Innovative systems in the production and organization of forest biomass and urban green areas

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Abstract

Urban green can be understood in a broad sense, thus indicating a place for leisure and with a filter or interruption function, between the different urban densities.

The presence of a proper function of urban green significantly improves the life of those who use the spaces; the aspects are manifold: sanitary, recreational, educational, psycho-social, cultural. In the classification of urban green as furniture green and functional green

forest residues are also included, resulting from the different types of forestry interventions, commonly referred to as forest biomass. For biomass harvesting operations, for energy purposes, they include both silvicultural interventions in forests managed by forest trees and interventions in coppiced forests. This article presents the results of an experiment conducted in an experimental test field, in the province of Treviso, where there is a poplar plant with 4 years of root, and two years of stem. The tests dedicated to the assessment of productivity were conducted in June 2015 by Cnr Ivalsa, in collaboration with Mombracco Energy srl, both partners of the MCV 2.0 project, funded by the Piedmont Region. The production performance of the machine has been analyzed in real working conditions, and in different operating environments, capable of representing the conditions of use typical of the foothills area, and, in particular, squares, poplars and woods, with the aim of obtaining a evaluation of the distribution of working times, productivity, fuel consumption and quality of the wood chips. Laboratory analyzes have made it possible to evaluate the quality of the wood chips and, in particular, the grain size of the same.

Introduction

Different spaces belong to the classification of urban green, whether they are designed or not, are planted and subject to maintenance. Urban green can be understood in a broad sense, expanding the concept to all the urban spaces typical of our suburbs, or to all those areas that affect the typical functions of green spaces, therefore where you can walk, play, spend time in the air open. They are, for example, the waterways, the paved or paved spaces for pedestrian use. Urban greenery, therefore, is a place for leisure and with a filter or interruption function between the various urban densities. The presence of a proper function of urban green significantly improves the life of those who use the spaces; the aspects are manifold: sanitary, recreational, educational, psycho-social, cultural. The residual spaces converted to green areas come from disused areas from traditional agriculture, abound in industrial areas, first incorporated into residential neighborhoods, and then become part of the entire urban fabric.

The need to expand, restore or design green areas for their countless benefits to the community is growing. It should be noted that inside the city
not a few natural elements remain, such as rivers, woods, areas with typical vegetation and more. On the concept of urban green, we find ourselves discussing the natural and historical value of the residual spaces, their maintenance, enhancement and social use. To the classification of urban green belong:

• green furniture;
• functional green;

Forest biomass originates from the common practices of naturalistic silviculture or from cutting and logging operations (trees but also shrubs), which allow the use of wood production without affecting the perpetuation process of the forest. The operations performed contribute to regulating the competition between plants of the same or different age; they also help to control the composition, the spatial structure (horizontal and vertical distribution) and the evolution of the forest. Forest residues, resulting from different types of silvicultural interventions, are commonly referred to as forest biomass.

For biomass harvesting operations, for energy purposes, they include both silvicultural interventions, in forests managed by forest trees, and interventions in coppiced forests. In the first case, an example of an operation may be the removal of minor assortments (cimals and twigs), commonly left in the woods, which occurred following cutting operations of the largest forest assortments (diameter of the trunks greater than 18 cm) for commercial use . Furthermore, biomass can also be obtained from broken or uprooted plants, following climatic and decomposition events. Another source of supply is made up of wood material derived from interlayer cuts, or interventions applied to young trees, or being reconstituted to increase stability, to regulate their specific composition and to increase their production of value. The use of coppice is also an imported source of forest biomass: Italian coppice, made up almost entirely of stumped plants, is mainly intended for the production of combustible biomass, such as firewood and poles for agricultural use. Where the supply chain requires it, the coppice as the fustaia are used purely for the production of biomass. Wood waste from sawmills, such as bark, sawdust and shavings, can also be an important source of forest biomass. Forestry residues are normally abandoned in the woods as waste, but can be collected and used as biofuel. In some Northern European countries, this is common practice and is also gaining ground in Central European countries. In Italy, due to technical, economic and working traditions, this possibility is scarcely exploited.

The residues from the uses do not have a market destination, therefore they can be classified as "waste", having no value, since the costs of use are normally borne by the main product. the primary source of wood for transformation into biomass (especially wood chips) remains the waste from sawmills and the wood industry. This source is the same from which the panel industry also supplies itself, given the continuous numerical growth of district heating plants. Biomass, coming from the forest, is present on the market in very different sizes, in terms of shape and degree of humidity. Depending on the request, densified forms (pellets and briquettes) or chopped forms of various sizes (wood chips) are produced. Among the most common are wood logs (especially in rural or mountain environments, where these cuts are often used for residential heating) and wood chips. The chemical-physical characteristics of biomass, combined with the product ones (i.e. those related to handling and buying and selling) give useful information of quality and cost of the material. The wide availability of the source at national level (over 32.3% of the Italian territory is covered by woods and forests) makes the energy use of forest biomass interesting. However, logistical difficulties hold back greater use of forest resources.

From the woody residues of urban greenery it is possible to obtain two types of fuels, which according to their origin and use are divided into: pieces of wood and wood chips (Veneto agriculture). The chopped wood is obtained from the use of trees or branches, having diameters greater than 15 centimeters. It is commonly used in small domestic heating systems and in wood-fired ovens for catering. Soft or light wood species such as poplars, willows, linden are not suitable for producing this type of fuel. The wood chips are reduced to 3 to 10 cm long flakes. The raw material can also come from pruning and felling of urban greenery. Wood chips are used in medium and large scale plants and in the panel or pulp industry. This fuel is the one that is best suited to be produced by the maintenance of urban green areas. The energy yield of the fuel does not vary depending on the species and the size of the wood residue. Conifers, being rich in resins, can give some problems to the chipping processes. The production of biomass for energy purposes depends on the possibility of setting up efficient construction sites. Not all types of urban green have economic interest in the production of biomass for energy use. With regard to historic greenery, recreational and ornamental greenery or furnishings, interventions on the tree component are minimal: in these situations, the cost of transporting the raw material to the chipping yards (or directly to biomass plants), can be far higher than the cost of maintenance. The setting up of the chipping site, near the maintenance area, can also be disadvantageous. The green areas that are of interest to the wood-energy supply chain are street green (consisting of trees, median strips and other road arrangements). Environmental greenery, consisting of areas managed extensively, including rivers and canals, agricultural areas and peri-urban woods. Like trees, tree-lined rows are also subject to regular pruning and scheduled replacements, producing large quantities of wood. According to good practice, the pruning shifts involve periods of one to two years, when the cormometric volume does not hinder the public and / or private good; it should be emphasized as periods greater than ten years, for cases where the cost of maintenance requires highly qualified personnel and personnel, and therefore consequences on maintenance costs. The Green Plan instead dictates that each tree is pruned, from the twentieth year of life of the plant, once every five years, and that at each intervention about 25% of the blastometric production is removed.

The current system for the disposal of wood residues requires that these be transferred to the composting plants. The green maintenance companies deal with the collection and transfer of the wood residues, which is used to give structure to the compost. This system is burdensome for businesses that have to bear costs for the disposal of green waste, around € 40 / tonne. In this process, exceptions are the large diameter wood logs, which are used for the production of biofilters, to be used in the ventilation systems, which are purchased at a price of 20 € / ton. For this reason, green companies are looking for alternative forms of disposal of the wood component.

The heaviest part of the wood residues is reused in various ways:

- self-consumption by green maintenance companies;
- free distribution to citizens near construction sites;
- sale of pieces of wood, for those companies that have equipped with splitting machines;
- wood chips and panel supply chain;
- disposal in agriculture.

Material and methods

Chemical characteristics. Wood biomasses are mainly composed of polymers, such as cellulose (50%), hemicellulose 10-30% and lignin 20-30%. In addition to these components, other organic compounds are present in the wood, such as non-structural sugars, terpenes, fats, gums, tannins, alkaloids and waxes.

Unlike other fuels, wood contains relatively low quantities of nitrogen, traces of sulfur and other mineral elements, which make up the ashes. The atoms that make up biomass are predominantly carbon, oxygen and hydrogen. Ash production varies in percentage terms between 0.6 and 1.5% of the biomass volume. The O / C and H / C ratios have a decisive influence on the fuel characteristics: high carbon and hydrogen content determine a higher calorific value, while the opposite effect has a high presence of oxygen, nitrogen and ash. A parameter of interest for the fuel value is volatility, given by the quantity of volatile material present in the wood, expressed in percentages on the dry weight; compared to that of other fuels, the volatility of wood is very high (75- 87%). Volatility is a chemical-physical property that represents the tendency of a solid or liquid to sublimate or evaporate respectively. In general, substances that under certain conditions, of pressure and temperature, have high vapor pressure are considered volatile. In other words, the system tends to evolve spontaneously towards the aeriform state, reaching the maximum level of stability, relative to the conditions in question.

Physical characteristics: important parameters for assessing the quality of forest biomass are some physical characteristics, such as humidity, density and specific gravity. These factors together with the chemical composition of the material affect the calorific value of the wood. Humidity expresses the amount of water present in the wood and is calculated as the ratio between the amount of water contained in a piece of wood and its dry weight. It is also calculated as a percentage of water on the fresh weight. This variable assumes significant importance because, in addition to acting on the combustion mechanisms, it has an influence on the chemical characteristics of the wood and its specific weight. The amount of water in the wood is extremely variable: it assumes different values depending on the species, age, the different part of the plant and the cutting season. Generally, the humidity values are lower for broad-leaved trees compared to conifers, in the lower parts compared to the upper parts of the plants, in summer, compared to winter. The moisture content affects the calorific value of the fuel: the higher the content, the more energy is consumed to evaporate the water during combustion. The moisture content of the wood, when cut, is very high, on average around 50%. It can vary from a minimum of 40% to a maximum of 60%, depending on numerous factors that include the species, the cutting season and the part of the plant. Conifers tend to be more humid than broad-leaved trees; the different parts of the plant have a different water content, which generally decreases from the base of the plant, towards the cimal. The moisture content influences the boiler's ability to reach full load, affecting both the effectiveness of combustion and the gaseous emissions.

The specific gravity is represented by the ratio between the basal density of the wood and the density of the water at 4 C. The basal density of the wood varies from 0.3 to 0.7 kg / m3, depending on the stationary conditions, of the species , age, part of the plant, and the form of government and forest treatment (APAT). Density is defined as the ratio between the mass and volume of a piece of wood, measured in km / m3. Density represents the most common indicator of the quality of the wood fuel, in fact the calorific value of the wood is directly proportional to it. It is necessary to differentiate between the basal density of the wood, i.e. the ratio between the mass of the dry wood and the volume of the wood with moisture (excluding the bark), and the mass density, i.e. the ratio between the mass of the wood in its fresh state and the volume of fresh wood. The density also varies according to the stationary conditions, the species (generally the density of the broad-leaved wood is higher than the conifers), the age, the part of the plant, the form of government. The density of the wood varies between 800 and 1120 kg / m3, if referred to the fresh state, and between 360 and 810 km / m3 if referred to the dry state.

Energy characteristics: an effective indicator of the combustible value of wood is represented by the calorific value, which is defined as the amount of heat produced by the complete combustion of a unit of weight an energy material. The calorific value is determined at a constant volume, inside a calorimetric bomb (PCS); in practice, with constant pressure combustion occurring, the water vapor from combustion is not a condenser; consequently, the condensation heat is not recovered. The number of calories actually resulting from burning wood is lower than the previous determination of about 300 kcal / kg (PCI). The lower calorific value is defined as the amount of heat that develops following the complete combustion of one kg of wood, considering the water in the vapor state at 100C, and is expressed in kcal / kg. The calorific value of forest biomass varies considerably according to the physical characteristics and chemical composition of the material. With the same weight, the wood of the conifers has a higher calorific value than that of the broad-leaved trees: this is due to the presence of resins and higher quantities of lignin. In fact, while for conifers a PCI of 5000 (pine) can be reached for deciduous trees, the PCI does not exceed 4500. With a percentage of humidity (referred to dry substances) varying between 11-12% and 15%, it is possible to affirm that the calorific value of conifers is around 3800 and that of broad-leaved trees around 3600 (APAT). The different characteristics of the biomass are related to each other, that is, the biomass can be considered good if it has reduced humidity, therefore a high PCI and high density. Lignin, which gives rigidity to the plant, is present in percentages ranging from 20 to 30% of the dry weight and has a high calorific value (about 6000 kcal / kg). Cellulose, the main component of wood (50% of dry weight) also has a high calorific value (3900 kcal / kg. The hemicellulose, present in the spaces left free by cellulose, constitutes 10 to 30% of the wood, and has a more modest calorific value. The wood chips have an average calorific value of 690 kwh / mst. If we consider that a meter of wood chips (mst) has a weight of about 300 kg, a calorific value of about 2.3 kWh / kg can be calculated. (APAT).

Result

During 2008, granulometric comparative tests of wood chips were performed between the experimental cra rotor and the claas jaguar series rotor. The test field and again the poplar SRF: the test sees plants of two years of root and two years of stem; the second sees plants of four years of root and two years of stem. The chips to be compared were divided into three diametric classes; the class <12.5-25mm>, the class <6.3-12.5mm>, and the class <6.3mm. At hourly intervals, identical quantities of wood chips were taken. The chips produced by the standard rotor show rather homogeneous dimensional intervals, improved by experimental tests of the past, but which maintains high percentages in the smaller dimensional classes, at the expense of the product's shelf life. Compared to the quality of the chips of the standard rotor, there is an increase in the larger size classes in the CRA rotor. In the 12.5-25 class there was an increase of 13.80%, in R2F2 and an increase of 12.10% in R4F2. The reduction of the product falling in the granulometric classes 6.3-

12.5 mm; 3.15 - 6.3 mm and <3.5 mm, respectively -17.80%, -4.60% and -5.20% for R2F2 and -4.10%, 2.90% and -4, 10% for R4F2 (Pari et al. 2009). Not all the desired results were achieved. The goal was to increase the size in the three anatomical directions of the chip. Only an increase in length along the longitudinal axis of 10mm, and increments of 1-2mm in thickness and width was achieved. These results were good from the point of research, but not sufficient in expectations. An increase in the axial length alone could be due to the intrinsic characteristics of the poplar wood. This wood is part of the porous-diffused woods: often the edge of the ring is not distinguishable, it has equally broken pots and of little variable diameter. Poplar wood can be classified as "soft".
To evaluate whether the poplar species is the reason for the results obtained in the previous test, the CRA decided to do a further chipping test, this time on forest plants. We will analyze whether the wood species affects the scale formation process, or evaluate the possibility of changing the mechanical parts that work in the experimental rotor cutting process. The standard rotor mounted on a claas jaguar 860 forage harvester and experimental experimental rotor on the FTC claas jaguar 890 was tested again. The shredding product came from soft and hard wood forest species. The plants used had a diameter of between seventy and one hundred millimeters, in line with the dimensions obtained by the SRF in the second year. For the softwood test, the maple flakes were examined, while for the hardwood, Turkey oak, locust, field elm and downy oak flakes were examined. The same number of plants for each species passed through the different forage harvesters equipped with the two models of rotors. The material taken in the woods was chipped with machines stopped, manually inserting it into the feeding mouth of the two operators. The procedure foreseen by the Technical Specifications of European Committee for Standardization (CEN / TS 15415/2006, 15414-1 / 2006 end 15401/2006) was used to measure the particle size distribution, the moisture content per unit of mass and the apparent density.

The experimental rotor, compared to the standard one, allowed to have a product with more homogeneous characteristics, therefore it presents a smaller quantity of wood chips with dimensions smaller than 12.5mm and more material in the fraction 12.5-25mm. The largest increase in the 12.5-25mm fraction was achieved by maple and locust, with values of + 11.6% and + 9.8%. The elm, the Turkey oak and the downy oak reached lower increases, with values equal to + 3.2%, + 5.2% and + 5.9%. The reduction in the percentage of product falling in the particle size classes, less than 12.5 mm, was variable from -7.1% for downy oak, to -12.3% for locust, in contrast with the field elm with an increase of the fraction less than 12.5 mm by 1.7%. As in the previous tests, the analysis of the flakes highlights, for the CRA rotor, a predisposition for increasing the longitudinal section, both for softwood species and for hardwood species. The increase is up to ten millimeters, with scale sizes ranging from 30 to 40mm. Downy flakes were smaller than poplar flakes in thickness and width. Again for downy oak, the different cutting mechanics of the two rotors are not affected, since the quantity of wood chips with a particle size of less than 6.3 mm has been kept constant. Cra-ing, during 2011, put the new experimental second generation rotor to the test. Compared to the crai-ing rotor, the new one is characterized by having a different cutting angle of the knives and a greater mass of the drum. The project derives from the collaboration between the Veneta Mais company and the CRA-ING research agency. The two rotors are different in length of the knives, cutting angle, length of knife holder inclination and finally in diameter and length of the rotor. In general it can be defined that the changes proposed by the CRA of mass, length and diameter of the second series rotor, are proportional to the dimensions of the first series rotor. As in the rotor tested in 2008, this second generation mounts 10 knife holders fixed by welding on a hollow steel drum.

However, the inclination of the knife holders has decreased, from 30 ° of the first series rotor to 15 ° of the second series rotor.
The overall mass was also increased, from 349 to 403 kg, with the great advantage of greater inertia during the processing phase. Consequently the diameter goes from 578 mm (first series) to 630mm (second series); the total length of the rotor goes from 701.5mm of the first rotor to 720mm of the second rotor. The cutting angle has gone from 4.6 to 4 ° which ensures a greater size of the flakes. To distribute the cutting effort on the drum, the knife holders have been lengthened, passing from 320 to 340mm. Last modification is the reduction in the length of the knives which has gone from 380 mm (CRA I) to 363mm (CRA II)
The mechanical availability of the machine (percentage of time spent on site excluding maintenance and repairs) was on average 94%, as expected from a new machine. Much of the mechanical downtime was represented by the change of knives. The average utilization (ratio between work time and total time on site) was 77%, with a range of variation between 69 and 83%. The poplar grove tests included direct access to the field, which the new machine has always performed without the slightest problem, even where the ground conditions would have been problematic for other vehicles. At this juncture, the AllRoad was able to recover and tow loaded trailers - and even a self-propelled wood chipper - when these had been blocked by the loose or slippery ground. The productivity of the new chipper was variable between 105 and 194 stere meters per hour of chipping net. The peaks were reached at 242 meters with the chestnut logs in the square, the minimum productivity instead was recorded in the processing of the pruning residues, which are notoriously more difficult to handle and produce a lower quality wood chip. The stacks arrangement had an important effect on productivity, judging from the performance obtained in the square with the sawmill residues and chestnut logs, both represented by individual pieces much smaller than the tops available in the poplar groves. Diesel consumption closely reflects productivity, and is as much lower as productivity and efficiency are greater. In fact, the minimum values of 0.3-0.4 liters per meter were achieved in the operations carried out in the square, on chestnut and poplar. On the other hand, consumption touched 0.6 liters per meter per meter during the processing of pruning waste at the mountain levies.
The study in the square also allowed to deepen the knowledge about the possible effect of the different regulation of the feeding and expulsion apparatus, on productivity and consumption. In particular, the machine was tested with two different adjustments of the feeding apparatus (no-stress in on-off mode and no-stress in proportional mode) and two different adjustments of the expulsion apparatus (fan at maximum and fan at minimum). Productivity was influenced by the type of material, but not by the regulation of the feeding apparatus. On the other hand, the adjustment of the expulsion system has shown to have a marked effect on the consumption of diesel fuel, for both the materials being processed and both adjustments of the no-stress device. By reducing the fan speed from 1,000 to 500 rpm, diesel consumption decreases from 8 to 13%.
Experimental test field was a poplar plant in the province of Treviso, with 4 years of root and two years of stem. The main plants had an average height of 7.86m (dev stand +/- 0.60) while the average diameter of 61.9mm (dev stand +/- 11.85). The secondary plants had an average height of 4.24m (dev stand +/- 1.00) and average diameters of 27.85mm (dev stand +/- 7.41mm). During the chipping, 1kg samples were collected for the particle size determination, ten volumetric cylinders (total 0.26 m3) for the calculation of the apparent density and six samples of 500gr each for the calculation of the humidity. Four sieves with mesh sizes of 63-45mm were used for the particle size classification; 45-16mm; 16-3,5mm; <3.5mm. The chips of the cra II rotor were compared with the

cra I rotor flakes and the claas jaguar series rotor scales produced in the 2008 tests. The dimensional analysis was carried out by measuring the weight, length and thickness values of 300 flakes or 100 flakes for each rotor. The only particle size fraction subject to dimensional investigation was 45-16mm. The apparent density and the quantities of each single particle size class reported in percentage were also compared. The 8 mm particle size class was 5.35% of the total, while it rose to 21.38% and 71.38% for the 8-16 mm and 16-45 mm classes respectively. Only 1.67% of the total represents the class greater than 45 mm. The over measures represent only 0.22%. Thanks to the dimensional analysis, attention was paid to the differences in the execution of the rotors. The flakes on average are thicker, wider and longer respectively of 18.70%, 24.76% and 28.79%. Again in comparison with the other rotors of the test, the average weight of the scale more than doubled with 111.20% more, going from 2.59 gr to 5.47 gr. The apparent density has decreased by passing 289 kg m-3 for the Claas rotor, to 279 kg m-3 and 265 kg m-3 for the CRA I and CRA II rotors.

Discussion

Across Europe there is a constant growth in the demand for wood chips due to its efficiency and low cost. Consequently, all over the world the manufacturers compete to offer the market innovative products, offering high productivity with low consumption. The Piedmontese company Pezzolato managed to design, build and test a type of machine from a new model. The chipper adjusts self-propelled, visibility and chipper group solutions. The chipper is approved for road circulation up to 40 km / h. The complete machine is 2.5 m wide and weighs 25,900 kg, equally distributed between the two axles. The drum, cabin and launcher assemblies are mounted on a two-axle hydrostatic transmission carriage. It features four 1500mm steering wheels in three modes: conventional, crab and counter steering. The vehicle can have road or work configuration. The transition between the two configurations takes place in two minutes through the opening mouth, lifting the launcher tube, telescopic crane opening, resting foot support and lifting the cabin. The job configuration or road configuration sequences takes place with a single button, which in the job configuration remains pressed. The chipper is approved for road circulation up to 40 km / hour. The cabin is supported by its own frame and has a shatterproof polycarbonate window. In work mode, the passenger compartment rises two meters and turns 45 ° to the right on the wagon axis or 45 ° to the left. In the cabin the controls are on two touch screens where you can view the images of the control cameras (back chipper, gooseneck view and chipper drum) also the control system reports and records all the parameters of the engine, chipper group and transmission . The chipper unit has been completely redesigned. It is 1400 mm wide, has a diameter of 820mm and a mass of 3500kg with the great advantage of greater inertia during the processing phase. The drum is of the sectional type with 5 staggered blades while the general design is of the closed drum type. The wood chip ejection fan takes place by means of a hydraulic speed variation drive.

The feeding mouth is relatively low and has a longer catenary than other models. The electronic control can display the No-Stress command. Regulated in two ways of working, instead of the classic On-Off; the rollers work until the system manages to maintain the set speed, otherwise they stop, waiting for the processed product to be unloaded from the drum, which thus returns to work in an optimal rpm range. The other working mode provides proportional speeds, where there is coordination between the speed of the feeder roller and the drum. All speed settings are made via touch screen. The engine is the 405 Kw Scania Euro Six (550 HP) which uses EGR (exhaust gas recirculation) and SCR (Ad-Blue) systems; this eliminates the need for a traditional diesel particulate filter, which generally represents a serious fire risk for machines working in dusty environments. The chipper was developed in collaboration with the end user of the product and with the CNR as scientific support, benefiting from the funding offered by the Piedmont Region with Measure 124, Action 2 of the 2007-2014 RDP.

Conclusion

The tests dedicated to the assessment of productivity were conducted in June 2015 by Cnr Ivalsa in collaboration with Mombracco Energy srl, both partners of the MCV 2.0 project funded by the Piedmont Region. The production performance of the machine was analyzed in real working conditions and in different operating environments, capable of representing the conditions of use typical of the foothills area, and in particular of squares, poplars and woods, with the aim of obtaining an assessment of the distribution working times, productivity, fuel consumption and quality of the wood chips. The tests were carried out at seven sites with very different materials and capable of influencing both the productivity of the chipping and the quality of the chips. The tests carried out in the forecourt have also allowed us to test the effect of the various possible adjustments of the feeding and ejection apparatus, to see if their wise adjustment can allow to optimize productivity and consumption when treating different materials. In each test the following were measured: the working times, recorded with a stopwatch on a laptop every time; the volumes worked, measuring the internal volume with a metric tape; the quality of the product, by taking a sample of wood chips per container and sending the sample to the laboratory, in order to determine its water content and particle size. Overall, the tests covered over 35 working hours, during which 114 containers of equivalent wood chips were produced equal to 3,493 meters steri (m3 of wood chips) or 929 tons of chips (average moisture content = 42.6%). Each field test lasted long enough to produce a minimum of 8 loads. The average density of the cips was 266 kg m-3. The chipping operations in the poplar grove sites (1, 2, 3) were carried out on the plain and the ease of maneuver that these sites offered was exploited. The two yards (sites 4 and 5) had been used in a large paved space and the wood was carefully set up in stacks of 4 m. Finally, the sites located in the mountains (sites 6 and 7) saw the dirt road as a workplace, where the wood was set up in stacks of about 4 m in height. The machine was managed by the same driver, expert and efficient, having about 5 years of experience with the chippers built by the same manufacturer.

The machine efficiency study was carried out by evaluating the times and the motion trying to identify the variables that influence productivity. Each work cycle was individually timed, using hand-held laptops, running software dedicated to the study of time. The production times were separated from the delay times, but further excessive details were avoided, in order to contain errors and ensure the repeatability of the experiment. All delays were included in the study, and not only delays below a set duration threshold, as such practice could erroneously represent the impact on interruptions. However, the delays caused by the study itself have been removed. The total volume was estimated by measuring the internal volume of all the containers and visually evaluating the volume of any mounds or voids. The total mass coming out of the gooseneck has been estimated by weighing, on a loading bridge, the total weight of the vehicle carrying the full container, and subtracting the certified weight of the vehicle. Weighing was carried out at the local wood chip power station. The size of the piece (size of the single wooden element - trunk, rounds, bulks etc. - inserted in the chipper) was determined by dividing the mass of each load by the number of wooden elements inserted in the chipper during the production of this load. Two 500 g samples were

collected from each container load to determine the moisture fraction and size distribution. Every 500 g of sample was obtained after the reduction of a larger sample, mixing more fractions collected in different points from the top of the container. The humidity fraction was determined with the gravimetric method, according to European standards (CEN 2009). The fresh weight was determined on site with a portable sling bar, immediately after specimen collection. The dimensional distribution of the material was determined with the oscillating bar method using four sieves to separate the sample into five classes of chip lengths:> 63 mm (oversize), 6346 mm (large chips), 45-17 mm (medium size chips), 16-3 mm (small size), <3 mm (under measurements). Each fraction was then weighed with a precision scale (0.1 g). For the purposes of the analysis, the particle size data were grouped into three functional classes: oversized (> 63 mm), required (63-3 mm) and sub-measures (<3 mm).
Fuel consumption was measured by parking the chipper on the same level point and filling the diesel tank with a fuel pump set at 0.1 dm3, before starting and after completing each test. The tank, pump and fuel meter were loaded onto a truck which followed the chipper to the workplace. The fuel consumption was the gross fuel consumption for the chipper and the loader, as both were powered by the same engine. The significance of each relationship between productivity and workpiece size was tested with regression analysis. In this case, the assumption of the statistical hypotheses was checked through the analysis of the residues. Laboratory analyzes made it possible to evaluate the quality of the wood chips and in particular the grain size of the same. The quality of the wood chips appears closely linked to the starting material. The splinters are more abundant in the sawmill residues, in the pruning residue and in the product coming from the mountain: the first perhaps because of the many short strips that tend to go sideways during the feeding of the drum producing splinters, the other two for the 'high content of twigs, which often pass through the drum without being effectively cut due to their flexibility. The presence of dust is maximum in the pruning residue, minimum in the logs and in the sawmill residue and intermediate in the others. This distribution seems to follow the proportion of foliage in the starting material, which is maximum precisely in the pruning residues, minimum in the logs and in the sawmill residue and intermediate in the others.

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