ENERGY ANALYSIS OF TWO EUCALYPTUS HARVESTING SYSTEMS IN BRAZIL

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Summary

Mechanized harvesting of timber is an activity with high investment in machinery, fuel and lubricant, representing an expenditure of energy. The main objective of this study was to analyze the energy consumption in “cut-to-length” and “tree-length” harvesting systems, used in Eucalyptus plantations in Brazilian forest companies. The “cut-to-length” system was composed by a Volvo excavator operating as a harvester machine, and a forwarder Timberjack 1210B. The “tree-length” system module was a feller buncher Timberjack 608L, a clambunk-skidder Timberjack 1710, and one slasher Timberjack 608B.

Operational data and fuel consumption were collected from twenty-two machines, which jointly worked 88,384 hours, producing 7,268,729 m³ of wood, operating in Eucalyptus plantations located at Southeast part of Brazil (São Paulo and Minas Gerais states). Worksheets calculated the energy expenditure, considering a 7-year old Eucalyptus plantation, with a productivity of 300 m³.ha⁻¹.

The “cut-to-length” system required the investment of 37.8 MJ of energy to harvest one cubic meter of wood. Energy consumed by labor represented only 0.3%, while the machines 6.1% (raw material, manufacture, and maintenance), and fuel consumption 93.6%, representing a total power consumption of 11,340 MJ.ha⁻¹. The energy investment in the “tree-length” system was 45.4 MJ.m⁻³. The relative distribution of the consumed energy was 0.2%, 6.1%, and 93.7%, respectively in labor, equipment, and fuel. Considering the production of 300 m³.ha⁻¹, the total energy expenditure was 13,620 MJ.ha⁻¹, what made this harvesting system be the largest consumer of energy.

Keywords: Energy analysis, Eucalyptus logging, timber extraction.

Introduction

The Brazil stands out on the world stage because of the importance of forest biomass and its potential with one of the highest rates of forestry productivity, reaching between 40 and 50 cubic meters (m³) of wood per hectare per year, more than 10 times the observed in temperate countries (STAPE, 2003). Two main mechanized systems are used in forest harvesting in Brazil, developed according to the types of machines and

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According to Serra et al. (1979), mechanization of operations emphasized the use of fossil energy in increasingly sophisticated ways, as a result of planning and use of machinery, fertilizers and pesticides, providing significant increases in productivity over time. The amount of energy used in the operations depends on several factors, not only the energy from the fuel, but also that aggregated in the manufacture and distribution of machinery, hydraulic and lubricating oil, and labor (BRIDGES and SMITH, 1979; FLUCK, 1985).

Athanassiadis et al. (2002) counted, in terms of fuel consumption, the input energy for timber harvesting of 82 MJ.m$^{-3}$ on Swedish conditions. Of this total, 11% are due to the energy expended in the stage of extraction and refining of fuel. The authors considered that on the energy investment in harvesting activity, 40% were provided by fossil fuel use.

Berg and Lindholm (2004) inventoried the use of energy in forest operations in Sweden between 1996 and 1997, involving all operations, including seedling production, silviculture, harvesting and transport to the main industry. Energy use was 150-200 MJ.m$^{-3}$ of wood depending on the country region. This inventory showed that the energy expenditure of the main transport was higher than that observed in the past decade. In contrast, expenditure at harvest was lower compared to same last period, possibly because of better technology and management.

Damen (2001) estimated for Brazilian conditions, the energy expenditure based on diesel cost per tonne of harvested wood, with values of 1996, focused on the production of eucalyptus for pulp and paper. The energy expenditure for mechanical harvesting, with feller-buncher, skidder and slasher, was approximately 123 MJ.t$^{-1}$. The author considered the cost of harvesting at US$ 8.11 per dry ton of wood, with an estimated energy cost of US$ 1.08.GJ$^{-1}$.

The total energy required to perform the activity in each harvesting system will be directly proportional to the number of operations involved, considering the performance and capacity of machines in each module, in addition to the type of machinery used in the modules.

The objective of this study was to analyze the consumption of energy invested in felling operations, prehauling and primary processing in two mechanized harvesting systems, “cut-to-length” and “tree length”, and also identify the most influential factors in each operation, to establish the relationship of energy expenditure on harvesting activities.

**Methodology**

A matrix was established to calculate the energy expenditure of the mechanized operations in harvest activity in two systems, “cut-to-length” and “tree-length”, and analyzed according to the demand of energy for its accomplishment, considering an eucalyptus stand producing 300 m³.ha$^{-1}$ at the end of seven years.
Four forestry companies, working with “tree length” systems, were visited in the years 2003 and 2004, and one company that adopted the “cut-to-length” system, comprising the states of Sao Paulo and Minas Gerais, which were selected in areas with similar conditions of cultivation and an average individual volume of 0.18 m³ per tree. The data from operational capacity and fuel consumption represent the performance of eight mechanized modules, totaling twenty-two machines, which jointly worked 88,384 hours, producing 7,268,729 m³ of wood. The average data of each company considered account for the overall average productivity of machines to harvest one hectare of eucalyptus with similar pattern. The machines were grouped according to Doering (1980) by the power and mass in each harvesting system, obtaining the average overall performance in each module to avoid comparisons of operational capacity among the trademarks or productivity between firms.

**Materials**

The direct energy was classified in terms of biological power of human labor and fuel. The energy depreciation was considered as indirect energy, because of the power consumption for the machine to be manufactured, being also considered the time spent (hours) and the mass of the machinery used in the operation.

**Harvesting description**

In both systems the final road side product is 2.20 m logs with bark arranged in the transverse direction. In the “cut-to-length” system considered, the module was composed of a harvester machine Volvo excavator based and one Timberjack 1210B forwarder. In the “tree length” system, the module was one feller buncher Timberjack 608L, one clambunk-skidder Timberjack 1710, and one slasher Timberjack 608B.

**Methods**

In this analysis, the energy inputs were classified and quantified according to the source, considering the characteristics of the machines, operational performance (machines and workforce), and fuel consumption in each forest enterprise activity. In matrix calculation, the energy inputs were organized in the vector called "entries vector", which corresponds to the energy intensities of each energy flow. The operating time (h.ha⁻¹) and fuel consumption (L.ha⁻¹) were organized in the matrix called "consumption matrix", according to Sartori and Basta (1999). Multiplying the input vector by the energy consumption matrix resulted in a vector with the values of energy expenditure in each activity expressed in units of energy per cubic meter or per hectare (J.m⁻³ or J.ha⁻¹). The machines used in each harvesting system were depreciated in terms of added energy, accounting the used raw material, energy consumed in manufacturing, with repairs and maintenance throughout life. Machine annual use, its mass and power were considered in calculations, according to the methodology proposed by Doering (1980) (Equation 1).
\[ E_{\text{RM}} = (E_{\text{MM}} + E_{\text{IM}}) \times m \times 0.333 \times \frac{\text{RM}}{L_U} \]  

where:
- \( E_{\text{RM}} \) = energy spent on repairs and maintenance (MJ.h\(^{-1}\));
- \( E_{\text{MM}} \) = energy value used to machine manufacturing: 14.6 MJ.kg\(^{-1}\);
- \( E_{\text{IM}} \) = energy value of the incorporated material: 50.0 MJ.kg\(^{-1}\);
- \( m \) = machine mass (kg);
- \( L_U \) = useful life (h);
- \( \text{RM} \) = coefficient for repairs and maintenance (0.74).

The energy spent by hour for machine manufacturing and incorporated material was calculated multiplying the energy value (MJ.kg\(^{-1}\)) by machine mass, and dividing the result by 82% of the useful life in hours (\( L_U = 5 \) years x 6,000 hours.year\(^{-1} = 30,000 \) hours), being 18% considered as a residual life.

Results

The results of machine operational capacity are presented in Table 1, with those results being utilized for the energy calculation. The results of energy calculations presented in Table 2 show that the higher powered machines had higher aggregate energy per hour, mainly due to the mass. This difference in energy depreciation data was considered in the energy inputs used in the calculations.

Matrix calculation of harvesting activities

The entries vector and consumption matrix are shown in Figure 1. The answer vector indicates the energy expenditure per type of machine used, and the sum of these values resulted on the final value of each module. The values express the expenditure of energy to handle a cubic meter of wood. The sum of the values in answer vector (Figure 1) resulted in the expenditures of energy in each system under study, as shown in Figure 2.

Table 1. Operational capacity and fuel consumption of machines in each harvesting system.

<table>
<thead>
<tr>
<th>System</th>
<th>Operation</th>
<th>Machine</th>
<th>( P ) (m(^3).h(^{-1}))</th>
<th>Diesel (L.m(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut-to-length</td>
<td>Harvesting</td>
<td>Harvester</td>
<td>35.4</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>Forwarding</td>
<td>Forwarder</td>
<td>42.8</td>
<td>0.40</td>
</tr>
<tr>
<td>Tree-length</td>
<td>Felling</td>
<td>Feller bunch</td>
<td>74.9</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>Skidding</td>
<td>Clambunk</td>
<td>55.5</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>Bucking</td>
<td>Slasher</td>
<td>57.0</td>
<td>0.33</td>
</tr>
</tbody>
</table>

\( P \) = machine productivity.

Table 2. Energy depreciation of logging machines.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Mass (t)</th>
<th>Power (kW)</th>
<th>Useful Life (h)</th>
<th>( E_{\text{IM}} ) (MJ.h(^{-1}))</th>
<th>( E_{\text{MM}} ) (MJ.h(^{-1}))</th>
<th>( (E_{\text{IM}}+E_{\text{MM}}) \times 0.82 ) (MJ.h(^{-1}))</th>
<th>( E_{\text{RM}} ) (MJ.h(^{-1}))</th>
<th>Total (MJ.h(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvester</td>
<td>19.5</td>
<td>160</td>
<td>30,000</td>
<td>32.7</td>
<td>9.5</td>
<td>34.6</td>
<td>10.4</td>
<td>45.0</td>
</tr>
<tr>
<td>Forwarder</td>
<td>19.5</td>
<td>160</td>
<td>30,000</td>
<td>32.7</td>
<td>9.5</td>
<td>34.6</td>
<td>10.4</td>
<td>45.0</td>
</tr>
<tr>
<td>Feller</td>
<td>27.2</td>
<td>180</td>
<td>30,000</td>
<td>45.5</td>
<td>13.2</td>
<td>48.2</td>
<td>14.5</td>
<td>62.7</td>
</tr>
<tr>
<td>Skidder</td>
<td>19.5</td>
<td>160</td>
<td>30,000</td>
<td>32.7</td>
<td>9.5</td>
<td>34.6</td>
<td>10.4</td>
<td>45.0</td>
</tr>
<tr>
<td>Slasher</td>
<td>27.1</td>
<td>180</td>
<td>30,000</td>
<td>44.8</td>
<td>13.2</td>
<td>47.6</td>
<td>14.3</td>
<td>61.9</td>
</tr>
</tbody>
</table>
E_{IM} = Added energy in raw materials; E_{MM} = Added energy in manufacturing; E_{RM} = Energy spent with repairs and maintenance.

<table>
<thead>
<tr>
<th>Entries vector</th>
<th>Workforce (MJ.h^{-1})</th>
<th>Machine 1 (MJ.h^{-1})</th>
<th>Machine 2 (MJ.h^{-1})</th>
<th>Diesel (MJ.L^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workforce (h.m^{-3})</td>
<td>0.028</td>
<td>0.023</td>
<td>0.013</td>
<td>0.018</td>
</tr>
<tr>
<td>Machine 160 kW (h.m^{-3})</td>
<td>0.028</td>
<td>0.023</td>
<td>0.000</td>
<td>0.018</td>
</tr>
<tr>
<td>Machine 180 kW (h.m^{-3})</td>
<td>0.000</td>
<td>0.000</td>
<td>0.013</td>
<td>0.000</td>
</tr>
<tr>
<td>Diesel (L.m^{-3})</td>
<td>0.53</td>
<td>0.40</td>
<td>0.39</td>
<td>0.40</td>
</tr>
<tr>
<td>Harvester</td>
<td>16.30</td>
<td>15.65</td>
<td>16.05</td>
<td>13.70</td>
</tr>
</tbody>
</table>

Figure 1. Matrix calculation of energy expenditure on harvesting activities.

The “tree-length” system presented power consumption approximately 20% higher when compared to the “cut-to-length” system. Considering the higher calorific value of wood equal to 19 GJ.t^{-1}, the harvest energy investment is about 0.5% of the energy potential from the eucalyptus plantation.

Figure 2. Final energy expenditure at each operational system.
Discussion

The higher power consumption in both systems was due to fuel consumption, 93.7% of the total. Lower demand was required by human labor, 0.2% of the total, indicating, of course, that labor is not a limiting factor in terms of energy. Energy depreciation took an average of 6.1% of the total for the two systems, and was not associated to the machine power, but to the machine mass, according to the method as proposed by Doering (1980), indicating that further repairs and maintenance were not of great expenditure of energy.

There was an influence of machine size and power on energy consumption, as verified by Bridges and Smith (1979). The harvester work, felling and processing trees, was responsible for 56.8% of energy demand, being forwarding the remaining 43.2%. In the “tree-length” system, felling and processing trees, made by feller buncher and slasher, required 64.7% of total energy and the remaining 35.3% was used by the skidder. There was a better distribution of the power demand on the first system, while the “tree-length” system has a concentrated demand of energy in the felling and processing operations.

The machine productivity was the most important factor to the energy consumption, with the “tree-length” system being more productive. It is suggested to study the influence of increased carrying capacity of the forwarder, as a way to increase its energy efficiency.

The matrix calculation was effective, but the level of details of the required inputs for the desired operation must be carefully considered. It is evident on this type of analysis, the possibility of the use of environmental indicators (energy efficiency) in the selection of mechanized systems to be adopted by the company, and also to monitor the impacts of outsourcing operations.

Conclusions

The higher demand was fuel consumption in both harvesting systems, around 94% of total energy investment. Felling and processing were the greater energy demand on logging operations, with a higher concentration on “tree length” system because the necessity of two machines instead of one single harvester used on “cut-to-length” system.

The most important factors were: fuel consumption, weight and number of machines, and the operational performance of the harvesting module. The largest number of machines and greater mass implies greater energy expenditure, which must be considered when choosing a harvesting system. The harvest of logs by the “tree-length” system had energy consumption 20% higher compared to the “cut-to-length” system.

From a technological standpoint, the energy invested in operations was proportional in the two systems, but in terms of energy efficiency, in relation to the flows of inputs and outputs, the energy investment in the “cut-to-length” equals 0.40% of the energy produced by eucalyptus plantation, and the “tree-length” system 0.48%. This difference corresponds to the energy equivalent of 60 liters of diesel oil per harvested hectare, which becomes relevant when considering the total volume of wood moved annually by companies.

Each company must evaluate the energy consumption in their specific operating conditions, in order to complement the decision-making and its implications in the long-term energy availability.
References


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