Energy Use of and Emissions from the Operation Phase of a Medium Distance Cableway System

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Abstract – Nacrtak

This paper presents an assessment of the life cycle operation phase of forest cableways Larix 550 and Larix 3T with respect to energy requirements and environmental pollution caused by emissions. Energy audit quantifies energy use based on the consumption of fuels and lubricants. Energy balance includes both the energy content and the energy needed for the production of fuels and lubricants. Fuel consumption measured for one year ranged from 1.2 – 1.4 l/m^3. Based on the consumption of fuels and lubricants the paper quantifies the amount of emissions in two scenarios (minimum consumption and maximum consumption) with a special focus on GHG emissions. Calculations are made of emissions for diesel fuel and for the alternatively applicable rape-seed methyl ester (RME), and a calculation is also made of emissions originating from fossil sources. By using RME as a fuel, the amount of CO_2 emissions from fossil sources discharged into the environment can be reduced by 3.4 kg per a cubic meter over the bark of timber extracted by cableway.

Keywords: GHG emissions, energy audit, fuel consumption, oil consumption

1. Introduction – *Uvod*

Anthropogenic greenhouse gases essentially affect the climate and a reduction of their emission into environment is one of primary objectives of the current EU environmental policy. In order to achieve the goal, it is absolutely necessary to increase the share of energy from renewable sources, where in fact a zero balance of CO_2 originating from fossil resources can be expected. However, clear zero balance of carbon dioxide is impossible in this case because of fossil fuel consumption during production of renewable energy sources.

Nowadays each product is loaded with a certain share of primary fossil resources and hence with a share of Green House Gas (GHG) emissions into environment. The impact of any technology (system) or product onto environment can be assessed by LCA methodology, which can identify inputs and outputs including their environmental impact (ISO 14040-2 standards, revised in 14044).

Also the main source of energy for logging and hauling machines used in forest operations are fossil fuels. Klvac et al. (2003) quantified the share of individual phases of the machine life cycle in the total energy consumption of fully mechanized technology in the conditions of Ireland. Phases included in the calculations were as follows: machine manufacture, repairs (including maintenance) and operation. The phase of disposal or recycling, which also participates in the energy balance, was not included. Results of research showed that the share of machine operation phase in the total energy balance amounts to approximately 80%. Athanassiadis (2000) established the energy use and the amount of emissions from a fully mechanized technology in Sweden at 82 MJ per cubic meter of wood processed, presenting the values of emissions for three fuel types: EC3, EC1 and RME. However, in his work the emissions are only quantified without establishing their share of fossil resources.

Berg (1996 and 1997) compared emissions from motor-manual and mechanized technologies in clear felling and shelterwood felling on the basis of the amount of combusted fuel. His works demonstrate that mechanized technology loads environment with emission substances rather more than motor-manual technology, and that shelterwood system puts on environment a greater load of CO_2 and NO_x emissions than clear-felling system due to a higher number of machine passes and their lower productivity. Karjalainen and Asikainen (1996) and Sambo (1997) estimated fuel consumption in the forestry of Finland and Canada. Based on the estimates, Karjalainen and Asikainen (1996) established the amount of emissions into environment.

The expected CO_2 emissions can be determined on the basis of molecular formula, carbon-hydrogen ratio (C:H), energy content and other factors (Calais and Sims 2006). However, as they mentioned, the simple calculation of CO_2 emissions based on the C:H ratio on stoichiometric basis is rather naive because the emissions and their composition are also affected by other factors. Moreover, the energy content in fuels was published by many authors with different results. Grägg (1994, 1998, 1999) and Furuholt (1995) established fuel energy content as follows: EC3 (Swedish Environmental Class 3 Fuel) = 36 MJ/l, EC1 (Swedish Environmental Class 1 Fuel) = 35.3 MJ/l, and RME (Rapeseed Methyl Ester) = 33.1 MJ/l. Altin et al. (2001) determined the energy content of diesel fuel at 36.14 MJ/l, McDonell (1996) mentions the value of 36.55 MJ/l for diesel and 35.67 MJ/l for a mixture with 25% of semi-refined rapeseed oil and 75% of diesel.

Emissions generated in combustion can be related to the engine output power, where they depend on thermal efficiency, i.e. on the capacity of transforming fuel energy to engine efficiency. Thermal efficiency of engines depends on the rate of compression and on the octane or cetane number of the fuel. Hamilton (2000) presented the relation between thermal efficiency, compression ratio and octane number for carbureted spark-ignition engines.

Table 1 Emission factors of diesel engine (g/MJ of engine output) generated in combustion (Athanassiadis 2000)

Tablica 1. *Faktori emisije dizelskih motora pri sagorijevanju, g/MJ (Athanassiadis 2000)*

	CO_2	CO	HC	NO_X	PM
Diesel	260	1.26	0.114	2.342	0.197
RME	260	0.87	0.022	2.917	0.148

Table 2 Emission factors of compression-ignition engines (C) and spark-ignition engines (S) in various machines as related to engine output power (kg/kWh) (USEPA 1985)

Tablica 2. *Faktori emisije dizelskih (C) i benzinskih (S) motora kod različitih strojeva s obzirom na snagu motora (kg/kWh) (USEPA 1985)*

Pollutant *Zagađivač*	Track-type tractor *Vrsta stroja*	Wheeled tractor *Kotačni traktor*		Wheeled dozer *Kotačni dozer*	Scraper *Skrejper*		Grader *Grejder*
		C	S		C	S	
CO	2.88E-03	9.84E-03	1.90E-01	4.70E-03	3.28E-03	3.28E-03	2.06E-03
Formaldehyde	2.28E-04	3.78E-04	3.41E-04	2.15E-04	3.75E-04	3.75E-04	1.62E-04
NO_X	1.05E-02	1.60E-02	8.54E-03	1.09E-02	1.00E-02	1.00E-02	9.57E-03
PM_{10}	9.28E-04	1.70E-03	4.84E-04	5.51E-04	1.06E-03	1.06E-03	8.38E-04
SO_2	1.14E-03	1.14E-03	3.04E-04	1.16E-03	1.21E-03	1.21E-03	1.17E-03
VOC_s	1.01E-03	2.36E-03	7.16E-03	5.00E-04	7.40E-04	7.40E-04	4.80E-04

Pollutant *Zagađivač*	Wheeled loader *Kotačni utovarivač*		Tracked loader *Utovarivač gusjeničar*	Off-highway truck *Terenski kamion*	Roller *Valjci*		Miscellaneous *Razni strojevi*	
	C	S			C	S	C	S
CO	3.63E-03	2.19E-01	3.03E-03	4.70E-03	8.08E-03	2.71E-01	6.16E-03	2.66E-01
Formaldehyde	2.64E-04	2.98E-04	1.34E-04	2.95E-04	2.63E-04	3.43E-04	2.72E-04	2.98E-04
NO_X	1.18E-02	7.27E-03	1.25E-02	1.09E-02	1.75E-02	7.08E-03	1.48E-02	6.48E-03
PM_{10}	1.08E-03	4.21E-04	8.78E-04	6.73E-04	1.04E-03	5.27E-04	1.21E-03	4.06E-04
SO_2	1.15E-03	3.19E-04	1.14E-03	1.19E-03	1.34E-03	3.73E-04	1.25E-03	3.54E-04
VOC_s	1.59E-03	7.46E-03	1.49E-03	5.00E-04	1.30E-03	1.24E-02	1.35E-03	8.70E-03

Conversion from kWh to MJ: 1 kWh = 3.6 MJ – *Pretvorba iz kWh u MJ: 1 kWh = 3,6 MJ*
PM_{10} – particular matters up to 10 microns and less – *Sitne čestice <10 mikrona*
VOC_s – volatile organic compounds – *Štetni organski spojevi*

Table 3 Total emissions generated in petroleum (P) and diesel (D) manufacture by individual countries (Davison and Lewis 1999)
Tablica 3. *Ukupna emisija iz proizvodnje benzinskih i dizelskih goriva, po državama (Davison i Lewis 1999)*

Country *Država*	CO_2 (kg/GJ)		CO (g/GJ)		NO_X (g/GJ)		VOC_S (g/GJ)		SO_2 (g/GJ)		CH_4 (g/GJ)		PM (g/GJ)	
	P	D	P	D	P	D	P	D	P	D	P	D	P	D
Austria / *Austrija*	9.4	6.8	5.4	5.0	45.7	39.1	213.0	87.9	62.7	45.1	17.4	15.7	2.7	1.1
Belgium / *Belgija*	9.2	6.8	5.1	4.6	42.2	36.0	211.5	87.6	65.6	48.4	17.4	15.7	2.4	1.0
Denmark / *Danska*	9.0	7.2	5.1	4.6	43.2	38.0	203.5	86.1	93.3	77.7	17.2	15.6	1.8	1.4
Finland / *Finska*	9.3	7.0	5.6	5.1	45.6	39.4	208.7	87.4	77.7	57.5	17.3	15.6	2.4	1.3
France / *Francuska*	9.3	6.7	5.1	4.6	42.2	35.8	212.3	87.8	62.7	44.9	17.3	15.7	2.5	1.0
Germany / *Njemačka*	9.2	6.9	5.1	4.6	43.2	37.1	208.3	87.3	78.1	57.8	17.3	15.7	2.2	1.2
Greece / *Grčka*	9.5	7.2	5.8	5.3	49.3	43.2	208.9	87.2	79.5	62.7	17.3	15.7	2.4	1.4
Ireland / *Irska*	8.9	7.2	5.0	4.5	42.5	37.4	203.5	86.2	93.1	77.5	17.0	15.5	1.8	1.4
Italy / *Italija*	9.3	7.0	5.4	4.9	46.0	39.9	208.8	87.3	77.9	59.0	17.2	15.6	2.3	1.2
Netherlands / *Nizozemska*	9.2	6.8	5.1	4.6	42.4	36.2	209.8	87.6	72.2	51.8	17.4	15.7	2.3	1.1
Portugal / *Portugal*	9.3	6.9	5.4	4.9	45.2	39.0	210.2	87.4	72.2	55.2	17.3	15.7	2.4	1.2
Spain / *Španjolska*	9.3	6.9	5.4	4.9	45.2	39.0	210.0	87.5	73.3	54.5	17.3	15.7	2.4	1.2
Sweden / *Švedska*	9.2	7.0	5.5	5.0	44.7	38.8	208.0	87.0	78.4	61.8	17.1	15.5	2.3	1.3
Switzerland / *Švicarska*	9.0	7.2	5.4	4.8	45.8	40.5	203.5	86.1	95.1	79.4	16.9	15.3	1.9	1.4
UK / *Engleska*	9.3	6.8	5.1	4.6	42.4	36.1	211.4	87.8	66.9	47.6	17.4	15.8	2.4	1.1

PM – particular matters – *Sitne čestice*
VOC_s – volatile organic compounds – *Štetni organski spojevi*

Emission factors of compression-ignition engines in combustion for harvester technologies were studied by Grägg (1999). They were established on engine Perkins 1006-T (133.5 kW) for EC3 fuel and on engine Valmet 420 DS (135.8 kW for EC3 and EC1 fuels). RME emission factors were established by Grägg (1994) on engine Scania DSC 1127 (144 kW). Based on the measurements, Athanassiadis (2000) determined emission factors of compression-ignition engines per engine output in MJ – these are presented in Table 1. In this study engine thermal efficiency was set up for both fuels at a level of 40%.

Emission factors need to be expressed at the best for each machine separately or the machines should be at least put together to form appropriate groups. Emission factors of various machine groups are studied and regularly updated by the United States Environmental Protection Agency (USEPA 1985). Table 2 presents emission factors for various machine groups with both spark- and compression-ignition engines.

Emissions generated by combustion however do not include all noxious substances emitted into the environment from the use of fuels. A general comparison must take into account leakages of operation fluids and the share of emissions generated in the extraction, production, transport and distribution of fuels. Emissions developing during the production of fuels were studied by Davison and Lewis (1999) and Table 3 presents these emissions in some selected countries.

The study was focused on the most energy demanding part of the machine life cycle i.e. production phase. The objective was to quantify the amount of energy required for an extraction of functional unit of production (m^3) by cableways and to establish the amount of emission load on environment.

2. Material and Methods – *Materijal i metode*

Cableway types assessed within the study were Model Larix 550 and Model Larix 3T. The powering and transport unit was a farm tractor.

The cableway Model Larix 550 is designed as a complete superstructure on the farm tractor (ZETOR 8540, 9540, 10540, or comparable types NEW HOLLAND, SAME, STEYR, JOHN DEERE), which provides a considerable advantage for passability through the terrain and alleviates laboriousness of cableway construction in the field. The cableway can be used universally with a possibility of timber skidding down the hill (100 – 550 m), up the hill and on the plain, with a fully suspended or semi-suspended load. Based on the terrain character the assembly can be made with a running line or with a skidding line. Basic technical parameters: pulling force 35 kN, reach 550 m, carrying capacity 2 tons, time consumption for track construction 48 hrs.

The cableway Model Larix 3T is a follow-up to Model LARIX 550 from which the concept was adopted with the running line, capstan and suspension onto the rear and front three-point linkage of a tractor. It differs in a reinforced load-bearing structure, simplified design and operation, greater capacity of drums and line boards. Carrying capacity of the Model LARIX 3T is increased to 3 tons and reach up to 850 m.

The system boundaries were set for the extraction chain from stump to road side (felling, delimbing and cross-cutting was not taken into the account) in operation phase of cableway life cycle. The Functional Unit (FU) used in the analyses was cubic meter of wood over bark (m^3). In cases when the calculated values were too small the unit 1000 m^3 was used.

The model that was calculated in this study had the following data inputs:

⇒ Fuel, engine oil and transmission oil consumption, liters,

⇒ Grease consumption, kg,

⇒ Type of fuel: mineral or rape methyl esterm, RME,

⇒ Type of oil in respect to biodegradability: mineral, synthetic or vegetable.

Note: Biodegradability is defined by CEC-L-33-A-93, which is an international assignation of fuel and grease production. A product is regarded as biodegradable if it is degraded by at least 80% in 21 days (CEC 1995). Raw vegetable oils have a biodegradability of around 98% (if there are additives included, it is 90–98%). Mineral oils have a biodegradability of about 20% and biodegradability of synthetic oils varies from 20 to 92% depending on the type (Anon. 1994).

An energy audit should include the combustion energy value of fuels and oils, and the energy used during their production. Athanassiadis (2000) estimated a combined fuel and oil energy use for harvesting and forwarding of 82 MJ per m^3ub (cubic meter under bark), however the calculation failed to include the energy used during the production of oils. The energy consumed during the production of diesel fuel is reported as ca. 4.5 MJ/l and 15.6 MJ/l for biodiesel.

The energy value of mineral oil has also been reported. Anon. (2000) presented lubricant mineral oil as 38.5 MJ/l. Goering et al. (1982) designated the energy value of vegetable oils (rapeseed oil used for hydraulics and lubrication) as 39.6 MJ/kg (density 0.912 kg/l). In this study rapeseed oil was taken as representative of vegetable oils. Synthetic oils are usually produced from vegetable oil bases, with only the »holder« (usually alcohol) of the fatty acid changed (Våg et al. 2000). Therefore, the same energy value (39.6 MJ/kg by density 0.912 kg/l) may be assumed for synthetic oils. Våg et al. (2000) presented energy consumption during the production of various lubrication oils as follows: mineral oil 45 MJ/l, synthetic ester 22 MJ/l and rapeseed oil 12 MJ/l.

The energy audit of the cableway operation phase in MJ/m^3 of wood production was done as the sum of:

⇒ Energy content of the fuel plus energy used in its production.

The energy inputs were calculated as follows (listed respectively): mineral diesel fuel as 36.14 + 4.5 = 40.64 MJ/l and rape methyl ester as 33.1 + 15.6 = 48.70 MJ/l.

⇒ Energy content of oils plus energy used during their production.

In the current study, these energy inputs were calculated as follows (listed respectively): vegetable oil as 36.1 + 12 = 48.1 MJ/l, synthetic oil as 36.1 + 22 = 58.1 MJ/l and mineral oils as 38.5 + 45 = 83.5 MJ/l.

Exhaust emissions generated from the fuel were calculated as a sum of emissions produced by fuel combustion (Efc) and emissions produced during the fuel production, transport and distribution (Efp). With 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. Anon. (2002) informs 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 calculated exhaust emissions resulting from fuel combustion (Efc) take into account the energy content of fuel, emission factors related to the engine output power, and the thermal efficiency of the fuel combustion process. The calculation was made using the below formula:

$$E_{fc} = F_c \times E_f \times C_v \times T_e \quad (1)$$

Where:

E_{fc} Exhaust emissions from fuel combustion, g/FU

F_c Fuel consumption, l/FU

E_f Emission factor, g/MJ of engine output

C_v Calorific value, MJ/l

T_e Thermal efficiency

Emission factors used for the calculation were those of wheel tractors (Table 2), only the calculation of CO_2 emissions was made with the emission factor at 263 g/MJ of engine output adopted from Athanassiadis (2000).

The calculation of emissions generated during the fuel production, transport and distribution (Efp) was based on the fuel energy content and emission factors.

$$E_{fp} = F_c \times E_f \times C_v \quad (2)$$

Where:

E_{fp} Emissions generated in the phase of extraction, production, transport and distribution, g/FU
F_c Fuel consumption, l/FU
E_f Emission factor, g/MJ of engine output
C_v Calorific value, MJ/l

The emission factors used were those holding for Austria (Table 3). Only the emission factor of 0.0862 used for HC was adopted from Athanassiadis (2000).

Emission load related to the consumption of oils was calculated as a sum of emissions emanated in the production of oils (E_{op}) and emissions generated in the reprocessing of used oils for the purposes of combustion (E_{or}). Emissions arisen in production were calculated on the basis of emission factors adopted from Ragnarsson (1994) and Marby (1999), see Table 4. Emissions generated in the transport and reprocessing of used oils for the purposes of combustion were calculated on the basis of emission factors adopted from Lenner (1990) and from Stripple and Wennsten (1997), see Table 5.

Table 4 Total emissions from oil production phase, g/l (Ragnarsson 1994; Marby 1999)

Tablica 4. *Ukupna emisija iz proizvodnje ulja, g/l (Ragnarsson 1994, Marby 1999)*

	CO_2	CO	HC	NO_X	PM
RBO	747.25	1.1294	0.9288	5.6169	0.315
MBO	260.92	0.077	2.64	2.662	0.31

RBO – rapeseed based oils – *Ulje uljane repice*
MBO – mineral based oils – *Mineralno ulje*

Table 5 Total emissions from oil transport and reprocessing, g/l (Lenner 1990; Stripple and Wennsten 1997)

Tablica 5. *Ukupna emisija iz transporta i prerade ulja, g/l (Lenner 1990, Stripple i Wennsten 1997)*

	CO_2	CO	HC	NO_X	PM
Transport *Prijevoz*	20.4	0.09	0.022	0.27	0.01
Reprocessing *Prerada*	64.1	0.01	0.0001	0.13	0.01
Total *Ukupno*	84.5	0.1	0.0221	0.4	0.02

Emission load by oil production (E_{op}) was calculated on the basis of oil consumption data and on the basis of emission factors as:

$$E_{op} = O_c \times E_f \quad (3)$$

Where:

E_{op} Emissions emanated in the production of oils, g/FU
O_c Oil consumption, l/FU
E_f Emission factor, g/l

Emission load from the transport and reprocessing of used oils for combustion was calculated on the basis of emission factors and oil consumption. Emission load from the transport for combustion was calculated only in oils used for this purpose.

$$E_{or} = O_c \times E_f \quad (4)$$

Where:

E_{or} Emissions emanated during transport and reprocessing, g/FU
O_c Oil consumption, l/FU
E_f Emission factor, g/l

3. Results – *Rezultati*

Values calculated on the basis of one-year measurement were as follows:

⇒ Productivity: 6 000 m^3/year
⇒ Fuel consumption: 1.2 – 1.4 l/m^3
⇒ Gear oil consumption: 6.7 l/1000 m^3
⇒ Engine oil consumption: 6.7 l/1000 m^3
⇒ Consumption of lubricants: 1.7 kg/1000 m^3
⇒ Greasing spray: 1 l/1000 m^3

Total energy consumed during the operation phase in the form of fuels and lubricants, including the energy required for their production, transport and distribution was calculated for two scenarios. With the use of minimum values (scenario 1) and maximum values (scenario 2) the energy consumption was 50 MJ/m^3 and 58 MJ/m^3, respectively.

The highest share in total energy use was that of the fuel – ca. 98%. The total energy use by consumed fuel was calculated at 48.8 MJ/m^3 for scenario 1 (fuel consumption 1.2 l/m^3) and 56.9 MJ/m^3 for scenario 2 (fuel consumption 1.4 l/m^3), respectively.

Energy use of 556.7 MJ/1000 m^3 is associated with gear oil consumption. Since the used engine oil was of semi-synthetic character, there were two scenarios of calculation, according to the ratio of mineral and synthetic components in the oil. Energy consumption at a mineral-to-synthetic ratio of 80:20 and 35:65 was calculated to be 522.8 MJ/1000 m^3 and 446.6 MJ/1000 m^3, respectively. Energy use for lubricants was calculated at 149.6 MJ/1000 m^3. Energy con-

Table 6 Emissions generated from fuel consumption, g/m^3
Tablica 6. *Emisija nastala potrošnjom goriva, g/m^3*

	Scenario 1 – *Slučaj 1.*					Scenario 2 – *Slučaj 2.*				
	CO_2	CO	HC	NO_X	PM	CO_2	CO	HC	NO_X	PM
E_{fc} Diesel	4510.27	47.41	1.82	77.09	8.19	5261.98	55.31	2.13	89.95	9.56
E_{fp} Diesel	294.90	0.24	3.74	1.70	0.05	344.05	0.28	4.36	1.98	0.06
Total Diesel	**4805.17**	**47.65**	**5.56**	**78.79**	**8.24**	**5606.03**	**55.59**	**6.49**	**91.93**	**9.62**
E_{fc} RME	4510.27	32.71	0.36	94.82	6.31	5261.98	38.16	0.43	110.64	7.36
E_{fp} RME	1187.63	1.43	1.27	8.18	0.40	1385.57	1.67	1.48	9.55	0.46
Total RME	**5697.90**	**34.14**	**1.63**	**103.00**	**6.71**	**6647.55**	**39.83**	**1.91**	**120.19**	**7.82**
Total RME*	**1420.59**	**3.12**	**1.29**	**103.00**	**6.71**	**1657.35**	**3.65**	**1.50**	**120.19**	**7.82**

Scenario 1: Fuel consumption 1.2 l/m^3 – *Slučaj 1: Potrošnja goriva 1,2 l/m^3*
Scenario 2: Fuel consumption 1.4 l/m^3 – *Slučaj 2: Potrošnja goriva 1,4 l/m^3*
Efc RME is calculated on the basis of emission increase or decrease between RME and EC3 adopted from Athanassiadis (2000)
Efc RME izračunat na osnovi povećanja ili smanjenja emisije između RME i EC3 iz Athanassiadis (2000)
Efp RME calculated on the basis of emission factors adopted from Ragnarsson (1994) – *Efp RME izračunat na osnovi faktora emisije prema Ragnarsson (1994)*
RME* calculated emissions which originate only from the fossil sources – *RME* izračunate emisija samo iz fosilnih goriva*

Table 7 Emissions generated from the consumption of lubricants (g/1000 m^3)
Tablica 7. *Emisija nastala potrošnjom maziva,* g/1000 m^3

	Scenario 1 – *Slučaj 1.*					Scenario 2 – *Slučaj 2.*				
	CO_2	CO	HC	NO_X	PM	CO_2	CO	HC	NO_X	PM
E_{op}	4885.88	2.66	40.55	47.16	5.04	6352.17	5.83	35.39	56.07	5.05
E_{or}	1132.30	1.34	0.30	5.36	0.27	1132.30	1.34	0.30	5.36	0.27
Total	**6018.18**	**4.00**	**40.84**	**52.52**	**5.31**	**7484.47**	**7.17**	**35.69**	**61.43**	**5.32**

Scenario 1: Fully mineral gear oils, semi-synthetic engine oil (mineral-to-vegetable ratio 80:20) and fully mineral lubricants
Slučaj 1.: Mineralna motorna ulja, polusintetička motorna ulja (omjer mineralnih i biljnih ulja 80 : 20) i mineralna maziva
Scenario 2: Fully mineral gear oils, semi-synthetic engine oil (mineral-to-vegetable ratio 35 : 65) and fully mineral lubricants
Slučaj 2.: Mineralna motorna ulja, polusintetička motorna ulja (omjer mineralnih i biljnih ulja 35 : 65) i mineralna maziva

sumption from the greasing spray was calculated at 78.4 MJ/1000 m^3.

The calculation of emission load on environment was made separately for emissions emanated from the use of fuels and for emissions arisen from the use of oils. In both cases the calculation was made for two scenarios. The scenarios in fuels were established according to fuel consumption, i.e. scenario 1 with a minimum consumption (1.2 l/m^3) and scenario 2 with a maximum consumption (1.4 l/m^3). RME can be used as an alternative fuel and therefore a calculation was carried out of emissions emanated in using RME, too. As to the use of diesel oil, it can be stated that all emissions originated from fossil sources. In the case of RME, however, a certain amount of emissions originates from renewable sources and therefore, emissions from fossil sources were calculated for the use of RME (in tables designated as RME*). Scenarios for oils were set up according to different types of oils used, i.e. scenario 1 is based on using fully mineral gear oils, semi-synthetic engine oil with ratio 80:20 and mineral lubricants, while scenario 2 is based on using fully mineral gear oils, semi-synthetic engine oil with the ratio 35:65 and mineral lubricants.

The minimum total CO_2 emission load on environment by cableway operation was determined at 4.8 kg/m^3 of wood extracted from stump to roadside in case of scenarios most favorable regarding emissions. Detailed calculated emissions associated with the consumption of fuels and the consumption of oils and lubricants are presented in Table 6 and Table 7, respectively.

4. Discussion and Conclusions
Rasprava i zaključci

Energy and emissions generated from oil consumption are almost irrelevant compared to energy and emissions related to fuel consumption.

Sheehan et al. (1998) enumerated the amount of energy used and emissions in using fuels based on

Table 8 Inputs of primary energy for production, transport and distribution of diesel-based fuels and SME
Tablica 8. *Uložena energija za proizvodnju, prijevoz i distribuciju dizelskih i bioloških goriva*

Stage – *Faza proizvodnje*	Inputs of primary energies, MJ/MJ *Uložena energija, MJ/MJ*	% of inputs – % *uložene energije*
Domestic production of diesel, U.S.A. – *Domaća proizvodnja dizela, SAD*	0.5731	47.73%
Production abroad – *Inozemna proizvodnja dizela*	0.5400	44.97%
Transport of diesel from domestic resources – *Prijevoz dizela iz domaćih izvora*	0.0033	0.28%
Transport of diesel from foreign resources – *Prijevoz dizela iz stranih izvora*	0.0131	1.09%
Refining – *Rafiniranje*	0.0650	5.41%
Fuel transport – *Prijevoz goriva*	0.0063	0.52%
Total – *Ukupno*	**1.2007**	**100%**
Soy production – *Proizvodnja soje*	0.0656	21.08%
Soy transport – *Prijevoz soje*	0.0034	1.09%
Soy pressing – *Prerada soje*	0.0796	25.61%
Soy oil transport – *Prijevoz sojina ulja*	0.0072	2.31%
Soy conversion to SME – *Proizvodnja sojina metil estera*	0.1508	48.49%
SME transport – *Prijevoz SME*	0.0044	1.41%
Total – *Ukupno*	**0.3110**	**100.00%**

diesel and soy methyl ester (SME) in U.S.A. and found out that in using classical extraction and refining techniques an investment of additional 1.2 MJ of primary energies is required per each 1 MJ of energy from diesel-based fuels and additional 0.311 MJ per each 1 MJ SME (see Table 8).

The emission load on environment from the fossil sources is markedly lower with methyl esters (RME and/or SME), the fact speaking for their preferred use. The question, however, of their practical application as related to engine functionality and service life, remains unanswered.

Energy use of fully mechanized technologies was calculated by Athanassiadis et al. (2000) and Klvac et al. (2003). The use of energy per FU is considerably lower in cable transport, as a result of the lower consumption of fuels and lubricants per FU. The operation phase of the life cycle is the part with the greatest share in total energy and emission requirements.

Generally, the issue of energy and emissions from forest operation has been widely discussed in Karjalainen et al. (2001) study, made as part of COST Action E9. In detail, Schwaiger and Zimmer (2001) built up their study on 0.9 kg/m^3 cableway fuel consumption, which is lower compared to the results obtained in this study. Also the emission factors are slightly different. Moreover, it is difficult to identify from which source the emission factors were adopted and whether the emission factors cover both combustion and production, respectively. However, using the same average fuel consumption, the amount of emission produced by cableway system would be comparable.

The productivity of cableways is significantly affected by felling methods, possible pre-bundling and by the number of choker setters as published by Visser and Stampfer (1998). These authors presented a markedly improved productivity of cableways (30 – 40 %) as compared with the power saw if the felling is made by harvester and if the logs are pre-bundled. As to the number of choker setters they concluded that in sites prepared in this way it is useful to have only one choker setter. The study was made both in deciduous and in coniferous stands. The employment of harvester technologies for logging operations in broadleaved stands is unsubstantiated in the conditions of the Czech Republic and results in considerable problems. This is why a lower energy consumption and emission load for using harvester in logging can be expected according to Visser and Stampfer (1998) only with the cableway working in spruce stands.

Fuel consumption was measured in main felling operations. Berg (1997) studied the environment load with fossil fuels at different forest operations. He found that as compared with the clear felling, the share of emissions is higher by 10% and 20% in felling and skidding operations, respectively, in the shelterwood system. The calculations suggest that fuel consumption is by about 10% higher in the shelterwood system.

The amount of greenhouse gas emissions produced from alternative fuel (RME) is higher than from diesel. However, if the calculation is made only for carbon dioxide emitted from fossil sources, the negative environmental load is significantly lower.

It has been calculated that the share of CO_2 emissions from fully mechanized harvesting system in the national context of countries with high forest coverage such as Sweden was 1% (Athanassiadis 2000). By using methylesters in diesel engines of mechanized logging technologies, the expected considerable reduction (by up to 70%) of CO_2 emissions originating from fossil sources will be accompanied by a 30% increase of NO_x emissions.

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Sažetak

Potrošnja energije i emisija štetnih plinova pri radu žičare

Kako staklenički plinovi značajno utječu na klimatske promjene, smanjenje je njihove emisije jedan od primarnih ciljeva okolišne politike Europske unije. Kako bi se ispunili zadani cilj, potrebno je ponajprije povećati udio energije dobivene iz obnovljivih izvora, gdje nema emisije CO_2 iz fosilnih goriva. U današnje vrijeme svaki je proizvod opterećen s određenim udjelom primarnih fosilnih goriva te stoga i s određenom emisijom stakleničkih plinova. Utjecaj bilo koje tehnologije ili proizvoda na okoliš može se procijeniti pomoću metode životnoga ciklusa, koja definira ulazne i izlazne parametre te njihov utjecaj na okoliš (norma ISO 14040-2). U radu je opisana energetski najzahtjevnija faza životnoga ciklusa proizvoda, na primjer faza proizvodnje. Cilj je ovoga rada bio odrediti količinu energije potrebne za iznošenje jedinice proizvoda (m^3) pomoću žičare te odrediti količinu emisije i utjecaj na okoliš.

Istraživane su žičare Larix 550 i Larix 3T, koje su kao transportno i pogonsko sredstvo koristile poljoprivredni traktor. Žičara Larix 550 napravljena je kao nadogradnja poljoprivrednoga traktora (ZETOR 8540, 9540, 10540 ili bilo kojega sličnoga (NEW HOLLAND, SAME, STEYER, JOHN DEERE), što joj pruža određene prednosti pri kretanju po terenu te olakšava posao postavljanja žičare za rad. Žičare se mogu koristiti prilikom svih načina rada, pri privlačenju niz brdo (100 – 550 m), privlačenju uz brdo te privlačenju na ravnom. Ovisno o svojstvima terena, žičara može biti postavljena s beskonačnim nosivim užetom ili s užetom za privlačenje. Osnovne su tehničke značajke žičare: vučna sila 35 kN, doseg užeta 550 m, nosivost 2 t, vrijeme postavljanja 4 – 8 sati. Žičara Larix 3T razvijena je na principu žičare Larix 550 s beskonačnim nosivim užetom, a može se postaviti i na prednju i na stražnju trozglobnu poteznicu traktora. Model 3T razlikuje se od modela 550 u pojačanoj nosivoj strukturi, pojednostavljenom dizajnu i upravljivosti, u većim bubnjevima, povećanoj nosivosti (3 t) i povećanom dosegu (850 m). Energetska bilanca sadrži energetski sadržaj i energiju potrebnu za proizvodnju goriva i maziva.

Potrošnja goriva koja je se mjerila kroz jednu godinu iznosila je 1,2 – 1,4 l/m^3, potrošnja je ulja za opremu iznosila 6,7 l/1000 m^3, potrošnja je ulja u motoru iznosila 6,7 l/1000 m^3, tokom istraživanja potrošeno je i 1,7 kg/1000 m^3 te 1 l/1000 m^3 spreja za podmazivanje. Godišnja je proizvodnja iznosila 6000 m^3. Potrošnja je energije izračunata za dva slučaja, gdje su u prvom slučaju korištene minimalne vrijednosti, a u drugom slučaju maksimalne vrijednosti. Potrošnja energije u istraživanom razdoblju iznosila je za prvi slučaj 50 MJ/m^3, a za drugi slučaj 58 MJ/m^3. Na osnovi potrošnje goriva i maziva u radu je određena količina emisije s posebnim osvrtom na *emisiju stakleničkih plinova (tablice 6 i 7). Također je istraživana i potrošnja energije ovisno o omjeru smjese ulja koje je korišteno za stroj i opremu; tako su korištena polusintetička ulja omjera smjese 80 : 20 i 35 : 65. Energetska je potrošnja iznosila 556,7 MJ/1000 m^3 za ulje 80 : 20, a za ulje 35 : 65 energetska je potrošnja iznosila 446,6 MJ/1000 m^3. Energetska je potrošnja za maziva iznosila 149,6 MJ/1000 m^3, a za sprej za podmazivanje 78,4 MJ/1000 m^3. U tablicama 6 i 7 izračunate su emisije za dizelsko gorivo i poslije primijenjeno biogorivo uljane repice (RME). Također je izračunata emisija koja potječe od fosilnih goriva. Uporabom se biogoriva uljane repice količina emisije CO_2 iz fosilnih goriva može smanjiti za 3,4 kg/m^3 privučenoga drva.*

Ključne riječi: emisija stakleničkih plinova, energetska bilanca, potrošnja goriva, potrošnja maziva

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