ANALYSIS OF SELECTED METHODS EFFECTIVENESS OF WOOD BIOMASS HARVESTING FOR ENERGY PURPOSES

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Abstract

The research focuses on estimation of amounts of energy spent on preparation and transportation of energetic biomass in form of chips or bundles from final felling residues and further comparison with the energetic output received in the Power Plant of Białystok. The study was performed in 3 forest inspectorates of Augustow Primeval Forest in Northern-East part of Poland.

Quantity of energy spent during technological process of logging of biomass and timber was a sum of energy used during machinery production and energy of fuel used in process of felling, chipping or slash-bundling and transportation of biomass. Final energetic effect was represented by the amount of energy received from biomass burning in an oven of a power plant.

Total emissions of carbon dioxide were calculated basing on quantity of fuel consumed by logging means and parameters of the biomass burned in a power plant.

Data collection was performed in form of working’s day activity study on 20 clear-cut areas. Various machinery operations were observed along 142 h of research.

Key words: energy, wood biomass, chips, carbon dioxide, logging

INTRODUCTION

Global warming seems to be scientifically confirmed fact. A wide-range and long-lasting analyses, performed especially in Europe and Northern America, prove that a result of rising carbon dioxide (CO₂) and other greenhouse gases (GHG) emissions are rapid changes of a temperature, ocean level and a surface of snow cover (IPCC, 2007).

Coal, burning of which is one of the most important sources of CO₂ emitted to atmosphere, is still a main mean of energy production in Poland, with a participation of about 82% in national electricity production (Gabryś, 2012). Such a structure of an energy production cannot be held for a long time. European Union, by its legislation acts – mainly Directive 2009/28/EC of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing
Directives 2001/77/EC and 2003/30/E – obligate Poland to reach level of 15% of renewable energy in total production of energy. The whole EU should reach 20% participation ratio of renewable energy by 2020. It must also be underlined that fossil fuels are about to finish soon: 90% of available coal resources will be exploited by 2070, reaching a ‘coal peak’ around 2030 with annual exploration 8350 Mt (Höök et al., 2008). Forest biomass, also the one logged of final felling residues, is an important resource of renewable energy that cannot be missed as in the European as in a global scale strategy of energy production.

The main aim of the research was comparison of energy spent during logging and transport of final felling residues in two different technological processes (chipping and bundling) with an energy output gained during burning the biomass in an oven of power plant in Bialystok. The study was focused on calculation of carbon dioxide emissions from logging and transport processes as well as burning wood biomass in the power plant. Moreover, the analysis of machinery’s workday structure was performed.

MATERIAL AND METHODS

Research was performed in a vast forest complex located in Northern-East part of Poland, named Augustow Primeval Forest. The total surface of its forests within Polish boarders is 115 000 ha. Predominant types of soils are: rusty soils (62.6%), peat soils (8.8%) and podzols (6.8%). Due to poor quality the soils the most common are coniferous and mixed-coniferous forests (68.7% of forest surface). The dominating tree species are Scots pine (*Pinus silvestris* L.) – 76.2%, Norway spruce (*Picea abies* (L.) Karsten) – 7.4%, Black alder (*Alnus glutinosa* (L.) Gaertn.) – 8.8% and Silver birch (*Betula pendula* Roth.) – 5.9% (Sokołowski, 2010).

Surveys took place in three forest inspectorates of State Forests: Augustow, Plaska and Pomorze, on clear-cut areas, with use of working’s day activity study. Time of machinery’s (chainsaw, mobile chipper, slash bundler and extraction tractor) activity was measured with accuracy up to 1 sec. Periodically the amount of motor-hours were noted basing on reading of machine’s motor-hour counter. Fuel consumption was estimated on a base of machine’s computer readings in case of mobile chippers, slash bundler and transport trucks. Chainsaws’ fuel consumption was measured manually by scaled measuring glass. In an energy balance the primary, in-built, energy of machinery has been taken into account. The primary energy level for logging equipment (except chainsaws) was assessed at the level of 66 MJ kg\(^{-1}\) and mean lifetime for all machines was 18 000 operational productive hours (PH) (Athanassiadis et al., 2002). As a result, the primary energy of mobile chipper was 2.9 MJ per m\(^3\) of loose volume of chips (m\(^3\) lv). In case of slash bundler the primary energy was 9.9 MJ m\(^3\) lv and 2.2 MJ m\(^3\) lv in case of farm tractor performing bundles extraction. CO\(_2\) emissions were calculated basing on the elaboration of Polish Ministry of Environment consisting the heating values and

Parameters of chips combusted at power plant were calculated basing on laboratory analysis.

RESULTS

Felling, delimbing and crosscutting

Lumberjacks were using professional chainsaws (Husqvarna 357 XP, Stihl 361 and Stihl 362) for felling, delimbing and crosscutting operations in short wood logging system. Their activity was observed during over 17 h of work on 4 clear-cuts in Pomorze Forest Inspectorate. 91 trees (Scots pines) were cut down. The total volume of logged wood was 176.5 m³. In that volume, 12 % (21.2 m³) was small-size wood (not exceeding diameter of 7 cm in thicker end), being later chipped or bundled as forest residues for energy purposes. Research showed that the most time-consuming operation was delimbing, representing 29% of observed working time. Together, times of felling, delimbing and crosscutting took 56% of the whole time. Working time of losses due to job organization and repairs did not exceeded 3%. Average labor productivity oscillated between 8.0 and 12.2 m³ h⁻¹. According only to the amount of logged small-size wood, quantity of 1.4 L of gasoline was consumed. Using conversion factor from m³ of solid wood into m³ of loose volume (lv) of chips equal 0.36 (Kofman, 2010) and calorific value of gasoline equal 33.8 MJ L⁻¹, an energy input in this part of biomass logging process was calculated. It was equal 0.8 MJ m⁻³ lv and resulted in an emission of 0.05 kg CO₂ m⁻³ lv.

Biomass logging with chipping on clear-cut surface

Observation of mobile chippers took place in Augustow and Pomorze Forest Inspectorates and referred to chipping units consisting of a chipper Bruks 804 CT or Bruks 805 CT mounted on an undercarriage of forest tractor John Deere 1410 D and 1410 D Eco III. In the observed working time of almost 54 h, 1.296 m³ lv of chips were made. Almost half of the time (49%) of mobile chipper activity was chipping. Among main times, extraction of chips (realized by the whole unit) and returning to the clear-cut took 8% and 7% respectively. Very efficient unloading of chips assured small (4%) participation of that operation. Average operation efficiency of chips logging was 32.8 m³ lv h⁻¹.

Logging of 18 m³ lv of chips (equivalent of cubic capacity of a container of a mobile chipper) lasted in average 0.49 PH.

Average fuel consumption of a chipper was estimated on 45 L PH⁻¹ (1.2 L m⁻³ lv) in case of chipping on a clear-cut. Calorific value of diesel fuel was 35.9 MJ L⁻¹ (43 MJ kg⁻¹) and emission of CO₂ calculated as 2.7 kg L⁻¹ of diesel fuel.

Fuel consumption of a forest tractor during process of chips logging was about 15 L PH⁻¹ (0.4 L m⁻³ lv). The transport of chips was realized by dual container trucks.
with single load of 72 m$^3$ lv and average transport distance was 186 km in both directions (including empty run from power plant to clear-cut localization). Fuel consumption of a truck was 38 L of diesel fuel during empty run and 57 L with a load.

The total energy input in the whole process of logging and transport of chips was estimated on 109.5 MJ m$^3$ lv and CO$_2$ emission was 7.9 kg m$^3$ lv (Fig. 1). Reached energy input did not depart significantly form values presented by Różański, Jabłoński (2009).

Fig. 1. Energy inputs and CO$_2$ emissions during logging of chips

**Biomass logging with bundling on clear-cut surface**

The process was observed on clear-cut areas in Plaska Forest Inspectorate. It consisted of 4 parts: bundling, extraction, transport and chipping of bundles. Bundles diameter was approximately 65 cm and its length was about 2.4 m.

The first part was realized by John Deere Slash Bundler mounted on a John Deere 1490 D Eco II tractor base. Prepared bundles, remained on clear-cut, were extracted by farm tractor Zetor Forterra 115 with specialized trailer aggregated Fao-Far 1142 equipped with a hydraulic manipulator. 45.5 h of the slash bundler (during bundling 845 bundles) and 22 h of farm tractor’s (during extraction of 720 bundles) working time was evidenced. The third part of the process was transport of bundles by a bulk container trucks. Finally, bundles delivered to the power plant’s timber yard were chipped by a mobile chipper. This last part of the technological process was required due to ability of power plant’s combustion system – the only approvable for burning forest biomass form was chipped material.
More than a half of slash bundler working time (53%) was bundling. Time used for servicing, regulations, refueling and refilling materials took 13%. Because of one serious malfunction and organization problems 16% of working time was qualified as losses. Bundling productivity was 28.5 bundles per PH, so even exceeded a productivity given by a producer. Fuel consumption of a slash bundler was 16 L PH\(^{-1}\) what resulted in energy input about 29.7 MJ m\(^3\) lv of bundles, what equals 67.1 MJ m\(^3\) lv of chips.

Main times dominated in an observed time of farm tractor activity: upload- ing, extraction, unloading and returning to the clear-cut took 76% of total time and changing a workplace on a clear-cut (maneuvering among remained bundles) took another 12%. Due to a long distances 7% of time referred to need of long distance transport runs, but on the other hand, practically no time of losses has been noted. Extraction productivity reached 43.1 bundles per PH and fuel consumption 10 L PH\(^{-1}\), what gives energy input about 27.8 MJ m\(^3\) lv of chips.

Single load of a transport truck was 64 bundles (equivalent of about 19 m\(^3\) lv of chips) located in two containers. Average transport distance (both sides) was 205 km and fuel consumption was 90 L, what gives an energy input at level of about 168.4 MJ m\(^3\) lv of chips.

Time of work of the mobile chipper, that was chipping delivered to the power plant bundles characterized with a small factor of main times participation. Only 49% of whole time was spent for chipping, extracting and unloading of material, reaching however very high productivity (60.4 m\(^3\) lv PH\(^{-1}\)). The malfunction of a hydraulic manipulator with 17% of time spent on repairs and the improper work organization - waiting for bundles delivery - with idle time accounting for 20%, had a great impact on the overall working time structure. In time of total 6.5 hours 780 bundles were chipped resulting in gathering 234 m\(^3\) lv of chips. Chipper and tractor energy inputs were 26.7 MJ m\(^3\) lv and 8.9 MJ m\(^3\) lv of chips respectively.

Primary energy of all machines engaged in the logging process (except chainsaws and trucks) was 13.9 MJ m\(^3\) lv of chips. Total energy input of the whole process was 313.6 MJ m\(^3\) lv and CO\(_2\) emissions were calculated as 22.1 kg m\(^3\) lv of chips (Fig. 2).

**Estimation of energy output of chips combustion in power plant with consideration of CO\(_2\) emissions**

Basing on data from laboratory analysis of chipped biomass delivered to Bialystok Power Plant a heating value of chips was estimated, which, in average, was 11 892.6 MJ t\(^{-1}\). Considering effectiveness of an oven equal 84% and average mass of 1 m\(^3\) lv of chips equal 333 kg, an energy effect of burning of 1 m\(^3\) lv of chips was 3326.6 MJ. Average CO\(_2\) emission was 434.7 kg m\(^3\) lv of chips. The research proved a strong correlation between heating value and chips moisture as well as total coal content (Fig. 3). Spearman correlation indexes were -0.92 and 0.99 respectively. Correlation between heating value and content of total sulfur (-0.10) and content of ashes (-0.19) was practically irrelevant, however content of ashes was correlated with content of sulfur (0.70).
In case of analytic samples (dried and prepared for laboratory analysis) the correlation was weaker but still significant: Spearman index was -0.64 for correlation between combustion heat and moisture and 0.91 between combustion heat and total coal content.

**Energy balance of logging technologies**

Analysis proved that energy inputs of researched logging and transport technologies are significantly lower than energy effects generated at Bialystok’s Power Plant oven. Although the process of slash-bundling is almost three times more energy-consuming than process of chipping, there still is a major difference between energy inputs and combustion effect (Fig. 4).

Received energy input-output ratio in case of chipping technology (3.3%) is similar to results reached by Wihersaari (2.1%) (2005) and in case of bundling technology (9.4%) lower than described by Gustavsson et al. (average 16.7%) (2011). The difference could be additionally enlarged if the transportation distances between logging sites and power plant were shorter. This could be achieved not only by logging the biomass in forest inspectorates located closer to Bialystok but also by building biomass combustion installations in a range of Augustow Primeval Forests, in cities like Augustow, Sejny or Suwalki. All three cities have local heating plants powered by coal that has to be transported for several hundred kilometers from Southern Poland or even from Ukraine or Russia. Supporting, in different ways, of modification of existing heating systems into biomass combus-
tion ovens would assure not only reduction of GHG emission but also upgrade efficiency of those installations.

![Figure 3](image1.png)

**Fig. 3.** Correlation between heating value and selected physicochemical properties of biomass in form of chips

![Figure 4](image2.png)

**Fig. 4.** Comparison of energy inputs and energy gathered during chips combustion

**CONCLUSIONS**

The most significant part of the logging processes – as in case of chipping as slash bundling – was the transportation of biomass. Its participation in a total energy inputs’ balance was 43% in chips logging process and 54 % in slash-bundling process.
Biomass logging – both in form of chips and bundles – was justified from energy balance point of view. Technology of biomass logging in form of chips was about three times less energy-consuming than biomass logging in form of bundles. However chips combustion in the power plant in Białystok assured 10 times more energy than required for biomass harvesting in a process of bundling and 30 times more energy than required for biomass harvesting in a process of chipping.

CO₂ emission in a small scope depended on a biomass harvesting technology as the greatest emission took place during combustion of chips in an oven of power plant. Total emission of CO₂ (including biomass combustion) was 442.5 kg in case of chips logging and 456.8 kg in case of bundles logging. In both cases over 95% of CO₂ emissions was a result of combustion.

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