ENERGY EFFICIENCY OF MECHANIZED THINNING IN BROADLEAF STAND

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Introduction

Efficiency of timber harvesting systems is traditionally expressed in time and/or monetary values per unit of a product. Unit cost of production is still regarded as a main factor for selecting harvesting systems in the planning phase and for the evaluation of their efficiency. Rapid development of the renewable energy sector, and bioenergy sector as its important part, raised a question of bioenergy competitiveness when compared to energy produced from fossil fuels as well as from other renewables. At this point, when timber harvesting systems had to be analysed as energy production systems, unit of a timber product could no longer be the sole denominator for calculating the efficiency and novel research methods had to be applied.

EROI (Energy Return On Investment) is a ratio between energy obtained from energy production process and energy consumption during separation, growth, etc. into new forms of energy [1]. Basic concept relies on the laws of physics that energy cannot be produced without a portion of it being consumed. In this respect, levels of consumed energy are a key indicator of the efficiency of the production process [2]. The general criterion used in the current debate on EROI is the question whether energy that returns as fuel is greater than the energy invested in the process of production of that fuel, i.e. whether the EROI is greater than 1 [1]. For energy wood the ratio between energy obtained and energy consumed amounts to 30 [3], meaning that one liter of oil is needed in the energy wood production to gain energy equivalent to 30 liters of oil.

The goal of this research was to determine the energy efficiency (expressed as EROI) of mechanized timber harvesting by a harvester–forwarder system in an 80-year old broadleaf harvesting site.

Material and Methods

The harvesting site, located in Management unit »Bjelovarska Bilogora« consisted of two adjacent sub-compartments. One was a European hornbeam dominated stand of an area 18.28 ha, harvesting density 98 trees/ha and 40 m^3/ha, average DBH of marked trees was 21.7 cm, and average primary transport distance amounted to 250 m. The second sub-compartment was a European beech dominated stand of an area 9.07 ha, harvesting density 62 trees/ha and 49 m^3/ha, average DBH of marked trees was 26.4 cm and average primary transport distance was 550 m. In both sub-compartments European hornbeam trees prevailed in the marked trees; both in number (92 trees/ha and 47 trees/ha) and volume (38 m^3/ha and 29 m^3/ha).

Mechanized harvesting system was composed of a harvester and a forwarder working as a harvesting team. Felling and processing of timber assortments was performed by a Timberjack 1470D harvester. The harvester was powered by the John Deere JD6081 HTJ 04, 6-cylinder, turbo diesel engine. The highest engine power is 180 kW at a speed of 1200-2000 min^{-1}, while the maximum torque is 1250 Nm at the engine speed of 1400 min^{-1}. Declared mass of the harvester was 18800 kg. The Harvester was equipped with a Timberjack 758 harvesting head with a declared maximum cutting diameter of 65 cm. The mass of a harvesting head, along with the rotator, was 1080 kg. Forwarder Timberjack 1710D was used for roundwood extraction. The forwarder was powered by the John Deere 6081H, a 6-cylinder, turbo diesel engine of 160 kW power at 2100 min^{-1}, with the highest torque of 1090 Nm at 1400 min^{-1}. It was equipped with hydraulic crane Boom CF885. Maximum reach of the crane is 8500 mm. The declared lifting moment is 151 kNm, while the torque is 41 kNm. The payload capacity was 17 000 kg, and declared mass of a forwarder was 19000 kg.

Field experiment consisted of time studies and measuring fuel consumption while other input data was gathered from own previous research in similar conditions or literature sources.

To measure the fuel consumption a fuel metering probe was installed in the fuel tanks of the investigated machinery. The probe was linked to a Fleet Management System (FMS) whose role is to wirelessly send data recorded using the mobile network (GPRS) and the Internet to the end user. Parallel with the recording of the fuel level in the tank, the position (movement) coordinates of the machine and the activity of the hydraulic crane were recorded. The above-mentioned monitoring parameters were available on the web platform from where daily reports were downloaded in the table view (MS Excel). The fuel consumption data analysis was performed using the ArcGIS program package and the MS Office Excel program.

System boundaries were set at the landing, i.e. roundwood delivered to the roadside is regarded as a system's final product. Energy investment was calculated on PMH (Productive Machine Hour) level enabling the use of input parameters of cost calculations as well as expressing the results in the span of main factors (DBH and extraction distance) used in the productivity models.

When calculating EROI it is important to include as many input parameters, or in this case the energy required to build all the machines used in forest harvesting operations, the energy of fuels and lubricants used by the machines and the energy required to build supplies.

In calculation, the energy invested in machinery and vehicles is assumed to be 66 MJ/kg [4, 5]. Masses of machines were taken from technical data of manufacturers. Service life of the investigated machines was set at 15000 PMH for harvester and forwarder and 7000 PMH for harvesting head [6]. In this way energy invested in the production of the machinery could be expressed on PMH level. Measured fuel consumption (l/PMH) were averaged on the PMH level and lubricant consumption was taken from the literature [6] Recalculated of fuel and lubricant consumption to energy values was done by applying conversion factors form the literature [4, 7, 8]. Consumption of spare tyres was calculated on the PMH level based on the cost calculations [9] and expressed in energy units using the mass of tyres and unit energy for their production reported in previous research [1, 10].

Energy return for beech and hornbeam wood in fresh state (45% moisture content) was calculated based on the results of laboratory analyses of wood samples. Net calorific value was determined at 8.84 MJ/kg (45% moisture content) and expressed as 9282 MJ/m^3 (based on 1050 kg/m^3 wood density).

Results and discussion

Energy investment of a harvester amounted to 1022.4 MJ/PMH (84% fuel; 9% production of a machine; 6% oil; 1% tyres) and that of a forwarder to 529.9 MJ/PMH (75% fuel; 16% production of a machine; 5% oil; 4% tyres). When expressed on a product level, energy investment of a harvesting system reached 130 MJ/m^3 (for average DBH = 23 cm and average extraction distance of 360 m). Energy return for beech and hornbeam wood in fresh state (45% moisture content) is 9282 MJ/m^3, thus the application of the investigated harvesting system under the conditions of the specified felling site results with EROI of 71.5. Furthermore, EROI is expected to range from 38 (for DBH 12.5 cm) to 102 (for DBH 42.5 cm) with the average extraction distance of 360 m (Fig. 1); and from 76 (for 100 m extraction distance) to 65 (for 800 m extraction distance) with the average DBH of 23 cm (Fig. 2).
When compared to similar research conducted with semi-mechanized harvesting system (felling and processing with a chainsaw, energywood forwarding) [1] felling with a harvester had 5.9 times higher energy investment per m^3, but forwarding in mechanized system lowered the energy investment of extraction per m^3 to 0.6 of the one recorded in semi-mechanized system. On the harvesting system level, mechanized system reached 1.6 times bigger energy investment than the semi-mechanized. Differences could be the result of different harvesting influencing factors, but surely reflect the high difference in energy consumption when using harvester instead of a chainsaw.

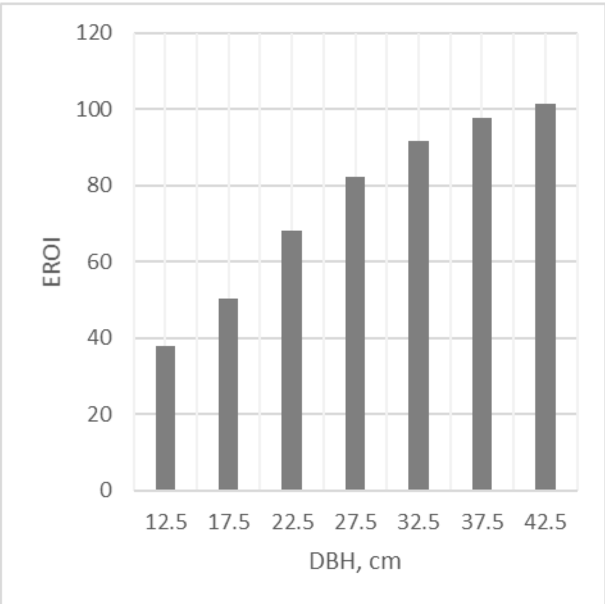

Figure 1. EROI of the investigated harvesting system vs. DBH

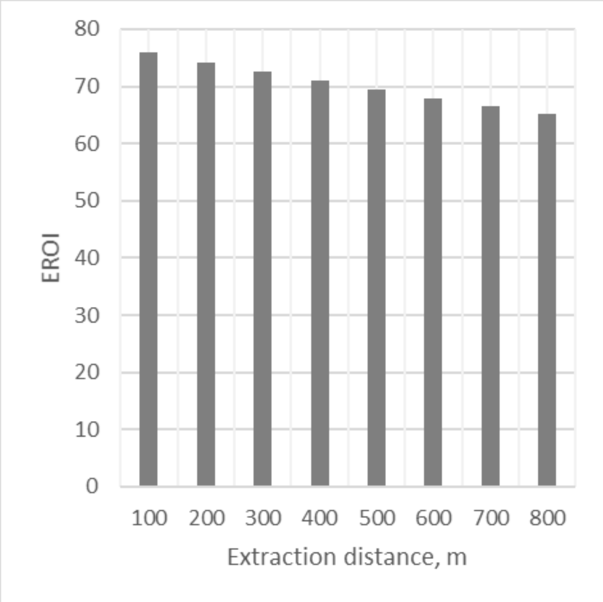

Figure 2. EROI of the investigated harvesting system vs. extraction distance

Conclusions

Research results indicate a high EROI of mechanized thinning in broadleaf stands. Although highly mechanized harvesting machines were used, that in relation to mechanization used in semi-mechanized harvesting system have much higher fuel consumption per PMH and generally require higher energy input in the system, their high productivity offsets the energy balance towards quite positive levels. But, when analysing results presented in this research, the fact that system boundaries were set in a way to include just the harvesting part of the whole production chain (thus not covering the complete energy investment) has to be taken into consideration. On the other hand, reduction of the moisture content to half of the initial value (by natural drying of energy wood) would increase the energy gain by 8%. But, in order to cover the EROI of the final energy product, system boundaries should be shifted to the end user. Energy investment calculation should cover the transportation and preferably explore different transformation processes (production of firewood in the household; mechanized production of oven-ready chopped firewood and production of wood pellets).

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