Productivity and Cost of Industrial Firewood Processing Operations

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Abstract

The study determined the performance of industrial firewood processing operations under the typical work conditions of Southern Europe. In particular, we surveyed five commercial operations processing 1-m-long oak logs from coppice forests. Mean log volume was very small, in the range of 0.01 to 0.02 m^3 solid. Machine utilization was quite high, ranging from 70 to 80 percent. Mechanical availability was excellent, always exceeding 90 percent of the total worksite time. Productivity varied between 1.4 and 4.9 m^3 per scheduled machine hour (SMH), inclusive of all delays. Processing cost ranged from 26 to 44 €/m^3. The largest machine in the group offered significant productivity and cost benefits over all the others. Owing to their multiple log handling capacity, firewood processors designed for Southern Europe may be less sensitive to log volume, compared with Nordic machines. The energy balance was always very favorable. The ratio between output and input was never smaller than 220 and peaked at 327. That was much higher than recorded for small-scale firewood processors, and it may depend on the use of more efficient electric motors compared with diesel engines. However, the main advantage of industrial firewood processors is production capacity and operator comfort and safety. This allows business growth, in the face of a very large market and a decreasing availability of skilled labor. Cost reduction is a secondary advantage, which becomes dramatic only when adopting machines at the higher end of the range.

Traditional firewood consists of tree stem and branch portions reduced to a size that allows stoking a fireplace or a stove—from primitive to highly sophisticated. Size reduction is obtained through crosscutting and splitting along the grain, as opposed to chipping, crushing, or grinding. Firewood is the most important biomass fuel in the world, whose total consumption is estimated at over 1.5 billion m^3/y (Parikka 2004). Firewood is especially important in the developing countries, where it accounts for 80 percent of the total supply of primary energy (Keam and McCormick 2008). India uses about 300 million m^3 of firewood per y, and China over 180 million m^3 (Eurostat 2013). However, traditional chopped firewood is still widely used in all industrialized countries, especially in rural areas (Lillemo and Halvorsen 2013). In rural areas, firewood was never 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. 2013). Although refined solid biofuels (e.g., pellets and briquettes) are increasingly popular in Europe, their consumption is still minor compared with traditional firewood (Trmborg et al. 2008). In modern countries like Finland, Norway, and Sweden, firewood still satisfies between 20 and 25 percent of the heating needs of detached households (Halder et al. 2010, Lindroos 2011, Statistics Norway 2013) and hovers around 5 million m^3/y in each country. Firewood consumption is even higher further south. It reaches 22 million m^3/y in France (Elyakime and Cabanettes 2013) and 18 million tonnes/y in Italy (Caserini et al. 2008). Overall, modern Europe still uses more than 100 million solid m^3 of firewood per y, about twice as much as Canada and the United States together (Food and Agriculture Organization of the United Nations [FAO] 2007). In addition, available statistics may be underestimating the size of the traditional firewood market, where transactions often go unrecorded.

Compared with other fuel types, traditional chopped firewood benefits from decentralized availability and a very simple production process. Once logs are extracted from the

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forest, fuel preparation only requires crosscutting 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, with an average annual output between 50 and 150 m^3 of firewood (Seppänen and Kärhä 2003). In fact, larger industrial operations coexist along with small-scale companies, and they are especially common in countries like France and Italy, among others. These operations use modern equipment, designed for maximizing productivity and reducing production cost. Industrial firewood processors are sophisticated machines, featuring a good level of automation as well as a number of devices capable of overcoming the limits of simpler small-scale units. In particular, all modern industrial firewood processors are capable of multiple log handling, for compensating the productivity losses incurred when processing small logs. In addition, these machines integrate a number of advanced safety systems that make firewood processing much less hazardous than it was in the past, especially with small-scale units (Owen and Hunter 1993, Lindroos et al. 2008). Industrial firewood processors are state-of-the-art machines and are very popular in Southern and Central Europe.

However widespread and efficient, these machines have attracted very little interest from the scientific community. Recent literature offers no single study specifically addressing the performance of industrial firewood processors. Most recent studies on firewood processing performance come from Nordic Europe and concern small-scale equipment (Lindroos 2008, Kärhä and Jouhiaho 2009). Looking further back, one finds more Nordic studies (Ryynänen and Turkkila 1982, Swartström 1986, Björheden 1989). 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 (*Betula pendula* Roth.), pine (*Pinus sylvestris* L.), and spruce (*Picea abies* Karst.), while beech (*Fagus sylvatica* L.), oak (*Quercus* sp.), and hornbeam (*Ostrya carpinifolia* Scop.) 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, as a result of the different extraction methods (Zimbalatti and Proto 2009, Magagnotti et al. 2012). In Southern Europe, firewood is often obtained from coppice forests (Suchomel et al. 2012), which offer a main crop of very small top and branch logs, intermixed with sparse heavy butt logs. The wide size range makes processing quite difficult, especially for small-scale machines (Manzone and Spinelli 2014).

The goal of this study was to determine the performance of industrial firewood processors under the typical work conditions of Southern Europe. In particular, we endeavored to determine the productivity, cost, and energy use of firewood processing with a range of industrial units.

Materials

Firewood processing trials were conducted in Central Italy, in the box delimited by the cities of Florence, Pisa, Livorno, and Rome. The authors identified five commercial operations, run by professional entrepreneurs and considered representative of the industrial firewood operations of Southern Europe. The sample represented a wide range of industrial firewood processing equipment, specifically designed for crosscutting and splitting firewood logs into stove wood. These were all stationary machines powered by electric motors. Figure 1 depicts one of these machines, showing the typical in-line layout. All machines used a disc saw for crosscutting and were designed for cutting log bunches, which were blocked during cutting by a grab arm, a set of bars, or a chain (Table 2). Cut pieces would be moved to the splitting station automatically, through belt conveyors. All machines were fitted with bypass devices for diverting smaller pieces directly to the stove wood pile without passing through the splitting station. The machines were typically served by a two-man crew, one at the feeding–sawing station and the other at the splitting station. One machine (Operation 3) was run by three operators, because it was equipped with two splitting stations instead of one. Occasionally, a machine could be run by one operator only, who alternated between the feeding–sawing and the splitting station, using the belt conveyor as a buffer. All machines were fitted with live decks for accumulating and feeding logs to the process line and with belt conveyors for moving stove wood to a pile, a container, or a delivery truck. Log decks were regularly supplied with logs by loaders available on site, used for general log yard maintenance. These were normally driven by an additional operator, who was not counted among the crew members because he would be busy with other miscellaneous tasks and devoted a very small part of his work time to resupplying the firewood processors.

At the time of the study, all machines were fed with a mix of hardwood species from the Mediterranean forest (Maquis), among which oak and hornbeam were prominent. Product output was measured by solid volume rather than weight, in order to minimize the moisture content bias. All

Table 1.—Physical characteristics of some tree species used for firewood.[a]

Common name	Latin name	Density at 15% moisture content (kg/m^3)	Compression strength (N/mm^2)	Shear strength (N/mm^2)	Bending strength (N/mm^2)	Modulus of elasticity (N/mm^2)
Norway spruce	*Picea abies* Karst.	450	38	6.5	73	15,000
Scots pine	*Pinus silvestris* L.	550	45	7.6	97	13,750
Birch	*Betula alba* L.	650	59	6.0	120	13,000
Beech	*Fagus sylvatica* L.	730	61	8.0	118	14,700
Common oak	*Quercus robur* L.	820	61	9.8	108	12,500
Hornbeam	*Ostrya carpinifolia* Scop.	820	48	8.5	133	12,560

[a] Source: Giordano (1986).

Figure 1.—Industrial firewood processor, showing the in-line layout, stationary installation, and electric power panels (Operation 4).

machines were operated by experienced professionals, who had run them for several years and knew them well.

Machines were observed while working at the company's log yard. All machines were fed with a mix of small and large logs, with a small-end diameter between 8 and 40 cm. Each repetition consisted of a single work batch amounting to 1 m^3 solid volume. The study was inherently observational, and the number of repetitions depended on machine productivity and on the time the machine was made available for the study. That resulted in an unbalanced number of repetitions, which was accounted for during the analysis.

Table 2.—Main characteristics of the operations and machines.[a]

	Operation:				
	1	2	3	4	5
Location	Pontassieve	Bibbona	Fauglia	Roma	Coltano
Province	Firenze	Livorno	Pisa	Roma	Pisa
Log volume (m^3)	0.018	0.020	0.010	0.008	0.021
Log length (cm)	116	106	116	108	166
Product length (cm)	30	35	35	38	37
Machine make	Comap	Comap	Pezzolato	Pezzolato	Pinosa
Machine model	SD 100	SD 100	TL 1000	TLC 1500	2400 EPLC
Power (kW)	25	25	25	75	35
Disc saw diam. (mm)	1,000	1,000	1,000	1,500	1,200
Cut capacity (mm)	420	420	400	600	470
Splitter force (t)	18	18	20	55 and 70	38
Operators	2	2	1–2	3	1–2
Price (€)	80,000	80,000	75,000	250,000	140,000
Test duration (h)	8.3	11.3	18.7	5.4	4.3
Test output (m^3)	15.5	21.1	24.1	25.3	11.2

[a] Data obtained from the manufacturers. In all cases the power source is electric, the cutter is a disc, and the splitter is hydraulic and travels in a horizontal direction.

Methods

Researchers recorded all work time separately for each machine and plot. Productive time was split into elements and separated from delay time (Magagnotti and Spinelli 2012). Delay time is typically erratic, and it may introduce excessive variability to a study conducted on relatively small observation units (Spinelli et al. 2012). For this reason, delay factors were calculated over the whole study period for each machine, and they were used for inflating the actual productive time recorded for each individual observation (Spinelli and Visser 2009).

Firewood output was determined by measuring the length and the diameter at midlength of all logs in each processing batch. Researchers collected five wood samples per trial in order to determine moisture content, according to the gravimetric method (Standard CEN/TS 14774-2, European Committee for Standardization 2004).

Machine costs were estimated with the method developed within COST (European Cooperation in Science and Technology) Action FP0902 (Eliasson 2013). Investment cost was obtained from the manufacturers, whereas electric consumption was estimated by applying a 60 percent load rate to the total power of the electric motors, as suggested by the manufacturers themselves. The cost of electricity was obtained from the official tariff tables published by the national utility, which report a price of €0.30/kWh for industrial users below 20 MWh/y (Energy Authority 2013). Annual use was estimated to 1,000 scheduled hours per y. Repair and maintenance cost was assumed equal to depreciation for all machines expect Machine 4. This was larger and sturdier than all the others, and therefore repair and maintenance was assumed to be 75 percent of depreciation. Labor cost was assumed to be €15/h, inclusive of indirect salary costs. The calculated operational cost of all teams was increased by 20 percent to account for overhead costs (Hartsough 2003). Further detail on cost calculations is shown in Table 3.

Direct energy use was assumed to be the actual power absorbed by the machines, while the indirect use represented by machine manufacture, repair, and maintenance was estimated as 44 percent of direct energy use (Mikkola and Ahokas 2010). Results are shown in Table 3. Wood volume figures were converted into weight using the mean measured density of 1,000 kg/m^3 (Giordano 1986). The energy content of oak firewood with a 32 percent moisture content was estimated at 11,780 MJ/m^3 using the methods reported by Magagnotti and Spinelli (2012).

Data were analyzed with the Statview advanced statistics software. Logarithm transformation was used to normalize data distributions that did not fulfill the normality assumption. Regression analysis was used to test the relationship between productivity and significant work conditions, such as piece size and crew number. The analyses were conducted on time consumption, in order to avoid any intercorrelation when testing the effect of piece size. However, the individual repetitions consisted of 1-m^3 batches, which allowed easy transformation of time consumption figures into productivity figures. Eventually, results were presented as productivity, in order to facilitate immediate understanding.

The study material consisted of 48 hours of total work time, during which the machines performed 96 repetitions, producing 96 m^3 of firewood (solid volume).

Table 3.—Cost and energy use: assumptions and total figures.

	Operation:			
	1 and 2	3	4	5
Make	Comap	Pezzolato	Pezzolato	Pinosa
Model	SD100	TL 1000	TLC 1500	2400 EPCL
Investment (€)[a]	80,000	75,000	250,000	140,000
Resale (20%) (€)	16,000	15,000	50,000	28,000
Service life (y)	10	10	10	10
Utilization (SMH/y)[b]	1,000	1,000	1,000	1,000
Interest (%)	4	4	4	4
Depreciation (€/y)	6,400	6,000	20,000	11,200
Interests (€/y)	2,048	1,920	6,400	3,584
Insurance (€/y)	2,500	2,500	2,500	2,500
Power (€/y)	4,500	4,500	13,500	63,00
Maintenance (€/y)	6,400	6,000	15,000	11,200
Total (€/y)	21,848	20,920	57,400	34,784
Total (€/SMH)	21.8	20.9	57.4	34.8
Crew[c]	2	1.7	3	1.9
Labor (€/SMH)	30	26	45	29
Overhead (20%) (€/SMH)	10.4	9.4	20.5	12.7
Machine rate (€/SMH)	62.2	56.6	122.9	75.9
Energy use (MJ/SMH)				
Direct	54	54	162	76
Indirect	24	24	71	33
Total	78	78	233	109

[a] Cost in Euros (€) as of November 22, 2013; €1 = US$1.35.

[b] SMH = scheduled machine hour, inclusive of other work and delays.

[c] Crew represents the average number of people working at the machine for the entire duration of the test, because some machines were alternately operated by one or two people.

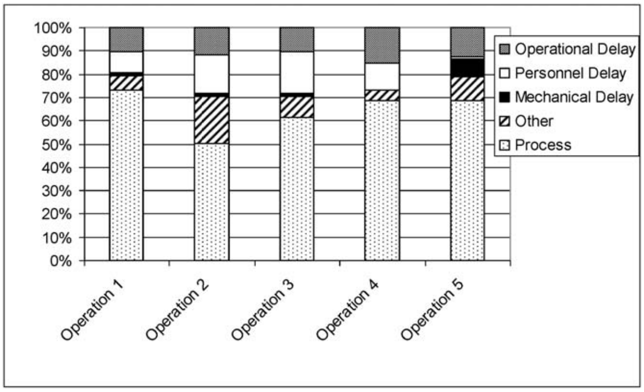


Figure 2.—Breakdown of worksite time by activity type.

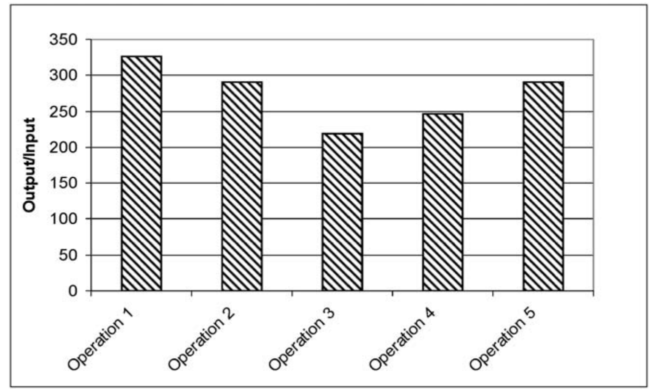


Figure 3.—Energy balance: output/input ratio.

Results

The tested machines provided a good representation of the industrial firewood processors currently available on the market, offering a wide capacity and price range. Test conditions were relatively even for an observational study: log length varied between 1.1 and 2 m, but 1.1-m-long logs represented more than 90 percent of the total. Logs were processed into 35-cm-long split stove wood. Processed wood was semidry, with a mean moisture content of 32 percent. In fact, there were large variations between and inside the log piles, which accounted for a moisture content ranging from 17 to 50 percent. Log volume varied between 0.002 and 1.104 m^3 (mean, 0.014 m^3), with no significant differences between operations. Product length ranged from 30 to 38 cm (mean, 35 cm), again without any differences between operations. The only significant difference was recorded for log length, which was higher for Operation 5 (e.g., 166 vs. 111 cm for all the others).

Figure 2 shows the breakdown of worksite time among the main activities. Utilization was quite high, ranging from 70 to 80 percent. However, actual processing time (i.e., feeding, sawing, and splitting) represented between 50 and 73 percent of the total. Mechanical availability (i.e., the time the machine was not under maintenance) was excellent, always exceeding 90 percent of the total time.

Pure processing productivity (i.e., feeding, sawing, and splitting) varied between 2.3 and 7.1 m^3/h, while actual productivity ranged from 1.4 to 4.9 m^3 per scheduled machine hour (SMH), inclusive of all other work and delays (Table 4). Operation 4 was significantly more productive than all others in both terms. It outperformed the nearest competitor by an 80 percent margin. Conversely, Operation 3 was significantly less productive than all others, reaching about 75 percent of the productivity level of the operation ranking just above it, when productivity was calculated based on total worksite time.

Processing cost ranged from €26 to €44 per m^3. However, the only significant difference was between Operation 3 and Operations 4 and 5. For the rest, lower cost partially offset higher productivity, removing statistical significance from all other comparisons. In general, there seemed to be a rough balance between cost and productivity. In particular, the high cost of Operation 4 was fully offset by its high productivity, resulting in a significantly lower production cost compared with Operation 3. The result for Operation 5 must be evaluated with caution because this operation processed longer logs than all the others, which may have boosted its productivity (Kärhä and Jouhiaho 2009).

Energy use varied between 36 and 53 MJ/m^3. The only significant difference was for Operation 3, which incurred a higher energy consumption per product unit, compared with Operations 1, 2, and 5. This result depended on the relatively low productivity of Operation 3. In any case, the energy balance was always very favorable. The ratio between output and input was never smaller than 220 and peaked at 327 (Fig. 3). In other words, the process required about 0.4 percent of the energy contained in the firewood.

The analysis of variance showed that both operation type and log volume had a highly significant effect on productivity and cost (Table 5). The rather high value of the residuals pointed to the observational character of the study, which presented a high background noise. It is worth

Table 4.—Firewood processing productivity and cost.[a]

Operation	Productivity		Cost	
	Net (m^3/h)[b]	Gross (m^3/SMH)[c]	Financial (€/m^3)	Energy (MJ/m^3)
1	2.945 A	2.157 AB	29.0 AB	42.0 A
2	3.814 B	1.915 B	33.3 AB	41.8 A
3	2.359 A	1.450 C	44.0 A	60.7 B
4	7.107 C	4.886 D	26.1 B	49.5 AB
5	3.906 B	2.683 A	28.9 B	41.6 A

[a] Different letters in the same column indicate that the differences between mean values are statistically significant at the 5 percent level, according to Scheffe's post hoc test.
[b] h = net processing hour, excluding other work and delays.
[c] SMH = scheduled machine hour, inclusive of other work and delays.

Table 5.—Analysis of covariance data for time consumption per product unit.[a]

Effect	df	SS	η^2	*F* value	*P* value
Pure processing time (log transformed)					
Operation	4	0.804	0.44	23.000	<0.0001
Log volume	1	0.046	0.03	5.263	0.0242
Interaction	4	0.211	0.12	6.044	0.0002
Residual	86	0.751	0.41		
Total worksite time (log transformed)					
Operation	4	0.725	0.42	20.735	<0.0001
Log volume	1	0.046	0.03	5.263	0.0242
Interaction	4	0.211	0.12	6.044	0.0002
Residual	86	0.751	0.43		
Processing cost per m^3 (log transformed)					
Operation	4	0.350	0.26	10.028	<0.0001
Log volume	1	0.046	0.03	5.263	0.0242
Interaction	4	0.211	0.16	6.044	0.0002
Residual	86	0.751	0.55		
Energy use per m^3 (log transformed)					
Operation	4	0.391	0.28	11.180	<0.0001
Log volume	1	0.046	0.03	5.263	0.0242
Interaction	4	0.211	0.15	6.044	0.0002
Residual	86	0.751	0.54		

[a] df = degrees of freedom; SS = sum of squares; η^2 = ratio between the SS for a specific effect and the total SS.

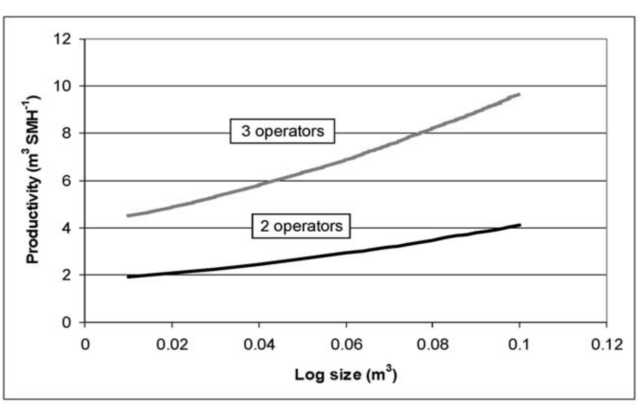
noticing the higher strength and significance of the interaction factor, compared with log volume alone. That may indicate that different operations (and machines) had different sensitivity to log volume, some being more suitable than others for the fast processing of small logs.

Figure 4 shows the relationship between total productivity, log volume, and crew number, based on the results of the regression analysis. Productivity was closely dependent on log volume and crew number, the latter being especially related to operation type. In fact, the study did not test all operations with different crews, on the hypothesis that each was designed for a specific crew size. In particular, Operation 4 was designed for a three-man crew, while the others were all designed for two-man crews. Therefore, the graph must be read as stating that a larger machine designed for a three-man crew will outperform smaller machines designed for two-man crews all along the log volume range. Taken together, piece size and crew/machine size explained 75 percent of the total variability in the data pool.

These results are reflected in Figure 5, which shows the relationship between processing cost, log volume, and crew number. Despite its higher operating cost, the three-man operation maintained a better cost efficiency compared with the cheaper two-man operations. In both cases, a fivefold increase of log volume will lead to halving process cost per product unit.

Discussion

The study spans a whole range of industrial firewood processors, showing once more that productivity is directly proportional and processing cost inversely proportional to operation size. Larger, more expensive machines have a higher output than smaller, cheaper ones. The observational nature of the study does not allow going into more detail,



	Estimate	SE	*t* value	*P* value
a	4.284	0.052	81.704	<0.0001
b	−3.704	0.730	−5.072	<0.0001
c	−0.374	0.022	−16.870	<0.0001

Log of total time (cmin/m^3) = $a + b \times$ LV + $c \times$ OP, where cmin = min × 10^{-2}, inclusive of all other time and delays; LV = log volume (m^3); OP = operators (*n*); SE = standard error. R^2 = 0.754; *n* = 96. Note: The cmin is commonly used in forest work studies as a decimal replacement for the second, the official SI unit. The minute is not an SI unit, but is accepted for use with the SI.

Figure 4.—Machine productivity as a function of log size.

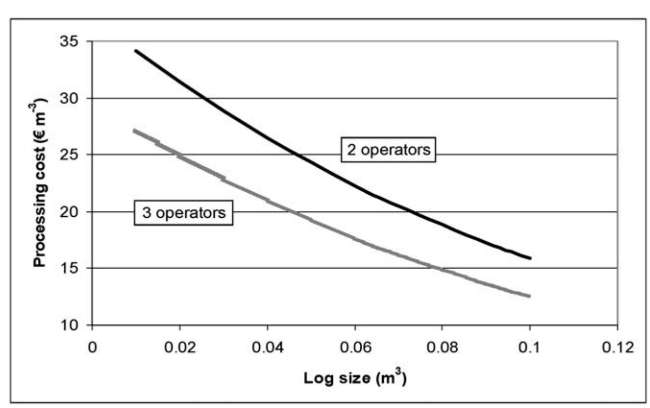


Figure 5.—Processing cost as a function of log size.

but it can still detect macroscopic differences, as for Operation 3 or Operation 4. In particular, different operator performance may account for a large variability, which makes it unsafe to look for more detailed comparisons.

In any case, the study clearly shows the effect of piece volume on machine productivity, pointing at the peculiar conditions of Mediterranean firewood processing operations. Fed with small logs from coppice forests, these operations are especially penalized by the log volume constraint. Although all machines on test were specifically designed for handling small logs, they would still react very positively to any increases of log volume. It is therefore logical to question why these machines are fed with 1-m-long logs, rather than with longer logs. Any increases in log length would certainly boost productivity and reduce cost, as already shown in Finland by Kärhä and Jouhiaho (2009). Extending log length would increase productivity all along the chain, not just during the processing stage.

There are currently two reasons for processing short logs. First, firewood harvesting operations are conducted motor manually with chainsaws, and the operators need to produce logs with a reasonable weight for manual handling (stacking, loading etc.). Second, minimal length specifications allow maximizing product recovery from generally crooked and branchy trees, which can offer long logs only from the central stem portion (Picchio et al. 2009). Increasing mechanization levels and the new opportunity to recover some value from the branch portion through chipping may lead to a future increase of log length, thus improving efficiency all along the chain (Spinelli et al. 2009). Future studies may address the balance between value recovery and productivity as a result of log length manipulation in firewood production chains, from felling to final processing.

The peculiar characteristics of Mediterranean firewood logs make it difficult to compare the results of this study with those of the Nordic studies mentioned in the introduction. Our productivity figures are quite similar to those reported for small-scale firewood processors in Finland. Kärhä and Jouhiaho (2009) indicate that these machines have a productivity range between 4 and 6 m^3/h. However, the same authors report a much higher productivity for the only industrial firewood processor represented in their study, whose output exceeded 10 m^3/h, excluding delays. That represents a 40 percent increment over the most productive operation in our study. However, Nordic work conditions are much more favorable, especially regarding piece volume and length. Fortunately, Kärhä and Jouhiaho (2009) also report regression equations for modeling the productivity of the machines in their study, including the industrial firewood processor. We used such equations to recalculate productivity for the same mean log length and log volume range as observed in our study. The productivity of the Nordic processor drops dramatically, especially with the smaller log volume figures. For the same log sizes, the productivity of the Nordic processor is between 400 and 15 percent lower than the productivity of the larger firewood processor in our study (three-man crew). Italian units designed for a two-man crew reach a higher productivity compared with the Nordic machine when log diameter is smaller than 18 cm. Of course, this exercise has the main purpose of showing how difficult it is to compare mean figures from different studies, and it is not meant to provide a reliable comparison of Nordic and Italian machines. Such a comparison was not the goal of our experiment, and it would require a specific study. Furthermore, the models estimated by Kärhä and Jouhiaho (2009) are valid for birch, which is much softer than the oak we used for our study. That also explains why the splitter on the industrial Nordic machine (Palax Monster) could develop a force of 16 tonnes (t), while the splitters on the Italian machines on test could apply a force between 18 and 70 t, depending on the model.

In contrast, the results of our study can be compared with those of a recent survey of small-scale firewood processors used in Italy (Manzone and Spinelli 2014). These were used with 2-m-long beech logs, which are not the same as 1-m-long oak logs, but they are still the closest match we could find. When dealing with unsorted material as in this study, the mean productivity of small-scale firewood processors was around 1.1 t/h, inclusive of all other work and delays. Therefore, smaller industrial firewood processors manned by two-man crews offer a mean productivity gain of 80 percent, while larger industrial units manned by a three-man crew outperform small-scale units by a factor of 3. However, the lower operating cost of small-scale units largely offsets their productivity handicap. Among the industrial firewood processors, only the larger three-man unit offers a clearly lower processing cost compared with small-scale machines. For the rest, the production cost advantage of industrial processors is much less definite. Again, the comparison is biased by the different log length and by the variability introduced by potentially different operator performance. However, such comparison is good enough for excluding the overwhelming superiority of smaller industrial units when it comes to cost efficiency. In that respect, upgrading from a small-scale firewood processor to an industrial unit at the small end of the range is unlikely to result in a dramatic reduction of processing cost. However, the upgrade offers a definite advantage in terms of production capacity, comfort, and safety. Despite all efforts, operators equipped with small-scale firewood processors cannot produce much more than 1,000 t of firewood per y, whereas industrial units allow doubling that figure, in the worst case. Increasing capacity may be tempting in a business that enjoys a very large demand and attractive profit margins. In that case, labor availability becomes the main constraint, which can be overcome by increasing the productivity of the current staff and by making the job more attractive for additional hands. Industrial firewood processors perfectly match these needs. Then, if further growth is possible, one may acquire a large industrial unit and achieve an additional dramatic reduction of processing cost.

Finally, energy efficiency is about three times as high as recorded for small-scale firewood processing units. Such a dramatic difference may depend more on the different power system than on machine scale. The industrial units in this study were all powered by electric motors, while small-scale units are generally powered by internal combustion engines. The latter are much less efficient, especially when they belong to obsolete farm tractors, too old for any other jobs. In that case, emissions can represent an additional risk for the environment and the health of the operators. Electric power solves the problem at the very source. In fact, small-scale firewood processors can also be equipped with electric motors, but very few customers take the option, since their yards are often too small for network coverage and they generally have old tractors available at little or no cost.

Conclusions

Industrial firewood processors are sophisticated, expensive, and very productive. In addition, they offer operator comfort and safety levels far above those available on small-scale units. Industrial firewood processors designed for Southern Europe are specifically equipped with a number of features that allow coping with short unsorted logs and with small-size irregular wood. For this reason, they can run fully automatically or semiautomatically, depending on raw material type. They can handle more logs per cycle, thus partly compensating for the negative effect of small log volume through mass handling, which may make them less sensitive to piece size compared with Nordic units. Designed for handling very hard wood, these machines are also equipped with powerful splitting stations. Their main advantage over small-scale units is production capacity and operator comfort. Cost reduction is a secondary advantage, achieved in some degrees by all industrial units, but never dramatic, with the exception of machines at the higher end of the range. This allows business growth, in the face of a very large market and a decreasing availability of skilled labor. Use of electric power allows cutting operating cost, increasing energy efficiency, and solving at the source all problems related to emissions.

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