temporary terminal			15	**15**
Comminution		27	25	**52**
Loading			6	**6**
Road transport to end use place	10	55	67	**132**
Labour				
Harvesting	50		160	**210**
Forwarding	65	106	193	**364**
Road transport to temporary terminal			45	**45**
Comminution		81	74	**155**
Loading			19	**19**
Road transport to end use place	31	164	202	**397**
Total number of operators	**146**	**351**	**693**	**1190**

Source: calculation of the authors



Source: calculation of the authors

Figure 2 **Distribution of employees by technological process**

be necessary for the stump production and delivery chain. No new machinery and employees are necessary for the firewood production because this resource is already fully utilized; however, there are huge areas of low valued forest biomass belonging to private persons and companies, where firewood is the most convenient output.

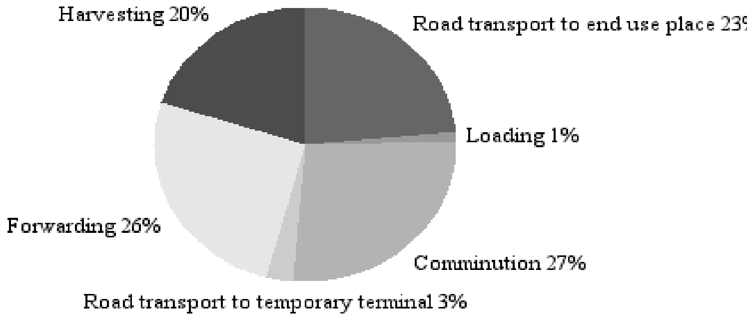
The estimation of the prime cost of the solid biofuel production is very approximate because the system analysis implemented for the study considers full

Table 6

Prime cost of production, thousand LVL, a year

Operations	Firewood	Harvesting residues	Stumps	Total
Harvesting	2 067.9		6 988.7	**9 056.6**
Forwarding	2 038.4	3 295.2	6 397.1	**11 730.7**
Road transport to temporary terminal			1 276.2	**1 276.2**
Comminution		5 116.5	7 086.8	**12 203.3**
Loading			496.2	**496.2**
Road transport to end use place	848.9	4 462.1	5 326.3	**10 637.3**
Total	**4 955.3**	**12 873.8**	**27 571.3**	**45 400.4**

Source: calculation of the authors



Source: calculation of the authors

Figure 3 **Distribution of prime cost by technological process**

Table 7

Emissions of carbon in the technological processes

Operations	Firewood	Harvesting residues	Stumps	Total
Harvesting	0.3		3.1	**3.4**
Forwarding	0.5	1.2	2.8	**4.4**
Road transport to temporary terminal			5.4	**5.4**
Comminution and loading		3.7	11.1	**14.7**
Road transport to end use place	0.4	3.4	4.9	**8.6**
Total	**1.1**	**8.2**	**27.1**	**36.4**

Source: calculation of the authors

utilization of the machines; however, it is hard to predict real figures, especially because some technologies are not yet implemented at an industrial scale, for instance, stump extraction. Administration and service costs, which are not evaluated in the system analysis, may be very important part of the market price of biofuel and it's dependant on organizational structure (size of companies, contracting principles) and comfort level of the industry – if the prices are high, administrative costs are rising, as soon as prices drops, administrative costs follow. The system analysis implemented in this study shows that prime costs of biofuel production in final felling if working to a full extent would be LVL 45 mill. annually (Table 6), and 62 % of the cost relates to the stump biofuel production. The weighted average prime cost of biofuel in final felling is 24.4 LVL ton^{-1} (4 LVL MWh^{-1}). Stump biofuel has the highest prime cost – 28.8 LVL ton^{-1}.

Total emissions (carbon released by incineration of diesel) during the production and delivery process could reach 36.4 ktons of carbon (C) annually (Table 7). Stump extraction would contribute to 74 % of the emissions. Comminution is the most energy consuming process (39 % of the total emissions); however, all types of transport consume even more (51 % of the total emissions). Average C emissions due to the incineration of fossil fuel are 3.4 % of carbon stored in the delivered solid biofuel or 3.2 kg MWh^{-1}.

Conclusions

According to the system analysis, the total potential solid biofuel resources in final felling in Latvia, based on the harvesting stock data, was 3 412.7 ktons in 2007. Technologically available resources (excluding the resources located on soils with low bearing capacity and losses during the procurement) are 62 % of the potential. The completely unused part of the resources is stumps (45 % of technologically available amount).

Full scale implementation of solid biofuel production in final felling would require about 400 units of different machinery and about 1200 qualified operators for the machines. Taking in account that in real world conditions the machines will not be utilized to a full extent, the necessary amount of the machines and operators would be by 30...40 % higher. The most of the investments and the new labour places relates to stump extraction.

The system analysis implemented in this study shows that prime costs of biofuel production in final felling if working to a full extent would be 45 mill. LVL annually. The most expensive solid biofuel resource in final felling is stumps (62 % of the total cost). The weighted average prime cost of biofuel in final felling is 24.4 LVL ton^{-1} (4 LVL MWh^{-1}). The most of the savings are possible in the comminution and road transport stage.

Total carbon emissions during the production and delivery process in case of full scale production would reach 36.4 ktons annually. Weighted average carbon emissions from the forest machines are equal to 3.4 % of carbon stored in the delivered solid biofuel.

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