ACTA SCIENTIARUM POLONORUM
*Acta Sci. Pol.*
*Silv. Colendar. Rat. Ind. Lignar. 11(4) 2012, 27-36*

# EFFICIENCY OF ENERGY WOOD CHIP PRODUCTION FROM FOREST BIOMASS*

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**Abstract.** Various activities are undertaken worldwide in order to counteract the visible climate changes. One of them is promotion of renewable energy sources. Aims established by the European Commission with respect to increasing the share of energy obtained from RES assume an average increase of up to 20% by the year 2020. Poland, as an EU member state has been obliged to increase the share of energy from RES to 15%. Promoting renewable energy sources contributes to diversification of supplies, thus providing conditions for the development of energetics at a local level. Taking into account Polish conditionings it is believed that biomass, including forest biomass, can be an important renewable energy source. The present study focuses on the problem of efficiency of energy wood chip production from forest biomass utilizing a Bandit 2090 wood chipper. Chipping efficiency, depending on the condition of particular tree stands, ranged from 14 to 17 $m^3 \cdot h^{-1}$.

**Key words:** renewable energy sources, forest biomass, energy wood chips, wood chipper

## INTRODUCTION

In the present situation, when the possibilities of fossil fuel acquisition are more and more limited and at the same time dangers connected with the results of greenhouse effect are increasing, forest biomass, as a basic renewable energy source, is gaining importance. Ecological features which justify the appropriateness of choosing such an energy source is the fact of coal neutralization and significantly less trouble connected with substances released while burning biomass in comparison to other energy carriers. Furthermore, binding of considerable amounts of carbon dioxide in the process of wood

*The research has been conducted within the framework of an international non-subsidized project: **Effectiveness of acquisition, processing and supply of forest biomass for energy** realized under COST ACTION FP0902.

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development is one of the factors preventing negative climate changes. Other advantages of forest biomass as an energy source worth promoting consist in its attractive price and its providing an opportunity to decrease unemployment rates in rural areas, which in some areas tend to be rather high.

Tree biomass has always been utilized by man for heating purposes, in various forms: either in its natural form or turned into charcoal, as well as in the form of gas. The 1970s abounded with new ideas with respect to searching for new energy sources. At that time, characterized by a shortage of raw tree material, the so-called logging residues were brought to the attention of specialists. A number of experiments led to a conclusion that the most convenient way of obtaining small-sized timber was its chipping in a forest and then transporting the loose chips to factories in containers. Depending on the quality of material, wood chips became the focus of interest of various industrial plants (i.e. factories producing chipboards and fiberboards) as well as electrical power and heating plants. In the recent years, all over the world and in Poland new technologies have been developed, which allow to compress logging residues to form them into bales.

At the beginning of the 1990s in Poland there arose a necessity to introduce standards which would make it possible to clearly distinguish industrial wood chips from fuel wood chips and to highlight differences between the two.

Polish standard PN-91/D-95009 ("Wood material. Forest wood chips") strictly defines fuel wood chips as raw material which may be characterized by 50% share of soft rot and in which the presence of twigs, needles and leaves is permitted. Another Polish standard, namely PN-91/D-95019 ("Wood material. Small-sized timber"), explains the connection between the type of raw material and the possibility of obtaining a specific type of processed material. According to this standard, logging residues constitute raw material in which all possible types of timber defects are permissible. Economic profitability of producing bioenergy from poor quality timber is possible only if a high level of mechanization characterizes both the process of material acquisition and its transport and the utilization of the manufactured material. Mechanization guarantees high work efficiency and at the same time allows for reduction of costs.

The present paper provides results of a research investigating work efficiency while producing energy wood chips from logging residues with the aid of a BANDIT 2090 wood chipper.

## AIM AND SCOPE OF THE STUDY

A basic aim of the study was the analysis of efficiency of forest biomass acquisition for energy production over carefully selected areas facilitating the acquisition of desired material in the shape of wood chips from timber material of low and average quality and market value, in conformity with sustainable forest management, according to the concept of multifunctional sustainable forestry which assumes that the condition of the natural environment after the works have been completed is equally important as the profitability of the works.

The research was conducted in 2011 within the area of the Dwukoły Forest Inspectorate, situated in northern Poland. An important element of the study was the analysis of source materials obtained from the forest inspectorate, specifying the level of energy wood chips acquisition over the area in question and the characteristic features of the ground in the locations where, after the completion of activities connected with silviculture, logging residues (tops and branches) were specifically utilized for wood chip production.

All data were analysed using the Statistica program.

## MATERIAL AND METHODS

Research plots where all efficiency measurements of the wood chipper were conducted were composed of four divisions, out of which three differed mainly with respect to chipping management methods resulting from differences in tree species composition and purposes of silviculture, and one division in which late thinning was applied as an upkeep treatment. Basic data regarding particular research plots are shown in Table 1.

BANDIT 2090 is the model of a wood chipper whose efficiency has been analysed. It is a typical compact drum wood chipper designed especially for chipping boughs with multiple twigs and whole trees. The machine is very popular with companies which specialize in conducting chipping in large forest areas.

Table 1. Characteristics of research plots
Tabela 1. Charakterystyka powierzchni badawczych

| | Cutting category<br>Kategoria cięć | | | |
|---|---|---|---|---|
| | IB | IIA | IIIA | TP |
| Division, subdivision<br>Oddział, pododdział | 243b | 10m | 94d | 63a |
| Forest district<br>Leśnictwo | Łomia | Narzym | Mostowo | Mostowo |
| Age of the forest, years<br>Wiek drzewostanu, lata | 81 | 100 | 92 | 65 |
| Type of the forest<br>Siedliskowy typ lasu | Fresh mixed coniferous forest BMśw | Fresh mixed hardwood forest LMśw | Fresh mixed coniferous forest BMśw | Fresh mixed hardwood forest LMśw |
| Forest cover<br>Zadrzewienie | 1 | 0.9 | 0.7 | 0.9 |
| Stand quality class<br>Bonitacja | I.5 | II | II | I |
| Area, ha<br>Powierzchnia, ha | 6.38 | 3.8 | 5.03 | 16.12 |

The following parameters connected with functioning of the machine were taken into account:

– productive capacity
– structure of a working day
– cost of wood chip production.

Productive capacity of the wood chipper, defined as the amount of energetic wood chips produced per unit of time, measured in $m^3 \cdot h^{-1}$, was specified on the basis of time which the machine required to process a particular amount of raw material under particular tree stand conditions. The amount of raw material was established according to data featured in settlements between Forestry Services Company and a respective Forest Inspectorate, in every case being based on the amount of small-sized timber material collected by a forester responsible for a particular area. Operational productivity was calculated according to relations generally adopted for working machines:

$$W = V_z / t, \text{ mp} \cdot \text{h}^{-1}$$

and

$$W = Q_z / t, \text{ m}^3 \cdot \text{h}^{-1}$$

where:

- $V_z$ – loose volume of wood chips produced during the operating working time under particular tree stand conditions, mp,
- $Q_z$ – solid volume of wood chips produced during the operating working time under particular tree stand conditions, $m^3$.

The loose volume of wood chips produced during one working cycle equalled the volume of a container placed on the ground where the wood chipper was operating, whereas the solid volume of wood chips was calculated according to a conversion unit featured in the [PN-93 D-95000] standard, whose value was assumed to equal 0.42.

The structure of a working day was based on the method of continuous time keeping using a timer to measure the duration of particular components of the working cycle.

The number of working cycles completed during a single working shift depended on the operation time $T$, because:

$$T = n_c \cdot t_c$$

where:

- $n_c$ – the number of working cycles,
- $t_c$ – duration of an individual cycle.

Before the study commenced, a number of sites with specific types of cover had been chosen, in order to ensure that making measurements would be possible in particular locations at particular times specified by the schedule of works developed by the forest inspectorate. The recorded results were entered into forms, which facilitated making calculations and interpreting the obtained values.

Components of a full working cycle of raw material chipping were the following:

- driving for the load ($t_1$) – transport of empty containers
- feeding and chipping of the raw material ($t_2$)
- driving with the load ($t_3$) – transport of loaded containers
- unloading ($t_4$)
- service breaks ($t_5$)
- maintenance breaks ($t_6$).

Due to the specific character of a wood chipper operation, $t_2$ was divided into the following time fractions:

- biomass picking up ($t_{21}$)

– feeding biomass into the throat of the wood chipper ($t_{22}$)
– relocation of the wood chipper between work areas ($t_{23}$).

Cost analysis was conducted with the aid of PlusCalc software.

## RESEARCH RESULTS

In the Dwukoły Forest Inspectorate a wood chipper has been used for nine years. In the recent years the areas where it was employed for utilization of residues left after activities connected with silviculture have considerably expanded. This has largely been the result of a growing demand for renewable energy sources.

The analysis of practical application of the technology of energy wood chip production in conjunction with the material supply to an electrical power and heating plant in Sweden [Jabłoński and Różański 2003] proved the key role of chipping conditions, since this factor was identified as responsible for 32% of the overall cost of supplying the plant with energy wood chips. The cost of wood chips transporting to the plant amounted to 25% of the overall cost, while the picking up of logging residues amounted to 20%, the price of logging residues – to 8% and the remaining 16% were defined as "other costs".

The average mean duration of a full working cycle in the analyzed research plots ranged between 2200 and 2550 s (Table 4). Similar values with respect to an average mean duration of a full working cycle were obtained while studying the efficiency of a self-propelled Bruks 805 CT chipper [Zychowicz and Gendek 2009].

Table 2. Share of particular time fractions in the course of a work shift, s
Tabela 2. Udział poszczególnych frakcji czasowych w trakcie zmiany roboczej, s

| | Cutting category<br>Kategoria cięć | | | | Average mean value<br>Średnia |
|---|---|---|---|---|---|
| | IB | IIA | IIIA | TP | |
| Work shift duration<br>Czas trwania zmiany roboczej | 27 561.6 | 27 613.4 | 28 422.7 | 26 490.2 | 27 521.3 |
| Driving for the load – $t_1$<br>Jazda po ładunek – $t_1$ | 1 135.5 | 1 104.5 | 1 898.6 | 3 200.0 | 1 849.4 |
| Chipping – $t_2$<br>Zrębkowanie – $t_2$ | 21 691.0 | 21 370.0 | 24 091.1 | 15 703.4 | 20 649.2 |
| Driving with the load – $t_3$<br>Jazda z ładunkiem – $t_3$ | 1 336.7 | 1 212.2 | 656.6 | 2 951.0 | 1 560.5 |
| Unloading – $t_4$<br>Rozładunek – $t_4$ | 1 736.4 | 1 877.7 | 1 142.6 | 1 406.6 | 1 543.9 |
| Service breaks – $t_5$<br>Przerwy techniczne – $t_5$ | 1 185.1 | 1 137.7 | 372.3 | 2 124.5 | 1 221.9 |
| Maintenance breaks – $t_6$<br>Przerwy technologiczne – $t_6$ | 476.8 | 911.2 | 261.5 | 1 104.6 | 696.3 |

Undeniably, the most crucial element during the whole working cycle of a wood chipper is the chipping itself, as shown by the fact that it takes up much more time than other activities of which the total working cycle is composed. The smallest share of chipping time in the overall time has been observed in the case of a thinned tree stand (ca. 60%). In areas where chipping is applied as a method of forest management, the share of chipping time in the whole working cycle ranges from 77% to 85%, which is due to a considerable concentration of the raw material and the manner in which the wood is prepared for chipping.

An average duration of a working cycle, i.e. filling one container with wood chips lasts from 2200 s to 2550 s. Detailed statistical characteristics of working cycle durations are shown in Figure 1. Obtained results were subjected to analysis of variance (Table 3), which showed significant influence of cutting categories on the duration of working cycles. Then the results were further subjected to RIR Tukey test (honest significance test). In the case of thinned out forest significant differences were observed in comparison to working cycles in other types of tree stand cover (Table 4).

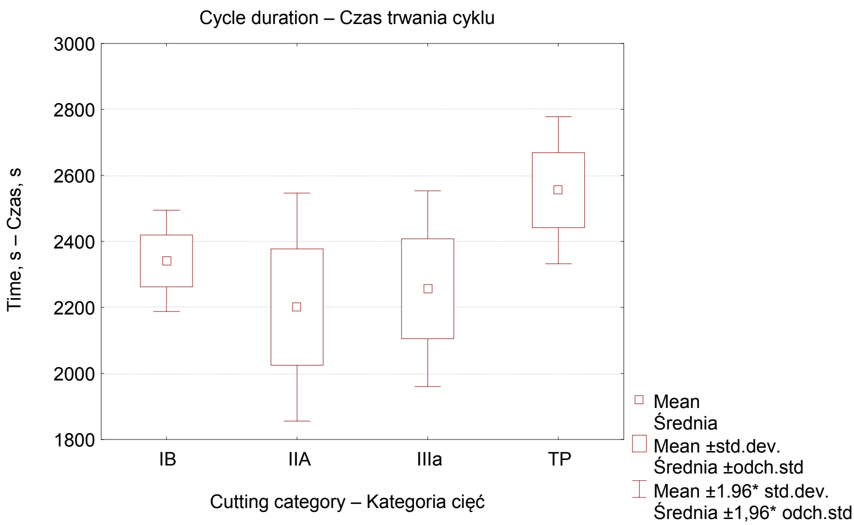


Fig. 1. Diagram of basic working cycle duration statistics while chipping wood representing various cutting categories
Rys. 1. Wykres podstawowych statystyk czasu trwania cykli pracy przy zrębkowaniu drewna w różnych kategoriach cięć

Table 3. Results of the analysis of variance regarding cycle duration for particular cutting categories
Tabela 3. Wyniki analizy wariancji czasu trwania cyklu w poszczególnych kategoriach cięć

| Variant<br>Zmienna | SS Result<br>SS Efekt | df Result<br>df Efekt | MS Result<br>MS Efekt | SS Error<br>SS Błąd | df Error<br>df Błąd | MS Error<br>MS Błąd | F | p |
|---|---|---|---|---|---|---|---|---|
| Time<br>Czas | 1 087 221 | 3 | 362 407.1 | 1 021 360 | 56 | 18 238.57 | 19.87037 | 0.000000 |

Table 4. Results of the post-hoc RIR Tukey test
Tabela 4. Wyniki testu post-hoc RIR-Tukeya

| Cutting category Kategoria cięć | RIR Tukey test; variant: cycle duration<br>Differences marked with bold type are significant for $p < 0.05$<br>Test RIR Tukeya; zmienna: czas trwania cyklu<br>Zaznaczone pogrubieniem różnice są istotne dla $p < 0{,}05$ | | | |
|---|---|---|---|---|
| | IB<br>M = 2 341.3 | IIA<br>M = 2 201.3 | IIIA<br>M = 2 257.0 | TP<br>M = 2 555.3 |
| IB | | **0.031176** | 0.328246 | **0.000477** |
| IIA | **0.031176** | | 0.673509 | **0.000159** |
| IIIA | 0.328246 | 0.673509 | | **0.000159** |
| TP | **0.000477** | **0.000159** | **0.000159** | |

Table 5 shows the analysis of working time of a wood chipper. It has been discovered that the number of crane movements depends mainly on the preparation of raw material for chipping. What is more, this factor also has a significant influence on the structure of time spent on other activities in the course of a working cycle. The share of time spent on picking up wood for chipping in the general working time is similar in the case of all cutting categories, ranging from 38% to 41%. Differences can be observed with respect to the chipping process itself, ranging from 17% in the case of the cutting category IA to 44% in the case of the cutting category IIIA.

Table 5. Analysis of time spent on particular activities during a working cycle of a wood chipper
Tabela 5. Analiza czasów w cyklu pracy maszyny zrębkującej

| | Cutting category Kategoria cięć | | | | Mean average value Średnia |
|---|---|---|---|---|---|
| | IB | IIA | IIIA | TPP | |
| Working time of a wood chipper<br>Czas pracy rębaka | 1 842.6 | 1 703.8 | 1 913.9 | 1 515.3 | 1 754 |
| Time spent on picking up biomass – $t_{21}$<br>Czas chwytania biomasy – $t_{21}$ | 757.86138 | 702.30636 | 734.9376 | 626.42502 | 708.9668 |
| Time spent on feeding biomass into the drum of a wood chipper – $t_{22}$<br>Czas podawania biomasy do gardzieli rębaka – $t_{22}$ | 315.82164 | 544.70486 | 842.49878 | 338.82108 | 514.4482 |
| Time spent on wood chipper relocation between work areas – $t_{23}$<br>Czas przemieszczania rębaka pomiędzy stanowiskami roboczymi – $t_{23}$ | 768.91698 | 456.78878 | 336.46362 | 550.0539 | 530.585 |
| Number of crane movements while picking up the load<br>Liczba ruchów żurawia po ładunek | 54 | 57 | 74 | 39 | 56 |

In the analysed cases, operational productivity ranged from ca. 13.7 to 16.6 $m^3 \cdot h^{-1}$ (Fig. 2). Observed disparities were due to differences in respective tree stands as well as the effect of various types of silvicultural activities performed prior to chipping. The highest productivity was observed in division 94d, under the category of group clear cutting, where three groups were cut, covering the total area of ca. 1 ha. The cutting was performed with chainsaws and low quality timber was arranged into piles, which considerably facilitated work of both a log skidder and a wood chipper. The lowest productivity was observed in the area of thinning performed by a harvester. The outcome was significantly affected by a wide dispersion of the raw material and the fact that the logging residues in that particular area were smaller in comparison to their counterparts in other areas. Similar results had also been obtained by other researchers [Moskalik and Sadowski 2006, Stampfer and Kanzian 2006, Eker 2011].

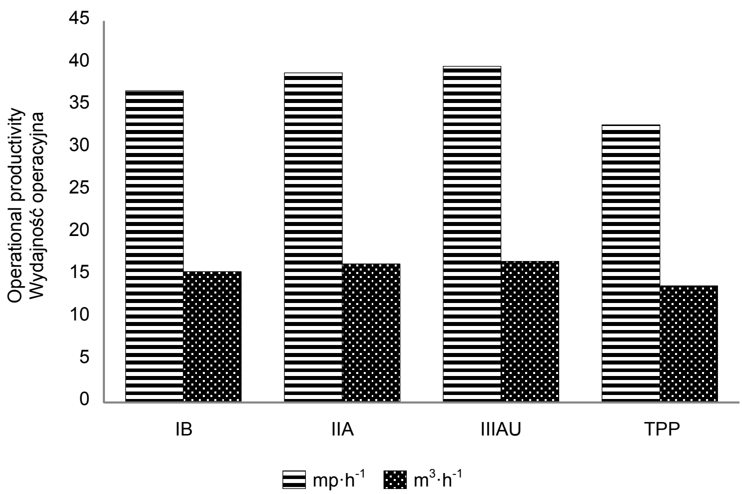


Fig. 2. Operational productivity of a working cycle of chipping logging residues
Rys. 2. Wydajność operacyjna cyklu pracy zrębkowania pozostałości pozrębowych

Cost analysis was made with the aid of CalcPlus software. The following results were obtained:

– Hourly cost of using a wood chipper towed by a tractor – PLN 209.20
– Hourly cost of using a log skidder – PLN 123.64
– Total cost of co-operation of a team of machines – PLN 332.84
– Cost of chipping of 1 $m^3$ of logging residues – PLN 13.22
– Cost of logging of 1$m^3$ of raw material – PLN 7.18
– Cost of producing 1$m^3$ of wood chips (cost of transport excluded) – PLN 21.40.

## CONCLUSIONS

On the basis of conducted research the following conclusions can be drawn:

1. A growing interest in forest biomass as a renewable energy source has definitely been observed in the recent years. An analysis of the scale of acquiring wood chips for energy production purposes in Poland allows for a conclusion that the demand for this type of raw material is constantly growing.

2. An average operational productivity calculated for the whole wood chipping process equaled 15.6 $m^3 \cdot h^{-1}$. The values changed depending on tree stand type and ranged from 13.6 to 16.7 $m^3 \cdot h^{-1}$. Factors determining the changing values of operational productivity included concentration and arrangement of raw material.

3. Hourly cost of the whole chipping process equaled ca. PLN 209. The cost of processing of 1 $m^3$ of logging residues amounted to PLN 21.40. Achieving such results was possible due to exemplary cooperation of machine operators in respective research plots and good training of people preparing the sites for work.

4. The most time-consuming element of a full working cycle was the operation of chipping, on average taking up ca. 75% of the total duration of work. Shares of particular time fractions in the course of a work shift depended on how many portions of material were picked up and the arrangement of the material on the ground, which directly affected the efficiency of the whole operation.

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## EFEKTYWNOŚĆ PRODUKCJI ZRĘBKÓW ENERGETYCZNYCH Z BIOMASY LEŚNEJ

**Streszczenie.** W celu przeciwdziałania obserwowanym zmianom klimatycznym podejmowane są na świecie różnego rodzaju działania. Jednym z nich jest promowanie odnawialnych źródeł energii. Cele wyznaczone w ostatnim okresie przez Komisję Europejską dotyczą wzrostu udziału energii pochodzącej z odnawialnych źródeł średnio do 20% w 2020 roku. Polska jako kraj członkowski UE jest zobowiązana do zwiększenia tego udziału do 15%. Promowanie odnawialnych źródeł energii przyczynia się do dywersyfikacji dostaw, stwarzając warunki do rozwoju energetyki na poziomie lokalnym. Uwzględniając nasze warunki, uważa się, że jednym ze znaczących jej źródeł może być biomasa, także pochodząca z lasów. W pracy przedstawiono efektywność produkcji zrębków energetycznych z biomasy leśnej, produkowanych z wykorzystaniem rębaka Bandit 2090. Wydajność zrębkowania, w zależności od warunków drzewostanowych, kształtowała się na poziomie 14-17 $m^3 \cdot h^{-1}$.

**Słowa kluczowe:** odnawialne źródła energii, biomasa leśna, zrębki energetyczne, rębak

*Accepted for print – Zaakceptowano do druku: 29.10.2012*

*For citation – Do cytowania: Moskalik T., Borkowska M., Sadowski J., Zastocki D., 2012. Efficiency of energy wood chip production from forest biomass. Acta Sci. Pol., Silv. Colendar. Rat. Ind. Lignar. 11(4), 27-36.*