Efficiency of small-scale firewood processing operations in Southern Europe

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Efficiency and cost of firewood processing technology and techniques

Abstract

The study determined the performance of small-scale commercial firewood processing operations under the typical work conditions of southern Europe. In particular, five units were tested, fed with the same 2.1-m long beech logs. All machines were tested with sorted and unsorted logs. Productivity varied between 1.1 and 2.1 t h^{-1}, and cost between 20 and 39 € t^{-1}. There were significant differences between machines, which may partly be attributed to operator effect. Feeding the machines with sorted logs has a strong and significant effect on the productivity of all machines on test, increasing production by 40% and reducing cost by 34%. Fuel use varied between 1.3 and 2.8 l t^{-1}. The energy balance was always very favourable. The ration between output and input was never smaller than 59 and peaked at 130. In other words, processing required about 1% of the energy contained in the firewood - or 1.7% in the worst case. The productivity figures reported in this experiment were much lower than reported for northern Europe, which seems to confirm the significant effect of regional work conditions – especially different wood species - on firewood processing performance.

Keywords: biomass, energy, productivity, forestry, beech

Introduction

The global consumption of firewood is estimated at over 1.5 billion m^3 per year (Parikka 2004). Use is especially intense in the developing countries, where it accounts for 80% of the total supply of primary energy (Keam and (McCormick 2008). India uses about 300 million m^3 of firewood per year, and China over 180 million m^3 (Eurostat 2013). However, traditional chopped firewood is still widely used in all industrialised countries, especially in rural areas (Lillemo and Halvorsen 2013). Here, firewood was never been completely supplanted by fossil fuels and it enjoyed a revival in recent years with the increasingly severe oil crisis (Warsco 1994). In fact, Europe still uses more traditional firewood than any other industrial energy wood product (Nybakk et al. 2003). Although refined solid biofuels (e.g. pellets and briquettes) are increasingly popular in Europe, their consumption is still minor compared to traditional firewood (Trømborg et al. 2008). In modern countries like Finland, Norway and Sweden firewood still satisfies between 20 and 25% of the heating needs of detached households (Halder et al. 2010, Lindroos 2011, Statistic Norway 2013) and hovers around 5 million m^3 per year and country. Firewood consumption is even higher further south. It reaches 22 million m^3 in France (Elyakime and Cabanettes 2013) and 18 million tonnes in Italy (Caserini et al. 2008). Overall, modern Europe still uses over 100 million solid m^3 of firewood per year, about twice as much as Canada and the US together (FAO 2007). What is more, available statistics may be underestimating the size of the traditional firewood market, where transaction often go unrecorded.

Compared to other fuel types, traditional chopped firewood benefits from decentralised availability and a very simple production process. Once logs are extracted from the forest, fuel preparation only requires cross-cutting and splitting (Lindroos 2008). That allows manufacturing at a local level by individuals and small-businesses, even on a part-time basis. As a result, the production of firewood is often a small-scale activity run by farmers, forest owners and small rural entrepreneurs (Kärhä and Jouhiaho 2009). In Finland, the average firewood producer runs a part-time operation processing between 50 and 150 m^3 of firewood per year (Seppänen and Kärhä 2003). Larger industrial operations are found in Italy, but even there the average company is quite small (Spinelli et al. 2013). For this reason, firewood production is important to rural development and forest management, especially where coppice forests are prevalent (Lasserre et al. 2011).

However economically and socially efficient, the dominance of diffused small-scale rural companies implies a very limited capacity to attract interest from all major actors in the technology development sector. Firewood producers are so small to be virtually invisible, and they can neither fund research nor leverage substantial political support for R&D in the area. So far, there has been little research on traditional firewood. None of the major bioenergy conferences held in Europe during the last decade have addressed the future of traditional firewood (Nybakk et al. 2013).

In particular, firewood processing has received the least attention, possibly because it is considered a very simple operation, with little potential for dramatic improvement. The large productivity variation between existing systems is a good witness to the contrary (Lindroos 2008), while the high frequency of work accidents highlights the urgent need for further development (Lindroos et al. 2008, Owen and Hunter 1993). Firewood processing cost could be further reduced through improved technology and work techniques, thus making firewood production safer and more competitive than it currently is (Nybakk et al. 2013). At present, all the few recent studies on firewood processing performance come from Nordic Europe (Lindroos 2008, Kärhä and Jouhiaho 2009). Looking further back, one finds more Nordic studies (Björheden 1989, Ryynänen and Turkkila

1982, Swartström 1986). These are very good studies, but they cannot represent Europe as a whole. The work conditions encountered in Nordic countries are much different from those of Central and Southern Europe, where firewood production is much larger (Eurostat 2013). The main difference is with species, which are generally denser and harder following a southern gradient. In northern Europe, firewood is obtained from birch, pine and spruce, while beech, oak and hornbeam are dominant further south. These species have dramatically different characteristics (Table 1). Additional differences concern log length, which ranges from 2 to 6 m in northern Europe, and from 1 to 2 m in southern Europe, due to the different extraction methods (Magagnotti et al. 2012, Zimbalatti and Proto 2009).

Therefore, the goal of this study was to determine the performance of commercial firewood processing operations under the typical work conditions of southern Europe. In particular, we endeavoured to determine the productivity, cost and energy use of firewood processing with a range of different machines, under two different work techniques.

Materials and methods

Firewood processing trials were conducted in Piemonte, north-western Italy. The authors identified 5 commercial operations, run by rural entrepreneurs and considered representative of the small-scale commercial operations of southern Europe. The sample represented a wide range of small-scale firewood processing equipment, specifically designed for crosscutting and splitting firewood logs into stove wood. The main differences between the models on test were in the crosscutting device and the splitting force, the latter always exerted through a hydraulic wedge device. All the main crosscutting devices were represented, including disc saw, chainsaw and band saw (Table 2). Crosscut pieces were automatically moved to the splitter, except for the band saw unit, where the cut piece was manually positioned onto the splitter plate. This specific machine adopted an older traditional design, and was served by two operators instead of one. All other machines were served by one operator only, since the cross-cutting/splitting sequence was automatic. All firewood processors were powered by old farm tractors, through the tractor's power take-off. Semi-stationary use at a log yard does not require a new tractor. Anything goes, as long as the engine and the power take-off are still in good shape. Resorting to an old tractor allows a dramatic reduction of investment cost, which is especially important for small-scale rural companies.

At the time of the study, all machines were fed with 2.1 m long beech logs, which they processed into 35 cm long split stove wood. Processed wood was semi-fresh, with a moisture content between 35 and 40%. All machines were operated by experienced professionals, who had run them for several years and knew them well. These operators were reputed as reliable and motivated, as they were the companies' owners or co-owners.

Machines were observed while working at the company's log yard. The study compared two different work techniques, with and without preliminary sorting. In the sorted treatment, the machines were fed with selected logs with a small-end diameter between 18 and 25 cm. In the unsorted treatment, the same machines were fed with a mix of small and large logs, with a small-end diameter between 8 and 30 cm. All machines were equipped with rubber-belt conveyors and discharged their product into bin trailers. Each repetition consisted of a full 8-hour work day. Each combination of machine and technique was replicated three times, for a total of 30 replications, or 30 work days.

The experiment consisted of a typical time and motion study (Magagnotti and Spinelli 2012). Work time was determined with stop watches, including all delays up to a maximum duration of 30 minutes (Spinelli and Visser 2009). Meal time was excluded from the records. Firewood output was determined by taking all bin trailers to the certified weighbridge available at the log yard.

Machine costs were estimated with the method developed within COST Action FP0902 (Eliasson 2013). Machine owners provided their own estimates for fuel consumption, insurance cost and maintenance cost. Machine owners also declared an annual production between 300 and 1200 tons, which was used to estimate a mean annual usage of 500 hours. Labour cost was assumed to be 15 € per hour, inclusive of indirect salary costs. The calculated operational cost of all teams was increased by 20% to account for overhead costs (Hartsough 2003). Further detail on cost calculations is shown in Table 3.

Both direct and indirect fossil energy use were estimated, reflecting the same principles followed by Pellizzi (1992) in his energy analysis of Italian agriculture. Direct energy use was estimated by multiplying the measured diesel consumption by the energy content of 37 MJ l^{-1} (Bailey et al. 2003), and then inflating this value by 1.2 in order to account for the additional fossil energy used in the production, transportation and distribution of diesel fuel (Pellizzi 1992). The indirect use represented by machine manufacture, repair and maintenance was estimated as 44 % of direct energy use (Mikkola and Ahokas 2010). No allowance was made for the embedded energy of a barn for housing the machines, on the assumption that machines used in forestry often rest outdoors, or under very simple makeshift structures, with a negligible energy content. Results are shown in Table 3. The energy content of beech firewood with a 38% moisture content was estimated at 10520 MJ t^{-1}, using the methods reported by Magagnotti and Spinelli (2012).

Data were analyzed with the Statview advanced statistics software (SAS 1999). Since data distribution violated the normality assumption, the statistical significance of the eventual differences between machine models was tested with Scheffe's test, which is particularly robust against such violation. The significance of differences between work techniques (sorted vs. unsorted) was tested with the Wilcoxon Signed Rank Test, which is the non-parametric equivalent of the standard paired t-test.

Results

All machines were simple and relatively inexpensive, as appropriate for adoption by small-scale entrepreneurs (Table 3). Using second-hand farm tractors gave a further contribution to containing capital outlay, which was slightly higher than 30,000 € at most. That was particularly important in view of the low annual usage, estimated at 500 h per year. Machine rates varied between 36 and 45 € h^{-1}, including a 20% overhead surcharge. Labour cost was a major contributor to machine rate, accounting for about 50% of the total (Figure 1). In contrast, fuel and lubricant represented less than 15% of total cost, even if none of the operators used tax-free red diesel, reserved to farmers.

Productivity varied between 1.1 and 2.1 t h^{-1} (Table 4). Both Pezzolato machines were significantly more productive than the others, regardless of work technique. As an average, productivity increased by 40% when working with sorted logs, rather than unsorted logs. In fact, different machines had different sensitivity to work technique. The Pezzolato 750TL had the lowest sensitivity, because it was specifically designed for processing multiple logs. That reduced the effect of small log handling and minimized sensitivity to sorting, which still allowed a 24% productivity increase. In any case, the effect of log sorting was highly significant (Wilcoxon Signed Rank test, $p = 0.0007$).

Processing cost ranged from 20 to 39 € t^{-1}. The BGU, Posch and Pezzolato A800 operations incurred significantly higher cost than the other operations, regardless of work technique. Lower productivity and relatively high capital cost can explain the result for BGU and Posch. As to Pezzolato A800, the higher cost was explained by its larger crew: the increased labour cost was not fully offset by the higher productivity, resulting in a relatively high processing cost per product unit. Work technique had a highly significant effect on processing cost (Wilcoxon Signed Rank test, $p = 0.0007$). Sorting logs before processing allowed saving between 5 and 13 € t^{-1}, or between 20 and 34% of the original cost incurred when processing unsorted logs.

Fuel use varied between 1.3 and 2.8 l t^{-1}. The machines on test were divided in two groups: BGU and Posch belonged to the first group, with a mean fuel use of 1.9 l t^{-1} (sorted) and 2.6 l t^{-1} (unsorted); Gandini and the two Pezzolatos belonged to the second group, with a mean fuel use of 1.3 l t^{-1} (sorted) and 1.8 l t^{-1} (unsorted). Working technique had the same effect and significance as recorded for processing cost, being calculated exactly the same way.

The energy balance was always very favourable. The ration between output and input was never smaller than 59 and peaked at 130 (Figure 2). In other words, processing required about 1% of the energy contained in the firewood - or 1.7% in the worst case. Sorting increased the overall energy efficiency by 40%.

Discussion

Despite the significant individual differences, the productivity of all machines on test is comparable, and no machine is dramatically outclassing the others. That was expected, since all machines were fed with the same assortment types, they cut the same stove wood length and they belonged to the same machine size class. Radically different results may have resulted from comparing small-scale with industrial firewood processor, or from feeding different machines with different assortments. Different operator performance may account for part of that variability, as already shown by Lindroos (2008) specifically for firewood processing. Therefore, we may generalize the results of this study to some extent, and state that the productivity of small-scale firewood processors used under southern European conditions commonly varies between 1 and 2 fresh tonnes per hour.

Such figures are much lower than reported for northern Europe by Kärhä and Jouhiaho (2009), who indicate a productivity range between 4 and 6 m^3 h^{-1} for machines in the same size class. Part of the difference can be explained by the different measurement units used in the study. Kärhä and Jouhiaho (2009) used cubic meters instead of tons, and net work hours instead of scheduled hours. One cubic meter of spruce or birch is much lighter that a ton, which may reduce the difference between northern and southern figures. What is more, the Nordic productivity figures were inflated by the absence of any delay time in the divider. In contrast, our study included delays up to a maximum duration of 30 minutes, which reduced the final productivity estimate. However, such methodology differences cannot fully account for a factor 3 difference in productivity levels. Therefore, this study seems to confirm the significant effect of regional work conditions on firewood processing performance, as it was hypothesized in the introduction of this paper, and indicated by the same Kärhä and Jouhiaho (2009) in their most interesting study of Nordic firewood processors. Productivity differences are the main reason for the much lower processing cost found in the Nordic study (ca. 10 € t^{-1}), since our labour cost and annual utilization assumptions are very near to those made by the Nordic colleagues.

Work technique has a powerful effect on productivity, which was also found earlier on by Lindroos (2008), although not to as strong as here (ca. 20% instead of 40%). The potential gains obtained through log selection raise the important issue of product strategy, and namely: whether it is best to convert all logs into firewood, or rather divide them between firewood and chip production, through integrated harvesting. In the latter case, logs in the ideal size class range could be used for firewood production, while smaller logs could be diverted to chip production. Processing of more logs in a single batch (i.e. mass handling) may make chipping more efficient than firewood processing when dealing with small logs. Even small chippers manually fed with small logs can exceed the productivity of 1 t h^{-1} reached by the firewood processor under the same conditions (Spinelli and Magagnotti 2010). However, a chipper incurs a higher investment cost and fuel use, which may partly offset the productivity gain over a firewood processor. A desk calculation performed with the Chipcost calculator (Spinelli and Hartsough 2001) allowed estimating the chipping cost of smaller logs as used in this study (diameter 10 cm, length 2.1 m) at 38 € t^{-1}, which is about the same cost sustained for turning them into stove wood.

Nor is fuel efficiency much higher for any of the two options, i.e. firewood or chips. A small scale chipper for rural contractors can use between 1.5 and 2.5 l of diesel per ton of chips (Spinelli and Magagnotti 2013), which overlaps quite well with the 1.3-2.8 l t^{-1} range found here for the firewood processors.

We do not deny the potential of product strategy in optimizing biomass operations, but we need to highlight that no option is overwhelmingly superior to the other. Therefore, choosing the best alternative requires exact knowledge of the specific work conditions and some fine-tuning of all operational aspects. At this stage, the only thing one can safely state is that chip production is preferable whenever dealing with the abundant species that cannot be marketed as firewood, such as alder, poplar, willow and most softwoods in Southern Europe.

Energy efficiency is very high, and in the same order of magnitude recorded for chip production chains (Timmons and Viteri-Mejia 2010, Marchi et al. 2011) after accounting for the different system boundaries considered in these studies. That should ease concerns about the energy performance of traditional firewood production chains.

Finally, we need to stress that this work focused on small-scale firewood processors rather than on larger industrial units. The latter are widespread all over Europe and are much more productive and expensive to purchase. These are stationary or semi-stationary plants, generally powered by electric motors and designed for advanced automation. Their performance should be investigated with further studies in the near future.

Conclusions

Small-scale firewood processor contain some level of automation and are relatively inexpensive, which allows purchase by small-scale companies. However, productivity is relatively low, which results in a high processing cost. Feeding firewood processors with sorted logs is a good way to boost productivity and contain processing cost. Such technique is especially effective with simpler machines, designed for processing one log at a time. Larger units that can handle multiple logs are less sensitive to sorting. Wood species may have a strong effect on productivity, possibly explaining the differences between the northern and the southern productivity figures. Energy efficient is very high, with the processing work requiring a very small proportion of the total energy contained in the firewood.

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Table 1 – *Physical characteristics of some tree species used for firewood*

Common name	Latin Name	Density at 15% mc kg m^{-3}	Compression strenght N mm^{-2}	Shear strenght N mm^{-2}	Bending strength N mm^{-2}	Modulus of elasticity N mm^{-2}
Norway spruce	Picea abies Karst.	450	38	6.5	73	15000
Scots pine	Pinus silvestris L.	550	45	7.6	97	13750
Birch	Betula alba L.	650	59	6.0	120	13000
Beech	Fagus sylvatica L.	730	61	8.0	118	14700
Common oak	Quercus robur L.	820	61	9.8	108	12500
Hornbeam	Ostrya carpinifolia Scop.	820	48	8.5	133	12560

Note: from G. Giordano 1986

Table 2 – *Main characteristics of the machines on test*

Make		BGU	Gandini	Pezzolato	Pezzolato	Posch
Model		SSA 310	Forest Cut 45	TL750	800	Spaltfix 320
Power source	type	Tractor	Tractor	Tractor	Tractor	Tractor
Tractor power	kW	35	35	33	37	44
Cutter	type	Disc	Chainsaw	Disc	Band	Disc
Cut capacity	cm	30	35	28	40	32
Splitter	type	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic
Splitter	travel	Horizontal	Horizontal	Horizontal	Vertical	Horizontal
Splitter	power	11	11	11	12	15
Transfer	type	Gravity	Gravity	Kicker	Manual	Gravity
Weight	kg	900	750	900	700	1450
Operators	n°	1	1	1	2	1
Price	€	12,700	9,200	16,500	8,500	22,000

Note: data obtained from the manufacturers; transfer = method for transferring cut log portions to the splitter

Table 3 – *Costing and energy use: assumptions and total figures*

Make		BGU	Gandini	Pezzolato	Pezzolato	Posch
Model		SSA 310	Forest Cut	TL750	800 A	Spaltfix 320
Investment	€	21,700	18,200	24,000	17,500	32,000
Resale (20%)	€	4,340	3,640	4,800	3,500	6,400
Service life	years	10	10	10	10	10
Utilization	h year^{-1}	500	500	500	500	500
Interest rate	%	4%	4%	4%	4%	4%
Depreciation	€ year^{-1}	1,736	1,456	1,920	1,400	2,560
Interests	€ year^{-1}	556	466	614	448	819
Insurance	€ year^{-1}	2,500	1,922	2,500	2,500	2,500
Diesel	€ year^{-1}	1929	1929	1819	2040	2426
Lube	€ year^{-1}	193	193	182	204	243
Maintenance	€ year^{-1}	1736	1456	1920	1400	2560
Total	€ year^{-1}	8,650	7,422	8,955	7,992	11,107
Total	€ h^{-1}	17.3	14.8	17.9	16.0	22.2
Crew	n.	1	1	1	1	1
Labour	€ h^{-1}	15	15	15	15	15
Overheads (20%)	€ h^{-1}	6.5	6.0	6.6	6.2	7.4
Machine rate	€ h^{-1}	38.8	35.8	39.5	37.2	44.7
			Energy inputs			
Direct	MJ h^{-1}	114	114	108	121	144
Indirect	MJ h^{-1}	50	50	47	53	63
Total	MJ h^{-1}	164	164	155	174	207

Note: ; Cost in Euro (€) as on November 22, 2013 - 1 € = 1.35 US$; *investment cost also includes the purchase of an old farm tractor, at a price between 7500 and 10000 € depending on rated engine power; all machines use standard diesel fuel, and not tax-free diesel for agricultural use*; h = Scheduled hours, including delays

Table 4 – *Firewood processing productivity and cost*

Make	Model	Unsorted	Sorted	Δ %
		Productivity (t h^{-1})		
BGU	SSA 310	1.05^{a}	1.47^{a}	40
Gandini	Forest Cut 45	1.31^{bc}	1.86^{b}	42
Pezzolato	TL750	1.45^{c}	1.80^{b}	24
Pezzolato	A 800	1.42^{c}	2.15^{c}	51
Posch	Spaltfix 320	1.16^{a}	1.58^{a}	36
		Processing cost (€ t^{-1})		
BGU	SSA 310	37.0^{a}	26.6^{a}	-28
Gandini	Forest Cut 45	28.5^{b}	20.0^{b}	-30
Pezzolato	TL750	27.4^{b}	22.0^{bc}	-20
Pezzolato	A 800	39.0^{c}	25.7^{c}	-34
Posch	Spaltfix 320	38.5^{ac}	28.3^{a}	-26

Note: t = fresh tons, with a 38% moisture content; h = scheduled hour, inclusive of delays; different superscript letter along the same column indicate that the differences between mean values are statistically significant at the 5% level, according to Scheffe's post-hoc test; differences between values on the same row (i.e. unsorted vs. sorted) are statistically significant at the 5% level according to the Wilcoxon Signed Rank test.

Figure 1– *Breakdown of equipment cost by main cost items*

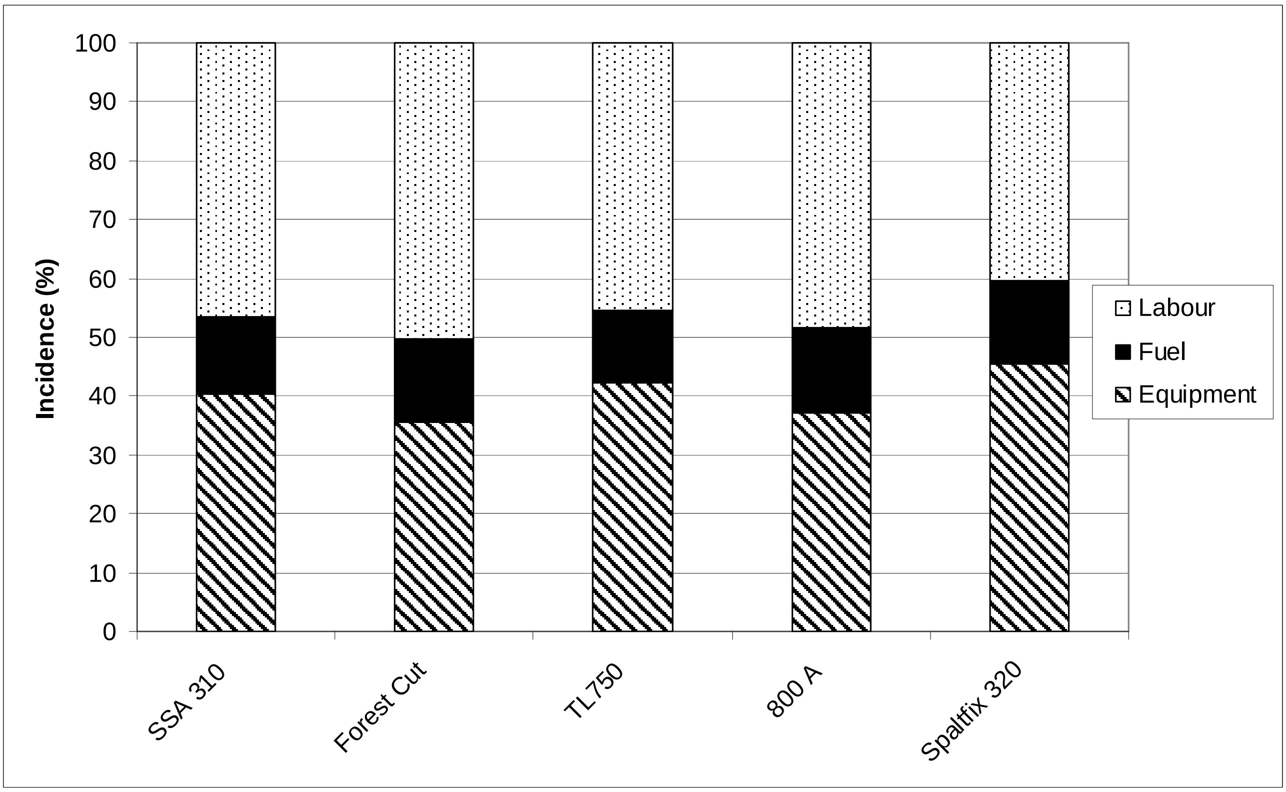

Figure 2 – *Energy balance: output/input ratio*