Supplementary materials

1. Life cycle inventory

1.1. Traditional mechanization

1.1.1. Felling

A chainsaw (50 cm³) was used to carry out felling operations. According to data provided by LIFC the average daily productivity for one worker was 30 tons of timber, while oil¹ and lubricating oil consumption were respectively 2.35 kg per hour and 3.5 l per day. Daily hours of work were calculated and are 2.3 hours per day, that meant a daily amount of oil used equal to 1.35 kg per hour. This data showed the working hours necessary per 1 ton of timber extracted is 0.107 h. All lubricating oil used is poured into the soil.

1.1.2. Extraction

This operation constituted the first part of comparisons performed in this study. Two different modalities of extraction were involved: (1) cable logging (model V 400 of Valentini firm) and (2) extraction by winch (Tajfun model EGV 35 A). According to AIEL (Italian Agroforestry Energies Association, 2009), cable logging has an hourly diesel consumption of 6 l, while for extraction by winch a consumption of 6.5 l/h was assumed; distance of extraction was considered to be 200 m. Since logging conditions were heavily influenced by the morphology of the region and varied considerably for each site (see section 1.1), two further scenarios were analyzed: (1) the first scenario implied the extraction of 1 log at a time, hence the extraction phase was performed before delimbing (cable-logging or winch pre-deliming); (2) the second scenario implied that extraction followed delimbing operations (cable-logging or winch post-deliming), which meant a major use of machine pulling power (about 3.1 tons for cable logging and 2.5 t for winch). Depending on the scenarios, the time required to perform the operations varied considerably. For the first scenario, the time required to extract 1 ton of timber was 0.035 h by cable logging (speed 4 m/s) and 0.059 h by winch (speed 1.2 m/s). The second scenario was faster, due to the possibility to extract more logs simultaneously. Hence, the time required with cable logging was 0.009 h for 1 ton of timber and with winch it is 0.0188 h for 1 ton of timber.

1.1.3. Delimbing

A chainsaw (50 cm³) was used to carry out delimbing operations. According to data provided by consortium, the average daily productivity for one worker was 20 tons of timber; oil and lubricating oil consumption were respectively 2.35 kg per hour and 2.5 l per day. Since daily hours of work were 1.66 hours per day, the amount of oil used was 1.35 kg per hour. We assumed that all lubricating oil used was poured into the soil. These data showed the working hours necessary per 1 ton of timber extracted was 0.083 h.

1.1.4. Stacking

Stacking was carried out with a digger Komatsu PC 75 UU-2 (volume power 50 kW). Primary data provided showed a daily productivity for one worker of 20 tons of timber and daily diesel consumption equal to 25 l. According to AIEL (2009) the hourly consumption for the digger was assumed equal to 16 l. Hence, the time necessary to perform this operation was 0.078 h for 1 ton of timber.

1.1.5. Loading

¹ Oil and lubricating oil density are assumed as 0.78 kg per liter and 0.9 kg per liter
Loading operations were performed by an Agroplus 80 tractor (volume power 59 kW) and trailer IB 6500 by Icar Bazzoli firm. An hourly consumption of 8l for the machines used was assumed (AIEL, 2009). Primary data provided by consortium stated that 0.011 h are necessary to load one trunk, it followed 0.019 h for 1 ton of timber.

1.2. Advanced mechanization

1.2.1. Transportation

Timber was transported with the same machines used for the previous phase, hence the data regarding fuel consumption were the same. Lorries capacities varied from 3 to 8 tons, but a maximum load of 3.5 tons of timber was assumed due to road load limits. Limit speed for this vehicle was 40 km/h, hence we could assume a hypothetical cruising speed of 30 km/h. The distance covered was 5 km, from this it follows that it took 0.17 h to transport 3.5 tons of timber and 0.098 for 1 ton of timber.

1.2.2. Felling and delimbing

The harvester enables workers to perform either felling operations or delimbing. In this case a heavy harvester John Deere 1270 D (volume power 160 kW) was used. Since the hourly diesel consumption is 10 kg and average productivity was 13.9 m$^3$/h, the time necessary to perform this operation for 1 ton of timber was deduced and equal to 0.072 h.

1.2.3. Extraction and loading

The operations were performed by a medium forwarder John Deere 1110 D (volume power 120 kW). Hourly diesel consumption was 9.35 kg and average productivity 14 m$^3$/h, from which it followed that it took 0.071h to extract and load 1 ton of timber onto the truck.

1.2.4. Transportation

The same considerations explained for the previous case were valid for advanced mechanization, but for this phase transportation was realized by a forwarder. Hence, the time necessary to transport 1 ton of timber was 0.098h.
2. Figures

Fig. S1 Results for characterization phase, assuming advanced mechanization at top productivity (in %)

Fig. S2 Comparison of three different advanced mechanization systems: baseline, with DPF and SCR technologies and top productivity