DOI: 10.1515/frp-2016-0006
Available online: www.lesne-prace-badawcze.pl

Leśne Prace Badawcze / *Forest Research Papers*
Marzec / March 2016, Vol. 77 (1): 50–55

ORIGINAL RESEARCH ARTICLE

e-ISSN 2082-8926

Economic methods for the utilisation of logging residues

Tomasz Gałęzia

Pomorze Forest District, Pomorze 8, 16–506 Giby, Poland

Tel. +48 87 5165786, fax +48 87 5165052, e-mail: tomasz.galezia@bialystok.lasy.gov.pl

Abstract. There are several ways of using logging residues, and the two most common ones in the State Forests are wood chip production for energy purposes by mobile machinery and crushing by tractor-powered crushers. In this research, an economy-based approach was used to compare these methods and assess whether chip production is superior to crushing for clearing a felling area. The average revenues from the sale of wood biomass in the form of wood chips and the average costs of crushing in the Pomorze Forest District were analysed for the period from January 2012 until June 2014. Both revenues and costs (such as fuel, operator's wage, piling costs, depreciation, insurance and garaging costs) were extracted from the State Forests' database using data-mining software.

The highest price for wood biomass was achieved in 2012 (104.00 PLN m^{-3}), and the lowest one was reached in 2014 (16.00 PLN m^{-3}). Revenues amounted to 1,353.87 PLN ha^{-1} on an average, whilst the average logging efficiency was 25.60 m^3 ha^{-1} with a share of logging residues compared to the total logged volume of 11.14%.

The highest costs for crushing (1,894.14 PLN ha^{-1}) incurred for clearing gaps in a stand after removing spruces infested with bark beetles. Labour productivity in this case was 0.07 ha pmh^{-1}. Significantly lower costs (1,256.42 PLN ha^{-1}) and greater productivity (0.16 ha pmh^{-1}) were achieved when clearing clear-cut areas.

Considering the above results, it is recommended to compress the logging residues into chips instead of crushing them. The removal of the residues from clear-cut sites may additionally affect forest health positively.

Keywords: crushing, wood chip production, logging residues

1. Introduction

Supporting continuity of forest existence is a basis of sustainable forest management. According to the Forest Act (1991), such management includes harvesting of timber material. The two most common timber harvesting methods in Poland – short-stem system and long-stem system – include delimbing of trees at the landing. In order to conduct future reforestation, the harvesting site should be cleared of logging residues. Whilst during the selection of residue utilisation method, it would be important to consider various economic and environmental aspects (Pierovich, Smith 1973).

Until recently, logging residue has been burned; however, such method was discontinued because of its negative impact on natural environment (Wojtkowiak et al. 2003a, b).

Crushing of logging residue and mixing it with soil using tractor-powered chippers (Maksymiak 2008) is a more environmentally friendly way of residue utilisation. However, such method of logging residue utilisation is quite costly (Różański, Jabłoński 2002).

In the recent years, the need to comply with the European Union directives, which oblige Poland to receive 15% of energy from the renewable energy sources in 2020 (Directive 2009/28/WE 2009), resulted in increased interest of logging residue utilisation for the purposes of energy production (Sadowski et al. 2012). This procedure could also guarantee forest districts additional revenues from sales of residue material. Previous research assumed that utilisation of logging residue as energy woodchips is more profitable than their chipping.

Submitted: 07.10.2014, reviewed: 20.01.2015, accepted after revision: 23.11.2015.

The goal of current work was to evaluate whether energy wood chip production or crushing of logging residue is more economically profitable. Moreover, the study also researches the factors affecting the costs of logging residue crushing as well as their actual share within the total volume of harvested timber.

2. Materials and methods

The research was conducted in the Pomorze Forest District (Regional Directorate of the State Forests in Białystok). The data on costs and profits was obtained using the Information System of the State Forests (SILP) as well as the data exploration software SAP Business Objects. The analysis included the years 2012 and 2013 as well as the first half of 2014.

Selling leftover logging residue in a form of energy biomass in order to prepare forest sites for regeneration is a primary activity implemented by the Pomorze Forest District. The raw material is auctioned using the Internet application 'e-drewno'. Clearing of residue to a degree that allows conducting soil preparation activities for forest regeneration is a mandatory condition of site inspection after biomass collection by the buyer. The amount of profits from energy biomass sales was calculated as a product of residue volume collected from a given site (marked as ZO, which stays for firewood particles) to the price shown on the contract signed with a buyer.

In cases when it was not possible to sell residue, the areas were cleaned up by the forest district services. A combination of a forestry mulcher AHWI FM600 fed by the tractor Valtra T-190 was used for such purposes (Table 1). Both types of machinery are the property of forest district and were bought in 2006. Table 1 presents technical specifications of that equipment.

Cost analysis of logging residue chipping involved two groups: fixed and variable costs. Variable costs included costs of the fuel consumed by tractor, salary of a tractor operator and costs of residue stacking. Within the Information System of the State Forests, the above costs are directly linked to a given position of the plan or the address of forest site where logging residue was crushed. Variable costs also included costs of lubricants, oils and other exploitation material and maintenance. Those costs were under equipment position of the annual plan (related to a tractor or a mulcher). They, however, were re-calculated per hour of machinery operation (h) estimated by work time of equipment on a given site, which was then proportionally added to other variable costs presented in the plan and corresponding to specific logging sites. Similar calculations were done for fixed costs that included amortization costs, costs of insurance and machinery storage (half of the property tax related to storage building was used, because another tractor was stored there as well) (Table 2).

Table 1. Basic technical specifications of machines for utilising logging residues

Valtra T-190	
Maximal power	154.5 kW (210 HP)
Nominal engine rpm	2.100 rpm
Engine capacity	7.400 cm^3
Number of cylinders	6
PTO shaft rpm	540 rpm
Weight	5.950 kg
Length	5.151 mm
Height	2.931 mm
Wheelbase	2.750 mm
Number of gears foreward	36
Number of reverse gears	36
AHWI FM600	
Required power of tractor	132.4–169.2 kW (180–230 HP)
Number of PTO rpm	1.000 rpm
Weight	3.030 kg
Operational width	2.300 mm
Total width	2.750 mm
Number of working elements	54 pcs.

3. Results

More than 1,500 m^3 of wood in the form of energy woodchips were collected during the period from January 2012 to June 2014. They were harvested by several different contractors. All the companies possessed chipping units that consisted of chippers attached to forwarders. In 2012, 209.88 m^3 of energy biomass was sold from 6 forest sites at the unit price of 104.00 PLN m^{-3}, and in 2013, 793.15 m^3 from 10 forest sites at the price of 47.00 PLN m^{-3}, whilst during the first half of 2014, 507.61 m^3 from 7 sites at the price of 16.00 PLN m^{-3}. The average yield from unit area was 25.6 m^3 ha^{-1}, which on an average amounted to 11.14% of total harvested timber volume. These numbers varied according to the forest habitat type (Figure 1).

At the same time, on some logging sites, forest district had to use logging residue on its own. In 2012, crushing of logging residue was implemented on 11 clear-cuts (IB), 5 shelterwood harvest sites (IIIA, IIIB) and 1 bark beetle gap. In 2013, the number of harvesting sites were, respectively, 13, 2 and 4, and in 2014, the work was conducted only on 7 clear-cuts. Cost analysis indicated that logging residue crushing costs were the

Table 2. Fixed costs of machines for utilising logging residues

	Valtra T-190	AHWI FM600
Year of manufacture	2006	2006
Initial value	357,889.00 PLN	140,830.00 PLN
Current value	375,531.28 PLN	140,830.28 PLN
Depreciation rate	14%	14%
Depreciation	26.08 PLN h^{-1}	9.78 PLN h^{-1}
Insurance	0.10 PLN h^{-1}	0.11 PLN h^{-1}
Garaging costs	0.01 PLN h^{-1}	0.01 PLN h^{-1}

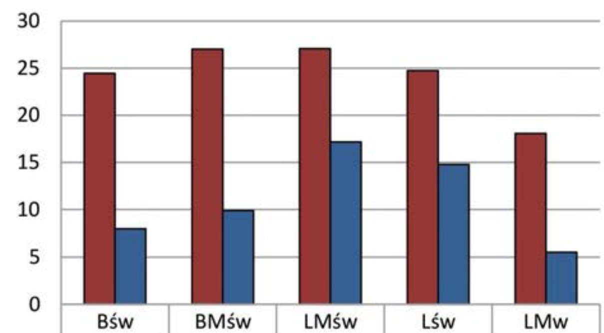
highest on bark beetle gaps. The average costs of chipping were 1,894.14 PLN ha^{-1}, and work efficiency was 0.07 ha mth^{-1}. The costs of crushing on shelterwood harvest sites were similarly high (1,858.60 PLN ha^{-1}), whilst work efficiency was slightly higher, 0.10 ha mth^{-1}. The lowest costs (1,256.42 PLN ha^{-1}) and the highest work efficiency (0.16 ha mth^{-1}) were observed on clearcutting sites.

Variable costs dominated the structure of general costs (between 61% and 65%), amongst which the largest share belonged to fuel costs (61%). The amortisation costs dominated within fixed costs reaching the monthly value of 6,024.21 PLN, which comprised 95% of the fixed costs. The average logging residue crushing costs per unit area were the lowest on shelterwood harvesting sites in 2013 (1,000.98 PLN ha^{-1}), whilst the highest on bark beetle gaps in 2013 (2320.82 PLN ha^{-1}) with the difference between them being 43.1%. Crushing costs on various forest habitat types differed from one another by 59.2% (with the lowest value of 1,162.23 PLN ha^{-1} observed in fresh coniferous forest (Bśw) and the highest value of 1,960.21 PLN ha^{-1} in ash-alder forest stands (OlJ)).

The differences between the costs of one operation hour were 54.5% in the case of analysis of costs on different harvest types (from 110.64 PLN h^{-1} on bark beetle gaps in 2012 to 203.17 PLN h^{-1} on shelterwood harvesting sites in 2012) as well as 49.1% in the case of analysis of costs on different forest habitat types (from 122.32 PLN h^{-1} in fresh broadleaved forest (Lśw) to 248.92 PLN h^{-1} in ash-alder forest (OlJ)).

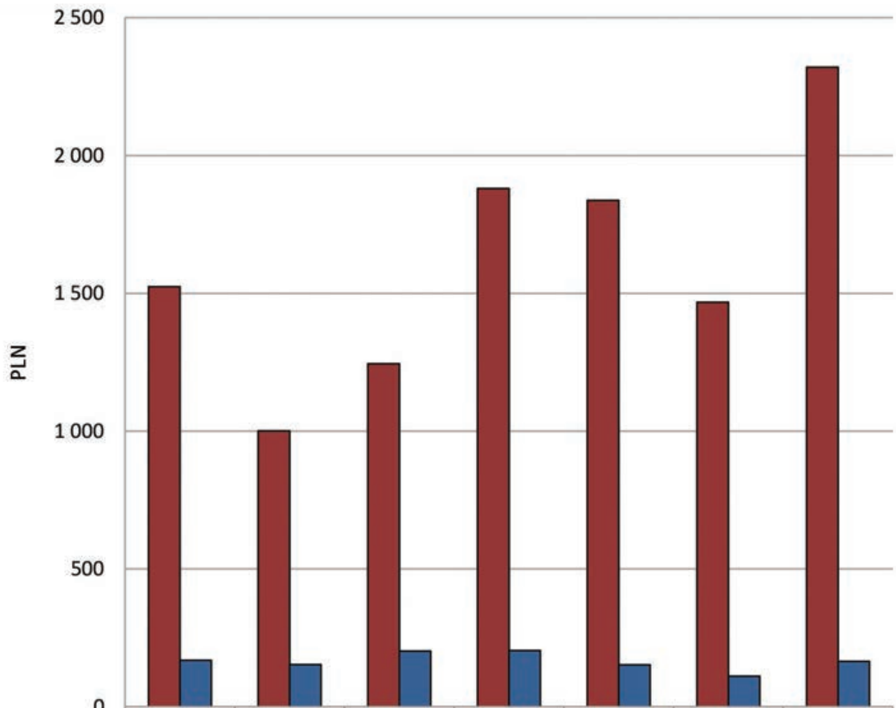
4. Discussion

Research results indicate that logging residue in the Pomorze Forest District amounts to 11.14% from the total volume of harvested timber, whilst their value varies from 6.85% to 17.15% depending on the forest habitat type and type of harvest. That value is about 4% lower than in research of Jabłoński and Różański (2009), which was implemented in a different part of country and included measuring of a possible share of residue volume by direct weighing of tree parts. Logging residue volumes estimated within this study are close to the results of a similar study conducted in all six forest districts of the Augustowska Forest, which includes Augustów, Głęboki Bród, Płaska, Pomorze, Suwałki and Szczebra Forest Districts. There the logging residue comprised about 11.96% of the total timber harvested (Gałęzia 2013). It sho-



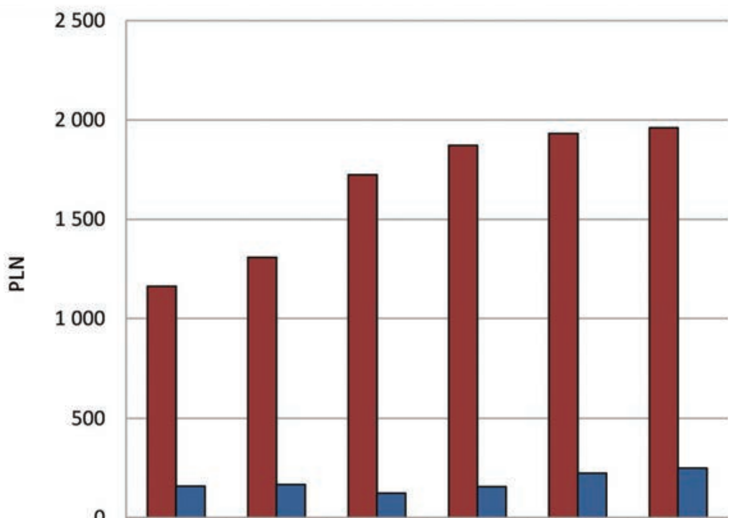
	Bśw	BMśw	LMśw	Lśw	LMw
Efficiency [m^3/ha]	24.44	27.01	27.07	24.73	18.04
Share in overall volume [%]	7.94	9.89	17.15	14.75	5.51

Figure 1. Volume of biomass and its share in an overall quantity of logged timber, referring to forest habitat types: Bśw – fresh coniferous forest, BMśw – fresh mixed coniferous forest, LMśw – fresh mixed broadleaved forest, Lśw – fresh broadleaved forest, LMw – moist mixed broadleaved forest



	Rzu 2012	Rzu 2013	Rzu 2014	Rzl 2012	Rzl 2013	Luki 2012	Luki 2013
PLN / ha	1 524.43	1 000.98	1 243.86	1 880.47	1 836.74	1 467.47	2 320.82
PLN / mth	167.65	152.16	201.44	203.17	151.52	110.64	164.18

Figure 2. Average costs of crushing of logging residues referring to shelterwood type; Rzu – clear-cuts, Rzl – complex shelterwoods, Luki – bark beetle gaps.



	Bśw	BMśw	Lśw	LMb	LMśw	OlJ
PLN / ha	1 162.23	1 307.11	1 723.89	1 872.66	1 931.72	1 960.21
PLN / mth	158.60	166.29	122.32	156.06	223.09	248.92

Figure 3. Average costs of crushing of logging residues referring to forest habitat type; key: Bśw – fresh coniferous forest, BMśw – fresh mixed coniferous forest, Lśw – fresh broadleaved forest, LMb – boggy mixed broadleaved forest LMśw – fresh mixed broadleaved forest, Olj – ash-alder forest

uld be noted that information on the share of small-diameter wood within total timber volume presented in current study was obtained in a different manner from the research of Jabłoński and Różański (2009). It presents real volumes of biomass collected from a given logging site in relation to the total timber volume.

The structure of variable costs (including the share of fuel costs being around 61%) is similar to results received by

Różański and Jabłoński (2005). The level of amortisation is, however, significantly higher than the above study.

The average cost of logging residue chipping was 1449.19 PLN ha^{-1}, which is almost three times higher than the costs presented by Różański and Jabłoński (2002). Such a big difference probably results from a significant growth in fuel prices during the past years and also a high price of mulcher, which translates into high amortisation costs. The average price of diesel fuel in 2002 was around 2.40 PLN dm^{-3} gross, and in 2012, it reached the level of about 3.99 PLN dm^{-3} gross (GUS 2014). The average diesel fuel price during the second quarter of 2014 reached the level of 5.27 PLN dm^{-3} gross (www.autocentrum.pl).

It would be important to note that in 2012, the costs on logging sites were higher than those in 2013. It could be explained by logging residue stocking, which was implemented during that year. The goal of such measure was to simplify chipping or crushing of logging residue, whilst costs acquired during that operation were included into the starting price of energy material. That caused high prices of energy chips obtained in the year 2012. During the consecutive years, stocking was excluded from the process. The drastic decrease in energy biomass prices in 2014 results, amongst others, from the large supply of the material during that year as well as significant decrease in value of 'green certificates'. However, the decrease in costs of residue crushing in 2014 was primarily caused by the lack of operations on shelterwood harvesting sites and the absence of bark beetle gaps, which in previous years generated significantly higher costs than residue utilisation on clear-cuts. Another important factor was replacement (as part of investment) of the chipper rotor shaft together with the set of blades, which significantly improved work efficiency and reduced maintenance costs.

Efficiency of a mulcher during its work on clear-cuts IB was 0.16 ha mth^{-1}, which is similar to that estimated in the research of Różański and Jabłoński on economic efficiency of logging residue crushing (2005). When converting that value per working hour, it would come to about 0.10 ha PMH^{-1} (productive machine hour), which is almost two times lower than theoretical efficiency of the Meri Crusher MJS-2,0 DT (Różański, Jabłoński 2008) and more than two times lower than that of Meri Crusher MJS-2,5 DT (Różański, Jabłoński 2006). It would, however, be necessary to consider necessity of every day trips to logging sites, which substantially affects work efficiency. Crushers with similar width (MJ 2.3 ST and DT) in actual conditions obtained efficiency, which was 0.025 ha PMH^{-1} higher (Różański, Jabłoński 2002).

Crushing of logging residue is far less economically profitable for a forest district than selling the residue in the form of energy material (Figure 4) even when prices of energy chips are significantly lower than those in previous years.

It should, however, be remembered that small branches and needle-cover contain significant amounts of nutrients valuable for ecosystems. Whilst traditional timber harvesting of stems does not lead to soil depletion because of low amount of nutrients, the inclusion of logging residue collection into harvesting process increases loss of nitrogen at about 40%, phosphorus at 55%, potassium at 76%, calcium at 31% and magnesium at 22% (Gornowicz 2004). Residual material, which is the most valuable for the forest nutrient cycle, includes branches with more than 4 cm in diameter as well as needle-cover, whilst removal of logging site branches that have been cut during delimbing intensifies leaching of nutrients (Gornowicz 2004). It would be important to note that modern mulchers allow mixing of crushed particles with soil to the depth of about 20 cm, which partially compensates the loss of nutrients because of timber harvesting and also accelerates cycling of other materials (Chlebowski 2007). Current research has not analysed the effect of biomass loss collected for energy purposes on forest habitats; however, according to other studies, it could be observed that total removal of biomass from the logging site could be associated with the improvement of forest sanitary condition (Kolk 2005). Crushing of logging residue along with its mixing with soil from one side allows inclusion of biomass into nutrient recycling (Robert 2005) and from another it increases damages caused by weevils (Korczyński 2004). Whilst estimating the loss of nutrients and microelements contained in the material reserved for energy purposes, it should be remembered that the fall-off of needles and small branches occurs during the whole period of forest stand life and during that time those tree parts are not being harvested. It should be added that technical structure of chippers allows separating logging residue from dirt such as soil, needles and small elastic twigs, because of which those elements remain on the surface of a logging site.

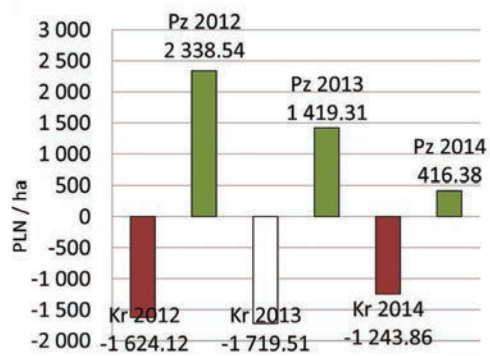


Figure 4. Average annual costs of crushing (Kr) and incomes from the sale of energy chips (Pz).

5. Conclusions

Based on the research results, forest districts should be advised to implement chipping of logging residue and to sell energy chips. From the economic point of view, the removal of logging residue without the use of equipment belonging to the forest district would be profitable even in cases when there would be no profits from residue sale.

Improvement of forest health state could be seen as an additional argument towards the benefit of energy chips sales.

At the same time, harvesting of small-diameter energy material could lead to depletion of forest habitats, which requires a special caution when making decisions on biomass harvesting for energy purposes from poor habitat types.

Conflict of interest

The author declares a lack of potential conflicts.

Acknowledgements and source of funding

The research was funded from personal means.

References

Chlebowski K. 2007. The analysis of the effectiveness of grinding of chip residue by Meri Crusher MJ 2.3 DT. *Acta Scientiarum Polonorum, Silvarum Colendarum Ratio et Industria Lignaria* 6(3): 17–23.

Gałęzia T. 2013. Analiza efektywności wybranych metod pozyskiwania biomasy leśnej na cele energetyczne w Puszczy Augustowskiej. Rozprawa doktorska, Szkoła Główna Gospodarstwa Wiejskiego, Warszawa.

Gornowicz R. 2004. Technologie utylizacji pozostałości zrębowych na terenach nizinnych. *Postępy Techniki w Leśnictwie* 87: 31–37.

Kolk A. 2005. Ocena wybranych sposobów utylizacji pozostałości zrębowych pod względem ochrony lasu. *Postępy Techniki w Leśnictwie* 92: 25–28.

Korczyński I. 2004. Ocena sposobów utylizacji drewna gorszej jakości z punktu widzenia ochrony lasu. *Postępy Techniki w Leśnictwie* 87: 38–43.

Maksymiak M. 2008. Badania porównawcze rozdrabniaczy leśnych. *Technika Rolnicza, Ogrodnicza, Leśna* 2: 22–24.

Pierovich J.M., Smith R.C. 1973. Choosing forest residues management alternatives. USDA Forest Service General Technical Report, PNW-7. Portland, USA.

Robert W. 2005. Technologie utylizacji pozostałości zrębowych w Nadleśnictwie Dąbrowa, *Postępy Techniki w Leśnictwie* 92: 29–32.

Różański H., Jabłoński K. 2002. Badania eksploatacyjne wybranych kruszarek do rozdrabniania pozostałości zrębowych, w: Użytkowanie lasu w wielofunkcyjnym, zrównoważonym leśnictwie. Wydawnictwo SGGW, Warszawa.

Różański H., Jabłoński K. 2005. Efektywność ekonomiczna rozdrabniania pozostałości zrębowych przy użyciu ciągnika Valtra T-190 i rozdrabniarki MJS-2,5 DT, w: Procesy produkcyjne w leśnictwie – technika, technologia, organizacja. Ogólnopolska Konferencja Naukowa, 21 czerwca 2005, Wydawnictwo SGGW, Warszawa.

Różański H., Kujawski M., Jabłoński K. 2006. Mechanics of the milling of logging residues with a Meri Crusher MJS-2.5 DT machine. *Acta Scientiarum Polonorum, Silvarum Colendarum Ratio et Industria Lignaria* 5(2): 95–102.

Różański H., Jabłoński K. 2008. Efficiency and technical parameters of the crushing of logging residues with a Meri Crusher MJS-2.0 DT machine. *Acta Scientiarum Polonorum, Silvarum Colendarum Ratio et Industria Lignaria* 7(1): 53–58.

Różański H., Jabłoński K. 2009. Economic effectiveness of logging residue bundling and chipping. *Acta Scientiarum Polonorum, Silvarum Colendarum Ratio et Industria Lignaria* 8(2): 47–51.

Sadowski J., Moskalik T., Zastocki D., Wrona T. 2012. Wybrane gospodarcze i przyrodnicze aspekty zagospodarowania pozostałości zrębowych. *Studia i Materiały CEPL w Rogowie* 32(3): 246–253.

Wojtkowiak R., Nowiński M., Tomczak R. 2003a. Spalanie pozostałości pozrębowych, a emisja lotnych produktów. *Sylwan* 147(8): 55–60.

Wojtkowiak R., Nowiński M., Tomczak R. 2003b. Spalanie pozostałości pozrębowych a nagrzewanie się gleby. *Sylwan* 147(6): 22–27.

Sources of information

Dyrektywa Parlamentu Europejskiego i Rady 2009/28/WE z dnia 23 kwietnia 2009 r. w sprawie promowania stosowania energii ze źródeł odnawialnych zmieniająca i w następstwie uchylająca dyrektywy 2001/77/WE oraz 2003/30/WE.

GUS 2014. Efektywność wykorzystania energii w latach 2002–2012. Informacje i opracowania statystyczne. Główny Urząd Statystyczny, Warszawa.

Ustawa z dnia 28 września 1991 r. o lasach, tekst jednolity Dz. U. z 2011 nr 12 poz.59 z późn. zm.

http://www.autocentrum.pl/paliwa/ceny-paliw/podlaskie/on/2014/

Translated by: Olga Zyrina