Evaluation of John Deere 1490D operation phase in typical conditions of the Czech Republic

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Abstract: The life cycle operation phase of John Deere 1490D energy wood harvester from the aspect of energy audit and environmentally negative influence caused by emissions were evaluated. Energy audit quantifies energy used in the form of fuels and oils as well as energy expended for manufacture, transport and distribution of these fuels and oils. Emissions produced by operation are determined according to the consumption of fuels and oils based on emission factors. We also made a comparison of the general calculation of costs based on data provided by the manufacturer with costs ascertained in real operating conditions. The costs are divided into purchase, operating and other costs. Total costs are subsequently converted into unit costs according to the assumed productivity of the machine, its estimated lifetime, and the mean real throughput of the machine. The machine throughput, and thus also its operating economics, is greatly dependent on the character of the processed material, its stem volume, moisture, way of dendromass preparation, and operator's skills. Energy use was calculated at 74.4 MJ·FU^{-1} (functional unit) related to fuel consumption and 13.4 MJ·FU^{-1} related to the consumption of oils. The total energy use of the life cycle operation phase of the slash bundler was determined as 87.8 MJ per each bundle produced. The real productivity of the machine in the given operating conditions was several times lower than the productivity indicated by the manufacturer.

Keywords: productivity; costs; energy audit; emissions; slash bundle

At present a considerable amount of primary fossil resources is used for the production of each product; therefore each manufacture contributes to the production of greenhouse gases. Recently, the utilization of biomass for energy purposes has been discussed ever more often as products based on biomass improve the balance of renewable and non-renewable resources. In forest management there are many variants of technologies processing logging residues. The basic method, currently the most frequently used in the Czech Republic, is wood chipping by means of chippers which are supplied to this market with a wide scale of output capacities. Woody biomass is chipped directly in the stand or at the roadside and transported to the customer. Another, less frequently used method is the processing of logging residues by an energy wood harvester. Slash bundles are transported to the customer where it is theoretically possible either to directly burn them or to chip them.

The environmental load of the individual technologies may be evaluated using the LCA method, which quantifies energy inputs and outputs expended per production unit (ISO 14040-2 standards). The main sources of energy for timber harvesting and hauling are fossil fuels. Klvac et al. (2003) determined the share of energies in the individual phases of the life cycle of fully mechanized technologies in the conditions of Ireland. The following life cycle phases were evaluated: manufacture of machine, operation and maintenance of machine including repairs. The energy required for liquidation and/or recycling of machine was not determined. The results of this study document that out of the total share of energies the greatest part (at least 80%) was used for the machine operation phase.

An inseparable part of the environmental load caused by the operation of this technology is the production of greenhouse gas emissions. The anticipated CO_2 emissions may be ascertained by means of molecular equation, C:H ratio, energy contents and other factors (Calais, Sims 2006). A simple calculation of greenhouse gases based on the C:H ratio is unsuitable as emissions and their composition are influenced by other factors as well. Fuel energy content was also measured by many authors: Grägg (1994, 1998, 1999) and Furholt (1995) determined the fuel energy content as follows: EC3 (Swedish environmental class 3 fuel) = 36 $MJ \cdot l^{-1}$, EC1 (Swedish environmental class 1 fuel) = 35.3 $MJ \cdot l^{-1}$, and RME = 33.1 $MJ \cdot l^{-1}$; Altin et al. (2001) determined the mineral oil energy content at 36.14 $MJ \cdot l^{-1}$; McDonell (1996) calculated the value of 36.55 $MJ \cdot l^{-1}$ for mineral oil and 35.67 $MJ \cdot l^{-1}$ for a mixture containing 25% of semi-refined rapeseed oil and 75% of mineral oil.

Emissions emerging with combustion are directly related with the engine output, whereas its calorific efficiency, i.e. the ratio of transformed fuel energy, is important. The calorific efficiency of engines depends on the ratio of compression and octane or cetane number of fuel. Hamilton (2000) presented the relation between calorific efficiency, compression ratio and octane number for spark ignition engines with carburettor.

Emission factors of spark ignition engines for harvester technologies were studied by Grägg (1999). They were determined for EC3 fuel on Perkins 1006-T engine (133.5 kW) and on Valmet 420 DS engine (135.8 kW for EC3 and EC1 fuels). Emission factors of RME (rapeseed methyl ester) were determined by Grägg (1994) on Scania DSC 1127 engine (144 kW). On the basis of measurements Athanassiadis (2000) determined emission factors of spark ignition engines for a fully mechanized technology. In this study the calorific efficiency of engines was calculated for both fuels at the level of 40%.

If possible, emission factors have to be determined for each machine separately, if not, they may be grouped by purpose and size. Emission factors of the particular groups of machines were studied by the United States Environmental Protection Agency (USEPA 1985) and are updated on a regular basis. However, emissions emerging with combustion do not include all harmful substances leaking away into the environment. Their inseparable part is also emissions emerging during manufacture, transport, and distribution of fuel. These emissions emerging during the production of fuels were studied by Davison and Lewis (1999).

The entire process of production of woody biomass as an alternative source of energy is greatly energy-consuming. Output capacities of machines declared by producers may markedly differ from the really achieved value. In operating conditions changes occur with a number of factors that influence the machine productivity; this in turn changes the production volume and subsequently the anticipated profit. These factors may be divided into technical (dependence on a machine), environmental (factors controllable by the operator) and physiological ones (sort and characteristics of dendromass) and their combinations.

The goal of this paper is to evaluate a slash bundling machine by means of energy audit and to determine produced exhaust emissions. The secondary goal is to compare costs based on a general calculation with real costs incurred during the operation of the given technology.

MATERIAL AND METHOD

John Deere 1490D bundler was studied during 2 years (2007 and 2008) in standard conditions of the Czech Republic. The machine was purchased in June 2004 with the aim of processing forest dendromass (logging residues) after main felling.

Technical data indicated by the manufacturer (John Deere):

Output (kW)		136
Total mass (kg)		23,000
Total length (mm)		11,105
Axles:	Balanced boogie axle, front and rear	
Bundling unit length (mm)		6,200
Input dimensions:	height (mm)	800
	width (mm)	1,020
Length of bundles (mm)		2,400–3,200
Diameter of bundles (mm)		700–800
Productivity ($bundles \cdot h^{-1}$)		20–30

John Deere 1490D is designed as medium to large sized machine class. The machine was used in stands after intended main felling. After harvesting operation the residues were concentrated onto small piles depending on striproads and processed by a harvester. The bundler was also applied in stands where the power chain saw was used for harvesting. The woody biomass was evenly scattered on the entire area there; for this reason the productivity was lower. Because of technological reasons the material was processed immediately after harvesting (the dendromass was not intentionally dried up). Bundles were then transported by means of a forwarder to the roadside and subsequently hauled to the customer. The bundles were mostly 3,200 mm long and their diameter was 700 mm. The bundling machine operated in the area of ca

120 km^2. The processed forest dendromass was at a ca 9:1 ratio of softwood/hardwood.

The process of data acquisition consisted in the collection and analysis of data required for the determination of productivity and costing of the machine in 2007 and 2008. Consequently an analysis and synthesis of these costs were carried out, and the costs per production unit were calculated. Production unit differs at particular points of the processing chain: costs are either calculated per bundle (pc), PMH (productive machine hour) or tonne (t).

For the determination of costs depending upon the purchase price of the machine, and on the basis of data provided by the manufacturer a general calculation adopted from Miyata (1980) was done.

Energy audit should include not only energy contained in fuels and oils used up during combustion but also energy used during the production of these fuels and oils. Athanassiadis (2000) determined the energy of fuels and oils for harvesters and forwarders amounting to 82 MJ·m^{-3} o.b. (over bark cubic meter), but his calculation did not include energy used during the production of oils. Energy use during the production of fuels was calculated by him as 4.5 MJ·l^{-1} for diesel and 15.6 MJ·l^{-1} for biodiesel.

Energy value of mineral oils was adopted from literature. Anonymous (2000) calculated the energy content of mineral oils as 38.5 MJ·l^{-1}. Goering et al. (1982) determined the energy value of vegetable oils (rapeseed oil) as 39.6 MJ·kg^{-1} (0.912 kg·l^{-1} density). In this study rapeseed oil was used as a representative of vegetable oils. Synthetic oils are mainly produced on vegetable oil bases with additives (usually alcohol) (Våg et al. 2000). For this reason the same energy value (39.6 MJ·kg^{-1} with 0.912 kg·l^{-1} density) may also be used for synthetic oil. Våg et al. (2000) presented energy use during production for various kinds of lubricants as follows: mineral oil 45 MJ·l^{-1}, synthetic ester 22 MJ·l^{-1} and rapeseed oil 12 MJ·l^{-1}.

Energy audit of the slash bundler operation phase expressed in MJ per bundle produced (FU – functional unit, unit of production) was calculated as a sum:

(1) Energy content of fuels and energy used during their production
Energy inputs were calculated as follows: diesel as 36.14 + 4.5 = 40.64 MJ·l^{-1} and rapeseed methyl ester as 33.1 + 15.6 = 48.70 MJ·l^{-1}.

(2) Energy content of oils and energy used during their production
In this study energy inputs were calculated as follows: vegetable oil as 36.1 + 12 = 48.1 MJ·l^{-1}, synthetic oil as 36.1 + 22 = 58.1 MJ·l^{-1}, and mineral oil as 38.5 + 45 = 83.5 MJ·l^{-1}.

Exhaust emissions emerging from fuel were calculated as a sum of emissions emerging with combustion (Eec) and emissions emerging during production, transport and distribution (Eep). In fuels that are products of photosynthesis in which plants assimilate carbon dioxide from the atmosphere, the total balance is calculated without the share of CO_2 assimilated in this way. Anonymous (2002) informed in the section on greenhouse gas balances that the fossil carbon content in RME amounts to 3.6% and the biomass carbon content is 69.7%. The emissions from fossil sources were calculated based on this carbon content distribution.

On the basis of information on calorific value, emission factors applied to engine output unit, emission load emerged by combustion of fuels and applied to production unit may be calculated as follows:

$$Eec = Fc \times Ef \times Cv \times Te \qquad (1)$$

where:
Eec – emissions emerging by combustion (g·FU^{-1}),
Fc – fuel consumption (l·FU^{-1}),
Ef – emission factor (g·MJ^{-1} of engine output),
Cv – calorific value (MJ·l^{-1}),
Te – thermal efficiency.

Emission factors used for the calculation were adopted from Athanassiadis (2000).

Calculations of emissions emerging during production, transport and distribution may be carried out on the basis of emission factors, consumption of fuels, and calorific value:

$$Eep = Fc \times Ef \times Cv \qquad (2)$$

where:
Eep – emissions emerging in the phases of extraction, production, transport and distribution (g·FU^{-1})
Fc – fuel consumption (l·FU^{-1}),
Ef – emission factor (g·MJ^{-1}),
Cv – calorific value (MJ·l^{-1}).

Emission factors were adopted from Davison and Lewis (1999) for the state of Austria as the nearest neighbour mentioned in the study. Only the 0.0862 emission factor used for hydrocarbons was adopted from Athanassiadis (2000).

Emissions related to the consumption of oils were calculated as a sum of emissions emerging with production of oils (Eop) and emissions emerging during the reprocessing of used oils for combustion purposes (Eor). Emissions emerging during production were calculated on the basis of emission factors adopted from Ragnarson (1994) and

Marby (1999). Emissions emerging during transport and reprocessing of used oils for combustion purposes were calculated on the basis of emission factors adopted from Lenner (1993) and Stripple and Wennsten (1997).

Emissions related to the production of oils (Eop) were calculated on the basis of information on oil consumption and emission factors as follows:

$$Eop = Oc \times Ef \quad (3)$$

where:

Eop – emissions emerging by production of oils ($g \cdot FU^{-1}$),

Oc – oil consumption ($l \cdot FU^{-1}$),

Ef – emission factor ($g \cdot l^{-1}$).

Emissions related to transport and reprocessing of oils used for combustion were calculated on

Table 1. General machine calculation

Costing factor	John Deere 1490 D
Machine cost data	
Purchase price (P), €	410,000
Engine output power, kW	136
Machine life (n), years	5
Salvage value (sv), % purchase price	10
Machine utilization rate (u), % SMH	75
Repair and maintenance cost (rm), % capital over life	56
Interest rate (in), % of average yearly investment (Y)	8
Insurance and tax rate (it), % of average yearly investment (Y)	7
Fuel consumption rate (fcr), $l \cdot h^{-1}$	7.3
Fuel cost (fc), €$\cdot l^{-1}$	1.16
Oil and lubrication consumption rate (ocr), $l \cdot h^{-1}$	0.62
Oil and lubrication cost (lo), €$\cdot l^{-1}$	3
Operator wage (w), €$\cdot SMH^{-1}$	12
Scheduled machine hours (SMH), $h \cdot year^{-1}$	4,258
Salvage value (S), €	41,000
Annual depreciation (D) in €$\cdot year^{-1}$, $D = [(P - S)/n]$	73,800
Average yearly investment (Y) in €$\cdot year^{-1}$, $Y = [(((P - S)(n + 1))/2n) + S]$	262,400
Productive Machine Hours (PMH) in $h \cdot year^{-1}$, PMH = (SMH × u)	3,193.5
Ownership costs	
Interest on capital (I) in €$\cdot year^{-1}$, I = (in × Y)	20,992
Insurance and tax cost (IT) in €$\cdot year^{-1}$, IT = (it ×Y)	18,368
Annual ownership cost (F) in €$\cdot year^{-1}$, F = (D + I + IT)	113,160
Ownership cost per SMH (Os) in €, Os = (F/SMH)	26.6
Ownership cost per PMH (Op) in €, Op = (F/PMH)	35.4
Operating costs	
Fuel cost (Fu) in €$\cdot PMH^{-1}$, Fu = (fcr × fc)	8,47
Lubricant cost (L) in €$\cdot PMH^{-1}$, L = (ocr × lo)	1.86
Repair and maintenance cost (RM) in €$\cdot PMH^{-1}$, RM = (rm × P/(PMH × n))	14.38
Operator cost (Opc) in €$\cdot PMH^{-1}$, Opc = (W/u)	16.00
Machine operating cost per PMH (Vp) in €$\cdot PMH^{-1}$, V = (Fu + L + RM + Opc)	40.71
Machine operating cost per SMH (Vs) in €$\cdot SMH^{-1}$, Vs = (Vp × ut)	30.5
Total costs	
Total machine cost per SMH in €$\cdot SMH^{-1}$, TCS = (Os + Vs)	57.1
Total machine cost per PMH in €$\cdot PMH^{-1}$, TCP = (Op + Vp)	76.11

the basis of emission factors and consumption of these oils. Emissions related to the transport of oils intended for combustion were calculated only for those oils that were utilised in this way.

$$Eor = Oc \times Ef \quad (4)$$

where:

Eor – emissions emerging by oil transport and reprocessing ($g \cdot FU^{-1}$),

Oc – oil consumption ($l \cdot FU^{-1}$),

Ef – emission factor ($g \cdot l^{-1}$).

RESULTS

For a general calculation (Table 1) 75% for machine utilization was used; this value is commonly used in literature.

However, the coefficient 0.75 is slightly lower than the real value that results from the analysis of forest machinery operation, but it was still chosen so as to take into account possible variable operating conditions instead of those in which the technology was followed within this study. Operating costs were calculated not only from the aspect of available working hours (Schedule Machine Hour – SMH) but also from the aspect of hours of operation (Productive Machine Hour – PMH). SMH is an hour of machine operation including downtime, delays or idle times; PMH is an hour of work without any delays. In this paper the costs for the machine operator are also figured in. A higher SMH was chosen for a general calculation as the machine was intentionally utilized to a greater extent (1.5-shift operation and 250 working days per year). The maintenance and repair costs percentage was adopted from Klvac et al. (2003).

The average utilization of the machine ascertained in real conditions amounted to 81.6% (Table 2).

The value is relatively high, apparently corresponding with the operator's greater experience in 2008 and preparedness of woody biomass for bundling. The utilization value is almost identical for both years under study but in 2008 the number of bundles was higher by almost 76%. It is the authors' opinion that the increase of productivity was mainly due to the operator's great skills. The resulting productivity was calculated inclusive of machine passes both within the given stand and between sites when the machine did not produce any bundles.

It ensues from the general calculation that the total costs per hour of machine operation amount to 76.11 €. After a detailed analysis of the machine operation the average cost of 42.59 $€ \cdot h^{-1}$ of operation (PMH) was calculated for the period under study (Table 3). In 2008 the total costs were higher, but the production volume of bundles also increased by 76%. However, if we compare unit costs, we arrive at a finding that with increased production the total costs were admittedly higher, but the costs per tonne or bundle decreased. It is obvious from the results that on the basis of general calculations the calculated costs per hour of operation are higher than the real operating costs of the machine.

Values calculated on the basis of measurements:

Mean productivity	13,844 bundles (FU)$\cdot year^{-1}$
No of operating hours	3,474 $h \cdot year^{-1}$
Consumption of fuel	7.3 $l \cdot h^{-1}$; 1.83 $l \cdot FU^{-1}$
Consumption of oils	0.62 $l \cdot h^{-1}$; 0.16 $l \cdot FU^{-1}$

Note: Consumption of oils includes gear oils, engine oils, hydraulic oils and chainsaw oils.

Energy consumption was calculated as 74.4 $MJ \cdot FU^{-1}$ depending on the consumption of fuels, and 13.4 $MJ \cdot FU^{-1}$ depending on the consumption of oils. The total energy consumption of the life cycle operation phase of the slash bundler was determined as 87.8 MJ per each bundle produced. The produced emissions loading the environment are shown in Tables 4 and 5.

DISCUSSION AND CONCLUSION

In their study, Patterson et al. (2008) determined the productivity of John Deere 1490D energy wood harvester as 22.3 $pc \cdot h^{-1}$ for main clear fell-

Table 2. Performance units of John Deere 1490 D energy wood harvester in 2007–2008

	2007	2008
PMH (hours of operation)	3,389	3,558
No of bundles (pc)	10,041	17,647
Tonnes (1 bundle = 340.85 kg)	3,360.6	6,015
Utilization (%)	79.6	83.6
Productivity $pc \cdot PMH^{-1}$	3	5

Table 3. John Deere 1490D energy wood harvester – costs per functional units

	2007	2008
Total costs (€)	132,994	163,450
In $€ \cdot PMH^{-1}$	39.24	45.94
In $€ \cdot pc^{-1}$	13.25	9.26
In $€ \cdot t^{-1}$	39.57	27.17

Table 4. Emission emerging by consumption of fuels ($g·FU^{-1}$)

	CO_2	CO	HC	NO_x	PM
Eec diesel	6,878.2	33.3	3.0	62.0	5.2
Eep diesel	449.7	0.4	5.7	2.6	0.1
Total diesel	7,327.9	33.7	8.7	64.6	5.3

Table 5. Emission emerging by consumption of oils ($g·FU^{-1}$)

	CO_2	CO	HC	NO_x	PM
Eop	222.08	0.18	1.42	2.02	0.19
Eor	52.39	0.06	0.01	0.25	0.01
Total	274.47	0.24	1.44	2.26	0.21

Scenario: Fully mineral gear oils, semi-synthetic engine oil (mineral-to-vegetable ratio 80:20), synthetic chainsaw oil and fully mineral lubricants

ing, 31.3 $pc·h^{-1}$ for second thinning, and 36.1 $pc·h^{-1}$ for first thinning with $200.07 total machine costs per production hour. With productivity increased like this the hourly costs certainly increased.

Karha and Vartiamaki (2006) studied the productivity and costs of John Deere 1490D energy wood harvester in Scandinavian conditions. They figured out the costs for the productivity of the machine at 84 $€·PMH^{-1}$, and the productivity at 18.1 $bundles·PMH^{-1}$. Neither of the studies calculated the costs of the machine transport between working areas.

The machine efficiency, and thus also its operating economics, is greatly dependent on the character of the processed material, its stem volume, moisture content, way of dendromass preparation and operator's skills.

The producer indicates the machine productivity amounting up to 30 $bundles·h^{-1}$. However, the real productivity of the machine with ascertained mean serviceability of 81.6% only reached the value of 4 $bundles·h^{-1}$ in the conditions of the Czech Republic. In case that the unit costs per bundle were calculated on the basis of general calculation and productivity of 20–30 bundles per hour indicated by the manufacturer, this value would be very low, and – according to our findings – totally unobtainable.

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