Motor-Based Energy Consumption in West Virginia Sawmills

Dayakar G. Devaru
Ramakrishna Maddula
Shawn T. Grushecky
Bhaskaran Gopalakrishnan

Abstract

Energy costs have risen immensely over the past decade and have strained US industrial sectors. The forest products sector is considered an energy-intensive industry group, and energy use has an important impact on a sawmill's financial integrity. This research focuses on developing specific energy consumption profiles for the manufacture of common Appalachian hardwood lumber species. Process, production, and energy data were gathered by visiting three sawmill facilities in West Virginia. With this information, the specific energy consumption (SEC) for each mill, mill production component, and species was developed. The SEC of sawmills varied between 84 kWh per thousand board feet (MBF) to 111 kWh/MBF with an overall average of 100 kWh/MBF for the three sawmills. In general, results show that denser species consume more energy than less dense species, that the SEC of hard-hardwood lumber was 98 kWh/MBF, and that the soft-hardwood lumber was 92 kWh/MBF. The SEC of Sawmill 3 was significantly different from the SECs of the other two sawmills. Results also indicated that the SEC increases as the percentage of four-quarter lumber increases during a particular shift along with an increase in the energy consumption of chipper, head saw, and resaw. Conversely, SEC decreases as the percentage of cants and timbers sawn increases.

In West Virginia, sawmills represent the largest component of the primary processing sector in both number of establishments and number of employees. West Virginia currently has approximately 110 sawmills that produce lumber of various grades from mostly hardwood species. The operators that have remained in business over the last economic downturn have been investigating ways to lower the costs associated with the production of hardwood lumber. One potential way to lower costs is to focus on reducing their energy consumption. Hardwood production is energy intensive, and energy use in the forest products sector accounts for 12 percent of the total energy input in the US manufacturing industry, 5 percent of which is consumed by the lumber manufacturing industry (Department of Energy [DOE] 2006). In 2001, the lumber manufacturing industry spent $368 million for electricity and $128 million for fuels (Bond 2008). If a sawmill produces only rough green lumber and has no kiln-drying facility, electricity will be the primary energy form consumed; otherwise, fuel used to produce heat for lumber drying will be the most important component of energy usage. Energy costs can be a significant component of operating costs in a lumber manufacturing industry (Gopalakrishnan et al. 2003) and can vary between 1 and 10 percent of the total operating costs (Mardikar 2007). With the addition of kilns at primary processing facilities, energy use can be much higher, potentially using six to nine times more energy than the sawmilling operation itself (Wengert and Meyer 1992).

Therefore, more attention is being given to energy consumption in light of increasing energy prices (Mate 2002) because they can have a significant impact on the profit margin of lumber production. Although it has recently declined, the price of natural gas for industrial use more than doubled from 1997 to 2007, and electric energy prices

The authors are, respectively, Graduate Research Assistant and Graduate Research Assistant, West Virginia Univ. Industrial Assessment Center (dayakar.devaru@gmail.com, kriss0072k@gmail.com), Assistant Director, Appalachian Hardwood Center (shawn.grushecky@mail.wvu.edu [corresponsing author]), and Professor of Industrial and Management Systems and Director, West Virginia Univ. Industrial Assessment Center (bhaskaran.gopalakrishnan@mail.wvu.edu), West Virginia Univ., Morgantown.
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have risen 40 percent during the same period. Wasting energy in sawmills is becoming more and more expensive.

A typical hardwood sawmill combines five main operations, including log debarking, log sawing, flitch edging and trimming, and waste chipping (Fig. 1). Most hardwood sawmills have similar designs in that they have multiple pieces of equipment that are being run by several large electric motors. In addition, most sawmills have an air compressor that operates additional equipment throughout the facility. Smaller sawmills will usually have similar equipment, but the power of the individual motors are typically smaller. Close to 90 percent of the electrical energy used in a typical sawmill will be consumed by motors alone (Lin et al. 2012).

There has been very little empirical work completed on the impacts of motor size and equipment configuration on production economics in hardwood sawmills. In Brazil, Poole and Pinheiro (2003) found that sawing hardwoods influenced peak demand more than softwoods and that most of the electrical motors being used were inefficient and could be replaced with new energy-efficient motors. The authors strongly believed that there was an opportunity to use ''disconnect controls'' on some motors to reduce the energy consumption when they are running at off-load (Poole and Pinheiro 2003). In West Virginia, Lin et al. (2012) conducted energy audits at 17 sawmills and compared their overall costs of production as well as ways to increase efficiency. This research found that the average consumption per mill was 220 kWh per thousand board feet (MBF) and that changes recommended by the research team could save the hardwood sawmills more than 14 percent of the annual energy used.

In a survey conducted by Espinoza et al. (2011) on 188 sawmills, 63 percent of the sawmills surveyed indicated that they are focusing on improving energy efficiency, 41.9 percent indicated that they are improving productivity, and 41.3 percent indicated that they are doing both to cope with rising energy prices. Around 8.6 percent of the sawmills surveyed indicated that they have established energy usage baselines and energy performance indicators that help them monitor their performance on a continual basis.

While the Lin et al. (2012) work provided gross estimates of energy use in West Virginia hardwood sawmills, more specific information on individual motor configuration as well as log and product characteristics and their relationships to energy usage is needed. In order to determine the impact of these factors on energy costs, an intensive investigation of energy use in three West Virginia hardwood sawmills was conducted. The fundamental hypothesis was whether the specific energy consumption (SEC) was the same in the hardwood sawmills studied. Further, the intent of this research was to document how log and product characteristics and mill configurations impact energy consumption and energy-related sawing costs in West Virginia. The individual objectives were the following:

1. Calculate the SEC for each sawmill and each species sawn
2. Compare and contrast the SEC of the participating mills
3. Determine the impact of species sawn on the SEC
4. Compare differences in the SEC among major equipment centers
5. Determine the impact of lumber size on energy consumption

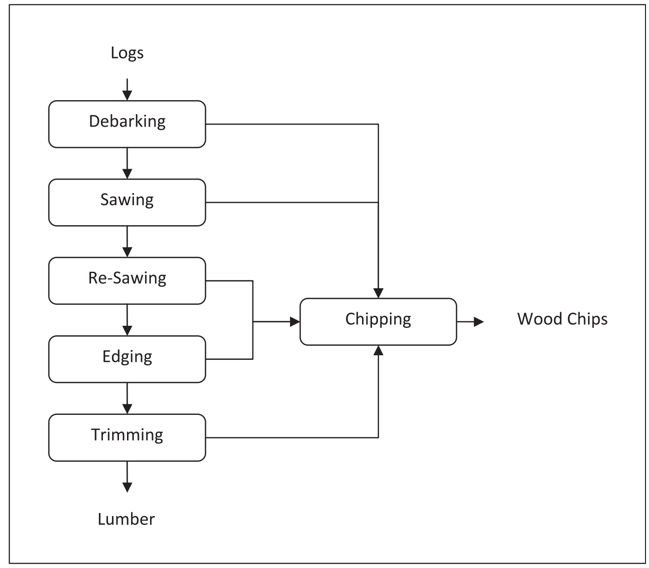

Figure 1.—Typical process flow diagram for a hardwood sawmill operation in West Virginia.

Methods

Data collection

Three medium-size sawmills in West Virginia were selected on the basis of their willingness to permit the research team to access their electric panels and to monitor their electrical energy consumption. Based on the work from Lin et al. (2012), the sawmills chosen for this research project were representative of the mills sawing hardwoods in West Virginia. During the original visit to each mill, energy, current, voltage, and power factor data were collected using an advanced electrical data collection device (AMPROBE) for approximately 20 minutes on each motor. This was done to measure the power factor for each of the motors and to have baseline data so that the results could be compared with those from the continuous monitoring equipment. Power factor is the ratio of real power to the apparent power and is critical for calculating power consumption of the induction motor.

Once baseline data were collected, data loggers (HOBO) with current transducers (Onset) were used to collect electrical energy consumption data in the cooperating mills. The data loggers were installed on each motor and were set to collect data every minute for 1 month.

Eight main motors were selected for monitoring in each of the three mills (Table 1). These motors were selected for data logging because they were the main energy consumers at each facility and the research team had access to a limited number of data loggers. Several other motors were sampled; however, the main eight were logged at each. Of the mills sampled, only the second mill had a different production flow in that it was lacking a resaw. In Sawmills 1 and 3, the head saw converted logs into cants, and then a resaw was used to saw the cants into lumber. In Sawmill 2, the head saw performed all of the log breakdown.

The subpanel used to supply power to each of the sample motors was located, and the data logger and transducer were installed in each panel (Fig. 2). The current transducer was secured around one of the demand-side legs in the motor control panel of each motor, and the transducer's output was

Table 1.—Characteristics of major motors monitored during sawmill energy consumption research in West Virginia.

	Sawmill 1		Sawmill 2		Sawmill 3	
No.	Motor name	Motor size (hp)[a]	Motor name	Motor size (hp)	Motor name	Motor size (hp)
1	Head saw	200	Head saw	200	Head saw	150
2	Carriage feed motor	100	Carriage feed motor	150	Carriage feed motor	300
3	Chipper	150	Chipper	150	Chipper	300
4	Debarker	50	Debarker	85	Debarker	150
5	Edger	50	Edger	50	Edger	150
6	Air compressor	60	Air compressor	40	Air compressor	300
7	Resaw	60	—	—	Resaw	250
8	Trimmer	10	Trimmer	25	Trimmer	20
9	Dust collector	15	Dust collector	37	Dust cyclone	150
10	Chip blower	30	Chip bin motor	30	Bark hog	125
11	Log turner	40	Conveyor motor	15		
12	Top saw	40	Barn sweep motor	5		
Total		805		787		1,895

[a] hp = horsepower.

connected to the data logger. The data logger was set to record current data every minute during the duration of data collection. The transducers and loggers were installed for a period of 30 days at each mill.

The logged motor horsepower of Sawmills 1, 2, and 3 were 83, 96, and 69 percent, respectively, of the total combined motor horsepower (Table 2). The electrical energy consumption of motors that were not logged was estimated on the basis of average load factor of the logged motors and the total operating hours using the following relationship:

$$\text{EC (Nonlogged motors)} = \frac{\text{Horsepower} \times \text{Load factor} \times \text{Operating hours} \times 0.746\left(\frac{\text{kW}}{\text{hp}}\right)}{\text{Average motor efficiency}} \qquad (1)$$

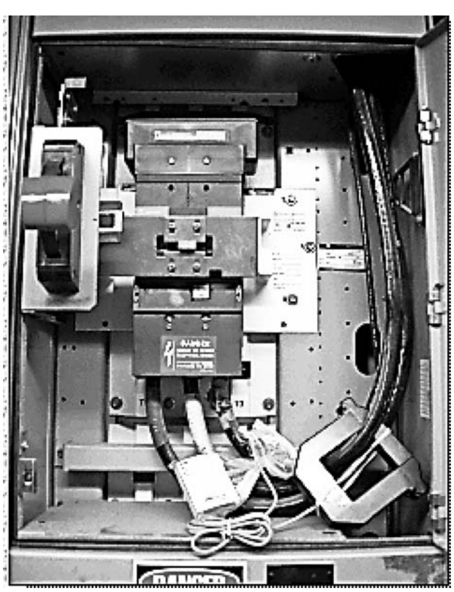

Figure 2.—Photograph of data logger and current transducer setup used during sawmill energy consumption research in West Virginia.

The research team also provided data sheets and asked the mill to record production data during the time period of energy usage sampling. Each mill provided its production schedule that included species sawn as well as the different size and grade combinations of the lumber produced during data collection. Data were provided at the shift level for each mill, which included new data runs each morning and afternoon as well as when the mill changed to a different species or production line. After the data collection period at each mill, data were downloaded from the loggers, and associated production data were recorded.

Analyses

The electrical and production data collected were used to calculate energy consumption for the lumber produced during a particular shift. Data were matched to production records based on the timestamps recorded by the data loggers. Total energy consumption in kilowatt hours for each motor was calculated for a particular time period using the logged data as follows:

$$EC_{logged} = \sqrt{3} \times V \times I \times \cos(\Phi) \times \text{Number of hours}/(1{,}000) \qquad (2)$$

where

EC_{logged} = energy consumption,
V = voltage,
I = amperage, and
$\cos(\Phi)$ = power factor measured using AMPROBE.

For example, the energy consumed by the resaw for sawing soft maple on April 14 in Sawmill 1 is calculated as follows:

Table 2.—Logged and combined total motor horsepower (hp) of sawmills used during sawmill energy consumption research in West Virginia.

Sawmill no.	Logged hp	Total hp	% logged
1	805	968	83
2	787	817	96
3	1,895	2,750	69

$$EC_{logged} = \sqrt{3} \times 477.6 \times 23.92 \times 0.253 \times 7.85/(1{,}000) = 39.30\text{kWh} \quad (3)$$

The number of hours used to calculate EC_{logged} were those recorded by the data loggers and not those provided by the mill. While they were similar, the data loggers captured the true operating time without any introduction of human error. Similarly, the energy consumption was calculated for all other motors logged. Once consumption data were developed, they were then used to create a standardized metric for each shift based on the total lumber production for the shift (specific energy consumption in kilowatt hours per thousand board feet – SEC). For example, the energy consumption recorded for the various motors were tallied and combined with the corresponding shift production (Table 3).

Total energy consumption (in kilowatt hours) was calculated by adding consumption from all the logged motors. The SEC or total kilowatt hours consumed per thousand board feet was then determined by dividing the total energy consumption during a set time period by the total lumber production for the same period. Energy consumption for lighting and heating, ventilation, and air conditioning (HVAC) was calculated on the basis of the data collected during sawmill sampling visits. The total energy consumption of motors, lighting, and HVAC closely matched the actual electricity bills (Table 4).

As a preliminary measure, analysis of variance (ANOVA) was used to test for differences in SEC among the various species sawn. The following model was used:

$$Y_{ij} = \mu + \alpha_i + \varepsilon_{ij} \quad (4)$$

where Y_{ij} is the overall SEC rate over all shifts, μ is the overall mean, α_i is the effect of the ith species group, and ε_{ij} is the unexplained variability. Because some species had limited samples across mills, logs were grouped into two main categories based on density: hard hardwoods and soft hardwoods. The Tukey Studentized range test (HSD) was used for multiple comparison testing between levels of hard hardwoods and soft hardwoods.

ANOVA was also used to assess the variability in overall and individual motor SEC that could be explained by each sawmill and could be stated as follows:

$$Y_{ij} = \mu + \alpha_i + \varepsilon_{ij} \quad (5)$$

where Y_{ij} is the overall and individual motor SEC rate over all shifts, μ is the overall mean, α_i is the effect of the ith sawmill, and ε_{ij} is the unexplained variability. Normality was tested using the Shapiro-Wilk test statistic for individual mill and aggregated data. All individual mill data met normality assumptions; however, due to increased dispersion in Sawmill 3 SEC, homogeneity of variance was also examined. To ensure equal variances, Levene's (1960) test was performed and found that SEC did not meet homogeneity of variance assumptions. Therefore, the Welch (1951) variance-weighted 1-way ANOVA model was used. This alternative statistic is robust to the assumption of equal within-group variances, and all F values are reported on the basis of the calculated Welch statistic. For multiple comparison testing, the HSD test was used for assessing individual differences among the sawmills sampled. Finally, the relationships between product size distribution and SEC were investigated using the Pearson correlation.

Table 4.—Total energy consumption of motors, lighting, and heating, ventilation, and air conditioning (HVAC) in each sawmill along with energy bills.

Sawmill no.	Energy consumption (kWh)				
	Motors	HVAC	Lighting	Calculated total	Energy bill
1	39,767	—	1,650	41,417	42,988
2	35,154	—	1,150	36,304	36,524
3	142,299	21,096	5,413	168,808	175,662

Results and Discussion

Production data

A total of 87 separate shifts where both production data and electrical consumption data corresponded were collected at the three sawmills during the study period. More than 2 million board feet of lumber were sawn during the data logging period. Sawmill 2 had the largest number of data points at 35, followed by Sawmills 1 and 3 with 30 and 22 separate observations, respectively. The experimental units typically corresponded to a particular species that was sawn during a particular period (a.m./p.m.) and represent multiple hours of data collection. Typically, one or two species were sawn during an 8- to 10-hour work period, and production data could be effectively tied to consumption data because the mill was ''cleared'' during species changes to avoid the mixing of lumber. A total of 15, 23, and 20 days of production and energy consumption data were collected from Sawmills 1, 2, and 3, respectively. Red oak was the most common species sawed during the study period, followed by white oak and yellow-poplar (Table 5).

Each mill sawed various lumber thicknesses during each shift. By far, 4/4 lumber was the most common thickness, representing 54 percent of the total lumber sawn (Table 6). Pallet parts, industrial cants, and railroad ties and timbers were also sawn by each of the mills during the study period. It was also noticed that Sawmill 3 did not produce any cants and 8/4 lumber during this period. Overall, 71 percent of the lumber produced was of 4/4, 5/4, 6/4, and 8/4, and the remaining 29 percent was in pallet, cant, and timber sizes.

Table 3.—Example of energy consumption recorded for motors used during the sawing of soft maple logs in a West Virginia hardwood sawmill.

Energy consumption (kWh)										
Head saw	Resaw	Edger	Trimmer	Chipper	Debarker	Compressor	Other motors	Total	MBF[a]	SEC[b]
152.7	39.3	43.8	8.5	159.1	74.4	446.1	1,344	2,267.9	32.374	70.05

[a] MBF = thousand board feet sawn during a given sampling period.
[b] SEC = specific energy consumption (total kilowatt hours per thousand board feet).

Table 5.—Total number of data points for hardwood species sawn, species group assigned, and total board feet sawn during energy consumption research at three sawmills in West Virginia.

Species	Species group[a]	No. of data points	Board ft	Percentage
White ash (*Fraxinus americana*)	HHW	2	43,861	2.3
Black birch (*Betula lenta*)	SHW	1	3,324	1.2
Black cherry (*Prunus serotina*)	SHW	3	40,250	3.5
Hickory species (*Carya* spp.)	HHW	5	86,775	5.8
Hard maple (*Acer saccharum*)	HHW	6	123,219	6.9
Red oak (*Quercus rubra*)	HHW	29	736,164	33.3
Soft maple (*Acer rubrum*)	SHW	6	136,263	6.9
White oak (*Quercus alba*)	HHW	20	443,034	23.0
Yellow-poplar (*Liriodendron tulipifera*)	SHW	15	553,408	17.2
Total		87	2,166,298	100.0

[a] HHW = hard hardwood; SHW = soft hardwood.

Each of the hardwood mills sampled focused on grade lumber production. During the study period, Sawmill 3 produced the largest amount of Common and Better lumber, about triple that of Sawmill 1 and six times more than Sawmill 2 (Table 7). The upper NHLA grades (FAS 1 Common) accounted for 62 percent of the grade lumber sawn (not including fiber in pallet lumber, cants, and timber materials).

Specific energy consumption

The SEC calculated for each sawmill varied from an average of 111 kWh/MBF for Sawmill 3 to 84 kWh/MBF for Sawmill 2. The overall average SEC for all the three sawmills was 100 kWh/MBF. During the sampling period, each sawmill produced lumber of different species with some mills sawing more hard-hardwood and some sawing more of soft-hardwood species.

While nine different species were represented on the shifts sampled, species-specific data were calculated only for those species that were found on at least five shifts. As would be expected, the hard hardwoods (red oak, white oak, hickory, and hard maple) consumed more energy than less dense species (soft maple and yellow-poplar; Fig. 3).

Logs were combined on the basis of their density into hard hardwoods and soft hardwoods. The hard-hardwood group included white ash, hickory species, hard maple, red oak, and white oak. The soft-hardwood group included black birch, black cherry, soft maple, and yellow-poplar. A total of 1,433,053 board feet of hard hardwoods and 733,245 board feet of soft hardwoods were sampled at the three mills during this study. While shifts that sawed hard hardwoods consumed more energy than those that sawed soft hardwoods, the difference was not significant ($F = 0.59$, $P = 0.4448$; Fig. 4).

Species data were then aggregated so that overall SEC rates could be investigated. Sawmill 3 had a significantly higher total SEC than both Sawmill 1 and Sawmill 2 ($F = 7.10$, $P = 0.0020$). The average SEC recorded for Sawmill 3 was approximately 27 kWh/MBF greater than the SEC for Sawmill 2. The SEC of Sawmill 1 was higher than the SEC of Sawmill 2 by approximately 3 kWh/MBF; however, this difference was not significant. While Sawmills 1 and 2 were quite different in terms of total horsepower capacity and production, SEC was not significantly different due to their production rate and load factors.

While production and capacity are contrasting in Sawmills 2 and 3, much of the difference in SEC between these sawmills can be attributed to the load factor/efficiency ratios of the motors. The SEC of Sawmill 3 was 32.6 percent greater than Sawmill 2. If the ratio between motor capacity and production is compared between these mills, Sawmill 3 is producing 9 percent less lumber per capacity than Sawmill 2. The real driver in SEC is that the motors used in Sawmill 3 are overloaded when compared with Sawmill 2. Load factor is the percentage of motor capacity used on average for doing the particular mechanical work. The load factor/efficiency ratio of Sawmill 3 is 39 percent compared with that of Sawmill 2, which is 30.2 percent. The

Table 6.—Total lumber produced (board feet) in various product categories measured at three sawmills during sawmill energy consumption research in West Virginia.

Sawmill no.	Total lumber	Four quarter	Five quarter	Six quarter	Eight quarter	Pallet	Cant	Timber
1	460,994	327,363 (71%)	23,905 (5%)	7,618 (2%)	9,820 (2%)	64,850 (14%)	17,403 (4%)	10,035 (2%)
2	420,687	158,100 (38%)	25,866 (6%)	12,284 (3%)	14,262 (3%)	14,666 (3%)	86,499 (21%)	109,010 (26%)
3	1,284,617	693,720 (54%)	200,215 (16%)	71,217 (6%)	0 (0%)	211,408 (16%)	0 (0%)	108,057 (8%)
Total	2,166,298	1,179,183 (54%)	249,986 (12%)	91,119 (4%)	24,082 (1%)	290,924 (13%)	103,902 (5%)	227,102 (10%)

Table 7.—Total production (board feet) of National Hardwood Lumber Association–graded lumber measured at three sawmills during sawmill energy consumption research in West Virginia.

Sawmill no.	FAS	FAS 1 Face	1 Common	2 Common	3 Common	COMBET[a]
1	0	135,953	65,532	95,442	71,779	201,485
2	26,371	16,279	61,769	75,870	30,223	104,419
3	381,672	0	265,306	318,174	0	646,978

[a] COMBET = FAS + FAS 1 Face + 1 Common.

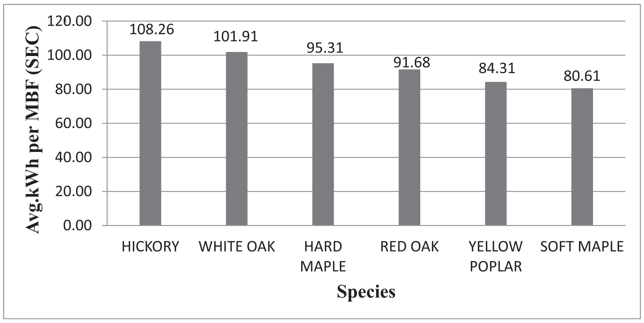

Figure 3.—Specific energy consumption (SEC) in kilowatt hours (kWh) per thousand board feet (MBF) during the sawing of different wood species in three West Virginia sawmills.

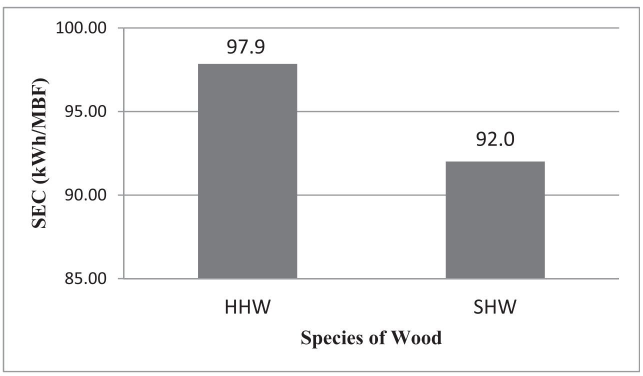

Figure 4.—Specific energy consumption (SEC) in kilowatt hours (kWh) per thousand board feet (MBF) for hard hardwoods (white ash, hickory, hard maple, red oak, and white oak) and soft hardwoods (black birch, black cherry, soft maple, and yellow-poplar).

difference in the load factor/efficiency ratio could be attributed to motor size, motor efficiency, and equipment design and would result in Sawmill 3 consuming 29.2 percent more energy than Sawmill 2 due to load factor/efficiency ratio alone.

The SEC calculated for the head saw was also significantly different among mills. The SEC of Sawmill 2 was significantly higher than the other sawmills sampled ($F = 273.75$, $P < 0.0001$; Fig. 5). Much of this difference in head-rig SEC can be explained by the use of a resaw.

When looking only at SEC for the mills with resaws, Sawmill 3 consumed significantly more electricity per thousand board feet on the resaw than did Sawmill 1 ($F = 40.75$, $P < 0.0001$; Fig. 6). The difference in resaw SEC can be attributed to the size of the resaw motor. The size of the resaw motor in Sawmill 1 was 60 hp, whereas the size of the resaw motor in Sawmill 3 was 250 hp. Sawmill 3 used a larger motor to increase production speed and capacity to achieve its higher yearly lumber volumes.

Chipper energy consumption (SEC) was also significantly different among sawmills ($F = 135.35$, $P < 0.0001$; Fig. 7). Sawmills 2 and 3 used significantly more energy at the chipper than Sawmill 1. Much of the difference in chipper SEC could be attributed to the slower production rate and longer production time of Sawmill 2. Thus, the chipper ran at idle or at a lower load for longer time periods and consumed more energy. Likewise, the SEC of Sawmill 3 was higher because of the size of the chipper motor. The chipper motor in Sawmill 1 was 150 hp, whereas the motor used in Sawmill 3 was 300 hp.

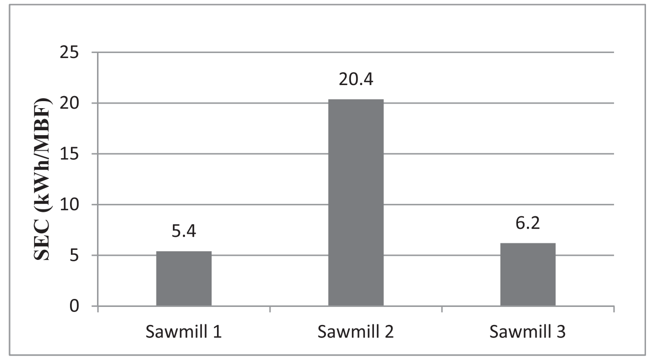

Figure 5.—Specific energy consumption (SEC) in kilowatt hours (kWh) per thousand board (MBF) feet sawn for the head saw motor at three sawmills sampled in West Virginia.

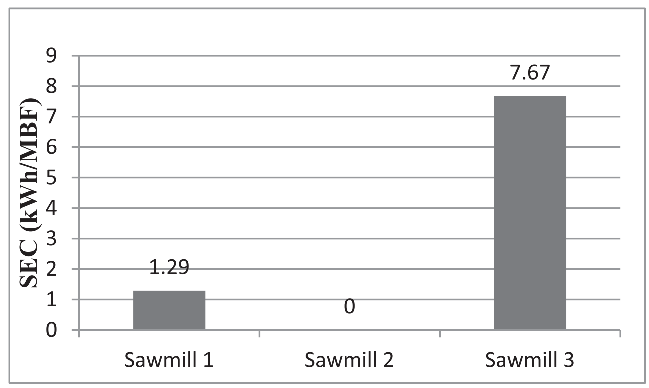

Figure 6.—Specific energy consumption (SEC) in kilowatt hours (kWh) per thousand board feet (MBF) sawn for the resaw motor at three sawmills sampled in West Virginia.

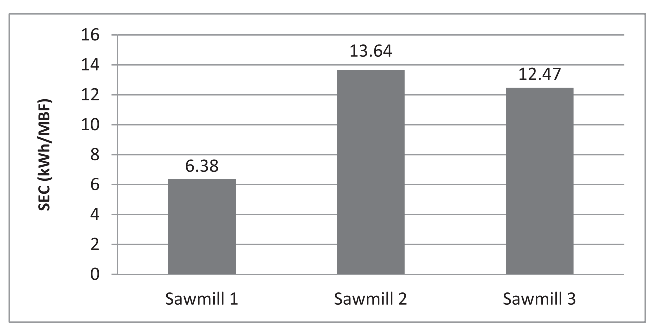

Figure 7.—Specific energy consumption (SEC) in kilowatt hours (kWh) per thousand board feet (MBF) sawn for the chipper motor at three sawmills sampled in West Virginia.

Debarker energy consumption was significantly different among all mills ($F = 314.15$, $P < 0.0001$; Figure 8). Debarker SEC of Sawmill 2 was significantly higher than Sawmills 1 and 3 ($P < 0.0001$). Again, this could be attributed to the slower production rate and longer production time of Sawmill 2. However, since the debarker motors do not idle to the same extent as chipper motors, more of this difference can be attributed to the debarker

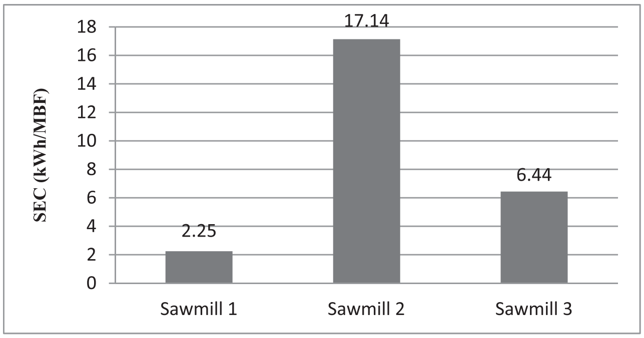

Figure 8.—Specific energy consumption (SEC) in kilowatt hours (kWh) per thousand board feet (MBF) sawn for the debarker motor at three sawmills sampled in West Virginia.

motor size. The SEC of Sawmill 3 was also significantly greater than Sawmill 1 ($P < 0.0001$). Again, this can be attributed to the size of the debarker motor. The size of the debarker motor in Sawmill 1 is 50 hp versus the much larger 150-hp motor used for the debarker in Sawmill 3. The larger motor would help increase the production capacity of Sawmill 3 at the expense of increased energy consumption per thousand board feet.

Another important observation from this research was the correlation between the SEC and the type and size of lumber sawn. The SEC was positively related to the percentage of four-quarter lumber being sawn (Table 8). This relationship also held true with the percentage of Common and Better lumber being sawn. Thus, as the mills sawed more grade lumber as opposed to industrial-type products, the energy consumption per thousand board feet increased.

Conversely, as the production percentage of cants (industrial products used in wood packaging materials) and timbers increased, the SEC decreased (Table 8). These findings follow the common view held by those in the industry. Most operators feel that their energy consumption is greater when sawing standard grade lumber versus sawing industrial products because of the increased number of saw lines. When the correlations were further investigated by comparing individual motor relationships, a cause for the consumption difference becomes apparent.

The percentage of timbers and cants sawn was also negatively correlated to the head saw, resaw, and chipper SEC (Table 9). As the percentage of industrial products sawn increased in a shift, less work was performed by the head saw, resaw, and chipper. Likewise, the percentage of four-quarter lumber processed is positively correlated to head saw, resaw, and chipper SEC. This helps to validate the data that were collected; as more four-quarter lumber was processed in a shift, the resaw, head saw, and chipper did more work. This will result in an increase in overall SEC for four-quarter lumber.

Table 8.—Spearman correlation coefficients for electrical consumption per thousand board feet and lumber sizes.

	% four quarter	% COMBET[a]	% cant[b]	% timber[c]
SEC[d]	0.30	0.09	−0.39	−0.05
P value	0.0048	0.3932	0.0002	0.67

[a] COMBET = FAS + FAS 1 Face + 1 Common.
[b] Pallet parts and industrial products that are resawn.
[c] Timber = large cants (7 by 9 in. and greater).
[d] SEC = specific energy consumption.

Table 9.—Pearson correlation coefficients for equipment electrical consumption per thousand board feet and lumber sizes.

Equipment SEC[a]	Value	% timber	% cant	% four quarter
Head saw	Coefficient	−0.19	−0.04	0.29
	P value	0.0783	0.7134	0.0061
Resaw	Coefficient	−0.52	−0.55	0.40
	P value	<0.0001	<0.0001	0.0001
Chipper	Coefficient	−0.27	−0.15	0.29
	P value	0.0101	0.1812	0.0058

[a] SEC = specific energy consumption.

The negative relationship found between the percentage of timbers produced and SEC has a bearing on the overall efficiency of the sawmills studied. Results from this study confirmed that Sawmills 1 and 2 had the best overall efficiency as suggested by their SEC; however, Sawmill 2 sawed less 4/4 lumber and more cants and timbers than did the other sawmills (Table 6). This relationship implies that the efficiency reported for Sawmill 2 may be less than reported because the impact of lumber size could not be differentiated. In order to understand the true efficiency differences among mills, the interaction between motor loads and lumber sizes needs to be further investigated by obtaining more information on lumber size characteristics in future studies.

Conclusions

The SEC in kilowatt hours per thousand board feet of lumber sawn was calculated for different sawmills, and the SEC was compared for different species. The recorded electrical data were processed with an individual mill's production data to calculate the SEC. Energy consumption of major equipment for different sawmills was compared. Results show that the SEC increases as the percentage of four-quarter lumber sawn in the lot increases. The SEC decreases as the percentage of cants and timbers sawn in the lot increases.

On average, the SEC of hard-hardwood lumber was 6 kWh higher than soft-hardwood lumber. The denser hardwoods (red oak, white oak, hickory, and hard maple) consumed more energy than less dense species (soft maple and yellow-poplar). The SEC calculated was 86 kWh/MBF for Sawmill 1, 84 kWh/MBF for Sawmill 2, and 111 kWh/MBF for Sawmill 3. The SEC of Sawmill 3 was significantly different from the other two sawmills. The main driving factors for SEC were load factor and size of the motors. Motors of Sawmills 1 and 3 had higher load factors when compared with Sawmill 2. Most of the motors of Sawmill 3 were more than twice the capacity of Sawmill 2 with production lagging the motor capacity ratio. Along with the lag in the production, larger motors resulted in higher energy consumption in Sawmill 3.

The average SEC of hard-hardwood lumber was 98 kWh/MBF and that of soft-hardwood lumber 92 kWh/MBF. Previous studies (Milota et al. 2005) done through a survey of sawmills estimated the SEC for sawing softwood lumber as 67.9 kWh/MBF for four sawmills of the southern region (Georgia, Alabama, Mississippi, and Louisiana) and 86.8

kWh/MBF for four sawmills of the western region (Oregon and Washington). The SEC values of soft-hardwood lumber determined from this research are closer to the SEC estimated for sawmills in the western region.

Another study (Bergman and Bowe 2008) done through a survey of 20 sawmills in the northeastern region estimated the SEC for sawing hardwood lumber as 137 kWh/MBF (304 MJ/m^3; 1 MJ = 3.6 kWh, and 1 nominal MBF = 1.623 m^3). The SEC from this study is higher than the average SEC values of hard-hardwood lumber determined by this research. It was found that the SEC of Sawmill 3 was higher than the other two sawmills because it was a bigger operation with oversize motors. It is likely that the mills surveyed in Bergman and Bowe (2008) were larger sawmills with correspondingly higher-volume lumber production.

Another interesting finding from this research is that the load factors recorded for each of the sawmills were lower than industrial standards. A lower load factor results in lower motor efficiency, yielding higher energy consumption. The typical load factor required to achieve good motor efficiency is around 50 percent (DOE Best Practices 2007). All three sawmills sampled in this study could benefit from improving their motor load factors, something that can be done by using properly sized motors.

Sawmills 2 and 3 produced approximately 5 and 15 million board feet (Table 7) of lumber, respectively, per year (420.7 MBF × 12 mo; 1,284.6 × 12 mo); the SEC of Sawmill 3 was higher than that of Sawmill 2 by approximately 27 kWh/MBF. This would result in an additional electricity consumption of approximately 405,000 kWh/y. Based on an average electricity rate of $0.0618/kWh in West Virginia (US Energy Information Administration [US EIA] 2011), this additional energy consumption would cost Sawmill 3 an additional $25,029/y in electricity. While this may not represent a tremendous savings opportunity in West Virginia, where power is relatively cheap, it can be more of a factor if estimated in other hardwood-producing states. The additional cost would equate to $54,189 in Massachusetts, where the average electricity cost ($0.1338/kWh) is the highest, and $21,101 in Iowa, where the average electricity cost ($0.0521/kWh) is the lowest for the hardwood states (US EIA 2011). To reduce the energy costs, it is recommended that sawmills improve their energy efficiency and productivity.

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