Productivity and Energy Balance in Conversion of a *Quercus Cerris* L. Coppice Stand into High Forest in Central Italy

Rodolfo Picchio, Mauro Maesano, Serena Savelli, Enrico Marchi

Abstract – Nacrtak

The work was carried out in Caprarola (Viterbo, Central Italy), in an aged Quercus cerris L. coppice positioned in hill zones, with 45% average slope. Harvesting was conducted according to the shortwood system (SWS). Felling and processing were done by chainsaw, while the bunching was performed with three different systems: in Plot 1 with mules, in Plot 2 with a tractor-mounted winch, in Plot 3 with poliethylene chutes. Logs were then forwarded to the roadside landing with a farm tractor, equipped with front and rear container bins. Finally, transportation from the landing to the company depot was performed with a truck and trailer unit. In order to speed up loading, a tractor equipped with a loader was used during this stage. On the basis of time consumption, product output and energy consumption, the authors estimated both the productivity and the energy balance obtained with each system. The best extraction productivity (PSH_0) was achieved in Plot 2 (winching, 0.8 $t_{d.w.}$ h^{-1} $worker^{-1}$), while the lowest one was achieved in Plot 1 (mules, 0.5 $t_{d.w.}$ h^{-1} $worker^{-1}$). The energetic efficiency was high in all the plots (on average, 97.6±0.3%). No correlation between time consumption and energy efficiency was observed. For Plot 3, high productivity, low time consumption and high system efficiency suggest that chutes are the most efficient bunching method from the energetic viewpoint. As the site was in a Nature Reserve and chutes are known to minimize damage to soil and seedlings, this system is to be recommended from both the energetic and environmental point of view, provided that wood can be extracted downhill.

Key words: forest operation, conversion of coppice to high forest, productivity, energy balance

1. Introduction – *Uvod*

Wood is still the dominant source of fuel in many developing countries (Matthews 2001). Until now, about 15% of world energy requirements have been provided by biomass. About 13% of biomass is used in developing countries, while 2% is used in developed countries (Baldini et al. 2007, Johansson and Lundqvist 1999). Among the many methods of potentially sustainable energy generation in the latter countries, biomass has received increasing attention (Matthews 2001). Between the biomass that may be used for energy production, wood shows the greatest potential from both the productive and the environmental point of view (Yoshioka et al. 2006).

However, the use of forest biomass must be supported by an energetic assessment, and must be compatible with a sustainable forest management, also in terms of careful planning and organization of silviculture and logging operations (Baldini et al. 2007). In Italy, there is a lack of information on the energetic balance of forest biomass harvesting and delivery.

Historically, coppice represents an important source of firewood, suggesting that low-input coppice may be an efficient and sustainable biomass production system. According to the data offered by the Forest and Carbon Sink National Inventory (INFC 2005), in Italy there are 3,663,143 ha of coppice stands (41.8% of the Italian woodlands), most of which included in the category »coppice with standard« (28% of the Italian woodlands).

After the 1950s the management of coppices has been deeply affected by economic and social changes, which triggered off the progressive abandonment of coppice stands. The suspension of cutting produced the so-called »aged coppices« and brought about alternatives to the traditional form of coppice management, such as their conversion into high forests (Amorini et al. 1996). Conversion into high forest is obtained through repeated thinning of an aged coppice, in order to build a transitional high forest. At present, adult or aged coppices represent 89% of the whole Italian coppice surface, and transitional high forests occupy about 150,000 ha (INFC 2005).

A coppice in natural evolution shows a great structural variability, revealing dynamic changes toward typical structures of the high forest and a good ability to safeguard biodiversity and valorize the non-productive functions of forests. New silvicultural approaches support the natural development of aged coppice, with the purpose of increasing the stability and functionality of stands until reaching the appropriate age for seed regeneration (Manetti and Gugliotta 2006). As a result, coppice conversion is expected to further increase in popularity (Ciancio et al. 2002).

The most widespread extraction systems, both in coppice management and conversion, are by tractors with forestry winches (winching and skidding), tractors with forwarding bins and pack mules. Chutes are increasingly popular among public forest operators and represent an interesting technological development in similar contexts. In fact, chutes are popular with some small-scale operators – mostly public – but not so popular with the majority of private companies, which need to achieve higher productivity levels than those allowed by chutes.

The main aims of this study were to determine both the productivity of harvesting operations and the energetic balance (input/output) of different Shortwood Logging Systems (SWS) in conversion of coppice to high forest in central Italy. In order to estimate the energetic balance, we quantified: indirect inputs, i.e. the energetic value for production of machineries and tools; direct inputs, i.e. fuel and oil consumption of machineries, and energetic consumption of humans and animals during the work; output, i.e. energetic value of total wood extracted. These data were used to determine the energetic sustainability of three Shortwood System (SWS) bunching methods. SWS is the logging system commonly used in Italian coppice and conversion and may give several advantages: small landings, very low damage to residual stand during bunching/extraction (Spinelli et al. 2004), low investment level and energetic input (Hippoliti 1997, Bagnaresi et al. 1987). The final aim is to evaluate the best harvesting systems from an energetic point of view.

The term »energetic analysis« refers to the study of energy implied in the production of a service or a product (IFIAS 1975). Such energy includes both the energy directly used during the production process (direct), and the energy stocked in the materials used for the production (indirect). The Gross Energy Requirements (GER) method is commonly used in energetic analysis (IFIAS 1975). The method underlines the importance of fossil energetic sources in the actual productive systems and focuses only on the fossil energy flow (direct and indirect). Although the GER method does not include the assessment of energetic human input, man work represents a relevant contribution in many production activities (IFIAS 1975, Biondi et al. 1989). A basic requirement for any bioenergy generation system is that the energy produced (output) must be greater than the inputs of non-renewable energy required to establish and operate the scheme (Matthews 2001).

2. Materials and methods – *Materijal i metode*

2.1 Characteristics of sites and plots – *Značajke mjesta istraživanja*

The study was carried out in a private forest in Caprarola Municipality (Viterbo Province – Central Italy – 42°19’25,02”N, 12°14’34,91”E). The forest road network in the area is quite developed with an average density of 38 m/ha. The climate is mild, with humid summers. Annual precipitation averages approximately 800 mm, winter temperature averages 13°C and summer temperature averages 21°C. As the forest is included in the Nature Reserve of Lago di Vico, silviculture is subject to the following constraints: the mass of felled trees has to be lower than 20–25% of the total mass; felling of large diameter trees is not allowed (Formulario Natura 2000 – IT6010057).

Forest operations were carried out in an aged *Quercus cerris* L. coppice. There were also big trees of *Acer* spp. and *Carpinus* spp. but only *Q. cerris* trees were cut. The main characteristics of the test area are shown in Table 1.

2.2 Logging methods – *Metode pridobivanja drva*

Logging operations were carried out in the summer of 2004 on a total area of 12.30 ha (all area surveys were made by GPS – Trimble Juno ST). All operations were carried out by the same private forest Company. Three plots with the same orographic, microclimatic and dendrometric characteristics were selected with random criteria, where to apply three

Table 1 Main characteristics of test site and of felled trees

Tablica 1. *Osnovne značajke staništa, sastojine i posječenih stabala*

Site *Stanište*	Average ground slope *Prosječni nagib terena*	%	45
	Altitude a.s.l. *Nadmorska visina*	m	790
	Exposure – *Ekspozicija*		south *južna*
Stand *Sastojina*	Age – *Starost*	year godina	75
	Trees – *Broj stabala*	n/ha	750
	DBH – *Prsni promjer*	cm	32
	Average tree height *Srednja visina stabala*	m	18
	Growing stock *Drvna zaliha*	m^3/ha	708
Felling *Sječa*	Felled trees *Posječena stabla*	n/ha	337
	Total felled volume *Ukupni posječeni obujam*	m^3/ha	177
	Total felled mass *Ukupna posječena masa*	$t_{d.w.}$/ha $t_{suhe\ tvari}$/ha	127.4
		$t_{33\%}$/ha $t_{33\%\ vlage}$/ha	166.4
	Wood density *Gustoća drva*	$t_{d.w.}$/ m^3 $t_{suhe\ tvari}$/m^3	0.72
		$t_{33\%}$/ m^3 $t_{33\%\ vlage}$/m^3	0.94

different bunching systems, one system per plot (Fig. 1). The sequence of steps was:

⇒ Felling and processing: in all plots, felling and processing were carried out by chainsaw (STIHL MS 390, 3.4 kW) and the same team of two workers.

⇒ Bunching:

⇒ Plot 1 (0.37 ha): bunching with two groups of 6 mules and one worker each. The workers loaded and unloaded the mules in each group. The firewood was stacked along a forest track.

⇒ Plot 2 (0.39 ha): bunching by winching. A Valtra Valmet 6050 tractor (75 kW) equipped with a Norse 450 winch with a pulling capacity of 50 kN, and a rope of 11 mm diameter and 100 m lenght was used. Winching operations were carried out by three workers. The firewood was stacked along a forest track. Unfortunately, in this plot the private forest Company applied a sub-optimum practice. In fact winching shortwood is more efficient than winching full-length stems.

⇒ Plot 3 (0.24 ha): bunching with chute. The chute sections were 4 m long and made of medium density polyethylene. Each section weighted 35 kg. Sections were overlapped and secured with special steel hooks locked by an eccentric mechanism. In order to identify the optimal set-up route spacing and slope, a preliminary planning was made using a clinometer (Meridian MI 4007). The set-up route slope was 35–40%. A total of 9 chute lines were set up. In order to reduce the workload, the initial set-up was installed with the aid of a small portable KBF winch. Three workers operated the system (set-up, extraction, dismantle and relocation). The firewood was stacked along a forest track.

⇒ Extraction – In all plots, extraction of firewood from the forest track side to the landing was made by a tractor (a Valtra Valmet 6050 – 75 kW) equipped with forwarding bins on the front and rear sides (Piegai and Quilghini 1993) (Fig. 2). Both containers had a capacity of 2.8 steres each (1 stere = 1 m^3 stacked wood). Three workers operated the system: one driver and two loaders. Two landing sites were available (Fig. 1). Firewood from Plot 1 and Plot 2 was forwarded in one landing, while firewood from Plot 3 was forwarded to a second landing.

⇒ Transport – The transport from the landing to the company depot was performed with a truck (DAF CF 85.430, carrying capacity 16 t) and trailer (VIBERTI 7 LOMASS 22 R, carrying capacity 17 t) unit. In order to make easier the loading operation, a Valtra Valmet 6600 tractor equipped with a loader (Terrmacch T5100A) was used. Loading operations were carried out by the loader operator and two stackers.

2.3 Measurement and calculation of productivity – *Mjerenje i proračun učinkovitosti*

The main dendrometric parameters (diameter at breast height – DBH and tree height) were measured in 2 sample plots per each study plot (total surface 9600 m^2). A Kruskal Wallis test (Sprent and Smeeton 2001) was applied to each dendrometric parameter and did not show any significant differences among the test areas. A non parametric test was selected because data showed low homogeneity of variance. A tree calibre (Silvanus type 1208, accuracy 0.5 cm)

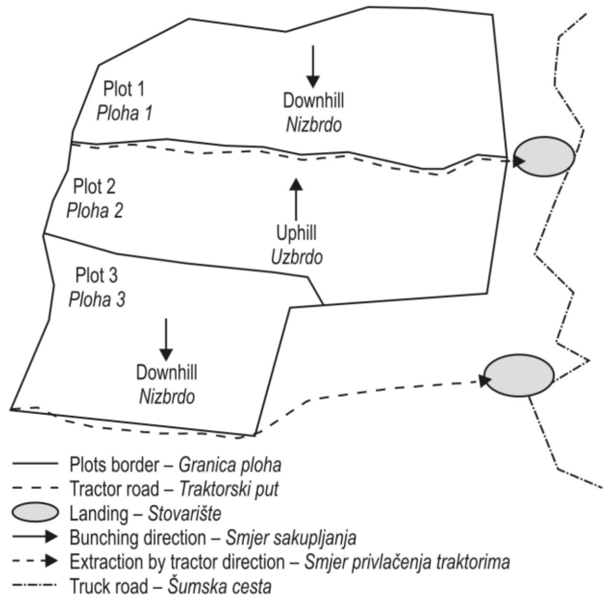

Fig. 1 Working site, plot schemes, landing, bunching and extraction directions

Slika 1. *Radilište, plohe, stovarište, smjerovi skupljanja i privlačenja*

was used for measuring the DBH of all the trees as well as the diameter of firewood logs at half length. The diameter and length of 300 randomly selected firewood pieces was measured at the two landings (150 by landing). For the calculation of moisture and wood density, 30 stem sections (3-cm thick) were collected at each landing. 60 wood samples were immediately weighed with a portable scale (Orma model BC16D) and transferred to the laboratory for moisture and wood density determination, using the thermo-gravimetric method (UNI ISO 3130 – 1985, UNI 9091 – 1987, CEN/TS 14774-2 – 2004; UNI ISO 3131 – 1985, CEN/TS 15103 – 2005). Statistical analysis (Kruskal Wallis) did not detect any significant differences (wood density $_{f.w.}$: KW 7.087, *p*-value 0.131; wood density $_{d.w.}$ KW 5.972, *p*-value 0.201) between the two landings.

Fig. 2 Valtra Valmet 6050 tractor (75 kW) forestry version, equipped with open-ended containers mounted on both front and rear sides

Slika 2. *Traktor Valtra Valmet 6050 (75 kW), šumska izvedba, opremljen otvorenim spremnicima na prednjem i stražnjem kraju*

Slopes were measured by means of a clinometer. A laser gauge (Stanley TLM 300 TRU LASER) was used to measure the bunching and extraction distances. A spring-loaded self-reeling tape (Walktax-r) was used to measure workers' and mules' walking distances. A CR10C CAMPBELL data-logger was used for the tractor engine data (power, engine load factor and using time). The transport distances by lorry were measured with the lorry odometer.

Working times were recorded for every single phase (except transport by lorry and trailer) by a chronometric table Minerva, equipped with three centesimal chronometers (Anon. 1988, Harstela 1991, Berti et al. 1989). In order to calculate outputs in different plots, effective time and delays in the work routine up to 15 min (unavoidable time UT and avoidable time AT) (Anon. 1988, Harstela 1991) were recorded.

Based on work times, volume and mass, the productivity per worker for different operations was calculated as follows: average gross productivity (PHS_{15}) calculated on the basis of time consumption, inclusive of all delays up to the maximum event duration of 15 minutes; average net productivity (PHS_0), calculated with the exclusion of delays. Productivity was also expressed in terms of both dry matter and fresh matter (measured in laboratory, 33% average moisture level).

2.4 Calculation of energy balance – *Proračun energijske bilance*

2.4.1 Machineries and tools – *Strojevi i oruđe*

According to the Gross Energy Requirements (GER) method (IFIAS 1975), the equation to calculate the energetic consumption of machineries and tools was:

⇒ Direct input (machinery only):

$$Cu = P \times Fc \times Cs \times Tu$$

where:

Cu – unit consumption of fuel (kg $t_{d.w}^{-1}$.).

P – nominal engine power (kW);

Fc – engine load factor (from 0 to 1);

Cs – engine specific fuel consumption (kg kW^{-1} h^{-1});

Tu – time of use for output unit (dry mass) (h $t_{d.w}^{-1}$.);

In order to convert the unit consumption (kg $t_{d.w}^{-1}$) to direct input (MJ $t_{d.w.}^{-1}$), the energetic values (MJ kg^{-1}) showed in Table 2 were applied. Lubricant consumption was assumed as 3 kg per 100 kg of diesel and as 1/3 kg per 1 kg of chainsaw mixed fuel (Biondi *et al*. 1989).

Table 2 Energetic input of fuel and lubricant (Biondi et al. 1989; Volpi 1992)

Tablica 2. *Energijska vrijednost goriva i maziva (Biondi i dr. 1989, Volpi 1992)*

Fuel *Gorivo*	Energetic value *Energijska vrijednost* MJ/kg
Diesel – *Dizelsko*	51.5
Mixed fuel (two-stroke) – *Mješavina (2-taktni)*	55.3
Lubricant – *Mazivo*	83.7

⇒ Indirect input (machinery and tools):

The indirect input $I_{ind.}$ (MJ $t_{s.s.}^{-1}$) of machineries and tools was determined by the average energetic values E_{cm} (MJ kg^{-1}) of raw materials (Table 3) in relation to: their quantitative presence *pm*%, total machinery mass *m* (kg), total service life of the machine t_1 (h $t_{s.s.}^{-1}$), and use of the machine in these forest operations *ut* (h) (Volpi 1992).

$$I_{ind}= \{[(\Sigma^1_n EV_I)\ m]/\ ut\ \}\ t_1 \qquad EV_I= E_{cm}\ pm\%$$

2.4.2 People and animals – *Ljudi i životinje*

On the basis of literature data, we developed a preliminary approach to estimate the energetic consumption of human work. Mean energetic consumption of forest workers was calculated by applying the value of 0.0502 MJ min^{-1} $worker^{-1}$ (Rodio et al. 2002) as human physiological requirement. Similar values were suggested by Hippoliti (1997) and Christie (2008), i.e. 0.036–0.045 MJ $min^{-1}worker^{-1}$ and 0.028–0.030 MJ min^{-1} $worker^{-1}$, respectively.

Table 3 Average energetic value of raw materials used in the construction of machinery and implements (Biondi et al. 1989; Volpi 1992)

Tablica 3. *Energijska vrijednost sirovina korištenih u konstrukciji strojeva i oruđa (Biondi i dr. 1989, Volpi 1992)*

Raw material *Sirovina*	Energetic value *Energijska vrijednost* MJ/kg
Iron matter (steel) – *Metal (čelik)*	67.5
No iron matter (copper and zinc) *Nemetali (bakar, cink)*	90.0
Alloy – *Legure*	360.0

We evaluated also the energy consumption of animal work (in our case the mules) by using the Forage Unit method (Ronchi 1988), summarized in the following equation (Table 4):

$$E_t = F_g\ uf\ E_m / 0.55$$

where:

- E_t – total energy (MJ d^{-1}),
- F_g – daily amount of feed per mule (kg d^{-1}), i.e. 3 kg hay, 2.5 kg straw and 4 kg oats (Ronchi 1988),
- *uf* – forage unit (kg^{-1}), a conversion factor to express equivalent energetic value of barley,
- E_m – nutritive value of 1 *uf*, corresponding to 11.4 MJ, which is the amount of energy actually available for work at a metabolic conversion rate of 55%.

Table 4 Calculation of a mule daily energetic consumption

Tablica 4. *Izračun dnevne potrošnje energije mule*

Feed *Hrana*	Daily amount *Dnevna količina* F_g kg/day (kg/dan)	Forage unit *Hranjivi odnos* *uf* kg^{-1}	Raw energy *Hranjiva vrijednost* E_g MJ	Total energy *Ukupna energija* E_t MJ/day (MJ/dan)
Hay *Sijeno*	3	0.42	20.72	26.11
Straw *Slama*	2.5	0.15	20.72	7.77
Oats – *Zob*	4	0.82	20.72	67.96

2.4.3 Energy output – *Energijski dobitak*

In order to calculate the energetic value of wood, the energy released by its combustion must be determined (Volpi 1992). The Higher Heating Value (*HHV*) was determined (CEN/TS 14918) on 20 random samples, one sample per tree, by means of an adiabathic calorimeter (Parr, model 6200) (Canagaratna and Witt 1988). A Kruskal Wallis test, suggests very limited variability (KW 5.763, *p*-value 0.218). The average *HHV* of *Q. cerris* wood was 20.62 MJ $kg_{d.w}^{-1}$.

Table 5 Characteristics, time consumption and productivity of different harvesting phases

Tablica 5. *Značajke, utrošak vremena i učinak različitih faza pridobivanja drva*

Felling and processing – *Sječa i izrada*													
Surface *Površina*	Workers *Radnici*	Chainsaw *Motorna pila*	Trees *Stabla*	Chainsaw time *Vrijeme rada motorne pile*	Fuel consumption *Potrošnja goriva*	Lubricant consumption *Potrošnja maziva*	Total gross time *Ukupno utrošeno vrijeme*	Unavoidable times *Opravdani prekidi*	Avoidable times *Neopravdani prekidi*	Log volume *Obujam trupaca*	Log mass *Masa trupaca*	Gross productivity *Učinak u ukupnom vremenu* PSH_{15}	Net productivity *Učinak u efektivnom vremenu* PSH_0	
ha	No.	No.	No.	h	L	L	h	h	h	m^3	$t_{33\%}$ $t_{33\%\ vlage}$	$t_{d.w.}$ $t_{suhe\ tvari}$	$t_{d.w.}\ h^{-1}\ worker^{-1}$ $t_{suhe\ tvari}\ h^{-1}\ radnik^{-1}$	
1.00	2	1	337	30.0	29.3	15.5	61.3	17.2	8.6	177	166.4	127.4	1.1	1.8
Bunching with mules (Plot 1) – *Skupljanje mulama (ploha 1)*													
Journeys *Turnusi*	Workers *Radnici*	Mules *Mule*	Logs *Trupci*	Av. logs per journey *Prosječni broj trupaca u tovaru*	Average mass per journey *Pros. masa tovara*	Av. extraction distance *Srednja udaljenost skupljanja*	Total gross time *Ukupno utrošeno vrijeme*	Unavoidable times *Opravdani prekidi*	Avoidable times *Neopravdani prekidi*	Log volume *Obujam trupaca*	Log mass *Masa trupaca*	Gross productivity *Učinak u ukupnom vremenu* PSH_{15}	Net productivity *Učinak u efektivnom vremenu* PSH_0	
No.	No.	No.	No.	$No.mule^{-1}$	$t_{33\%}$	m	h	h	h	m^3	$t_{33\%}$ $t_{33\%\ vlage}$	$t_{d.w.}$ $t_{suhe\ tvari}$	$t_{d.w.}\ h^{-1}\ worker^{-1}$ $t_{suhe\ tvari}\ h^{-1}\ radnik^{-1}$	
24	2	12	3361	12	0.2	200.0	49.3	1.5	0.0	65	61.1	46.8	0.5	0.5
Bunching with tractor (Plot 2) – *Skupljanje traktorom (ploha 2)*													
Total winching *Broj privitlavanja*	Workers *Radnici*	Tractor time *Vrijeme rada traktora*	Logs *Trupci*	Av. logs per journey *Prosječni broj trupaca u tovaru*	Fuel consumption *Potrošnja goriva*	Av. extraction distance *Srednja udaljenost skupljanja*	Total gross time *Ukupno utrošeno vrijeme*	Unavoidable times *Opravdani prekidi*	Avoidable times *Neopravdani prekidi*	Log volume *Obujam trupaca*	Log mass *Masa trupaca*	Gross productivity *Učinak u ukupnom vremenu* PSH_{15}	Net productivity *Učinak u efektivnom vremenu* PSH_0	
No.	No.	h	No.	No.	L	m	h	h	h	m^3	$t_{33\%}$ $t_{33\%\ vlage}$	$t_{d.w.}$ $t_{suhe\ tvari}$	$t_{d.w.}\ h^{-1}\ worker^{-1}$ $t_{suhe\ tvari}\ h^{-1}\ radnik^{-1}$	
143	3	10.4	3568	25	30	42.0	22.7	1.7	0.7	69	64.9	49.7	0.7	0.8
Bunching with chutes (Plot 3) – *Skupljanje točilima (ploha 3)*													
Chute lines *Točila*	Workers *Radnici*	Av. chute per line *Broj dijelova točila*	Logs *Trupci*	Winch time *Vrijeme privitlavanja*	Fuel consumption *Potrošnja goriva*	Av. chute line length *Srednja duljina točila*	Total gross time *Ukupno utrošeno vrijeme*	Unavoidable times *Opravdani prekidi*	Avoidable times *Neopravdani prekidi*	Log volume *Obujam trupaca*	Log mass *Masa trupaca*	Gross productivity *Učinak u ukupnom vremenu* PSH_{15}	Net productivity *Učinak u efektivnom vremenu* PSH_0	
No.	No.	No.	No.	h	L	m	h	h	h	m^3	$t_{33\%}$ $t_{33\%\ vlage}$	$t_{d.w.}$ $t_{suhe\ tvari}$	$t_{d.w.}\ h^{-1}\ worker^{-1}$ $t_{suhe\ tvari}\ h^{-1}\ radnik^{-1}$	
9	3	22	2224	4.2	4	86	20.4	3.9	1.4	43	40.4	31.0	0.5	0.7
Extraction by tractor – *Privlačenje traktorom*													
Journeys *Turnusi*	Workers *Radnici*	Tractor time *Vrijeme rada traktora*	Logs *Trupci*	Av. logs per journey *Prosječni broj trupaca u tovaru*	Fuel consumption *Potrošnja goriva*	Av. extraction distance *Srednja udaljenost privlačenja*	Total gross time *Ukupno utrošeno vrijeme*	Unavoidable times *Opravdani prekidi*	Avoidable times *Neopravdani prekidi*	Log volume *Obujam trupaca*	Log mass *Masa trupaca*	Gross productivity *Učinak u ukupnom vremenu* PSH_{15}	Net productivity *Učinak u efektivnom vremenu* PSH_0	
No.	No.	h	No.	No.	L	m	h	h	h	m^3	$t_{33\%}$ $t_{33\%\ vlage}$	$t_{d.w.}$ $t_{suhe\ tvari}$	$t_{d.w.}\ h^{-1}\ worker^{-1}$ $t_{suhe\ tvari}\ h^{-1}\ radnik^{-1}$	
33	3	34	9155	277	11.8	570.0	20.4	0.0	0.0	177	166.4	127.4	2.1	2.1
Loading on truck and trailer – *Utovar na kamionski skup*													
Loads *Tovari*	Workers *Radnici*	Tractor time *Vrijeme rada traktora*	Logs *Trupci*	Av. logs per load *Prosječni broj trupaca u tovaru*	Fuel consumption *Potrošnja goriva*	Av. mass per load *Prosječna masa tovara*	Total gross time *Ukupno utrošeno vrijeme*	Unavoidable times *Opravdani prekidi*	Avoidable times *Neopravdani prekidi*	Log volume *Obujam trupaca*	Log mass *Masa trupaca*	Gross productivity *Učinak u ukupnom vremenu* PSH_{15}	Net productivity *Učinak u efektivnom vremenu* PSH_0	
No.	No.	h	No.	No.	L	$t_{33\%}$ $t_{33\%\ vlage}$	h	h	h	m^3	$t_{33\%}$ $t_{33\%\ vlage}$	$t_{d.w.}$ $t_{suhe\ tvari}$	$t_{d.w.}\ h^{-1}\ worker^{-1}$ $t_{suhe\ tvari}\ h^{-1}\ radnik^{-1}$	
6	3	15.0	9155	1526	43	27.0	18.5	0.7	0.2	177	166.4	127.4	2.3	2.4

4. Results and discussion – *Rezultati s diskusijom*

4.1 Productivity – *Učinkovitost*

Productivity (PSH_{15} and PSH_0) of each working phase was good (Table 5), as compared to literature data of manual logging operations in central Italian *Q. cerris* coppices (Calafatello et al. 2005, Fabiano et al. 2002, Piegai 2005, Piegai 2008). Technical problems in the use of the tractor and winch increased the time consumption for bunching, in particular during log hooking and winching, whereas bunching by mules or by chutes proceeded smoothly.

The best bunching productivity was recorded in Plot 2 (winching, 0.8 $t_{d.w.}$ h^{-1} $worker^{-1}$), while the lowest one was recorded in Plot 1 (mules, 0.5 $t_{d.w.}$ h^{-1} $worker^{-1}$) with Plot 3 showed intermediate results (chutes, 0.7 $t_{d.w.}$ h^{-1} $worker^{-1}$). The best PSH_{15} was still in Plot 2 (0.7 $t_{d.w.}$ h^{-1} $worker^{-1}$), while Plot 1 and Plot 3 showed the same PSH_{15} (0.5 $t_{d.w.}$ h^{-1} $worker^{-1}$), because of longer unavoidable delay times (UT) in Plot 3 (Table 5). Then the tractor and winch performed best, despite the technical problems.

Because of the high concentration of wood on the site and the optimal chute slope (30–35%, Hippoliti 1997), chute productivity was higher than the average values reported in the literature (PSH_{15} 0.22–0.34 $t_{f.w.}$ $h^{-1}worker^{-1}$, Calafatello et al. 2005). Due to the use of appropriate tractors and the availability of a good trail network, forwarding productivity was also higher than previously reported for similar work conditions (2.1 $t_{d.w.}$ h^{-1} $worker^{-1}$ vs. 1.2–1.8 $t_{f.w.}$ h^{-1} $worker^{-1}$ in Piegai 2005, Piegai 2008). A preliminary assessment of transport productivity by truck and trailer showed that the truck needed 5 full trips of 60 km each at an average speed of 60 km/h to transport 166.4 $t_{33\%}$ of firewood.

4.2 Energetic balance – *Energijska bilanca*

The lowest energy efficiency was recorded in Plot 1 (mules, with a total input of 71 GJ ha^{-1} or 0.56 GJ $t_{d.w.}^{-1}$); the results for Plot 2 were only marginally better (winch, –2.6% or 0.54 GJ $t_{d.w.}^{-1}$ compared to Plot 1); the highest energy efficiency was calculated in Plot 3 (chutes, –22.7% or 0.43 GJ $t_{d.w.}^{-1}$) (Table 6 and Fig. 3). Direct inputs were 34% higher in Plot 2 (winch) than in Plot 1 and Plot 3 (on average, 45 GJ ha^{-1} or 0.36 GJ $t_{d.w.}^{-1}$). The most mechanized system (Plot 2, winch) had a 19% lower human input and a 16% higher indirect input than the system based on mules and chutes (on average, 1.22 GJ ha^{-1} humans or 0.01 GJ $t_{d.w.}^{-1}$ and 6.22 GJ ha^{-1} indirect input or 0.05 GJ $t_{d.w.}^{-1}$).

Table 6 Energetic value of outputs and inputs (all working phases, transport included)

Tablica 6. *Energijska vrijednost dobitka i utroška*

Plot *Ploha*	Output *Dobitak*	Input – *Utro{ak*				
		Machines & Tool *Strojevi i alati*		Human *Ljudi*	Mules *Mule*	Total *Ukupno*
		Direct *Izravni*	Indirect *Neizravni*			
	GJ ha^{-1}					
1	2627.24	43.46	5.93	1.24	20.50	71.13
2	2627.24	61.01	7.25	0.99	0.00	69.25
3	2627.24	47.31	6.51	1.20	0.00	55.01

Concerning the role of single work phases (Fig. 3), the energetic input of truck transport contributed the most in all treatments (from 33% to 43% – average 192.16 MJ $t_{d.w.}^{-1}$), followed by extraction in Plot 1 and Plot 2 (from 28% to 30% or average 159 MJ $t_{d.w.}^{-1}$).

The input/output ratio was 28% higher in Plot 3 than in Plot 1 and Plot 2 (Table 7). Due to the large amount of biomass harvested, the input/output ratio was on average even three times higher than that reported in literature for chip harvesting (8.6–11.7, Baldini et al. 2007). Our ratios were, however,

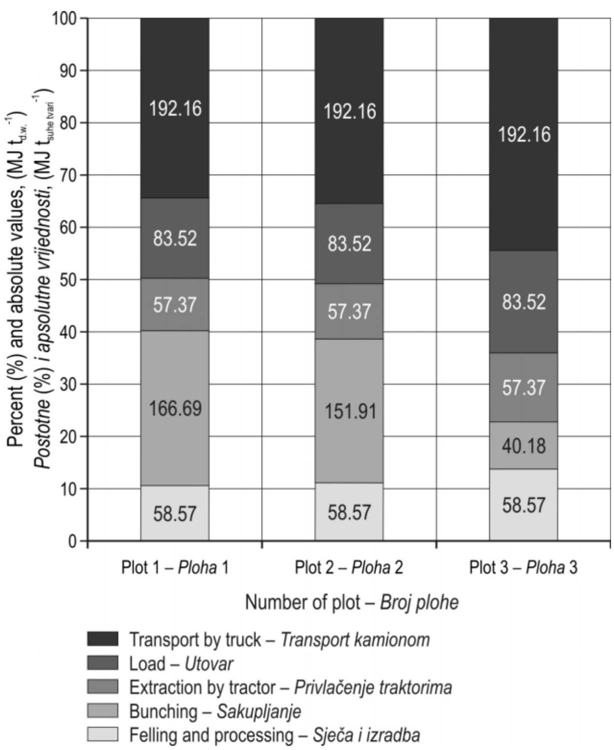

Fig. 3 Contribution of single work phases to the total energy inputs

Slika 3. *Udio pojednih radnih faza u ukupnom energijskom utrošku*

Table 7 Energy efficiency, time consumption and productivity (PSH_{15} e PSH_0) in three plots
Tablica 7. *Energijska učinkovitost, utrošak vremena i učinak*

Plot Ploha	Input/output *Dobitak/Utrošak*	System efficiency *Korisnost sustava*	Time consumption *Utrošak vremena*	Gross productivity *Učinak u ukupnom vremenu* PSH_{15}	Net productivity *Učinak u efektivnom vremenu* PSH_0
		%	min $t_{d.w.}^{-1}$ worker^{-1} min $t_{suhe\ tvari}^{-1}$ radnik^{-1}	$t_{d.w.}$ h^{-1} worker^{-1} $t_{suhe\ tvari}$ h^{-1} radnik^{-1}	$t_{d.w.}$ h^{-1} worker^{-1} $t_{suhe\ tvari}$ h^{-1} radnik^{-1}
1	36.94	97.3	213.12	0.26	0.29
2	37.94	97.4	168.93	0.32	0.37
3	47.76	97.9	205.16	0.27	0.34

slightly higher than the literature data for the forestry sector (25–50, Scholz et al. 1998). Higher values (100–180, Bagnaresi et al. 1987) were also reported in some studies, which however did not include transport by lorry from landing to the company depot. If we remove transport from our calculation, our ratios will climb to 80–180.

The percentage energy efficiency (Table 7) (Energy efficiency = ((output – input)/output)*100) was high in all the plots (97.6±0.3%). No correlation between time consumption and energy efficiency was observed: the operation with the highest energy efficiency (Plot 3) showed intermediate specific time consumption, whereas the operation with the lowest specific time consumption (Plot 2) showed an intermediate level in energy efficiency.

Plot 3 offered an intermediate high productivity and specific time consumption and high energy system efficiency, suggesting that HDPE chutes are the most efficient system from the energy viewpoint. In addition, the site was in a Nature Reserve and chutes are known to minimize damage to soil and seedlings (Eroglu et al. 2007, Hippoliti 1997): therefore, this system is to be recommended from both the energy and environmental point of view, provided that bunching is performed downhill.

4. Conclusions – *Zaključci*

An energy analysis of productivity in logging operations carried out with three different bunching methods (mules, winch and chutes) in a *Q. cerris* coppice in central Italy showed input/output ratios of 37–48. These values are in the range already reported by previous studies on the subject, but the large variation of literature data (4–180 in Baldini et al. 2007, Scholz et al. 1998, Bagnaresi et al. 1987) suggests that more investigations are needed to further refine the estimates.

From an energy point of view, the best harvesting system is that were bunching is performed with log chutes, which also offer good productivity and significant environmental protection. As high mechanization in Shortwood System (SWS) operations in coppice can be difficult, the chute system is therefore recommended for use in the conversion of coppice stands into high forest systems. At the same time, more research is needed to develop efficient Full Tree Systems operations in coppice, in order to remove residues from the forest floor, in fire prone environment, such as Mediterranean countries. In fact, in coppice stands branches and tops can represent 10–30% of the total mass (Baldini et al. 2008), and their release into the stand improves dead fuel accumulation and increases the risk of the occurrence of wildfires, which represent a serious hazard for woodland, infrastructure and people (Marchi et al. 2007).

As the highest energy contribution to inputs was given by transport, the development of local markets should be encouraged. Adequate training of workers and planners is also needed for a sustainable use of forest biomass as renewable resource, which can provide increased energy output and a favourable carbon balance.

5. References – *Literatura*

Amorini, E., Bruschini, S., Cutini, A., Di Lorenzo, M. G., Fabbio, G., 1996: Treatment of Turkey oak (*Quercus cerris* L.) coppices. Structure, biomass and silvicultural options. Annali Istituto Sperimentale Selvicoltura Arezzo 27: 105–111.

Anon, 1988: Introduction to work study. International Labour Office, Geneva.

Bagneresi, U., Baldini, S., Berti, S., Minotta, G., 1987: Ricerche sui bilanci energetici e sui costi di utilizzazioni forestali (*Researches on the energetic balance and on the costs of forestry utilization*). Annali Accademia Italiana di Scienze Forestali XXXVI: 159–183.

Baldini S., Artese C., Laudati G., Picchio R., Stirpe F., 2008: Individuazione, quantificazione e localizzazione delle biomasse forestali utilizzabili (*Individualization, quantification and localization of the usable forest biomasses*); atti della giornata di studio »Produzione di energia da fonti biologiche rinnovabili: le risosrse primarie«, svoltosi a Firenze il 15 febbraio 2007, Accademia dei Georgofili. Quaderni »I Georgofili«, 2007-II: 101–135.

Baldini, S., Picchio, R., Savelli, S., 2007: Energy analysis of light mechanization yards for the Eucalyptus coppice harvest. Journal of Agricultural Engineering 3: 49–56.

Berti, S., Piegai, F., Verani, S., 1989: Manuale di istruzione per il rilievo dei tempi di lavoro e delle produttività nei lavori forestali (*Training manual for the relief of the working times and the productivities in forestry work*). Quaderni dell'Istituto di Assestamento e Tecnologia Forestale dell'Università di Firenze IV: 65.

Biondi, P., Panaro, V., Pellizzi, G., 1989: Le richieste d'energia del sistema agricolo italiano (*The energy requests of the Italian agricoltural system*). Progetto finalizzato energetic, p. 79.

Calafatello, A. R., Catania, P., Vallone, M., Pipitone, F., 2005: Technical analysis of mechanized yards in the farest utilization in Sicily. Journal of Agricultural Engineering 3: 55–59.

Canagaratna, S. G., Witt, J., 1988: Calculation of temperature rise in calorimetry. Journal of chemical education 65(2): 126–129.

Carter, A. P., 1974: Applications of input-output analysis to energy problems. Science 184, 4134: 325–329.

Christie, C. J., 2008: Relationship between energy intake and expenditure during harvesting tasks. Occupational Ergonomics 8(1): 1–10.

Ciancio, O., Iovino, F., Menguzzato, G., 2002: Prove sperimentali di avviamento a fustaia con il metodo del rilascio intensivo di allievi: i cedui di leccio in Aspromonte (Calabria) (*Conversion in a high forest research with stand release: the Quercus ilex coppice in Aspromonte*). Il bosco ceduo in Italia, Accademia di Scienze Forestali, Firenze, 125–145.

Eroglu, H., Acar, H. H., Sinan Ozkaya, M., Tilki, F., 2007: Using plastic chutes for extracting small logs and short pieces of wood from forests in Artvin, Turkey. Building and Environment 42: 3461–3465.

Fabiano, F., Marchi, E., Piegai, F., 2002: Sistemi di lavoro nelle utilizzazioni dei cedui e nei tagli di conversione (*Working systems in the coppice and conversion harvesting*). In »Il bosco ceduo in Italia« a cura di Orazio Ciancio e Susanna Nocentini, Accademia Italiana di Scienze Forestali, Firenze.

Formulario Natura 2000, cod. nature 2000, IT6010057 Lago di Vico-Monte Venere e Monte Fogliano, site F.

Harstela, P., 1991: Work study in forestry. Silva Carelica 18: 1–41.

Hippoliti, G., 1997: Appunti di meccanizzazione forestale (*Forestry mechanization*). Studio Editoriale Fiorentino, Firenze.

Hippoliti, G., Piegai, F., 2000: Tecniche e sistemi di lavoro per la raccolta del legno (Working t*echnics and systems for wood harvesting*). Compagnia delle Foreste, Arezzo.

IFIAS, 1974: Energy Analysis and Economics. Workshop report n°6, Stoccolma.

IFIAS, 1975: Energy Analysis and Economics. Workshop report n°9, Stoccolma.

Johansson, J., Lundqvist, U., 1999: Estimating Swedish biomass energy supply. Biomass and Bioenergy 17: 85–93.

Lettens, S., Muys, B., Ceulemans, R., Moons, E., Garcia, J., Coppin, P., 2003: Energy budget and greenhouse gas balance evaluation of sustainable coppice systems for electricity production. Biomass and Bioenergy 24: 179–197.

Manetti, M. C., Gugliotta, O. I., 2006: Effetto del trattamento di avviamento ad alto fusto sulla diversità specifica e strutturale delle specie legnose in un ceduo di cerro (*Effect of the treatment of starting to high forest on the specific and structural diversity of the trees in a turkey oak coppice*). Annali dell'Istituto Superiore della Selvicoltura XXXIII (2002–2004): 105–114.

Marchi, E., Tesi, E., Monterselli Brachetti, N., Bonora, L., Conese, C., Romani, M., 2007 – Forest Fire Prevention: An Integrate Risk Analysis to Improve Management and Planning Actions. Proceedings of »Bottlenecks, solutions, and priorities in the context of functions of forest resources«, the 150th Anniversary of forestry education in Turkey – October 17–19, 2007 – Harbiye/Istanbul (Turkey).

Matthews, R. W., 2001: Modelling of energy and carbon budgets of wood fuel coppice systems. Biomass and Bioenergy 21: 1–19.

Ministero delle Politiche Agricole, Alimentari e Forestali, Corpo Forestale dello Stato, 2005: Inventario Nazionale Forestale e dei serbatoi di Carbonio »*Forest National inventory and of the Carbon Sink*«.

Piegai, F., Quilghini, G., 1993: Esbosco a soma con trattore (*Extraction by tractor loaded as a mule*). Monti e Boschi 1: 36–44.

Piegai, F., 2005: Tagli di utilizzazione e di avviamento nei cedui quercini. Produttività a confronto (*Coppice and conversion felling for Quercus* spp., *productivity*). Sherwood – Foreste ed Alberi Oggi 117: 5–8.

Piegai, F., 2008: Tagli di utilizzazione e di avviamento nei cedui quercini. Produttività a confronto (*Coppice and conversion felling for Quercus* spp., *productivity*). http://www.compagniadelleforeste.it/SHERWOOD/AulaMagna/DAulaMagna.htm

Rodio, A., Rosponi, A., Fattorini, L., Delussu, S., Marchetti, E., Marchetti, M., 2002: Costo energetico durante attività forestali in ambiente alpino (*Energetic cost for the human* *work during forest activity in the Alps*). Atti del convegno »Lavoro in foresta e salute«, Trento, 172–181.

Ronchi, B., 1988: Zootecnia nelle regioni di montagna (*Farm animals in mountains regions*). Athena Editrici, Roma.

Scholz, V., Berg, W., Kaulfuâ, P., 1998: Energy Balance of Solid Biofuels. Journal agricultural Engineering Research 71: 263–272.

Spinelli, R., Owende, P. M. O., Ward, S. M., Tornero, M., 2004: Comparison of short-wood forwarding systems used in Iberia. Silva Fennica 38(1).

Sprent, P., Smeeton, N. C., 2001: Applied Nonparametric Statistical Methods, 3rd ed. Chapman & Hall/CRC, London, 461.

UNI 9091, parte 2°, 1987: Wood – Determination of moisture content – Oven drying.

UNI ISO 3130, 1985: Wood – Determination of moisture content for physical and mechanical tests.

Volpi, R., 1992: Bilanci energetici in agricoltura. »*Energy balance in agriculture*«. Laruffa Editore, Reggio Calabria.

Yoshioka, T., Aruga, K., Nitami, T., Sakai, H., Kobayashi, H., 2006: A case study on the costs and the fuel consumption of harvesting, transporting, and chipping chains for logging residues in Japan. Biomass and Bioenergy 30: 342–348.

Sažetak

Učinkovitost i energijska bilanca pri konverziji šikara hrasta cera u viši uzgojni oblik

Šikare pokrivaju 41,8 % šumskoga zemljišta (3 663 143 ha) u Italiji. One su značajan izvor ogrjevnoga drva te se stoga njima može učinkovito i potrajno gospodariti radi proizvodnje šumske biomase. Sa stanovišta uzgajanja šuma potiče se konverzija sastojina u viši uzgojni oblik da bi se povećala stabilnost i funkcionalnost šumskih sastojina te postigla njihova prirodna obnova. Konverzija se šikara u viši uzgojni oblik provodi ponovljenim proredama, što daje znatnu količinu ogrjevnoga drva. Pri tome se ogrjevno drvo prikraja u kratke sortimente.

Pri privlačenju drva kod radova na konverziji šikara ili pri potrajnom gospodarenju šikarama najčešće se koriste traktori opremljeni šumskim vitlima ili traktori opremljeni utovarnim spremnicima te sprege mula. Točila kao zanimljivo tehnološko rješenje privlačenja i skupljanja drva također dobro prihvaćaju privatni poduzetnici.

Cilj je rada odrediti učinkovitost radova pridobivanja drva i energijsku bilancu različitih sustava pridobivanja drva pri konverziji šikara u viši uzgojni oblik. Krajnji je cilj istraživanja procijeniti najbolji sustav pridobivanja s energijskoga stajališta. Osnovni je zahtjev da je pridobivena energija, koju predstavlja količina privučenoga i transportiranoga ogrjevnoga drva, veća od ukupno utrošene energije u sustavu pridobivanja drva. Ukupno utrošena energija uključuje izravno utrošenu energiju strojeva, ljudi i životinja, ali i energiju utrošenu u proizvodnju materijala, oruđa i strojeva koji se koriste u sustavu pridobivanja drva.

Istraživanje je provedeno u privatnoj šumi pri konverziji šikare hrasta cera u viši uzgojni oblik. Šumska je površina smještena u zaštićenom području te je sječa obavljena prema ovim propisima: ukupni posječeni drvni obujam ne smije biti veći od 20 do 25 % ukupne drvne zalihe, sječa stabala većih prsnih promjera nije dopuštena (Formulario Natira 2000 – IT6010057). Osnovne značajke staništa i sastojine te podaci o posječenom drvnom obujmu prikazani su u tablici 1. Stabla su posječena motornim pilama.

Površina je šumske sastojine podijeljena u 3 ispitne plohe na kojima su primijenjene različite metode skupljanja drva (slika 1). Statističkim testiranjem podataka izmjere prsnih promjera i visine primjernih stabala nisu uočene razlike između postavljenih ploha. Na prvoj su plohi drvo skupile dvije skupine od 6 mula i jednoga radnika po skupini. Ogrjevno je drvo slagano pored traktorskoga puta. Na drugoj plohi tri su radnika skupljala ogrjevno drvo pomoću traktora Valtra Valmet opremljenoga šumskim vitlom Norse 450, nazivne vučne sile od 50 kN, uz primjenu užeta promjera 11 mm i duljine od 100 m. Na trećoj plohi ogrjevno se drvo skupljalo točilima. Pojedinačni dijelovi točila bili su duljine 4 m, mase 35 kg, izrađeni od polietilena. Njihovim spajanjem i učvršćivanjem izrađeno je 9 točila uz pomoć prijenosnoga KBF vitla. Radi optimalnoga prostornoga rasporeda

točila i postavljanja dopuštenoga nagiba (35 – 40 %) prethodno su označeni pravci uz izmjeru terena padomjerom. Tri su radnika sudjelovala u skupljanju drva točilima.

Za privlačenje ogrjevnoga drva do stovarišta je korišten traktor Valtra Valmet 6050 (75 kW) opremljen spremnicima, kapaciteta od 1 m^3 prostornoga drva, na prednjem i stražnjem kraju (slika 2). Dva su radnika radila na utovaru ogrjevnoga drva u spremnike, a jedan je radnik upravljao traktorom. Ogrjevno se drvo s ploha 1 i 2 privlačilo na prvo stovarište, a s plohe 3 na drugo stovarište.

Drvo se dalje prevozilo kamionskim skupom (kamion DAF CF 85.430 nosivosti 16 t i prikolica VIBERTI 7 LOMASS 22 R nosivosti 17 t). Uz dva radnika na utovaru se također koristio traktor Valtra Valmet 6600 s utovarnim hvatalom Terrmach T5100A.

Duljina i srednji promjer ogrjevnoga drva izmjereni su na stovarištu. Za određivanje gustoće i mokrine drva sa 60 komada ogrjevnoga drva otpiljen je kolut 3 cm debljine. Uzorci su odmah vagani na terenu prijenosnom vagom, a zatim analizirani u laboratoriju termogravimetrijskom metodom. Laserskim su mjeračem izmjerene udaljenosti skupljanja i privlačenja, a mjernom trakom udaljenosti hoda ljudi i mula. Prijeđeni je put kamionskoga skupa očitan s brojila prijeđenih kilometara. CR10C CAMPBELL data-logger je korišten za prikupljanje podataka o radu traktora.

Snimljena su utrošena vremena po radnim operacijama te vremena opravdanih i neopravdanih prekida rada. Na temelju utrošenih vremena, obujma i mase ogrjevnoga drva izračunat je učinak po radniku za istraživane sustave pridobivanja drva. Pri tome je učinak izražen u ukupnom vremenu rada (uključujući dopuštene prekide u najdužem trajanju od 15 min) te u efektivnom vremenu rada (bez prekida). Dodatno je učinak također izražen s obzirom na masu svježe tvari, suhe tvari i mase tvari uz 33 % vlage u drvu.

Energijska je bilanca izrađena prema GER (Gross Energy Requirements) metodi (IFIAS 1975). Izračun je utrošene energije u sustavima pridobivanja drva podijeljen na izravni i neizravni utrošak strojeva i oruđa te utrošak energije ljudi i životinja.

Jedinična je potrošnja goriva (kg/$t_{suhe\ tvari}$) izračunata kao umnožak nazivne snage motora, faktora opterećenja motora, specifične potrošnje goriva i norme vremena za svako sredstvo rada. Potrošnja je maziva određena temeljem pretpostavljene vrijednosti od 3 kg maziva na 100 kg dizelskoga goriva, odnosno 1/3 kg na 1 kg smjese goriva motorne pile. Energijske vrijednosti prikazane u tablici 2 korištene su za određivanje utrošene energije (MJ/$t_{suhe\ tvari}$).

Neizravni utrošak energije strojeva i oruđa izračunat je na osnovi prosječnih energijskih vrijednosti sirovina (tablica 3), kvanititativnoga udjela pojedine sirovine, mase strojeva, vremena održavanja stroja i vremena primjene stroja.

Utrošak je energije radnika izračunat na osnovi fiziološke potrebe čovjeka od 0,0502 MJ/min (Rodio i dr. 2002). Metoda hranjivoga odnosa (Ronchi 1988) primijenjena je za izračun utroška energije mula. Izračun se zasniva na potrebnoj dnevnoj količini sijena, slame i zobi za jednu mulu, hranjivu odnosu (faktor koji izražava ekvivalent energijske vrijednosti ječma) i hranjivoj vrijednosti namirnica (tabllica 4).

Dobivena energija predstavlja energiju koja nastaje izgaranjem privučenoga i prevezenoga drva. Određena je gornja ogrjevna moć drva kalorimetrom na 20 uzoraka te je ustanovljena srednja vrijednost od 20,62 MJ/$kg_{suhe\ tvari}$.

Najveća je učinkovitost pri skupljanju drva zabilježena pri primjeni traktora s vitlom. Zatim slijedi učinak pri skupljanju točilima, a najmanji se učinak postiže pri skupljanju drva mulama (tablica 5).

Najveći je utrošak energije (71 GJ/ha) ostvaren na plohi 1 gdje se drvo skupljalo mulama (tablica 6). Izravni utrošak strojeva i oruđa najveći je pri skupljanju drva traktorom s vitlom. Taj sustav pridobivanja drva ima oko 19 % manji utrošak ljudske energije i oko 16 % veći neizravni utrošak energije od sustava s upotrebom točila i mula. Najveći je udio kamionskoga prijevoza u ukupno utrošenoj energiji (slika 3).

Najveći je odnos dobitka/utroška energije (47,76) ostvaren na plohi 3 primjenom sustava pridobivanja drva koji uključuje skupljanje točilima (tablica 7). Energijska je korisnost svih sustava vrlo velika – od 97,3 % kod sustava koji primjenjuje skupljanje mulama do 97,9 % kod sustava s primjenom točila. Učinak sustava pridobivanja drva s primjenom točila od 0,32 $t_{suhe\ tvari}\ h^{-1}$ radnik^{-1} u ukupnom vremenu, odnosno 0,37 $t_{suhe\ tvari}\ h^{-1}$ radnik^{-1} u efektivnom vremenu, nalazi se u sredini vrijednosti učinaka promatranih sustava.

Sustav se pridobivanja drva s primjenom točila odlikuje povoljnim mogućim učinkom te najvećim odnosom dobitka/utroška energije. Primjena točila znatno utječe na smanjenje oštećenja šumskoga tla i pomlatka te se

preporučuje za izvođenje radova skupljanja drva u zaštićenim područjima, kao što je bilo mjesto istraživanja. Pri tome treba napomenuti da je primjena točila moguća jedino pri skupljanju drva niz nagib.

Iz svega navedenoga donosi se zaključak o ekonomskoj i okolišnoj povoljnosti primjene točila u sustavu pridobivanja drva.

Ključne riječi: šumski radovi, konverzija šikara u viši uzgojni oblik, učinkovitost, energijska bilanca

Authors' address – *Adresa autorâ*:

Rodolfo Picchio
e-mail: r.picchio@unitus.it
Department of Environment and Forests (DAF)
University of Tuscia
Via San Camillo de Lellis
01100 Viterbo
ITALY

Mauro Maesano
e-mail: mauro.maesano@unimol.it
EcoGeoFor Lab
Science and Technology Department for Environment and Territory
University of Molise
C.da Fonte Lappone
86090 Pesche (IS)
ITALY

Serena Savelli, PhD.
e-mail: s.savelli@unitus.it
Department of Ecology and Sustainable Economic Development (DECOS)
University of Tuscia
Largo dell'Università (Blocco E)
01100 Viterbo
ITALY

Assoc. Prof. Enrico Marchi, PhD.
e-mail: emarchi@unifi.it
Dipartimento di Scienze e Tecnologie Ambientli Forestali
University of Firenze
Via S. Bonaventura 50145
Firenze
ITALY

Received (*Primljeno*): December 16, 2008
Accepted (*Prihvaćeno*): June 2, 2009