A COMPARISON IN TERMS OF CARBON EMISSIONS, COST AND PRODUCTIVITY OF THE MOST USED TECHNOLOGIES IN THE YOUNG THINNED STANDS – THE CASE OF ROMANIA

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***Abstract**: Reduction of Green House Gases (GHG) emissions represents a challenge for today's industries (as it is stated by the Kyoto Protocol) as a prerequisite for the sustainable development and environment protection. Usually, the latter are regarded as complementary strategies in attaining the overall goal.*

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Timber harvesting represents one of the most technical components of the overall timber production process. In most cases it is realized using heavy machinery which is deployed in mature stands to be harvested. The participation level of the machinery tends to increase in the case of stands from which the primary production results. Due to the increased densities of the stands (in thinning), animal means are used, frequently, for timber logging, which can be associated with increased capacity mechanized means.

This paper presents an evaluation of production efficiency, fuel consumption, costs and carbon emissions using comparisons between animal logging and mechanized logging means. As resulted from the study, the utilization of animal logging is less efficient from the productive and cost point of view but it is cleaner (no carbon emissions). Data presented in this paper may provide the necessary tools for developing policies related to timber harvesting and carbon emissions.

Keywords*: animal logging, thinning, evaluation, efficiency, carbon emissions*

JEL Classification*: O0, O3, Q4*

1. Background

Timber harvesting, as a production process, is aimed to mobilise the necessary raw resources from forest to the manufacturing and processing industries, or directly to the end users[1]. Similarly to other extractive industries, timber harvesting involves the mobilisation of labour force and means; the associated extraction processes are complex due to the specific conditions of the work places, applied technologies and the silvicultural prescriptions.

Work places[2] are characterised by the timber distribution in the forest, specific slope conditions, terrain roughness and accessibility of the harvested areas (their position related to the permanent transport infrastructure).

In Romanian practice, the forests are managed by considering two main modalities, reflected in the attributed management regime: high forest and coppice. According to the management measures, the forests (no matter what regime is applied) are managed by applying a set of silvicultural measures. This set of measures includes the tending operations. Thinning represents a constituent part of the last category, and in relation to the specific conditions it can be applied at different time intervals.

First thinning is characterised by an increased density of the stand to which operations are applied, increased number of trees to be extracted, reduced volumes per tree and, generally, harder access conditions for the equipment and mechanised means due to the environmental concerns – damaging the residual trees[1]. Also, the reduced volumes per tree as well as the reduced extraction intensities (in terms of volumes per hectare) represent key factors which make this kind of operations unattractive for harvesting companies[2], especially after the transition to the free market economy.

This means, technologically, fewer solutions for timber harvesting from the first thinning. In case of terrains which present reduced slope conditions, technological systems which associate animal traction and farm tractors equipped for forest operations are used[1]. Work productivity is correlated with logging distance and production efficiency is negatively correlated with logging distance[1,3,4]. On the other hand, the development of skid trails, in order to reduce the animal logging distances, leads to the increment of operating costs as well as additional fuel consumes. The latter lead to supplementary carbon dioxide emissions which are greater in comparison with less productive variants which involve the development of animal logging on longer distances. Also, as the vast majority of the used machines (tractors) in Romania are obsolete machines, the carbon dioxide emissions from fuel burning are bigger as a result of increased needs for fuel due to engine aging[5]. Finding solutions for the utilisation of some eco-efficient means in timber logging represents one of the most popular preoccupations among specialists.

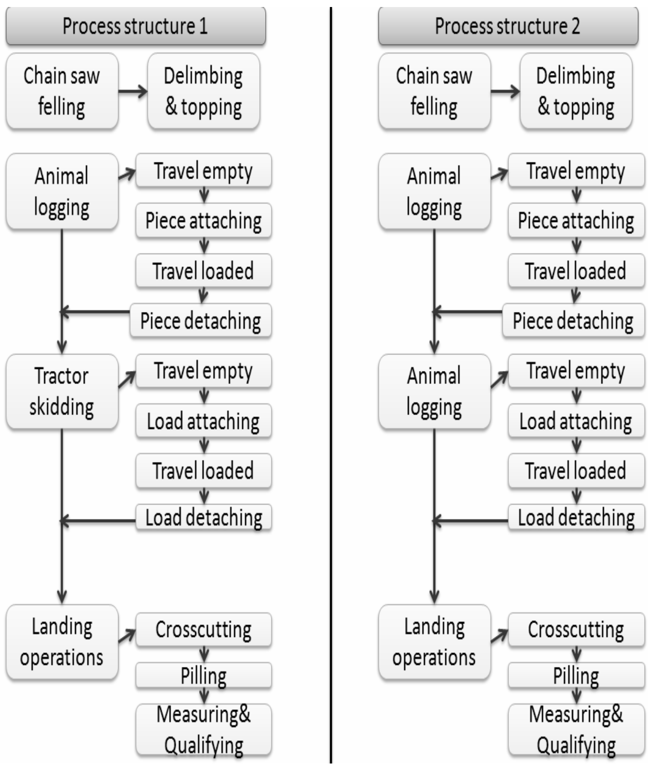
By considering the above mentioned, the present paper aims to offer a tool in assisting the efforts channelled to identifying eco-efficient solutions in timber logging, as well as for policy modelling in the related domain; this purpose can be attained especially through the applied logging systems analysis by considering three key aspects: production efficiency, involved costs and Green House Gases (GHG) emission – carbon dioxide. In order to attain this purpose, we present the operational structure of the analysed technological systems; after that, scenarios are built in order to compare production efficiency, fuel consumptions, costs and GHG emission in relation to thinning-specific main influence factors.

2. Experimental basis

2.1. Description of the Applied Technological Systems in First Thinning

Logging alternatives for first thinning (Romania case) are quite few. In gentle slope terrains, animal logging is used either in tandem with farm tractors or skidders[1], or independently. In case of increased slope terrains cable yarders are used, due to the fact that economically and ecologically tractor roads are not feasible[6]. Excepting some short-distance mobile machines, traditional cable yarders are not feasible in thinning operations due to increased set up – taking down costs. For the time being, short distance mobile cable yarders are used a small scale in Romania[7]. Traditional harvesting systems for first thinning in Romania are presented in Figure 1.

Figure 1 – Description of Traditional Romanian Harvesting System in First Thinning



Technological systems which involve animal logging up to a skid trail are used also in other countries since several authors reported it[4, 8-12] and even emphasised the fact that solutions shall be found for protecting animal logging in timber harvesting business[12]. However, in some specific situations in Romania, animal logging is extended to long distances despite the fact that acceptable productivities may be attained for distances up to 100 m[1].

2.2. Scenario Modelling

In Romania, productivity for logging operations is enforced by specific standards[3], in relation to average volume per tree (m^3), species group (resinous and broadleaved), logging distance (m) and the used logging means (animal, tractor). For comparison, there have been chosen the process structures presented in Figure 1. Also, it was assumed that:

- felling, delimbing and topping is common to both process structures and there cannot be any difference between them;
- first logging stage (animal logging) is common to both process structures and there cannot be any difference between them;
- landing operations differs only in case of pilling (tractor or manual), and there modelling it was assumed that these operations are done manually;
- average volume per tree is <0.14 m^3;
- logging is made in flat terrain and warm season conditions.

Thus, comparisons in terms of productivity, costs and carbon emissions are made for the second logging stage (animal versus tractor).

Production efficiency (hours/m^3) was reversely engineered from Romanian standards[3], thus obtaining regression equation production tables. Fuel and lubricant consumes were obtained (also as regression equations), by reverse engineering, in relation to Romanian consumption standards[5].

Production efficiency for logging operations is standardised without the consideration of logging trails slope, whereas fuel consumption standards are set by specifying these aspects. Usually, for carbon emission estimation the harvested area[13] is considered. However, logging network development depends on felling areas and their position in relation to a permanent transportation infrastructure.

Total logging costs were evaluated by considering the hourly wages provided by National Forest Administration, applicable from 1st January 2013, based on the methodology described by Oprea and Borz[14]. Operation costs for different logging means were calculated either by considering the practice statistics (the case of animal logging where the operating costs were evaluated to 85% of the wages) or by using a specific calculus methodology[14]. Due to the fact that most of the used skidders are old, depreciation was excluded from calculus. Tyre consumption was evaluated according to the Romanian standards[5]. Fuel costs as well as lubricants costs were included as averages from main national suppliers.

Fuel and lubricant consumptions were corrected by considering the number of functioning hours of the related machines. Due the fact that these machines are no longer produced, and they have been operated (usually) more than 10,000 hours, a correction of 16% was considered for calculating the fuel consumption[5]. Lubricant consumption was evaluated as a proportion from the consumed fuel: 3% in case of farm tractors and 1.5% in case of specialised skidders[5].

Carbon emissions were evaluated in case of skidder or farm tractor utilization by considering their fuel and lubricant consumption as well as conversion factors described by Markevitz[13].

All the necessary data in terms of regression equations was processed in MS Excel, by using Data Analysis – Regression sequence, after the realization of a database containing the necessary inputs. In case of fuel and lubricant consumptions, transformations of the provided measurement units (litre / kilometric tonne) into l/m^3 were necessary. All calculations regarding the production efficiency, fuel-lubricant consumptions, costs and carbon emissions were done in the same software.

2.3. The Resulted Equations for Production Efficiency and Fuel Consumption

Following the procedures described in paragraph 2.2, we obtained the necessary equations for inclusion in scenarios modelling. Equations for estimating production efficiency and fuel consumption (base case, less than 2000 functioning hours) are included in Table 1.

Table 1 – Equations for Scenario Modelling (T – time, FC – fuel consumption, D – logging distance)

Specifications	*Species group*	
	Resinous	*Broadleaved*
1.Efficiency (hours/m^3)	-	-
Horses	T[h/m^3]=0.516203+0.001685xD	T[h/m^3]=0.528346+0.002271xD
Oxen	T[h/m^3]=0.513421+0.002061xD	T[h/m^3]=0.527857+0.003148xD
TAF 650 Skidder	T[h/m^3]= 0.105576+0.000125xD	T[h/m^3]= 0.142848+0.000190xD
U650 Farm Tractor	T[h/m^3]= 0.149364+0.000267xD	T[h/m^3]=0.202515+0.000477xD
2.Fuel consumption (l/m^3)	-	-
Horses	-	-
Oxen	-	-
TAF 650 Skidder	FC [l/m^3]=0.117082+0.000432xD	FC [l/m^3]=0.179436+0.000662xD
U650 Farm Tractor	FC [l/m^3]=0.070484+0.000610xD	FC [l/m^3]=0.108044+0.000935xD

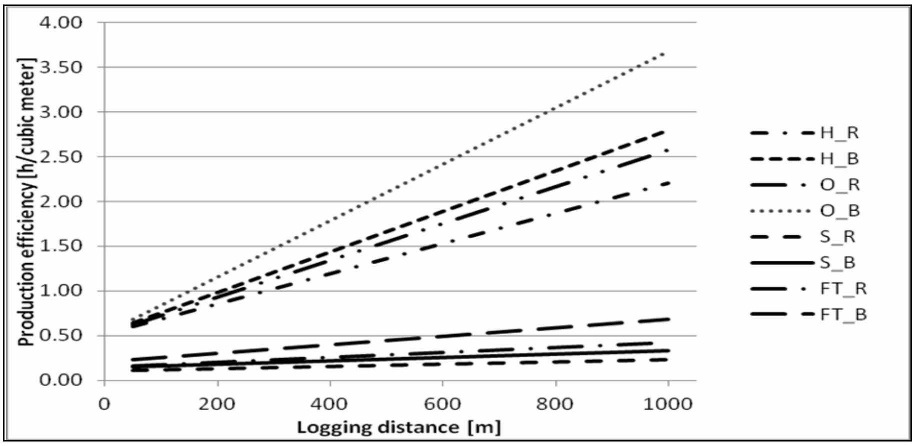
Based on the obtained equations, the costs and the conversion factors presented in paragraph 2.2, we calculated (related to operating distances) the following elements: production efficiency (h/m3), fuel consumptions (l/m3), unit logging costs (RON/m3) and carbon emissions (kg/m3). These indicators are presented in section 3 – Results and Discussions.

3. Results and discussion

3.1. Production Efficiency

Production efficiency is an indicator which emphasizes the efficiency for different activities. It can be calculated for different logging means, no matter what their specific operational patterns were Figure 2 shows the productivity efficiency for the studied logging means by considering the utilised logging means, distance and species group (resinous or broadleaved).

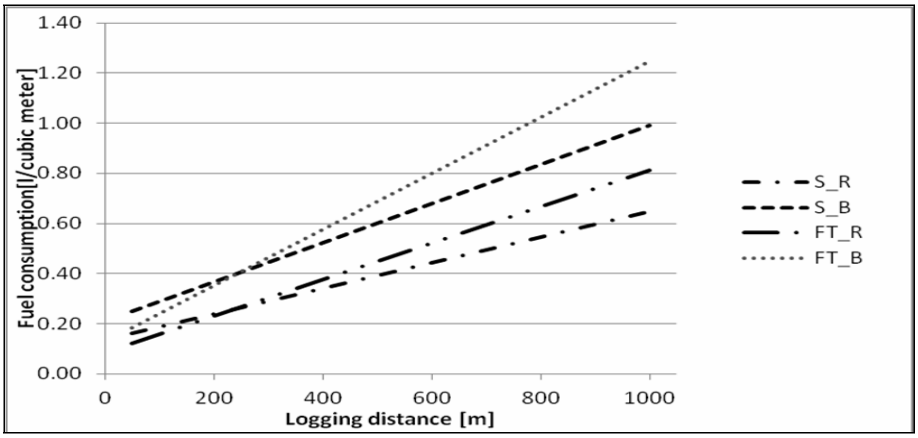
Figure 2 – Production efficiency for the studied logging means by considering distance and species group (H-horses, O-oxen, S-skidder, FT-farm tractor, R-resinous, B-broadleaved)



3.2. Fuel Consumptions

Fuel consumptions were calculated for skidders and farm tractors by considering the procedures presented within paragraph 2.2. Figure 3 shows the resulted fuel consumptions for the studied logging means – skidders and farm tractors – by considering logging distance and species group (resinous or broadleaved).

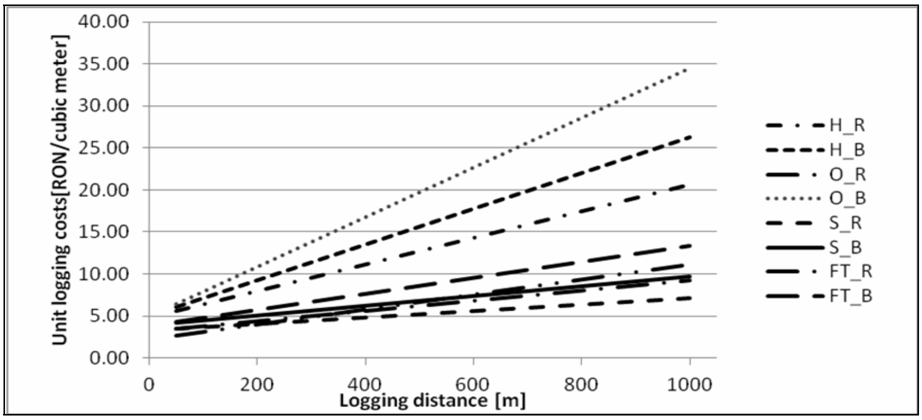
Figure 3 – Fuel consumption for skidders - TAF 650 and farm tractors - U650 (S-skidder, FT-farm tractor, R-resinous, B-broadleaved)



3.3. Unit Logging Costs

Logging costs per produced unit as resulted from the calculation methodology (paragraph 2.2) are presented in Figure 4. They include fixed and operating costs related to the used logging means and influence factors: logging distance and species group.

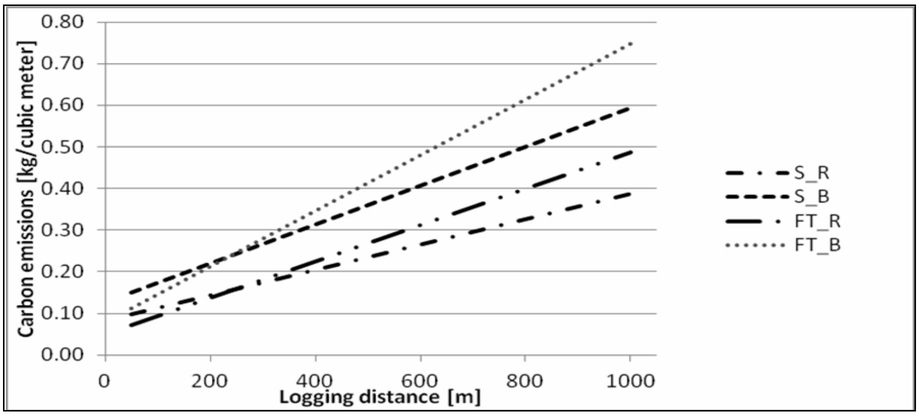
Figure 4 – Logging costs for the studied logging means (H-horses, O-oxen, S-skidder, FT-farm tractor, R-resinous, B-broadleaved)



3.4. Carbon Emissions

Carbon emissions as resulted from the calculation methodology (paragraph 2.2) are presented in figure 5. They include carbon emissions from fuel burning as well as from lubricants. A conversion factor of 0.6 was used in order to transform the burned fuel into carbon emissions[13].

Figure 5 – Carbon emissions from fuel burning and lubricants for skidders - TAF 650 and farm tractors - U650 (S-skidder, FT-farm tractor, R-resinous, B-broadleaved)



3.5. Interpretations

Logging distance represents the main influence factor when trying to assess production efficiency, production costs, fuel consumptions and carbon emissions (mechanized logging means). A reduced capacity of animal logging means generates lower production efficiencies when compared with mechanized logging means (Table 2) – for example, in case of a logging distance of 500 meters, the efficiency of mechanized logging means is 4-8 times greater than that of horses. Also, in case of animal logging means, the reduced capacity and production efficiency generate increased production costs (2-3 times greater for horses than for mechanised logging means in case of a logging distance of 500 meters). Under these circumstances, animal logging cannot compete with mechanized logging means (Table 3).

Currently, in Romania logging machines are not subject to taxation for carbon emissions, due the fact that a traffic registration is not compulsory. By comparison, taxation refers only to vehicles which are registered for traffic, this policy being developed in order to apply the directives of the Kyoto Protocol[15]. However, obsolete machines do generate considerable carbon emissions per produced (transported) unit. Carbon emissions per produced unit are in direct correlation with the logging distance, ranging from 0.10 to 0.75 kg/m^{3}for distances between 50 and 1000 meters, as presented in Figure 4. Also, animal logging (which uses green energy for propulsion) is not stimulated by any law.

Table 2 – Percent increments of production efficiency. Comparisons between different logging means (H-horses, O-oxen, S-skidder, FT-farm tractor, R-resinous, B-broadleaved)

Distance	H versus O		FT versus O		S versus O		FT versus H		S versus H	
	R	B	R	B	R	B	R	B	R	B
50	2.60	6.33	73.61	66.97	81.86	77.77	72.90	64.73	81.38	76.27
100	4.84	10.35	75.53	70.31	83.59	80.79	74.29	66.88	82.76	78.58
150	6.52	13.11	76.97	72.60	84.89	82.87	75.37	68.46	83.83	80.28
200	7.82	15.11	78.09	74.26	85.89	84.38	76.23	69.68	84.70	81.59
250	8.87	16.64	78.99	75.53	86.70	85.52	76.95	70.64	85.40	82.63
300	9.72	17.84	79.72	76.52	87.36	86.43	77.54	71.43	86.00	83.48
350	10.43	18.81	80.34	77.33	87.91	87.15	78.04	72.08	86.50	84.18
400	11.03	19.60	80.85	77.99	88.37	87.75	78.48	72.62	86.93	84.77
450	11.55	20.27	81.30	78.55	88.77	88.26	78.85	73.09	87.30	85.27
500	12.00	20.84	81.68	79.02	89.11	88.68	79.18	73.49	87.63	85.70
550	12.39	21.33	82.01	79.42	89.42	89.05	79.47	73.85	87.92	86.08
600	12.73	21.75	82.31	79.78	89.68	89.37	79.73	74.15	88.18	86.42
650	13.04	22.13	82.57	80.09	89.92	89.65	79.96	74.43	88.41	86.71
700	13.31	22.46	82.81	80.36	90.13	89.90	80.17	74.67	88.61	86.98
750	13.56	22.75	83.02	80.61	90.32	90.12	80.36	74.89	88.80	87.21
800	13.78	23.02	83.21	80.83	90.49	90.32	80.53	75.09	88.97	87.43
850	13.99	23.25	83.39	81.02	90.65	90.50	80.69	75.27	89.13	87.62
900	14.17	23.47	83.55	81.20	90.79	90.66	80.83	75.44	89.27	87.80
950	14.34	23.67	83.69	81.36	90.92	90.81	80.96	75.59	89.40	87.96
1000	14.50	23.85	83.83	81.51	91.04	90.95	81.08	75.73	89.53	88.11

Table 3 – Percent cost reductions. Comparisons between different logging means (H-horses, O-oxen, S-skidder, FT-farm tractor, R-resinous, B-broadleaved)

Distance [m]	H versus O		FT versus O		S versus O		FT versus H		S versus H	
	R	B	R	B	R	B	R	B	R	B
50	2.60	6.33	39.51	33.96	40.03	34.35	37.90	29.50	38.43	29.91
100	4.84	10.35	43.72	40.23	45.81	42.94	40.85	33.33	43.05	36.35
150	6.52	13.11	46.87	44.53	50.14	48.82	43.16	36.17	46.66	41.11
200	7.82	15.11	49.32	47.66	53.50	53.11	45.02	38.34	49.56	44.76
250	8.87	16.64	51.28	50.04	56.19	56.37	46.54	40.07	51.93	47.66
300	9.72	17.84	52.88	51.91	58.39	58.93	47.81	41.47	53.91	50.01
350	10.43	18.81	54.22	53.42	60.23	61.00	48.89	42.63	55.60	51.97
400	11.03	19.60	55.35	54.66	61.78	62.70	49.81	43.61	57.04	53.61
450	11.55	20.27	56.32	55.71	63.11	64.13	50.61	44.44	58.29	55.01
500	12.00	20.84	57.15	56.59	64.26	65.34	51.31	45.16	59.39	56.22
550	12.39	21.33	57.89	57.35	65.27	66.39	51.93	45.79	60.36	57.27
600	12.73	21.75	58.54	58.02	66.16	67.30	52.49	46.35	61.22	58.20
650	13.04	22.13	59.11	58.60	66.95	68.09	52.98	46.84	61.99	59.03
700	13.31	22.46	59.63	59.11	67.66	68.80	53.43	47.27	62.69	59.76
750	13.56	22.75	60.09	59.57	68.29	69.43	53.83	47.67	63.32	60.42
800	13.78	23.02	60.51	59.98	68.87	69.99	54.20	48.02	63.89	61.02
850	13.99	23.25	60.89	60.36	69.39	70.50	54.53	48.34	64.41	61.56
900	14.17	23.47	61.24	60.69	69.87	70.96	54.84	48.64	64.89	62.05
950	14.34	23.67	61.56	61.00	70.31	71.38	55.12	48.91	65.34	62.51
1000	14.50	23.85	61.85	61.28	70.71	71.76	55.38	49.15	65.74	62.92

4. Conclusions

This paper provides an overview on the current used technological systems in thinning operations with focus on the first thinning. By analysing the production efficiency and costs, it resulted that animal logging means are less efficient in comparison with mechanized logging means. However, the utilization of animal logging means is carbon neutral and it may still represent a future solution to harvesting timber resulted from thinning. Currently, animal power is employed in many logging situations around the world, despite the fact that its usage is less efficient. It is the case of Romania, where small logging companies still use this logging means. Resinous species, presenting a density which is smaller in comparison with broadleaved species, show better efficiencies in case of animal logging usage. Also, in case of short logging distances, the discrepancies between the used logging means are smaller both from time efficiency and a production cost perspective. Maintaining the use of animal logging means in timber harvesting business may depend in the future on coherent strategies regarding the use of green production means. We can also mention that (i) the use of animal logging means preserves the social and cultural heritage (traditions) of different regions, (ii) the use of animal logging means still represents an accepted solution to timber harvesting on sensitive sites and (iii) no supplementary GHG emissions are released in their life cycle in comparison with the production of different machinery. However, in case of voluminous timber, having a high mass, the use of animal logging may be impossible, especially when the designated strategies result in assortments presenting increased dimensions. The same problem affects to increased slope terrains where these logging means cannot operate.

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