Evaluation of the Performances of some Vehicles for Wood Chips Transport

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Abstract:
One of the weak links in the energy-wood chain is the transport of wood chips from the forestry yard to the power station. This operation is critical because the vehicles used must be very versatile to suit different operating conditions and, at the same time, to have low operating costs. The goal of this study has been that of implementing the information on this subject by examining different categories of vehicles considered appropriate for this purpose. For each of these, working time, working rate, fuel consumption and energy and economic cost were processed.
Field trials were conducted using both "agricultural convoys" (tractor + trailer) and "industrial vehicles" (lorry).
All vehicles were tested on two itineraries with different length: one of short length (about 25 km) and one of medium length (about 50 km). In the first itinerary were used only agricultural vehicles, while in the second itinerary were tested both agricultural vehicles (only the ones with bigger load capacity) and lorries.
The study showed the highest average transfer speed (42 km h^{-1}) for lorries use, while the lowest speed (24 km h^{-1}) for agricultural vehicles (value obtained on routes longer than 25 km).
The transport costs depending by the distance and the type of vehicle used and the cost per kilometer traveled is high especially for distances less than 20 km (up to 5 € km^{-1}).
If these values are applied to a thermal power unit of 1 MW fed with biomass with an annual use of 2,000 hours and a supply of biofuels of the radius of 70 km, it appears that the duration of bestowal of chips needed for its power (37,000 tss) is 1,500 h $year^{-1}$ with a total cost of approximately 148,000 € $year^{-1}$ if done with a lorry and about 4 times higher if performed with agricultural convoys.
The energy required to perform the wood chips transportation is only about 90 MJ m^{3-1} for agricultural vehicles and 35 MJ m^{3-1} for lorries. These values, in any case, represent to small claim (2%) of energy value of biomass transported.

Keywords: biomass, transport, truck, agricultural convoys, productivity, energy cost, economic cost

1 Introduction

Increasing petrol cost and environmental sensibility have generated a great interest for renewable energy production, as obtained from agricultural and forestry biomass.

In Italy, recent economic incentives for the production and use of biofuel caused a steady increase of the agricultural surface grown with short rotation forestry (Pinazzi 2005; Peri e Pretolani 2006). At the present, the wood chips produced from these crops are one of the main fuels used by large and medium-scale biomass power stations, with a power range from 0.5 to 3 MW electric (Francescato *et al.* 2004).

One of the weak links in the energy-wood chain is transportion from the forest landing to the end user (Picchi and Spinelli, 2009). This operation is critical because the vehicles used must be very versatile to suit different operating conditions and at the same time they must have a low operating cost (Grigolato and Raise 2005). The versatility of these vehicles is gauged through their capabilityt to load the wood chips directly in the field, and the possibility to use standard farm equipment for loading them.

The goal of this study was to examine different vehicle types normally used for chip transport. For each type, we determined: productive performance, energy efficiency and operating cost.

2 Materials and methods

2.1 Vehicles considered

Field trials were conducted using both “agricultural convoys” (tractor + trailers) and “industrial vehicles” (3 truck types). The former consist of 4 WD agricultural tractors equipped with 5 different trailer types. In particular, the study compared trailers with two or more axles grouped together at the rear end of the chassis with “conventional” farm trailers with a turning front axle, placed on a slewing ring (Table 1).

The trucks considered in the study belonged to four different types: 1) a truck and trailer road train; 2) a semi-trailer rig; 3) a truck equipped with a open-top hook-lift containers and 3) a truck fitted with light alloy body for the transportation of cereal (Table 2).

In the transportation sector, trucks are defined “large volume” when equipped with a container sized to reach the maximum volume allowed by road standards. Generally, these vehicles are used for transporting loads with a low bulk density, like wood chips.

Table 1: Main technical characteristics of the agricultural convoys

Trailer type	Tractor power [kW]	Load volume [m^3]	Total weight [t]	Axles [n°]	Container dumping	Opening/closing of doors	Width [mm]
Single-axle	88	18	6	1	Three sides	Hydraulic	1.930
2 axles (turning)	103	22	12	2	Rear gate	Manual	1.870
2 axles (turning)	103	25	14	2	Three sides	Hydraulic	2.090
2 axles (tandem)	95	22	14	2	Rear gate	Hydraulic	2.090
3 axles (turning)	106	35	20	3	Three sides	Hydraulic	2.090
3 axles (tandem)	103	30	20	3	Rear gate	Hydraulic	2.090

Table 2: Main technical characteristics of the trucks

Truck types	Power [kW]	Load volume [m^3]	Total weight [t]	Axles [n°]	Container dumping	Opening/closing of doors	Width [mm]
Truck and trailer	308	105	44	6	Three sides	Manual	2.040
Semitrailer	308	95	44	5	Three sides	Manual	2.040
Container truck	191	22	25	3	Rear gate	Manual	2.040
Cereal transport truck	191	25	25	3	Three sides	Manual	2.040

3 Productivity

All vehicles were tested on two itineraries with different length (25 and 50 km). On the shorter itinerary the test was conducted only with agricultural vehicles, while on the longer itinerary both vehicles types were tested, as long as their load capacity reached at least 35 m^3.

Time consumption for unloading was recorded following the methodology set up by the University of Florence (AA. VV. 1989). Each time element was recorded with a centesimal digital stopwatch. In this study, productive work time was divided into the following time elements: maneuver, opening and closing of the container doors and dumping (time necessary time for tipping the container and placing it back into the traveling position).

Average speed of the transport was calculated with the analytic method as a function of travel distance and travel time.

Productivity was expressed as volume units (m^3) transported per hour and kilometer.

3.1 Energy cost

The total energy cost was calculated as the sum of direct energy cost (fuel and lubricant consumption) and indirect energy cost (energy used for the vehicle construction). In particular, energy cost was estimated on the basis of the primary energy content of component materials, and namely: diesel fuel 51,5 MJ kg^{-1}, lubricant 83,7 MJ kg^{-1}, prime mover 92,0 MJ kg^{-1} and trailer 69,0 MJ kg^{-1} (Jarach 1985). The amount of fuel used for the whole operation was determined by filling the tank of the vehicle before and after the test. The tank was refilled using a 2000 cm^3 glass pipe with 20 cm^3 graduations, corresponding to the accuracy of our measurements.

Lubricant consumption was determined as a function of fuel consumption, using the algorithm calculated by the mechanics section of DEIAFA – University of Turin (Piccarolo, 1989).

3.2 Machine cost

Machine cost was calculated using the procedure described by Ribaudo (1977) for the “industrial vehicles”, and the procedure proposed by Piccarolo (1989) for the “agricultural convoys” (tractor + trailer). An service life of 10000 h was considered for all vehicles. Annual utilization was estimated to 5oo hours for Agricultural vehicles, and 1000 hours for industrial vehicles (trucks). Repair and maintenance costs were obtained directly by the machine owner. Labor cost was set to 18.5 € $hour^{-1}$. Fuel and lubricant costs were assumed to be 1.1 € dm^{-3} and 5.5 € kg^{-1} respectively. The total cost was inclusive of 20 % profit and overheads (Hartsough 2003).

4 Results and discussion

4.1 Productivity and time consumption

Data analysis showed that on short routes (<25 km) the travel time is about the same for all transport types, and the mean speed is about 23 km/h. The highest productivity (0.6 m^3/h x km) was obtained with high-capacity (35 m^3) trailers, which highlights the importance of load size also for short distances. Time spent for maneuvers was only 3% of total work time: this value can double when traditional trailers are used, and tripled when the opening and closing of the doors is manual. The analysis of unproductive work times showed the considerable incidence (about 70%) of waiting times, normally experienced before loading and unloading.

For long-distance transportation (50 km), the highest mean speed was obtained with trucks (42 km/h), the lowest with agricultural convoys (24 km/h). Similar results were obtained for productivity, where the best performance was achieved by "large volume" trucks (0.27 m^3/h x km), and the lowest by agricultural convoys (0.05 m^3/h x km).

Productive work time was about 90% of the total worksite time. 80% of the unproductive time was caused by the paperwork at the entrance of the user plant.

When transporting over long distances (50 km) truck and trailer road trains are characterized by a higher incidence of loading time (about 40% of the total time) and a lower incidence of transfer time (about 50% of the total time). The contrary is true for agricultural convoys. Simple trucks offered an intermediate performance.

The average traveling time depended on the type of road and the traffic. Performance during maneuvers can be affected by driver proficiency and vehicle type. Furthermore, it should be noted that the unproductive times caused by waiting for the unloading at the user plant are not predictable and, in some cases, they can exceed 3 hours (25% of total work time).

Regardless of vehicle type, performance was directly proportional to load capacity and inversely proportional to transportation distance. Vehicles equipped with "large volume" containers offer a higher productivity, but at decreasing rate with increasing transportation length. In particular, these values range from 450 m3/h at 2.5 km to 35 m3/h at 200 km. Conventional trucks have a lower performance than “large volume” truck and trailer rigs (about 300%), yet higher (double) than agricultural vehicles (Fig. 1).

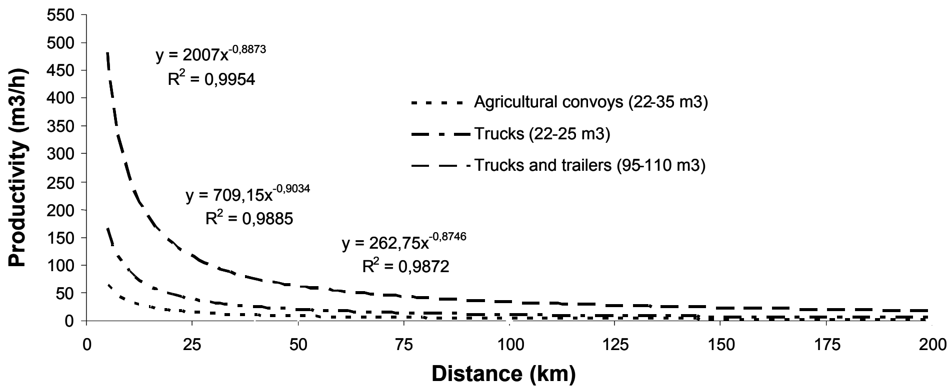

Figure 1: Productivity of different vehicles tested

4.2 Machine cost

Machine cost is related more to transportation distance than vehicle type. They are very high (up to 5 €/km) over distances shorter than 20 km because, in this situation, the downtime required for the unloading and loading of the material contribute significantly to the overall cost (Figure 2).

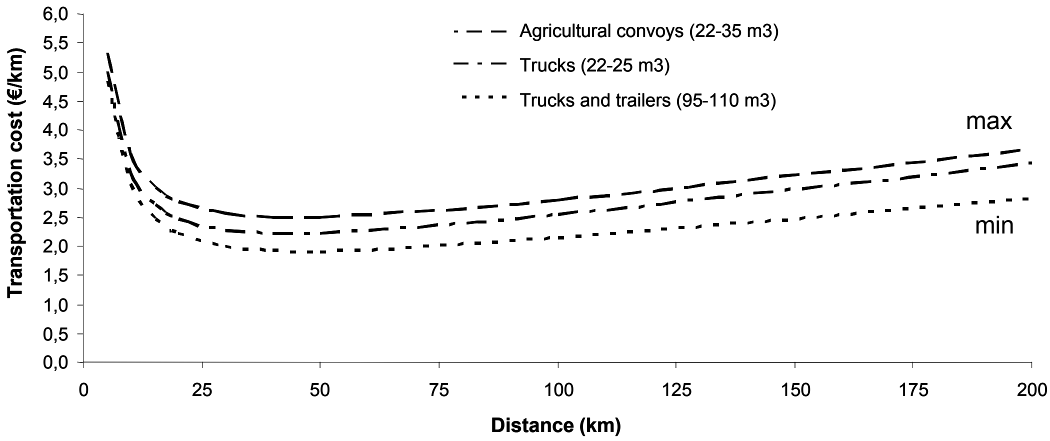

Figure 2: Cost per kilometer of different vehicles tested

Furthermore, referring these costs to volume unit transported, returns a figure of 12 €/m^3 for agricultural convoys and 3 €/m3 for trucks (95 - 110 m^3 capacity), over a distance of 50 km. (Figure 3).

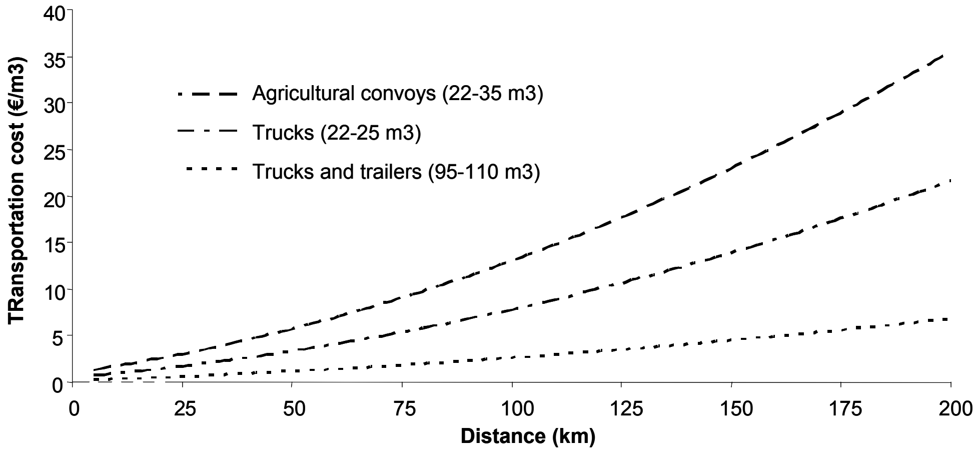

Figure 3: Transportation cost referred to volume unit transported

4.3 Energy evaluation

The energy cost of wood chip transportation increases linearly with transportation distance. In particular, it ranges from 25-50 MJ/m^3 for distances of 25 km to over 250 MJ/m^3 on distances longer than 250 km. Energy cost is also linked vehicle type. Assuming a 50 km distance, this value is 127 MJ/m^3 in the case of transport with trucks and agricultural vehicles, and only 48 MJ/m3 when using "large volume" vehicles.

This value is significant especially if compared to the biomass energy content: it represent over 10% of the energy content of the load when using agricultural vehicles or standard trucks, and less than 2% when "large volume" vehicles(Figure 4).

For all classes of vehicles analyzed, the total energy cost consists for 10% of indirect cost and 90% of direct cost (fuel and oil).

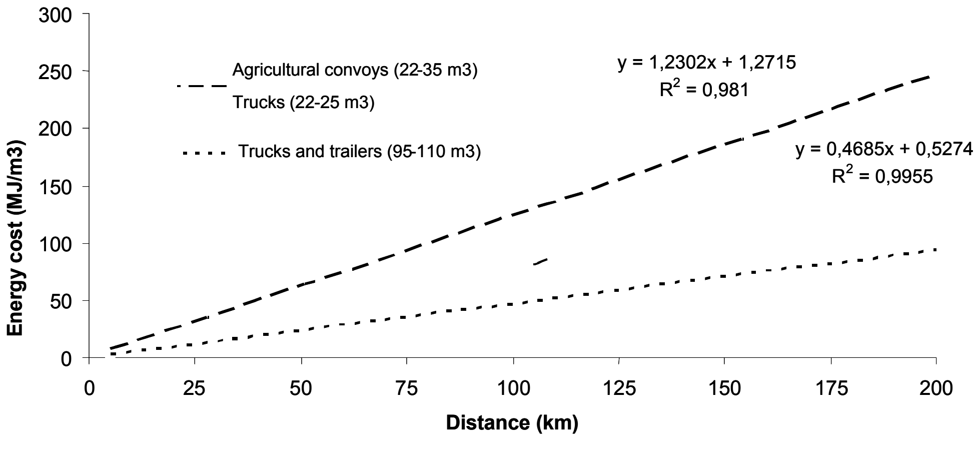

Figure 4: Energy cost of different vehicles tested

5 Conclusion

From the study it was found that the highest average travel speed (42 km/h) is obtained with industrial vehicles, and the lowest (24 km/h) with agricultural convoys (value obtained on distances longer than 25 km).

The time study showed that productive time represented between 75 and 90% of total work time, respectively for short and long distances. Maneuvers for the loading and unloading of the biomass accounted for 3-5%; the highest value is reached when using conventional trailers with manual opening and closing of the container doors.

Transport cost is inversely proportional to the distance, in fact for distances of less than 20 km, the value is about 5 €/km because unproductive working time required for loading and unloading have a heavy incidences on overall costs. Energy cost required for wood chip transportation is relatively small when using "large volume" trucks. In summary, this work showed that in order to reduce unproductive transport times and, therefore, to contain chip transportation costs, one needs to choose vehicles with a high load capacity and a large landing site so as to reduce as much as possible the time spent maneuvering.

6 References

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