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Battery- and Petrol-Powered Chainsaws: An Investigation of Productivity in Conifer Thinning

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Abstract: In recent years, battery technology has been greatly improved and some types of battery chainsaws are currently comparable with light-type petrol machines, suggesting their possible introduction into forest operations. In this context, the aim of this study was to test and compare the performance, in a Douglas-fir thinning, of two chainsaws similar in terms of weight and power, the Stihl MS 220 CB battery-powered saw and the Stihl MS 201 CM petrol-powered saw, measuring the working times and calculating the productivities. The results showed that, within a working day (about 6 h gross time), an average of 15 trees of 0.56 m^3 was felled in each area. No statistically significant differences between the two chainsaws were found in terms of gross and net productivity; and the same result was obtained when focusing the analysis only on operations conducted using the chainsaws. Moreover, the average battery charge duration was 1.04 h, while the full tank duration for the petrol model was 1.12 h. In conclusion, our study demonstrates that, on the basis of their performance, battery chainsaws can be introduced into thinning operations, but a solution is needed to manage batteries in the forest, since the actual need is for 7–8 charges per workday.

Keywords: battery; petrol; chainsaw; productivity comparison; forest operation

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1. Introduction

One of the most common pieces of equipment used today for tree pruning, felling and processing is the chainsaw [1–3], as it is extremely versatile and implies low investment [4,5]. As is cross-sectorial, the use of chainsaws is widespread not only in arboriculture, professional forestry, and rescue work, but also in households and public and private gardens. The highest performance and power are required in the fields of rescue and forestry [6], in the latter of which must be highlighted the long duration of its use per day, often to its maximum power. As evidence of this last aspect, the lifespan of a chainsaw in forestry is achieved in 1500–3000 working hours [7,8]. There are evident differences in the types of saws used in the different sectors: petrol chainsaws are largely preferred in forestry, while electric and battery ones are almost exclusively used for professional garden maintenance or for hobby purposes [9].

However, the use of chainsaws presents numerous hazards and has one of the highest accident rates, both in professional and non-professional work [10,11]. In addition, users' long and recurring exposure to unfavourable or even extreme weather and climatic conditions leads to different typologies of occupational diseases, besides the negative mid- and long-term consequences for workers due to several hazards [12–14] such as noise, hand–arm vibration, exhaust gases, and wood dust [15,16].

With increasing attention being paid to workers' well-being, top international chainsaw brands have invested in improving the performance of their battery-powered chainsaws, in terms of both power and battery autonomy, striving to create new and more competitive products [17,18].

Under controlled conditions, vibration and noise exposure during log cross-cutting at the roadside by two battery-powered and two cable-supplied electric saws was investigated by a study conducted by Neri et al. [9]. Another study [6] in small-scale thinning compared the noise and vibration produced by a battery chainsaw with those produced by a petrol one. The results of both studies showed a decrease in occupational health risks related to both noise and vibration exposure from the battery-powered models.

For this reason, and considering the elimination of the hazard due to exhaust fume inhalation, battery-powered chainsaws represent a very interesting option to reduce health risks in both the professional and non-professional sectors. In gardening and arboriculture, for instance, owing to the lower demands for power and reliability than in forestry, battery chainsaws seems to be a viable alternative to petrol models [19,20].

Furthermore, thanks to the investments in technology by the leading chainsaw brands, battery-powered chainsaws represent an alternative to light petrol ones, as the low battery duration has been significantly improved, along with performance in terms of power and efficiency [18]. In addition, the performance of modern Li-ion batteries has increased the autonomy to 40 min of actual cutting, with a recycling efficiency of 97% w/w of the valuable active materials [21,22]. Other advantages are fewer requirements in terms of maintenance, no air pollution on site, and no cables [23].

For all these reasons, and considering that few studies have focused their attention on the potential use of battery chainsaws in forest operations, two top-level chainsaws, a battery- and a petrol-powered model, were compared in terms of productivity (m^3h^{-1}) in a conifer thinning in Central Italy to understand if their performance is comparable in a context of real forest operations.

2. Materials and Methods

A survey on productivity was carried out during a regular forest operation using both the battery- and petrol-powered chainsaws.

2.1. Study Area

The study site was identified in the Vallombrosa Forest (province of Florence, Tuscany, Italy, 43°44′34.6″ N 11°32′40.0″ E). The stand was a 70-year-old Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) plantation. The total area of the compartment was 1.979 ha, with a stand density of 678 stems·ha^{-1} (in total 1341 trees) and an average tree basal area of 67 m^2·ha^{-1}. In line with local legislation, the silvicultural treatment was a thinning cut, removing about 15% of the trees, which had previously been marked by a forest technician of the Vallombrosa Forest Service. The stand was divided into two adjacent sections of approximately 1 ha, where site conditions and tree characteristics were similar, as needed to obtain a reliable comparison between the two chainsaws being analyzed. DBH were checked and analyzed to ensure evenness (reported in Section 3), while tree height was uniform, the trees of the stand being equal in age. To optimize investigation time and to ensure an adequate number of productivity records, thinning was carried out by two expert forest operators with more than 10 years of experience and qualified as forest instructors by a government public institution (Tuscany Region). Each section was assigned to one operator, who used the battery- and petrol-powered chainsaws on alternate days. The study area extended for about 100 m uphill from the forest road located on the lower border, with an average slope of 25%. The large section dimension allowed the two operators to work while always maintaining the necessary safe distance from each other.

2.2. Description of the Tested Chainsaws

In order to assess their eventual differences in operational performance, two models of chainsaw produced and distributed by the same manufacturer (Stihl S.p.A.) were chosen; their technical characteristics are reported in Table 1. In detail, the MS 220 C-B (Li-ion battery-powered, designated "B" from here on) and the MS 201 C-M (petrol-powered, designated "P" from here on) were compared during felling and processing operations in a conifer thinning.

Table 1. Technical characteristics of the two chainsaws used in the study.

	Stihl MSA 220 C-B "B"	Stihl MS 201 C-M "P"
Power	2.1 kW	1.8 kW
Saw bar length	35 cm	35 cm
Chain type	Half-chisel	Half-chisel
Chain pitch	3/8′P	3/8′P
Drive link thickness	1.3 mm	1.3 mm
Number of drive links	50	50
Fuel supply	Electricity (battery)	Mixed (gasoline + oil)
Battery/Fuel type	AP300S	Stihl MotoMix
Chain speed (m s^{-1})	23.3	26.0
Total weight *	5.6 kg	5.4 kg

* Including saw bar, chain, and battery or mixed fuel and chain oil.

B was chosen because it was the professional battery model with the best performance on the market (at the beginning of 2021), while P was chosen because of its comparable power and weight with B, according to the official values declared by the manufacturer.

The choice of two chainsaws from the same brand was made to ensure use of the same type and quality of tool (i.e., saw bar and chain). In fact, during the study both the machines were equipped with the same chain type and guide bar with sprocket nose.

A comparison of the chainsaw performances was made, calculating the productivity in the felling and processing phase ($m^3 \cdot h^{-1}$) by recording the working times and calculating the volume of timber felled and processed in the thinning operation, using national double-entry tables based on measured DBH and height [24].

2.3. Time Study

During harvesting, two researchers followed the forest operators (one researcher for each operator) and recorded time consumption, DBH and total height of each tree, fuel consumption, and delays. Work time was split into time phases [25], recorded separately for each operator.

All time data were recorded with centesimal (1 min = 100 cmin) stopwatches.

Many working phases were divided into two sub-phases because some operations did not involve the use of the chainsaw. In fact, given the scope of the study, the productive time using the chainsaw was recorded separately (chainsaw "in use") from the productive time spent using other tools or doing operations without using the chainsaw (chainsaw "not in use"). The workday and operational cycle were recorded as follows:

- *General preparation*: this covered the time spent relocating from the roadside to the stand at the beginning of the workday, tool preparation, and safety checks before the felling and processing operations began;
- *Approach and tree study, chainsaw "in use"*: this included all site preparation activities with the chainsaws before starting the direction cut (e.g., shrub clearance);
- *Approach and tree study, chainsaw "not in use":* this included the forest operators' walk to the next tree to be cut, the tree evaluation, the felling technique choice, and all site preparation activities with the chainsaw off (e.g., the removal of stones);
- *Felling cut, chainsaw "in use"*: this was the felling cut execution carried out with the chainsaw on, from the beginning of the direction cut to the point at which the tree started to fall;
- *Felling cut, chainsaw "not in use"*: this covered all the operations for which the chainsaw was not needed, from the beginning of the direction cut to the point at which the tree started to fall (e.g., the check on falling direction, the insertion of wedges in the cut, etc.);

- *Tree falling, chainsaw "in use"*: this covered the time needed to use the chainsaw to allow the tree to fall after the completion of the felling cut. Normally this was needed to solve a problem (e.g., the tree being felled got caught in another tree);
- *Tree falling, chainsaw "not in use"*: this covered the time taken for the tree to fall to the ground after the end of the felling cut;
- *Stump cleaning, chainsaw "in use"*: this included cuts to make regular the cut surface on both the stump and the bottom of the first log. It ended when the operator started the log measurement;
- *Delimbing, chainsaw "in use"*: this was the delimbing time with the chainsaw on;
- *Delimbing, chainsaw "not in use"*: this included all the operations carried out manually with the chainsaw off to remove obstacles along the trunk (e.g., to move branches) or to turn the trunk to complete the delimbing below;
- *Cross-cutting, chainsaw "in use"*: this related to cross-cutting time with the engine-running;
- *Cross-cutting, chainsaw "not in use"*: this recorded the time needed to check the measurement of the logs and other time spent without using the chainsaw;
- *Refuelling*: this covered the period from when the battery or petrol ran out until the chainsaw was ready to continue being used;
- *Chain sharpening*: this was the time dedicated to sharpening during the work in the forest. If the operator sharpened the chainsaw at the beginning or end of the workday, the relevant time was included in general preparation;
- *Rest time*: this recorded all pauses, including lunch;
- *Problems and drawbacks* [26].

The diameters and heights of the cut trees and the working times were recorded.

The wood volume processed during each work cycle was associated with time consumption in order to calculate productivity [27].

2.4. Productivity Calculation

The research hypotheses were that productivity (m^3h^{-1}) of the B and P chainsaws was similar in terms of: (1) gross productivity; (2) net productivity; (3) productivity in the felling cut and processing phases (delimbing and crosscutting); and (4) productivity, considering only the times in which the operator was using the chainsaw ("chainsaw in use"). The difference between the chainsaw being "in use" and "not in use" was considered because in many work phases the operator spends some time using directly the chainsaw and others not using it. For example, during felling, the operator cuts the notch (chainsaw "in use") and uses wedges or other tools (chainsaw "not in use"). This difference was considered in time collection to better identify the eventual role of chainsaw types, explaining possible differences in productivity.

Table 2 shows the working phases and the productivities analyzed.

Table 2. Details of the working phases and the productivity type, showing where each working phase is included or excluded.

Working Phase (Chainsaw "in use" or "not in use")	Productivity			
	Gross	*Net*	*Felling/Processing*	*Chainsaw "in use"*
General preparation	✓			
Approach and tree study—in use	✓			
Approach and tree study—not in use	✓			
Felling cut—in use	✓	✓	✓	✓
Felling cut—not in use	✓	✓	✓	
Tree falling—in use	✓	✓	✓	✓
Tree falling—not in use	✓	✓	✓	
Stump cleaning—in use	✓	✓	✓	✓
Delimbing—in use	✓	✓	✓	✓
Delimbing—not in use	✓	✓	✓	
Cross cutting—in use	✓	✓	✓	✓
Cross cutting—not in use	✓	✓	✓	
Refuelling	✓	✓		
Chain sharpening	✓			
Rest time	✓			
Problems and drawbacks	✓			

As reported in Table 2, gross productivity was calculated by dividing the volume of timber felled and processed in a day (from each chainsaw model, i.e., B or P) by the number of hours worked in the whole day. In order to calculate net productivity, the timber volume felled and processed in a day was divided by the total working time (considering the time with the chainsaw "in use" and "not in use", and the time spent refuelling). Productivity in the felling and processing phases was calculated by dividing the timber volume felled and processed in a day by the total time needed for felling and processing, less the time spent refuelling. Furthermore, to compare the two chainsaws only in the actual productive phases, the timber volume felled and processed was divided by the working time with the chainsaw "in use".

Moreover, to understand if any differences in the dimensions of the trees cut and processed by the two operators using B (Table 3) may have affected the results, a further analysis on a sub-sample of 54 trees (27 per B and 27 per P), selected in a range of 20 to 26 cm of DBH, was performed, considering the only "chainsaw in use" phases. For this analysis, the following working phases were considered: felling, delimbing, and cross-cutting, to calculate total time with chainsaw "in use". The relative productivities were then calculated by dividing the timber volume of a single tree by the relevant working time.

Table 3. Diameter dimensions (cm) of the cut trees, showing mean, maximum, minimum, and SD values for each chainsaw model (B = battery MSA220 C-B; P = petrol MS201 C-M) and each operator (1 and 2). Different lowercase letters show the presence of a significant difference (p value < 0.05).

Chainsaw Model	Operator	N.	Minimum	Mean	Significant Difference			Maximum	SD
B	*1*	24	21.00	26.38	a			33.00	2.93
	2	40	16.00	23.60	b			34.00	4.06
	Tot	**64**	**16.00**	**24.64**			**a**	**34.00**	3.89
P	*1*	43	16.00	22.91		a		30.00	3.66
	2	24	18.00	24.25		a		32.00	4.08
	Tot	**67**	**16.00**	**23.39**			**a**	**32.00**	3.84

2.5. Statistical Analysis

The obtained dataset of the productivities (gross, net, felling/processing phase, and chainsaw "in use") of the different chainsaw models was analyzed. First, normality and homoscedasticity were tested using, respectively, the Shapiro test and Bartlett test. Based on the test results, a parametric approach, using a one-way ANOVA and a post-hoc Tukey's honestly significant differences (HSD) test, was applied to investigate differences between B and P in terms of productivities. Deepening the investigation, the performances of the two chainsaw models were tested considering productivity at single-tree level for each phase, analysing a smaller homogeneous sub-sample. Owing to a non-normal distribution, a non-parametric statistical approach was applied to the comparison of net productivity measured for each working phase. As the delimbing productivity data results were homoscedastic, a Kruskal-Wallis rank sum test was used, while a two-sample Kolmogorov–Smirnov test was used for the comparison of net productivities in the felling and cross-cutting phases, due to non-homogeneous variances of the measured data.

3. Results

During the study, 131 trees were felled and processed using the two chainsaws (64 trees with the B chainsaw and 67 with the P chainsaw). The average wood volume felled and processed per day using the two chainsaws was 7.61 m^3 for B chainsaw and 7.05 m^3 for P.

Felled trees in the analyzed stand had an average diameter of 24 cm and an average height of 26 m (0,56 m^3 average wood volume per tree), and the two chainsaw models cut similar trees (Table 3). The values of the cut diameters had a dimensional range between a minimum of 16 cm and a maximum of 34 cm.

To fell and process all the trees, 27 batteries were needed (64 trees for B, i.e. 2.37 felled and processed trees per battery) as well as 26 refuels (67 trees for P, i.e. 2.58 felled and processed trees per full tank). In terms of gross working time, the average battery charge duration was 1.04 h, while the full tank duration for the P model was 1.12 h. Considering the chainsaws' "in use" working time, the average battery charge duration was 0.45 h, while the full tank duration for the P model was 0.47 h.

The gross working time was 28.25 h for B and 29.09 h for P (corresponding to a total of 5 working days for each chainsaw with an average of 6 h per day of gross time). The working time with the chainsaws "in use" was 12.26 h for both B and P chainsaws, corresponding to 43% of the gross working time for B and 42% for P. The distribution of total work time in the different work phases is available in Table 4.

Table 4. Distribution of work time between the considered work phases (in %).

Working Phase (Chainsaw "in use" or "not in use")	Work Time %			
	Operator 1		*Operator 2*	
	B	**P**	**B**	**P**
General preparation	4.5	4.2	3.1	6.2
Approach and tree study—in use	0.4	0.1	0.0	0.2
Approach and tree study—not in use	9.5	11.9	13.5	13.1
Felling cut—in use	9.3	8.9	7.5	9.0
Felling cut—not in use	1.3	1.3	2.6	1.9
Tree falling—in use	0.6	0.5	0.6	2.1
Tree falling—not in use	6.7	3.8	5.4	8.9
Stump cleaning—in use	1.6	2.2	3.0	3.6
Delimbing—in use	22.8	24.2	23.6	17.7
Delimbing—not in use	0.0	0.0	0.2	0.3
Cross-cutting—in use	6.9	6.8	10.2	9.0
Cross-cutting—not in use	0.4	0.0	0.1	0.3
Refuelling	7.8	5.0	4.9	4.3
Chain sharpening	0.0	1.8	0.5	1.0
Rest time	25.0	27.2	24.3	21.7
Problems and drawbacks	3.3	1.9	0.5	0.8

The average gross daily productivity was 1.27 $m^3 \cdot h^{-1}$ (average value: B = 1.34 $m^3 \cdot h^{-1}$; P = 1.21 $m^3 \cdot h^{-1}$), with a minimum of 1.05 $m^3 \cdot h^{-1}$ (values found in B) and a maximum of 1.64 $m^3 \cdot h^{-1}$ (values found in B). No significant differences were recorded when comparing the daily productivity of the two models of chainsaw (Table 5). Furthermore, the gross productivity of the two operators was compared and was found to be similar (average daily gross productivity values in $m^3 \cdot h^{-1}$: B = 1.34, of which 1.48 for operator 1 and 1.26 for operator 2; P = 1.21, of which 1.27 for operator 1 and 1.12 for operator 2).

Table 5. Gross daily productivity ($m^3 \cdot h^{-1}$), mean, maximum, minimum, and SD values for each chainsaw model (B = battery MSA220 C-B; P = petrol MS201 C-M) and for each operator (1 and 2). Similar lowercase letters show the absence of a significant difference (p value > 0.05).

Chainsaw Model	Operator	Minimum	Mean	Comparison			Maximum	SD
	1	1.31	1.48			a	1.64	0.23
B	*2*	1.05	1.26			a	1.45	0.20
	Tot	**1.05**	**1.34**	**a**			**1.64**	**1.27**
	1	1.07	1.27		a		1.42	0.18
P	*2*	1.09	1.12		a		1.15	0.04
	Tot	**1.07**	**1.21**	**a**			**1.42**	**1.09**

For B chainsaw, the average net daily productivity was 2.34 $m^3 \cdot h^{-1}$, with a minimum value of 2.00 $m^3 \cdot h^{-1}$ and a maximum of 3.30 $m^3 \cdot h^{-1}$. No statistically significant differences were found when comparing the daily net productivity of the two models of chainsaws (Figure 1). In fact, P was shown to be only 0.10 $m^3 \cdot h^{-1}$ lower than B.

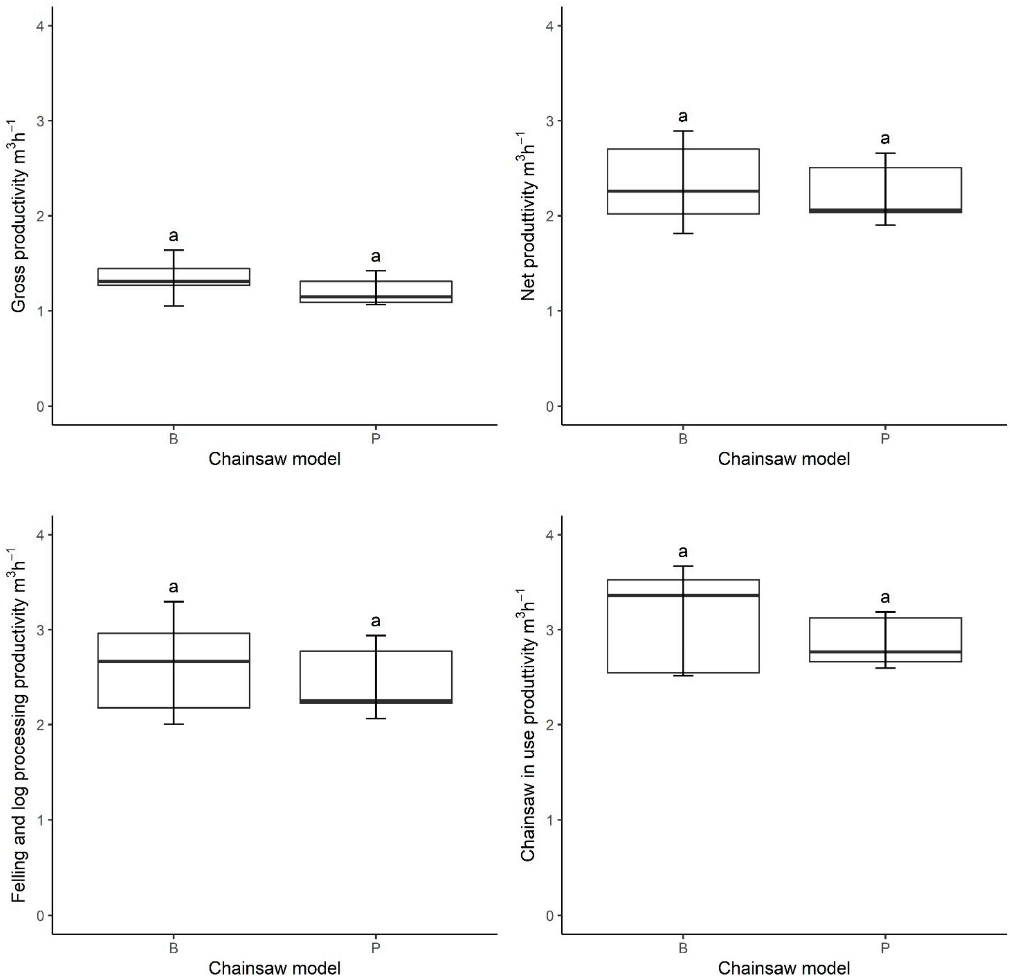

Figure 1. Productivities analysis (gross, net, felling, and processing, and chainsaw "in use") applied to the two models of chainsaw (B = battery MSA220 C-B; P = petrol MS201 C-M). The median and spreading-range values of productivity are represented. Similar lowercase letters reported above each boxplot show the absence of a significant difference (p value > 0.05) between chainsaws according to the ANOVA test and the multiple comparison using the HSD test.

Analysis of the felling and processing phases showed similar productivity for B and P, with average values of 2.62 $m^3 \cdot h^{-1}$ for B and 2.44 $m^3 \cdot h^{-1}$ for P. Maximum productivity values in the felling and processing phases were recorded during the use of B (3.30 $m^3 \cdot h^{-1}$) and minimum values were also found for B (2.00 $m^3 \cdot h^{-1}$); in fact, the productivity range of P showed a lower variability (range 2.06–2.94 $m^3 \cdot h^{-1}$).

Comparing productivity for B and P "in use", the average values were: for P, 2.86 $m^3 \cdot h^{-1}$, with a minimum value of 2.59 $m^3 \cdot h^{-1}$ and a maximum of 3.19 $m^3 \cdot h^{-1}$; and for B, an average 3.12 $m^3 h^{-1}$, with a minimum value of 2.51 $m^3 \cdot h^{-1}$ and a maximum of 3.68 $m^3 \cdot h^{-1}$ (Table 6). No significant differences were found when comparing the daily productivity of the two models of chainsaw (Figure 2). In fact, daily productivity related to the chainsaw "in use" phase of the battery-powered chainsaw was only 8% higher than that for P (difference of 0.26 $m^3 \cdot h^{-1}$ between B and P).

Table 6. Summary of all daily productivities (gross, net, felling, and processing, and chainsaw "in use") with mean, maximum, minimum, and SD values for each chainsaw model (B = battery MSA220 C-B; P = petrol MS201 C-M).

	Productivity (m^3h^{-1})							
	Gross		*Net*		*Felling/Log Processing*		*Chainsaw "in use"*	
Chainsaw Model	***B***	***P***	***B***	***P***	***B***	***P***	***B***	***P***
Mean	1.34	1.21	2.34	2.23	2.62	2.44	3.12	2.86
Min	1.05	1.07	1.81	1.90	2.00	2.06	2.51	2.59
Max	1.64	1.42	2.89	2.66	3.30	2.94	3.68	3.19
SD	1.27	1.09	0.45	0.33	0.54	0.38	0.55	0.27

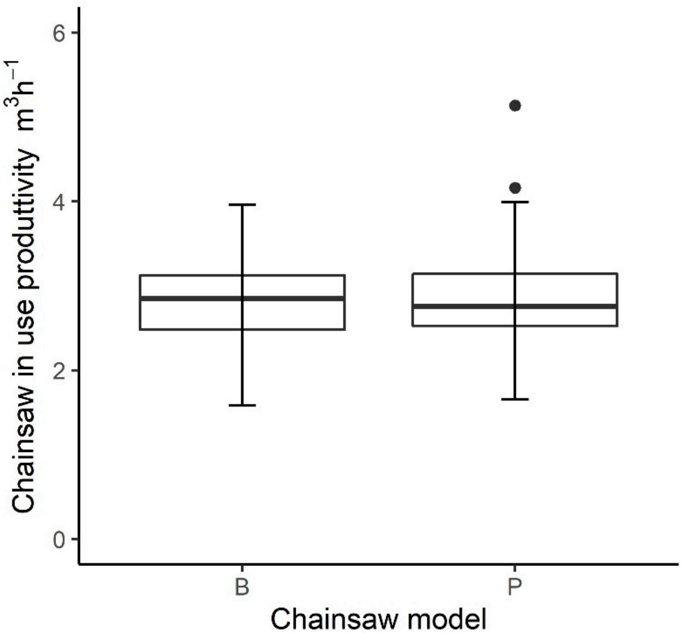

Figure 2. Results of the analysis of the productivity per tree of the chainsaw "in use" for each chainsaw model (B = battery MSA220 C-B; P = petrol MS201 C-M) in the sub-sample of 54 trees. The median and spreading-range values are represented. Black dots are outliers.

Considering the sub-sample of 54 out of 131 trees homogeneous in terms of DBH distribution, the performance analysis of the B and P chainsaws, in relation to the volume of each tree during the chainsaw "in use" phases, showed no significant difference (Figure 2). Moreover, no significant differences were found when analysing the single working phases (Table 7).

Table 7. Results of the productivity analysis per tree in single working phases (felling, delimbing, and cross-cutting), applied to each chainsaw model (B = battery MSA220 C-B; P = petrol MS201 C-M). Similar lowercase letters show the absence of a significant difference (p value > 0.05).

	Productivity Chainsaw "in Use" (m^3h^{-1})—Sub-Sample 54 Trees											
	Felling				*Delimbing*				*Cross-Cutting*			
Chainsaw Model	**Median**	**Mean**		**SD**	**Median**	**Mean**		**SD**	**Median**	**Mean**		**SD**
B	15.39	17.11	a	7.03	5.16	5.21	a	1.29	13.49	14.42	a	5.15
P	15.08	15.04	a	4.44	5.30	5.75	a	1.90	16.92	16.76	a	7.96

4. Discussion

This study highlighted that all the productivities investigated in conifer-thinning operations showed similar results for battery- and petrol-powered chainsaws, with no recorded statistical differences. Therefore, considering the obtained results, the battery chainsaw represents a good alternative to the petrol chainsaw in terms of productivity in small tree felling and processing operations.

The reasons behind the obtained non-significant differences in terms of productivity are probably related to the limited diameters of the processed trees. In another study performed by Neri et al. [28], productivity in cross-cutting operations was lower for the battery chainsaw (MS 220 CB) than for the petrol-powered chainsaw (Stihl MS 201 C-M); thus a lower performance by the battery chainsaw was expected also in this study, but it was not found. The reason probably relates to the succession of working phases, where the demand for maximum performance is required only a few times during the working day. In fact, maximum cutting efficiency is requested in felling and cross-cutting phases only when operating with trees of larger diameter. For this reason, the study results should not be extended to bigger trees, where technological differences in chainsaws can be reflected more clearly regarding productivity, and this should be properly investigated. Moreover, our findings are in line with previous studies that analyzed battery chainsaws, even if they compared the cutting efficiency only in cross-cutting operations [28,29].

Another factor that may affect and increase cutting time, as stated by Neri et al. [28] under controlled conditions, is the presence of wood defects, such as knots, which, with their higher wood density, may worsen chainsaw performance [30,31]. This effect is most significant in conifer species such as Douglas fir and black pine, but it was not investigated in this study.

Furthermore, our research shows that battery charging capabilities are currently one of the biggest problems to solve in order to enable the use of battery chainsaws in real forestry operations, at least in those involving small trees. In fact, in this study, a 36 V/7.2 Ah battery performed work effectively for about 30 min (chainsaw in use), which is the same value as that recorded for one full tank of the petrol chainsaw [6]. It should be also considered that some of the fuel in petrol chainsaws is also used at idle speed, which requires an additional 37.4% [6] of time on average, when considering the effective working time. Therefore, for use in forestry, the main problem to be solved is the number of batteries (or charges) required for a large number of hours of running the chainsaw under full load [7]. In fact, an empty petrol chainsaw simply needs to be refuelled, while exhausted batteries must be replaced with fully charged batteries, which means that several sets of batteries are required, or a system to allow an easy charging process in a forest setting is needed. In practice, the substitute for a standard double tank for mix (5 L) and chain oil (3 L) is a set of 8–10 batteries; in the first case, a full tank weighs less than 10 kg, while a set of batteries weighs about double that (2 kg per battery). To seek to address this problem, an option has been developed by some battery-powered chainsaw manufacturers: it consists of a high-capacity battery carried on the operator's back [6]. As a result of this system, battery autonomy is significantly increased, but operators must each bear a load of 7 kg on their back, exposing them to the associated ergonomic problems that would arise. Moreover, in terms of cost, the batteries used in this study cost around EUR 500 each, which requires a significant initial investment. To fully understand the cost implications, a detailed economic analysis would be interesting. Moreover, at the end of the workday, the operator needs to spend time putting the batteries on charge, in order to be ready for the next workday.

Other limitations that can slow down the development of battery systems in comparison with traditional petrol ones are related to the availability of resources for the manufacturing of lithium-ion cells [32,33] and interests related to the oil industry, despite the current goals of a constant reduction of emissions into the atmosphere. These are crucial topics for the continuing development of electric engines. However, our research showed that, despite a worse cutting performance [28] by the battery-powered chainsaw, in this study, productivity in felling and processing operations was not affected. Furthermore, battery technology is undergoing increasingly rapid evolution and the improvements in terms of performance are evident year by year [18,34]. In this context, in recent years battery power has been introduced to the world of chainsaws, firstly in gardening and tree-climbing, especially for pruning, and in the past few years it has appeared in forestry [35,36].

For all these reasons, battery-powered chainsaws can be considered as an alternative to internal-combustion-engine chainsaws for pruning and first thinning operations in conifer stands. The benefits of using them relate to the aspects of lower pollutant-gas emissions, acoustic pollution, and vibration levels than those caused by electric motors.

5. Conclusions

In this study, the performance in terms of productivity of battery- and petrol-powered chainsaws in regular forest operations was investigated. The chainsaws were compared during felling and processing operations in a conifer thinning exercise, resulting in comparable levels of productivity.

These results show that battery-powered chainsaws are a good alternative to petrol chainsaws for first thinning operations or in those applications where it is recommended to avoid loud noise and/or pollution. However, even if battery-powered chainsaws have produced interesting results in terms of reliability and productivity, there remain some technical aspects to be improved for their regular use in the forest. The limiting factor regarding work in forest operations seems to be related only to the number of batteries (or charges) needed to complete a standard eight-hour working day in the forest. Considering that the evolution of electrical tools for forest settings is intensifying, and more powerful batteries and electrical engines will be developed, researchers will have to move forward in evaluating the performance of these tools to keep on testing their usability and reliability in forest operations. In this context, a detailed study could be carried out to understand if different weather conditions can positively or negatively affect the performance of battery chainsaws in terms of both productivity and charge duration. Moreover, among technical and safety issues, it will be crucial to evaluate the environmental performance of battery-chainsaws, on a local but most importantly on a large scale (life cycle assessment).

Finally, future developments in this research field can focus on cost evaluation, which must consider the total number of batteries needed for a whole working day and the energy required to recharge them throughout the technical life of the machine.

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