Evaluation of two harvesting systems for the supply of wood-chips in Norway spruce forests affected by bark beetles

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Abstract – Nacrtak

For sanitary reasons, spruce trees affected by bark beetles (Ips typographus L.) should be removed out of the stand as soon as possible, to avoid the propagation of the beetles to healthy trees. One possibility, to utilize the accruing crown material in a reasonable way (instead of burning it) could be, to use it as wood-chips for biomass heating plants. The aim of this project was therefore to determine the productivity of two harvesting and processing systems for wood-chips as a joint-product of round wood in Norway spruce (Picea abies L.) forests affected by bark beetles. Two systems with different sorting criteria were studied: processing of sawlogs, pulpwood and wood-chips (System A) in comparison to the processing of only sawlogs and wood-chips (System B). In System A, the energy wood was chipped with a chipper mounted on a forwarder that was working directly in the stand. In System B, the material to be chipped was previously concentrated along the forest road with a forwarder, and a chipper mounted on a truck was used for chipping.

In System A, 0.18 t of dried chips could be harvested per m^3 of round wood, and in System B 0.26 t of dried chips per m^3 of round wood. The cost of chipping in the stand was 4.74 €/m^3 of chips and the cost of chipping along the forest road after transporting the chipping material by a forwarder was 5.63 €/m^3 of chips. Therewith, a cost-covering supply of wood-chips may be obtained out of such stands. Concerning the ratio of energy input to energy output it can be said that the systems required 1.5% and 2% of energy output that was obtained using the respective system.

Keywords: biomass, wood-chips, Picea abies, bark beetle

1. Introduction – *Uvod*

In the last years, governments of EU member countries have promoted the use of renewable energy sources. One of the main sources for renewable energy is the combustion of biomass, which is nearly neutral in the cycle of CO_2. Therefore, many biomass-heating plants have been constructed. Actually, most of these plants are supplied with residues from the wood industry (Heller et al. 2004). As this raw material is limited, new resources have to be tapped. For example up to now the biomass produced in agricultural and forestry systems has not been fully mobilized and used for energetic purposes, due to still unsolved technical problems, high costs or missing information about the potential and quality of such biomass (FAO 1997, FAO 2003, Andersen et al. 2005). Therefore, it is necessary to evaluate the potentials of biomass and its quality coming from forestry and agriculture, and especially to examine the technology available for harvesting and processing it.

One possibility to obtain woody biomass for energetic purposes is the utilization of trees that have to be felled and removed due to attacks of bark beetles (*Ips typographus* L.). These operations show special characteristics. Typically, they are small clear cuts with an area ranging between 0.3 and 1.0 ha. This is due to the fact that the trees, surrounding the infected trees, are often affected by bark-beetles, too, although they do not show yet any visible signs of attack on the surface. A further spread of the beetle should be hindered by cutting the neighbouring trees. Contrary to conventional harvesting operations, all

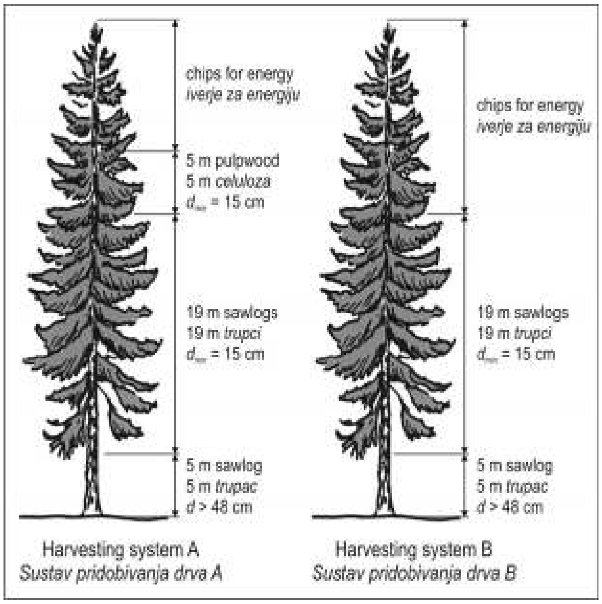

Fig. 1 Processing systems studied (*d* – the top-diameter of the stem-parts)

Slika 1. *Istraživani sustavi izradbe drva (d – promjer na tanjem kraju dijela debla)*

the crown material has to be taken out of the stand, to deprive the bark beetles' breeding material. Typically, the material is then burnt, which means very high labour costs and no income at all. Furthermore, the felling of affected trees is more difficult than the felling of trees that are not affected, as their crowns have less weight. Therefore the trees do not fall as easy as trees with green, living crowns. So far only very few studies have been made on the harvest of trees affected by bark-beetles (example KWF 2004). Although many foresters have to deal with these problems in their day to day work, hardly any recommendations can be found as to how to best deal with them.

Therefore, the objective of the present work was to compare different approaches for harvesting and

Table 1 Main characteristics of the stands

Tablica 1. *Osnovne značajke sastojina*

Stand – *Sastojina*	1	2
Harvesting system – *Sustav pridobivanja drva*	A	B
Species – *Vrsta drveća*	*Picea abies* (L.)	
Area – *Površina*, ha	0.46	0.56
Medium DBH – *Srednji prsni promjer*, cm	49	44
No. of trees per hectare – *Broj stabala po ha*	124	264
Terrain slope – *Nagib terena*, %	2	5
Skidding distance – *Udaljenost privlačenja*, m	350	500

processing trees in Norway spruce (*Picea abies* L.) stands affected by bark beetle (*Ips typographus* L.). Hence, the goal was to compare the profitability of processing sawlogs, pulpwood and wood-chips (System A) with the profitability of processing only sawlogs and wood-chips (including the chipping of the traditional pulpwood-assortments (System B). The sorting criteria of both systems can be seen in Figure 1.

Additionally, two chipping systems (chipping directly in the stand and chipping along the forest road) were analyzed in order to prove techniques that could be suitable for certain stands. In both systems the following parameters were evaluated: productivity, costs and energy balance of the whole supply chain and the volume of wood-chips that could be obtained with the respective system.

2. Material and Methods – *Materijal i metode*

The main characteristics of the stands to be harvested can be seen in Table 1. In both systems conventional (motor-manual) chainsaw felling and processing and skidder log extraction have been carried

Table 2 Main characteristics of the machines

Tablica 2. *Osnovne značajke strojeva*

Machines – *Strojevi*	Manufacturer and model – *Proizvođač i model*
Chainsaw – *Motorna pila*	Husqvarna 394XP – Husqvarna 357XP
Skidder – *Skider*	Mercedes Benz Trac 800
Forwarder (System B) – *Forvarder (sustav B)*	Gremo 950R
Chipper mounted on a forwarder (System A) *Iverač postavljen na forvarder (sustav A)*	ERJO 7/65 RC (»ERJOFANT«) Power – *Snaga*: 272 kW Opening – *Ulazni otvor*: 40 x 67 cm, Chip reservoir – *Obujam spremnika iverja*: 10 m^3
Chipper mounted on a truck (System B) *Iverač postavljen na kamion (sustav B)*	Man Truck, Wüestling 600 CV Power – *Snaga*: 442 kW; Opening – *Ulazni otvor*: 70 x 120 cm

Fig. 2 Mobile chipper working in the stand
Slika 2. *Rad mobilnoga iverača u sastojini*

Fig. 3 Chipper mounted on a truck, working along the forest road
Slika 3. *Iverač postavljen na kamion pri radu na šumskoj cesti*

out. The team was formed by two workers. One of them only cut and processed the trees; the other worker drove the skidder and occasionally supported the felling. In System A, the energy wood was chipped directly in the stand using a mobile chipper mounted on a forwarder (Figure 2). In System B, the energy wood was concentrated with a forwarder in piles along the forest road and then chipped using a chipper mounted on a truck (Figure 3). The characteristics of the machines used are shown in Table 2.

To evaluate the productivity, all operations were supported by time studies. The time of effective work and the total working time were recorded for each worker and machine. All times were defined according to the REFA-guidelines (1991). At the same time, the volume was measured of all the logs produced during the operation, as well as the volume of each container filled with chips.

In addition to this, the following parameters were determined for every container filled with chips:

⇒ Moisture content of chips (%) (determined according to prCEN/TS 14774-2)

⇒ Ratio of different size fractions (%) (determined according to CEN/TC 335/EG 4)

⇒ Calorific value at different moisture contents and separated for different size fractions (determined with a calorimeter (IKA 2000))

⇒ Coefficient of wood-chips potential, calculated by the following equation:

$$\lambda_{\mathrm{i}} = \frac{V_{\mathrm{i\ chips}}}{V}$$

Where λ_{i} is the gravimetric coefficient of the potential biomass for energetic utilization in a system of i-characteristics; this coefficient is defined as tons of dry chips ($V_{\mathrm{i\ chips}}$) that can be obtained as a by-product by recovering the residues generated from the harvest of 1 m^3 of conventional roundwood – sawlogs and/or pulpwood (V).

3. Results and Discussion – *Rezultati s diskusijom*

3.1 Processed timber products – *Izrađeni drvni proizvodi*

The products obtained in both systems are shown in Table 3: a remarkably lower volume of sawlogs and wood-chips was harvested in System A. This is due to the fact, that in System A some trees (especially fir – *Abies alba* Mill.) could be left in the stand, whereas in System B all trees had to be taken out. As in System B a bigger part of the trees' biomass is used for energetic purposes instead of producing pulpwood as in System A, the coefficient for the wood-chips potential in System B is 0.26 and therewith 44.4% higher in comparison to System B, where the coefficient is 0.18.

3.2 Productivity for felling and processing of sawlogs and pulpwood – *Proizvodnost sječe i izrade pilanskih trupaca i celuloznoga drva*

The distribution of the effective work time and the productivity of forest workers in both systems are shown in Figure 4. It can be noticed that forest workers had a higher productivity in System B, although the average diameter of trees in System A was 5 cm bigger than the average diameter of trees in System B, and hence a higher volume of wood as-

Table 3 Processed timber products
Tablica 3. *Izrađeni drvni proizvodi*

Stand – *Sastojina*	1	2
Harvesting system – *Sustav pridobivanja drva*	A	B
Number of trees – *Broj stabala*	57	148
Sawlogs (diameter > 48 cm, length 5 m), m^3_{solid} *Pilanski trupci* (*promjer* > 48 cm, *duljina* 5 m), $m^3_{oblovine}$	24.6	16.7
Sawlogs (diameter > 15 and < 48 cm, length max. 19 m), m^3_{solid} *Pilanski trupci* (*promjer od* 15 cm *do* 48 cm, *najveća duljina* 19 m), $m^3_{oblovine}$	70.6	189.4
Pulpwood (diameter > 15 cm, length 5 m), m^3_{solid} *Celulozno drvo* (*promjer* > 15 cm, *duljina* 5 m), $m^3_{oblovine}$	11.8	-
Total volume of sawlogs and pulpwood, m^3_{solid} *Ukupni obujam pilanskih trupaca i celuloznoga drva*, $m^3_{oblovine}$	107	206.1
Total volume of wood-chips, m^3_{loose} *Ukupni obujam drvnoga iverja*, $m^3_{nasipni}$	88	243
Total mass of wood-chips (oven dry), kg *Ukupna masa drvnoga iverja (suhe tvari)*, kg	19,530	53,940
Coefficient λ_i, (tons of wood-chips per m^3 of sawlogs and pulpwood) *Koeficijent* λ_i, (*tona drvnoga iverja po* m^3 *pilanskih trupaca i celuloznoga drva*)	0.18	0.26

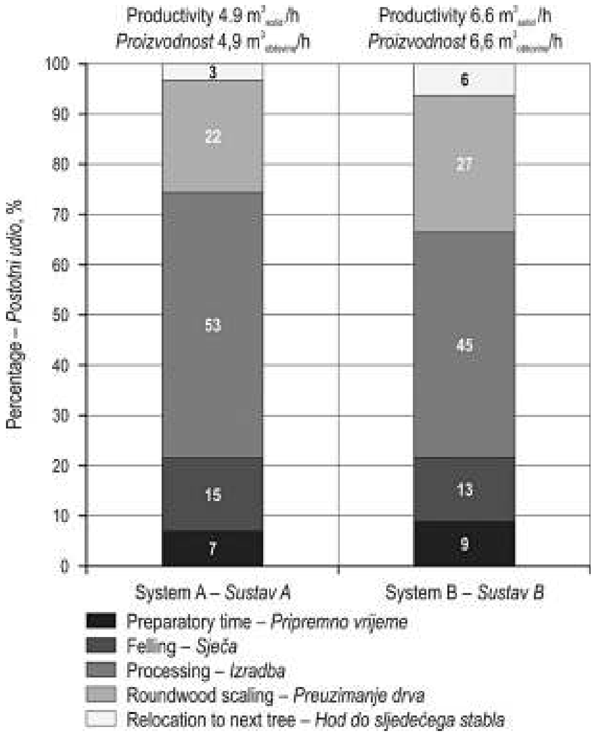

Fig. 4 Effective work-time distribution and productivity of forest workers – Motor-manual felling and processing

Slika 4. *Raspodjela efektivnoga vremena rada i proizvodnosti radnika sjekača pri strojno-ručnoj sječi i izradi*

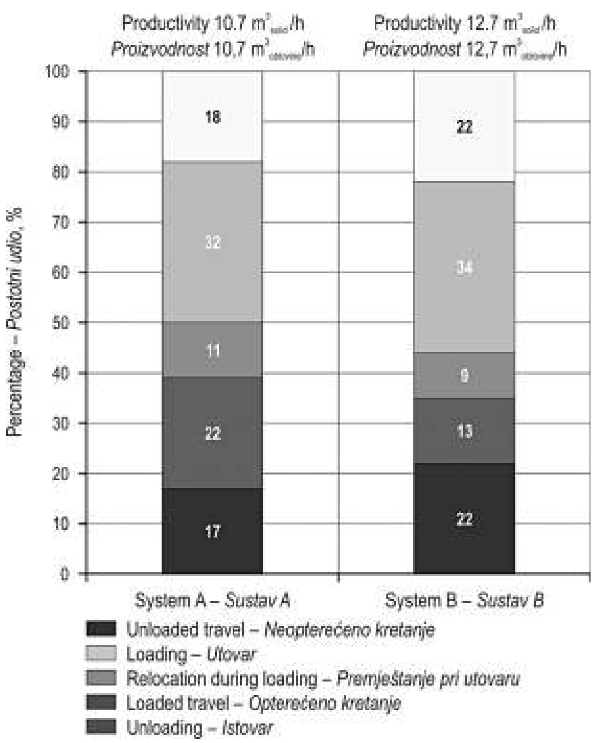

Fig. 5 Effective work-time distribution and productivity of the skidder

Slika 5. *Raspodjela efektivnoga vremena rada i proizvodnosti skidera*

sortments was obtained. This is mainly due to the fact, that in System B no pulpwood was produced. Therefore, less time was needed for debranching, cross-cutting and measuring the assortments. Consequently, the processing ratio in System A is 53% of effective work, whereas it is only 45% in System B.

The evaluation of working times and the productivity of the skidder are depicted in Figure 5. The effective work-time distribution of the skidder does not differ much between the two systems. In System A, less time is needed for driving into the stand and driving back to the piling site, which can be explained with a shorter skidding distance (System A: 350 m, System B: 500 m). Nevertheless, more time is needed for unloading the skidder in this system. This is due to the fact, that, by processing pulpwood, three instead of two assortments had to be transported, which means less productivity due to a lower volume per piece and more time for sorting at the piling site.

3.3 Productivity of the forwarder (only System B) and the chipper – *Proizvodnost forvardera (samo u sustavu B) i iverača*

The forwarder, required in System B for concentrating the chipping material along the forest road, had a productivity of 23.7 m^3_{loose}/h. This rather high productivity that was fostered by a comparably low skidding distance (<100 m) is remarkably higher compared to e.g. a study conducted by the KWF (2004) in comparable stands, where a forwarder reached a productivity of only 17 m^3_{loose}/h.

The following chipper mounted on a truck in this system reached a productivity of 69.8 m^3_{loose}/h. This is slightly higher in comparison to other studies done for example by Asikainen and Pulkkinen (1998) or Basse et al. (2002) for chippers with similar characteristics. Asikainen and Pulkkinen (1998) determined a productivity of 55 m^3_{loose}/h, whereas Basse et al. (2002) calculated a productivity of 40–60 m^3_{loose}/h, depending on the average volume of the trees chipped. In studies by Deutschländer-Wolff (2006) or Schuler (2007) comparable chipping systems reached (only) similar productivities, although the chipping conditions were more favourable in comparison to the present study, due to a much higher pre-concentration of the chipping material.

In System A, the productivity of the mobile chipper working directly in the stand is 36.4 m^3_{loose}/h. Therewith, the chippers' productivity is higher in comparison to other studies: Lechner et al. (2007), calculated for a comparable chipper in beech-stands that are ready for thinning a productivity of only 22.5 m^3_{loose}/h and in a study of Thor (1996), a similar chipper reaches a productivity of approx. 30 m^3_{loose}/h in spruce-beech-stands.

When only looking at the productivity of the chipper, it can be said that the productivity of a chipper working at the forest road is nearly 50 % higher in comparison to a chipper working directly in the stand. The higher productivity resulted from the fact that the material was very well concentrated in piles along the forest-road and the chipper therewith could work more continuously. Additionally, the assortment that could have been used for pulpwood was chipped, too, which obviously increases productivity, too. Another reason – of course – is the higher engine power of the chipper working at the forest road (442 kW in comparison to 272 kW of the chipper working directly in the stand), which also highly influences productivity.

In Figure 6, the differences between the two chipping systems can clearly be seen: the time for manipulating the wood is 34.1% when looking at the mobile chipper working directly in the stand and therewith remarkably higher in comparison to the chipper working at the forest road with only 4.9%. On the other hand, the ratio of the time for the chipping itself is significantly higher when looking at the chipper working at the forest road (58.6%) in comparison to the mobile chipper working in the stand (38.8%). The working time for driving in and out the stand, that do not exist in System B, are relatively low (8.8% and 6.3%), due to a rather short skidding distance of less than 100 m. In the study by Lechner et al. (2007) that was already mentioned above, slightly higher ratios occur, as a consequence of a longer skidding distance. As the transport of the chips was well organised when working with the mobile chipper in the stand, no waiting times for empty containers need to be noted.

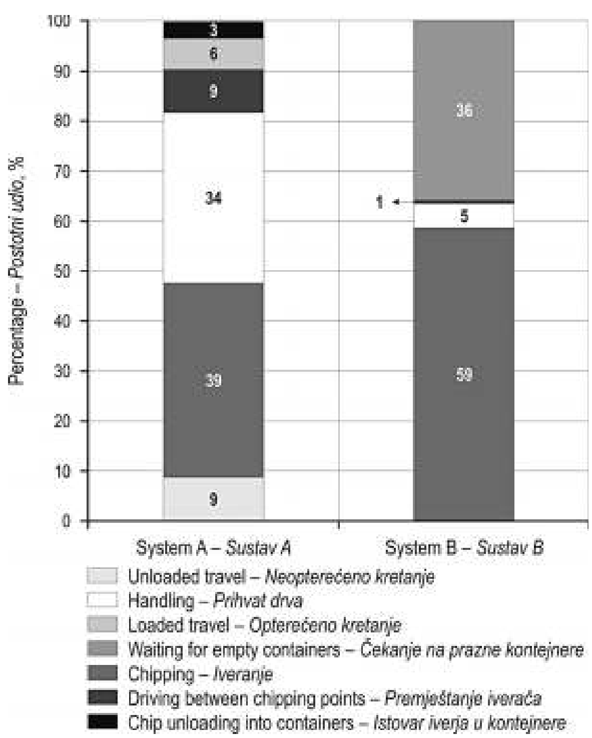

Fig. 6 Effective work-time distribution of the chipper

Slika 6. *Raspodjela efektivnoga vremena rada iverača*

On the other hand the chipper in System B was waiting about 40% of the working time for new, empty containers (Figure 6), which is a very high quota, and still – according to Wittkopf (2005) – this is a rather usual proportion in practice. The goal of chipping operations should always be to minimize standing-times of the chipper and there is still a rather high potential for optimising logistics. If the logistic system were organised in a better way, and if waiting-times could be reduced to 10%, the productivity of the chipper working at the forest road would be close to 100 m^3_{loose}/h. Therewith, it can clearly be seen that an optimization of logistics in chipping operations (continuous transport of chips and delivery of new, empty containers) is crucial.

3.4 Costs for the supply of wood-chips – *Troškovi dobave drvnoga iverja*

The costs for tree felling are related to different assortments of round wood obtained (saw logs and pulpwood). Therewith, no costs accrue for the harvest of the chipping material and only the costs for forwarding the material out of the stand and the costs for chipping have to be considered. In the System A, the calculated cost per working hour of the mobile chipper were 150 €/h (including 15% additional times for delays and rests). In System B, the underlying costs were 65 €/h for the forwarder and 150 €/h for the chipper mounted on a truck (also including 15% additional times for delays and rests). The total costs of both systems are shown in Figure 7.

The costs of both systems are comparable: 4.74 €/m^3_{loose} in System A and 5.63 €/m^3_{loose} in System B (including forwarder and chipper). Therewith, assuming a revenue for wood-chips of 12 €/m^3_{loose} at forest road, a net revenue between 6.37 and 7.26 €/m^3_{loose} can be gained when producing wood-chips with the presented systems. Of course, the costs only for chipping of the material are remarkably higher in System A. However, as the costs for forwarding the chipping material to the forest road are obligatory in System B, System A is a more favourable solution, when taking into consideration overall costs for the supply of wood-chips. This is even truer, when looking at the assortments produced in both systems. It

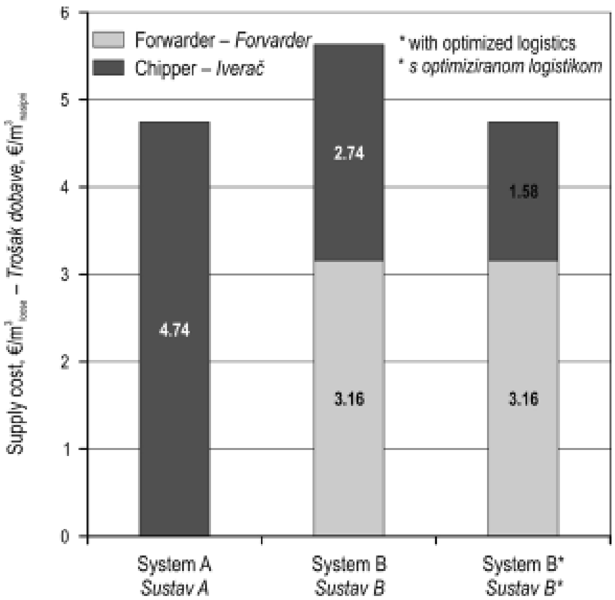

Fig. 7 Costs for the supply of wood-chips
Slika 7. *Troškovi dobave drvnoga iverja*

can be assumed that the mobile chipper in System A would have a significantly higher productivity if the pulpwood-assortments were chipped, too, as in System B. In reverse, the productivity of the forwarder and chipper in System B would both reach a lower productivity, if the pulpwood assortments were chipped. As costs per m^3_{loose} differ only by 1 €/m^3_{loose}, it can be assumed that the mobile chipper working directly in the stand is a more favourable system. On the other side, if costs per working hour of the chippers rise up to 250 €/h, costs per m^3 chips approximate and differences become only marginal. Still, it should be taken into consideration that when using a mobile chipper working directly in the stand, fewer machines are needed and the organizational efforts, etc. are lower.

These results are significant insofar, as the conventional wisdom is refuted that chipping in the stand is more expensive and not profitable (Wittkopf et al. 2003). On the other hand, the results gained by Lechner et al. (2007) are confirmed. On a cautionary note, however, it has to be said that skidding distance is a factor that highly affects the productivity of a mobile chipper working directly in the stand: in this study, skidding distance was less than 100 m. From a certain distance onwards, a shuttle-forwarder for transporting the chips to the forest road has to be used. This again leads to higher costs and fosters therewith a chipping of the traditional pulpwood assortment together with the remaining crown-material. As shown in Figure 4 and 5, the productivity of forest workers and skidder is lower when producing stem wood and pulpwood instead of producing only stem wood and avoiding the processing of pulpwood. The same is true for the chipper: its productivity is remarkably higher, when chipping crown material and the traditional pulpwood assortments. Therewith, costs for felling, skidding and chipping rise when pulpwood is processed as a separate assortment. Consequently, it can be estimated, that with a motor-manual supply of pulpwood, a cost recovery for this assortment can scarcely be reached. This conclusion is confirmed through a study made by Köberle (2007), who also states lower costs for the motor-manual felling and processing of trees, when only stem wood in combination with wood-chips is produced and no pulpwood is processed. However, it has to be clearly pointed out that this conclusion is not true for fully mechanized harvest, when a harvester is used, as the additional working time for processing pulpwood is only marginal for a harvester! In this situation, the processing of pulpwood is – assuming current revenues for pulpwood – a more favourable solution (see also Cremer 2007, Lechner 2007).

3.5 Wood energy characteristics – *Energetske značajke drva*

The chips of Norway spruce (*Picea abies* L.), produced in this study, had a moisture content of 34.7% in respect to wet weight (M_h), and 56.2% in respect to dry weight (M_s). This rather low moisture content is not surprising, as the trees were standing dead in the forest for several months before they were felled and chipped. At this moisture content, chips density was 217.14 kg/m^3_{loose} and the obtained calorific value was 12.35 MJ/kg. Both values are comparable to the values determined by Golser (2004). After oven-drying the chips, the density was 141.8 kg/m^3 and the calorific value increased up to 19.33 MJ/kg.

The ratio of different fractions and its characteristics that were obtained after sifting the chips is shown in Table 4. It can be noted that the smaller fractions have lower calorific values. This is surprising: often, the smaller fractions contain a high proportion of needles and bark (Suadicani and Gamborg 1999), which have – due to a high content of extractives – a significantly higher calorific value in comparison to stem wood (Nurmi 1993), which is mainly found in the coarser fractions. On the other side, the trees in this study were dead for several months before they were felled and most of the needles and high portions of the bark were already fallen down. Therewith, the calorific value of the smallest fraction obviously decreased (Suadicani and Gamborg 1999). Additionally, a high mineral

Table 4 Characteristics of different chip-fractions

Tablica 4. *Značajke različitih čestica drvnoga iverja*

Fraction diameter *Veličina čestice*	Ratio *Udjel*	Density *Gustoća*	Calorific value* *Ogrjevna vrijednost**
mm	%	g/cm^3	MJ/kg
63	3.2	0.1821	19.52
45	32.9	0.2391	19.24
16	31.2	0.1996	18.95
5	21.0	0.1929	18.31
3.15	11.7	0.2270	17.32

* oven dried – *suha tvar*

content is often found in the smallest fraction due to contamination with mainly mineral soil, which again decreases the calorific value.

According to Table 4, it can be said that it is useful to sift the chips. Therewith it is possible to eliminate the smallest fractions of the chips and the energy that can be obtained increases by 6%. Hence, the uniformity and quality of the chips increases and the chips can be sold at a better price.

3.6 Energy balance – *Energetska bilanca*

As the calorific value of diesel is approx. 47 MJ/kg and its density is 680 kg/m^3, the calorific value per litre of diesel is 31.96 MJ/L. In System A, the calculated diesel consumption per effective working hour of the mobile chipper resulted in approx. 40 L/h. In System B, the average diesel consumption of the forwarder was approx. 10 L/h and diesel consumption of the chipper mounted on the truck was 68 L/h in average. In Table 5, the energetic balance is carried out. It can be noted that System B requires an energetic input that is 34.7% higher in comparison to System A. This is due to the fact that the chip production in System B needs two machines (forwarder and chipper) whereas in System A only one machine (the chipper) is needed. Still, the energetic input in both systems is generally low: as it can be seen in Table 5, in System A, 1.5% of the energy that is obtained has to be put into the system to produce wood-chips. In System B, slightly more energy has to be used to obtain the same energetic output. Still, these results strongly support an application of both systems for the production of wood-chips from trees affected by bark-beetles.

4. Conclusions – *Zaključci*

Summarizing the results, it can be said that a cost-effective supply of wood-chips out of stands affected by bark beetles is possible. Consequently, a reasonable utilization is given of the crown material that was burnt so far. When looking at suitable supply chains, the differences in costs are less than 1 €/m$^3_{loose}$ between the two chipping systems and therewith surprisingly small.

Regarding the optimal sorting, it can be said that avoiding the processing of pulpwood (and producing only stem wood assortments and wood-chips) seems to be a favourable alternative when harvest is done motor-manually. As a consequence, forest workers as well as the skidder and chipper reach a higher productivity and therewith cost per piece for stem wood and for wood-chips decreases.

The calorific value of wood-chips did not differ significantly from other studies. Sifting of chips can be useful to eliminate the smallest fractions and thereby to increase the energy output. Additionally, the chips can be sold at a better price. In both systems, the energy output of the chips is by far higher in comparison to the energetic input that has to be invested to produce the chips.

Table 5 Energetic balance of the production of wood-chips

Tablica 5. *Energetska bilanca pridobivanja drvnoga iverja*

System – *Sustav*	A	B
Fuel consumed for the supply of wood-chips, L/m$^3_{loose}$ *Utrošak goriva pri dobavi drvnoga iverja, L/m$^3_{nasipni}$*	1.13	1.74
Energetic input per m^3 of chips at natural moisture content, MJ/m$^3_{loose}$ *Uložena energetska vrijednost po m^3 iverja pri prirodnom sadržaju vlage, MJ/m$^3_{nasipni}$*	36.11	55.61
Energetic output per m^3 of chips at natural moisture content, MJ/m$^3_{loose}$ *Dobivena energetska vrijednost po m^3 iverja pri prirodnom sadržaju vlage, MJ/m$^3_{nasipni}$*	2681.68	2681.68
Energetic balance (ratio energetic input / output), % *Energetska bilanca (odnos uložene i dobivene energetske vrijednosti), %*	1.5	2

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Sažetak

Ocjena dvaju sustava pridobivanja drvnoga iverja iz smrekovih šuma oštećenih pojavom potkornjaka

Smrekova je stabla oštećena napadom potkornjaka potrebno izvaditi iz sastojine što je prije moguće kako bi se spriječilo širenje štetnika. Pri tome se na malim površinama izvodi čista sječa oštećenih stabala i susjednih stabala na kojima još nisu vidljivi znakovi oštećenja. Za razliku od uobičajenih postupaka pridobivanja drva potrebno je sve drvo (oblo drvo i granjevinu) iznijeti iz sastojine. Dosadašnje spaljivanje drva imalo je visoke troškove rada bez financijske isplativosti. Stoga se preporučuje iskoristiti drvo iz sanitarne sječe za pridobivanje iverja. Cilj je rada usporediti dva različita sustava pridobivanja drvnoga iverja iz smrekovih sastojina oštećenih pojavom potkornjaka. Sustav A razumijeva izradu pilanskih trupaca, celuloznoga drva i drvnoga iverja iz preostaloga drva. Sustav B razumijeva izradu jedino pilanskih trupaca iz debla, dok se celulozno drvo pridodaje drvu za iveranje. Kriterij je razvrstavanja dijelova stabala u navedene drvne proizvode u sustavima A i B prikazan na slici 1. Također su analizirana dva sustava iveranja (iveranje u sastojini i iveranje na šumskoj cesti) radi određivanja prikladnije metode u uvjetima sanitarne sječe smrekovih stabala. Pri tome su promatrani ovi parametri: proizvodnost, troškovi, energetska bilanca sustava i obujam drvnoga iverja koje se može proizvesti primjenom određenoga sustava pridobivanja.

Osnovne su značajke ispitivanih sastojina prikazane u tablici 1. U oba se sustava sječa i izrada stabala obavljala motornom pilom, dok su se pilanski trupci i celulozno drvo privlačili skiderima. U sustavu A drvo se iveralo u sastojini mobilnim iveračem postavljenim na forvarder (slika 2), dok se u sustavu B drvo za iveranje (uključujući celulozno drvo) prikupljalo forvarderom i slagalo u složajeve pored šumske ceste gdje se iveralo iveračem postavljenim na kamion (slika 3). Osnovne su značajke korištenih strojeva prikazane u tablici 2. Za određivanje proizvodnosti proveden je studij rada i vremena za svakoga radnika i stroj u sustavu te izmjereni obujmi izrađenih drvnih sortimenata i obujmi kontejnera napunjenih drvnim iverjem. Iz uzorka je svakoga kontejnera određen sadržaj vlage iverja, raspodjela iverja po veličini čestica, ogrjevna vrijednost i koeficijent iverja određen odnosom mase suhe tvari koja se može pridobiti od drvnoga obujma obloga drva.

U sustavu A značajno je manji obujam izrađenih drvnih sortimenata (pilanskih trupaca i celuloznoga drva) jer su pojedina jelova stabla ostala na površini sječine, dok su u sustavu B sva stabla posječena na površini sječine. U sustavu B veći se dio stabala koristi za pridobivanje drvnoga iverja te je značajno veći ukupni obujam dobivenoga drvnoga iverja (tablica 3).

Utrošci su efektivnoga vremena rada i prozvodnosti radnika sjekača i skidera prikazani na slikama 4 i 5. Radnik sjekač u sustavu B ima veću proizvodnost, iako je u sustavu A veći srednji promjer stabala i ukupni obujam izrađenih drvnih sortimenata. Razlog leži u činjenici da se u sustavu B iz debla izrađuju jedino pilanski trupci te je potrebno manje vremena za kresanje grana, trupljenje i preuzimanje. Efektivno se vrijeme rada skidera ne razlikuje između sustava A i B. U sustavu A udaljenost je privlačenja manja, ali je veći utrošak vremena na pomoćnom stovarištu zbog razvrstavanja drvnih sortimenata iz tovara na pilanske trupce i celulozno drvo.

U sustavu A proizvodnost mobilnoga iverača iznosi 36,4 $m^3_{nasipni}$/h. U sustavu B proizvodnost forvardera pri izvoženju energijskoga drva iznosi 23,7 $m^3_{nasipni}$/h, a iverača postavljenoga na kamion 69,8 $m^3_{nasipni}$/h. Veća je proizvodnost iverača na kamionu posljedica veće snage pogonskoga motora te skupljanja drva za iveranje u složajeve uz šumsku cestu, čime se omogućuje neprekidan rada iverača (slika 6).

Ukupni su troškovi po jedinici izrađenoga drvnoga iverja (slika 7) izračunati na osnovi proizvodnosti i određenoga troška radnoga sata, koji iznosi 150 EUR/h za mobilni iverač i iverač na kamionu te 65 EUR/h za forvarder (uz dodatno vrijeme od 15 % za sve strojeve). Jedinični je trošak iveranja manji u sustavu B, ali je ukupni jedinični trošak veći nego u sustavu A zbog troška forvardera pri izvoženju drva za iveranje.

Pri sječi i izradi stabala preporučuje se izrada jedino tehničke oblovine iz debla te iveranje celuloznoga drva uz preostalo drvo, što će za posljedicu imati veću proizvodnost radnika sjekača, skidera i iverača. Mobilni iverač u sustavu A može postići značajno veću proizvodnost ako se za pridobivanje drvnoga iverja koristi i celulozno drvo. Prednost sustava A također se ogleda u primjeni manje sredstava rada te time u jednostavnijoj organizaciji rada. Na osnovi se rezultata zaključuje da je pridobivanje drvnoga iverja metodom iveranja u sastojini povoljniji sustav.

Sadržaj je vlage u iverju vrlo nizak (34,7 % u odnosu na masu svježe tvari, tj. 56,2 % u odnosu na masu suhe tvari) jer je pridobiven iz suhih smrekovih stabala zbog napada potkornjaka. U tablici 4 vidljivo je da manje čestice drvnoga iverja imaju manju ogrjevnu vrijednost, što je posljedica velikoga udjela iglica i kore. Veće se čestice iverja pridobivaju ponajprije iveranjem drva debla te stoga imaju veću ogrjevnu vrijednost. Razdvajanje drvnoga iverja po veličini čestica može biti opravdano radi povećanja dobivene energetske vrijednosti i postizanja veće cijene drvnoga iverja.

Za proračun se energetske bilance (tablica 5) u sustavu A uzela potrošnja goriva iverača na forvarderu od 40 L/h, odnosno u sustavu B potrošnja goriva iverača na kamionu od 68 L/h i forvardera od 10 L/h. Sustav B troši 34,7 % više energije od sustava A jer zahtijeva uporabu dvaju strojeva – forvardera i iverača. No, općenito je u oba sustava malen utrošak energije s obzirom na energetsku vrijednost dobivenoga drvnoga iverja.

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