forests

Article

Energy Consumption and Cutting Performance of Battery-Powered Chainsaws

Zdravko Pandur [1], Marin Bačić [1,*], Marijan Šušnjar [1], Matija Landekić [1], Mario Šporčić [1], Branimir Jambreković [2] and Kruno Lepoglavec [1]

[1] Faculty of Forestry and Wood Technology, Institute of Forest Engineering, University of Zagreb, Svetošimunska Cesta 23, 10000 Zagreb, Croatia; zpandur@sumfak.unizg.hr (Z.P.); msusnjar@sumfak.unizg.hr (M.Š.); mlandekic@sumfak.unizg.hr (M.L.); msporcic@sumfak.unizg.hr (M.Š.); klepoglavec@sumfak.unizg.hr (K.L.)
[2] Faculty of Forestry and Wood Technology, Institute of Wood Science, University of Zagreb, Svetošimunska Cesta 23, 10000 Zagreb, Croatia; bjambreko@sumfak.unizg.hr
* Correspondence: mbacic1@sumfak.unizg.hr

Abstract: The aim of this research is to measure the energy consumption and compare the cutting performance of three types of battery-powered chainsaws (Stihl MSA 200, Stihl MSA 220, and Stihl MSA 300). Tested chainsaws were powered by two different battery packs (Stihl AP 300 S and Stihl AP 500 S) with different energy capacity and output current when cutting two wooden beams, European beech (*Fagus sylvatica* L.) and black locust (*Robinia pseudoacacia* L.) with different densities and moisture content. Energy consumption was measured using a multimeter built-in battery charger housing, and consumed energy was noted in watt-hours. Each individual cut was recorded with an action camera at 60 frames per second, and the duration of the cuts recorded in centiseconds was observed on the obtained recordings. Results show significant differences in energy consumption and cutting duration between individual chainsaw/battery combinations. Energy consumption ranged from 2.45 to 4.50 Wh per cut for beech (Stihl MSA300E_AP500S and Stihl MSA220_AP300S, respectively) and from 3.10 to 5.00 Wh per cut for black locust (Stihl MSA300M_AP500S and Stihl MSA220_AP500S, respectively). Duration of the cut ranged from 3.48 to 9.24 s per cut for beech (Stihl MSA300M/H_AP500S and Stihl MSA220_AP300S, respectively) and from 3.74 to 9.35 s per cut for the black locust (Stihl MSA300M_AP500S and Stihl MSA220_AP300S, respectively). In general, it can be concluded that more powerful chainsaw/battery combinations (Stihl MSA300_AP500S) consumed less energy per cut and had better cutting performance (shorter cut). In that regard, more powerful chainsaws had greater cutting efficiency, i.e., more cuts on one charge (battery) but shorter cutting time on one charge. The effect of tree species (fresh-sawed beech/air-dried black locust) on energy consumption and cutting performance is absent on the most powerful chainsaw/battery combinations. Today, lithium-ion batteries still have 70 times less energy density than petrol. However, if there is a significant increase in the energy density of the batteries in the coming times, battery chainsaws will most certainly displace petrol chainsaws from use in the future.

Keywords: battery chainsaws; energy consumption; cutting performance

check for updates

Citation: Pandur, Z.; Bačić, M.; Šušnjar, M.; Landekić, M.; Šporčić, M.; Jambreković, B.; Lepoglavec, K. Energy Consumption and Cutting Performance of Battery-Powered Chainsaws. *Forests* **2023**, *14*, 1329. https://doi.org/10.3390/f14071329

Academic Editors: Mariusz Kormanek, Stanisław Małek, Jiří Dvořák and Jozef Krilek

Received: 26 May 2023
Revised: 15 June 2023
Accepted: 26 June 2023
Published: 28 June 2023

1. Introduction

Despite the development of technology and forestry machinery for felling and processing, most trees in the world are still cut manually with chainsaws, especially in less developed countries and in countries with a higher proportion of natural forests [1–3]. Energy consumption and the amount of emissions of harmful exhaust gases per unit of volume of wood produced are significant, although a downward trend is noticeable in the last few decades [4]. The petrol-powered chainsaw has a lower energy consumption per unit compared to the harvester [3,5], but due to the two-stroke engine, the emission of harmful exhaust gases is very unfavorable [6]. In addition to harmful exhaust gases, operators are also exposed to a high noise level [7] which can lead to hearing loss [8], as well as the harmful impact of vibrations transmitted to the hand–arm system [9].

Battery-powered chainsaws do not emit harmful exhaust gases [10] because instead of a two-stroke petrol engine, a brushless DC (Direct Current) motor is installed in such chainsaws, which reduces noise and vibration levels [10,11]. Use of battery-powered chainsaws, in comparison to the petrol ones, can reduce the daily vibration exposure by more than 51% and the noise dose by 11% [12]. Due to these benefits, battery-powered chainsaws should be deployed in all non-professional and professional applications [10]. The major problem of battery-powered chainsaws is insufficient power capacity and overheating of battery packs due to hard work, which requires the use of several batteries for normal work [9], and consequently, lower productivity [9,13]. The latest research proved that there is no significant difference in productivity between the equal power of battery and petrol chainsaws in real conditions [14]. Because of the lower power, lower efficiency, and lower speed of the chain rotation of battery-powered chainsaws, their usage could be viable only in plantation forests due to the smaller and more homogeneous tree dimensions [10].

The cutting efficiency and energy consumption of chainsaws are influenced by the chain type, chain tensioning [15], wood density, i.e., tree species, moisture content [16,17], and mostly by the chain sharpness [10]. Also, the cutting force issues could be different using battery-powered chainsaws in comparison to traditional petrol-powered chainsaws. The assumption is that higher cutting force requirements are needed for higher wood densities [18].

In recent years, leading manufacturers of power tools constantly improve the performance of battery-powered chainsaws, and nowadays, thanks to the improvements in electrical-instrument technologies, the declared power values of battery-powered chainsaws are comparable with their lightweight petrol counterparts [18,19]. Also, the performance of the modern Li-Ion (lithium-ion) batteries (higher output current, prolonged battery life) and improved brushless DC motors in combination with a BMS (battery management system) can enable an effective working time of more than 50 min with one charge [13,18,20]. Less maintenance, absence of harmful exhaust gasses, absence of cables, less workload (noise level, vibrations), and high output torque at low motor speeds are some other advantages of battery-powered chainsaws [21,22].

Some main disadvantages of battery-powered chainsaws are the high price and high weight of the battery pack, while at the same time, the battery pack still has extremely low energy density comparable to petrol [23]. For professional users in forestry, 8–10 battery packs will be enough for the whole working day, which weigh in at a total of around 20 kg and require a significant initial investment (the cost of one battery pack is around EUR 500). The possibility of charging batteries at the worksite is the current greatest limitation to the use of battery-powered chainsaws. It is also important to mention the availability of resources for the manufacturing of lithium-ion cells that can slow down the development of battery systems in comparison with traditional petrol ones [14,24].

The aim of this research is to measure the energy consumption and compare the cutting performance of three types of battery-powered chainsaws. Tested chainsaws were powered with two different battery packs with different energy capacities and output currents. Chainsaws were tested during the cutting of two wooden beams of different densities and moisture content. The main hypothesis is that the lowest energy consumption and the highest cutting time will occur for the chainsaw with the lowest electric motor power and the slowest chain rotation speed. The second hypothesis is that the chainsaws powered with a battery pack with a higher capacity and output power will have higher efficiency. The third hypothesis is that in wood with higher dry density and lower moisture content (black locust), energy consumption will be higher.

2. Materials and Methods

Three types of battery chainsaws and two types of batteries were observed in this study (Table 1).

Table 1. Chainsaw and battery characteristics.

Chainsaw Type	Mass [1]	Max Power Output [2]	Bar Length	Chain Type	Chain Speed
Stihl MSA200	2.9 kg	1.1 kW	30 cm	1/4″ PM3	19 m/s
Stihl MSA220	3.6 kg	2 kW	40 cm	3/8″ PS3	24 m/s
Stihl MSA300	4.5 kg	3.3 kW	45 cm	0.325″ RS Pro	20; 24; 30 m/s [3]
Battery Type	**Mass**	**Nominal Voltage**	**Capacity (Amp-Hours)**	**Capacity (Watt-Hours)**	**Li-Ion Technology**
Stihl AP300S	1.8 kg	36 V	7.2 Ah	281 Wh	Cylindrical cells
Stihl AP500S	2 kg	36 V	8.8 Ah	337 Wh	Laminated

[1] without battery, bar, chain, and oil; [2] measured during the test; [3] values for three operating modes.

As the chainsaw MSA300 has three operating modes, of which two are unlocked while using an AP500S battery, the total number of chainsaw/battery combinations observed was 8. Operating modes were denoted as MSA300E—eco mode, MSA300M—medium mode, and MSA300H—high mode. Chainsaw energy consumption and cutting performance were measured on 16 × 16 cm beams of European beech fresh-sawed wood and black locust air-dried wood. The raw density and the moisture content of the sawed wood beams were determined in the Laboratory of Anatomical Properties of Wood and Wood Preservation at the Faculty of Forestry and Wood Technology (Table 2). A total of 40 cuts were made with each chainsaw/battery combination, 20 per beechwood beam and 20 per locust beam. The MSA200 was excluded from cutting a locust beam due to overheating of the chain and bar.

Table 2. Density and moisture content of the wood beams.

Species	Raw Density (g/cm^3)	Dry Density (g/cm^3)	Moisture Content (%)
European beech	0.847	0.678	47.59
Black locust	0.783	0.742	15.72

During the cuts, chainsaw operator input was minimal as the chainsaw would make the cut under its own weight. The operator's task was to activate the switch and keep the chainsaw at 90 degrees according to the beam. All the tested chainsaws were equipped with new chains. After each 20 cuts, the battery was fully charged and the chain properly sharpened.

To measure the energy consumption of each cut, a measuring instrument—multimeter Pichler C7282—was connected to the positive and negative pins of a Stihl AL300 charger housing. An external battery powered the multimeter. Lead wires of an original Stihl connecting cable were connected on the load side of the multimeter, and a Stihl AP adapter was used to provide power to a chainsaw. Two additional signal wires required for chainsaw operation were connected directly to Stihl AL300 housing pins. To power up a chainsaw, batteries were inserted in the Stihl AL300 housing (Figure 1). The multimeter instantaneously measured voltage (V), amperage (A), and electric power (W). Furthermore, with the passage of time under load, information on cumulative amp-hours (Ah) and watt-hours (Wh) was also provided. Through a simple subtraction in Microsoft Excel®, energy consumption of an individual cut expressed in Wh was calculated.

Chainsaw cutting performance was measured with a GoPro® camera. Videos were taken at 60 frames per second and reviewed in VLC media player®. The cutting time of each cut was noted in centiseconds.

Figure 1. Measuring setup (a—multimeter Pichler C7282, b—Stihl AL300 charger housing, c—battery pack, d—GoPro® camera, e—chainsaw, f—wood beam, g—field computer).

Statistical analysis was conducted in SPSS® (IBM-SPSS Inc., version 28, Armonk, NY, USA). Due to the nature of the obtained data (normality and homogeneity of variance), non-parametric tests were used. To test differences in energy consumption and cutting duration between all chainsaw/battery combinations a Kruskal–Wallis test ($p < 0.05$) was used. Significance values were adjusted by the Bonferroni correction for multiple tests. Wilcoxon signed rank test ($p < 0.05$) was used to test the differences in energy consumption and cutting duration between two beams (beech and locust) that were cut with the same chainsaw/battery combination. Furthermore, the predicted number of cuts on one charge (battery) was calculated by dividing the declared capacity of the battery (Wh) by the median energy consumption of a single cut. The predicted cutting duration on one charge was calculated by multiplying the predicted number of cuts with the median cutting time of a single cut.

3. Results

3.1. Energy Consumption

Recorded energy consumption shows a significant difference between approximately half of the pairs of chainsaw/battery combinations both in beechwood and locust beams.

In the beechwood beam, out of 28 tested pairs of chainsaw/battery combinations, statistically significant energy consumption differences were confirmed between 15 pairs (Figure 2).

In the locust beam, out of 15 tested pairs of chainsaw/battery combinations, statistically significant energy consumption differences were confirmed between 8 pairs (Figure 3).

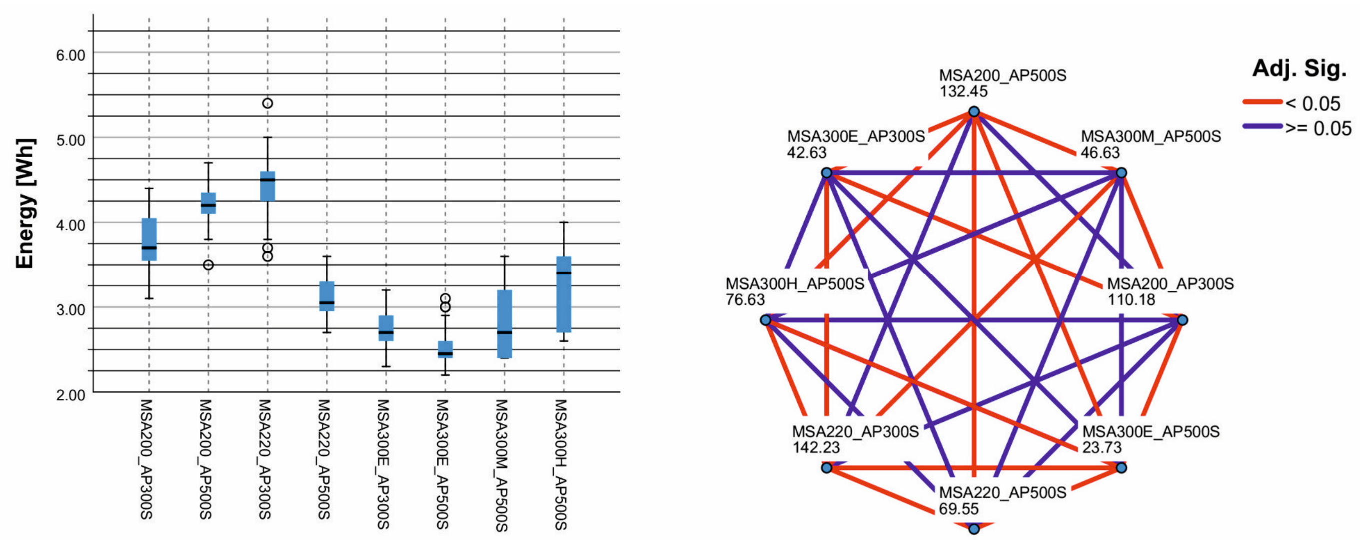

Figure 2. Energy consumption per cut in beechwood beam; box plot (**left**); Kruskal–Wallis test results with mean rank displayed (**right**).

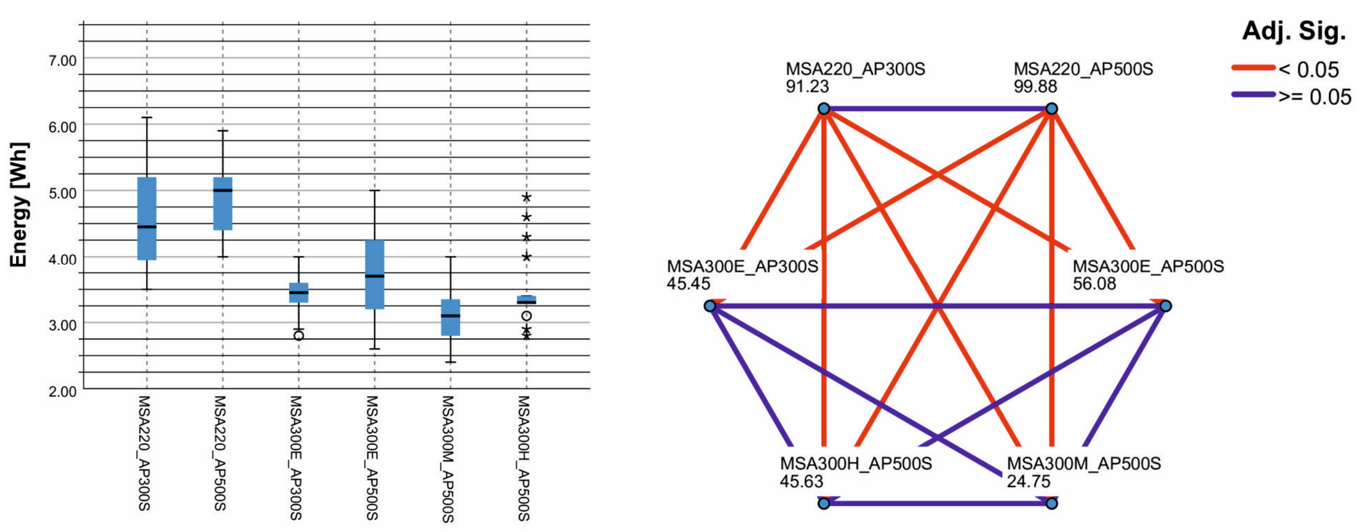

Figure 3. Energy consumption per cut in locust beam; box plot (**left**); Kruskal–Wallis test results with mean rank displayed (**right**).

3.2. Cutting Performance

Observed cutting duration shows a significant difference between approximately half of the pairs of chainsaw/battery combinations in beechwood beams and two-thirds in locust beams.

In the beechwood beam, out of 28 tested pairs of chainsaw/battery combinations, statistically significant cutting duration differences were confirmed between 15 pairs (Figure 4).

In the locust beam, out of 15 tested pairs of chainsaw/battery combinations, statistically significant cutting duration differences were confirmed in 10 pairs (Figure 5).

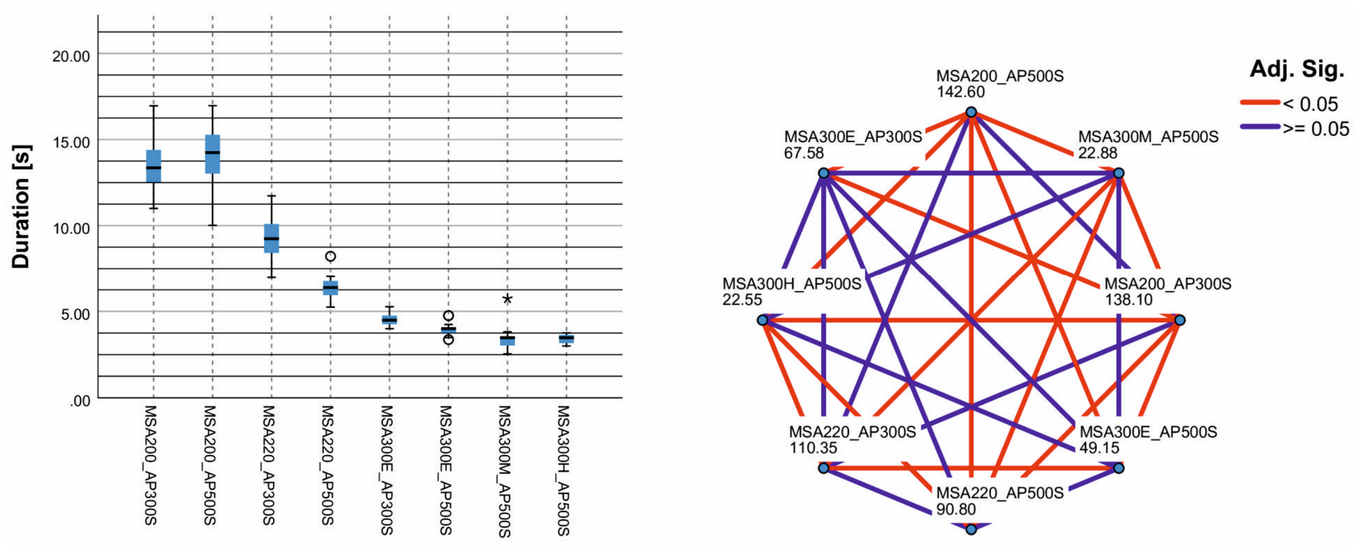

Figure 4. Duration of cut in beechwood beam; box plot (**left**); Kruskal–Wallis test results with mean rank displayed (**right**).

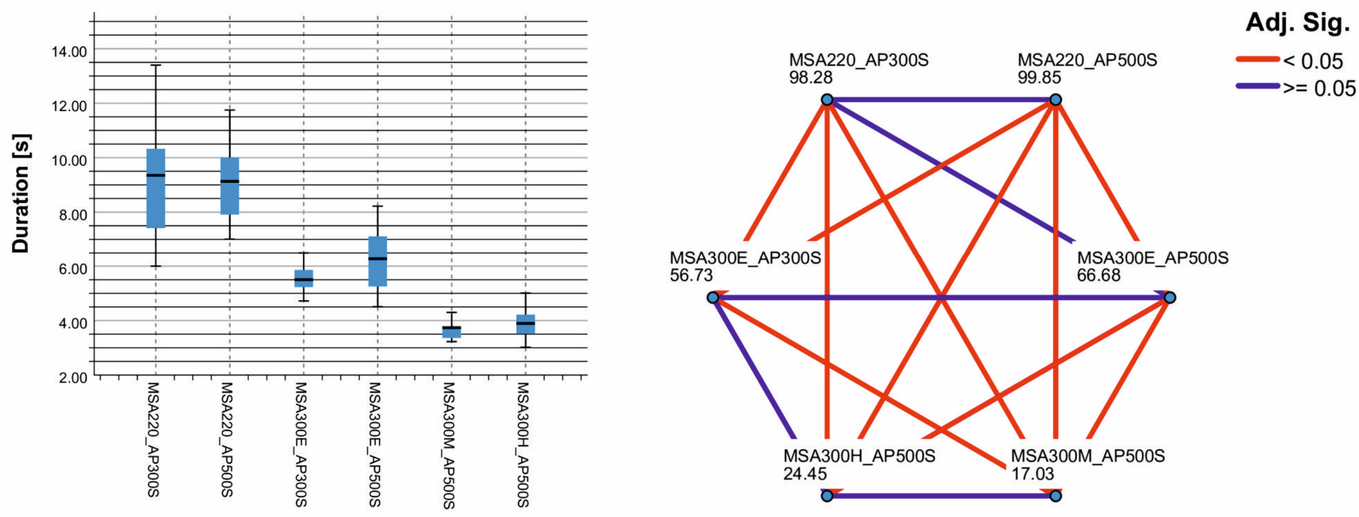

Figure 5. Duration of cut in locust beam; box plot (**left**); Kruskal–Wallis test results with mean rank displayed (**right**).

3.3. *Differences between Tree Species (Beams)*

A statistically significant difference between two beams in energy consumption was confirmed for three chainsaw/battery combinations out of six that were tested. In terms of cutting duration, statistically significant differences between two beams were confirmed for four chainsaw/battery combinations out of six that were tested.

For chainsaw/battery combinations MSA220_AP500S, MSA300E_AP300S, and MSA300E_AP500S, there is a statistically significant difference in energy consumption between the two different beams (Table 3).

For chainsaw/battery combinations MSA220_AP500S, MSA300E_AP300S, MSA300E_AP500S, and MSA300H_AP500S, there is a statistically significant difference in cutting duration between the two different beams (Table 4).

Table 3. Wilcoxon signed rank test results for energy consumption (Wh) per cut.

Chainsaw/Battery Combination	Beech Mean Rank	Beech Median	Locust Mean Rank	Locust Median	Z Value	*p* Value
MSA220_AP300S	10.07	4.50	9.96	4.45	−0.988	0.323
MSA220_AP500S	0.00	3.05	10.50	5.00	−3.923	<0.001
MSA300E_AP300S	2.00	2.70	10.95	3.45	−3.852	<0.001
MSA300E_AP500S	0.00	2.45	10.50	3.70	−3.922	<0.001
MSA300M_AP500S	9.80	3.25	9.38	3.10	−1.592	0.111
MSA300H_AP500S	8.07	3.40	11.13	3.30	−1.552	0.121

Table 4. Wilcoxon signed rank test results for duration (s) of cut.

Chainsaw/Battery Combination	Beech Mean Rank	Beech Median	Locust Mean Rank	Locust Median	Z Value	*p* Value
MSA220_AP300S	9.27	9.24	11.00	9.35	−0.282	0.778
MSA220_AP500S	0.00	6.38	10.50	9.13	−3.921	<0.001
MSA300E_AP300S	1.00	4.50	11.00	5.50	−3.884	<0.001
MSA300E_AP500S	1.00	4.00	11.00	6.27	−3.883	<0.001
MSA300M_AP500S	9.07	3.48	11.27	3.74	−1.550	0.121
MSA300H_AP500S	9.33	3.48	10.71	3.90	−2.876	0.004

3.4. Predicted Performance on One Charge

The lowest predicted number of cuts on one charge was noted for the beechwood beam on an MSA220_AP300S chainsaw/battery combination, while the highest was also for the beechwood beam on an MSA300E_AP500S combination. Generally, for the same chainsaw/battery combination, more cuts on one charge were predicted for the beechwood beam (Figure 6).

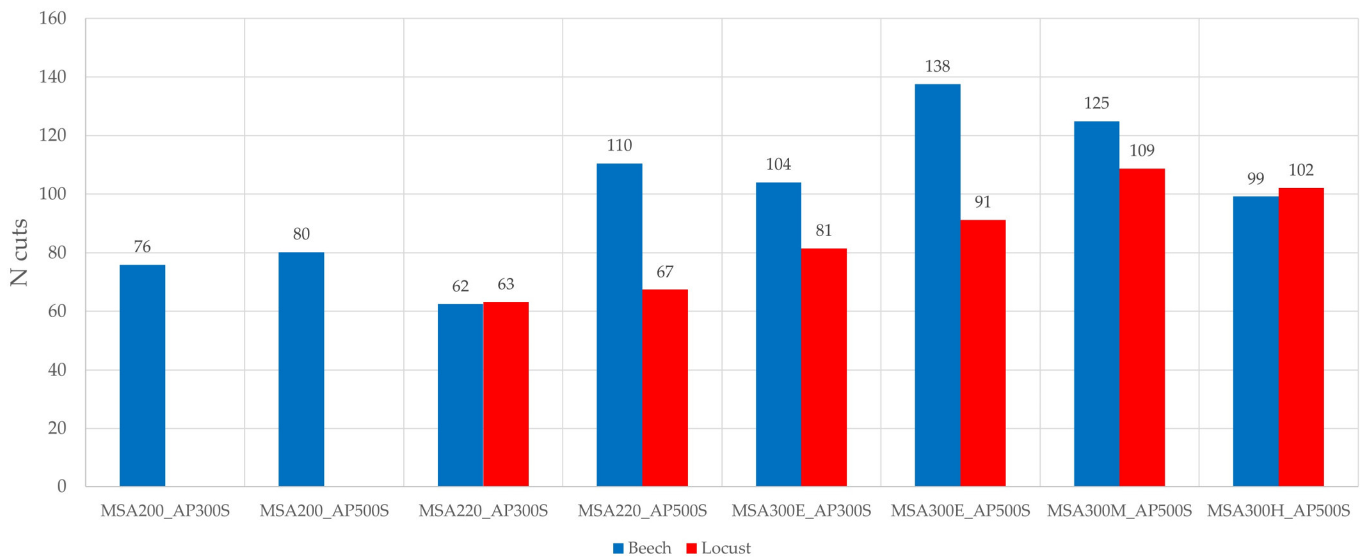

Figure 6. Predicted number of cuts on one charge.

The least cutting time was predicted for the beechwood beam with an MSA300H_AP500S combination. With an MSA200_AP500S combination, the greatest cutting time was noted. There is no clear indication whether the tree species is influencing total cutting time on one charge (Figure 7).

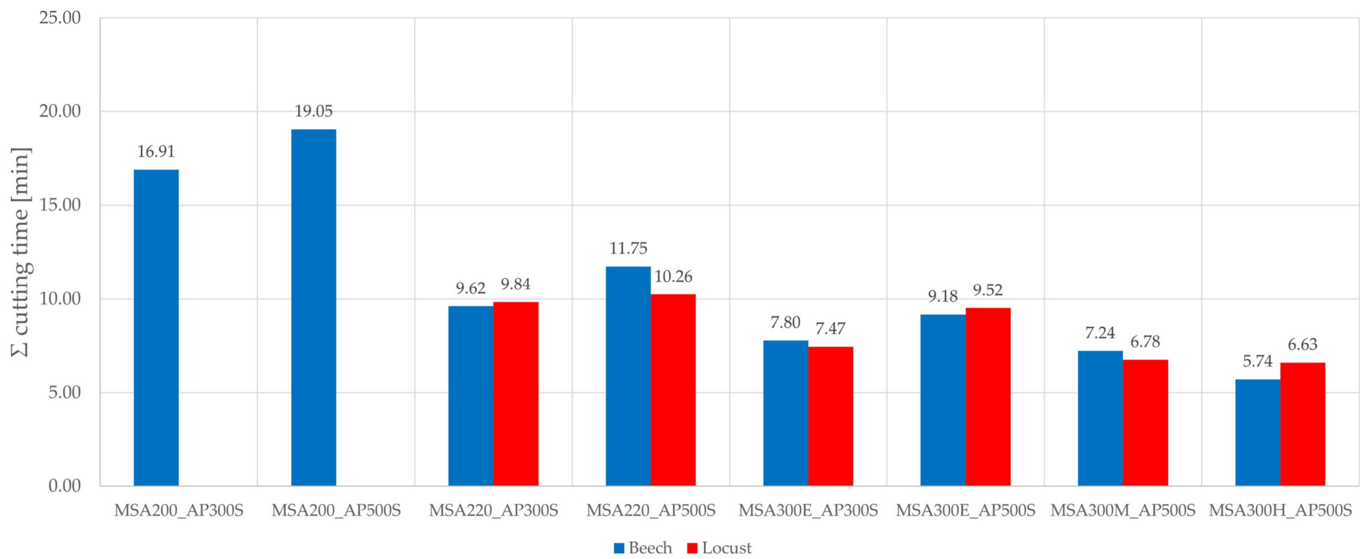

Figure 7. Predicted total cutting time on one charge.

4. Discussion

The main goal of this research was to determine the electrical energy consumption of three different models of battery chainsaws with the hypothesis that the least powerful model consumes the least energy. According to the results (Figure 2), this hypothesis was not accepted. The highest energy consumption was measured for the least powerful MSA200 chainsaw and the MSA220 chainsaw with an AP300S battery, respectively. When cutting a beechwood beam with the MSA220 chainsaw, a statistically significant difference was observed when using different batteries, i.e., a higher energy consumption was measured when using the AP300S battery type. We cannot give a coherent explanation for such a result, except that there was an anomaly during the measurement because, with other chainsaws, no statistically significant difference was observed when using different batteries to cut wooden beams of different densities and moisture content. The lowest energy consumption was observed with the largest chainsaw model when it was operating in eco mode (MSA300E) in the cutting of beechwood beams (Figure 2) or medium mode (MSA300M) in the cutting of locust beams (Figure 3). It is important to emphasize that in cutting a locust beam, there is no statistically significant difference in energy consumption, regardless of the operating mode of the MSA300 chainsaw. At the same time, higher consumption and a statistically significant difference in energy consumption were observed with the less powerful MSA220 chainsaw compared to the MSA300 chainsaw (Figure 3). Battery-powered chainsaws have significantly higher energy efficiency compared to petrol-powered chainsaws [9]. The difference is a consequence of the high efficiency of the brushless DC motor (>90%) in comparison to a two-stroke petrol engine (≈25%) [25].

The next hypothesis of this research was that the longest cutting duration of a wooden beam will be measured with the least powerful chainsaw, which has the slowest rotation speed of the chain but also the smallest pitch of the chain. This hypothesis was confirmed. According to Figure 4, the MSA200 chainsaw (13.6/14.4 s per cut) took the longest time to cut a beechwood beam. The MSA220 chainsaw took a little less time at 9.24/6.38 s per cut, and the most powerful chainsaw MSA300 had the fastest time of 3.48 s per cut in medium and high modes of operation, during which this chainsaw develops the highest power and chain speed of 24 and 30 m/s, respectively. Neri et al. [18] presented similar results for MSA220 (median value was 8.87 s per cut) during crosscutting of a beechwood beam (15 × 15 cm) with a similar dry density and moisture content. Compared with petrol-powered chainsaws, the battery-powered chainsaw has the highest (slowest) cutting time [18]. When cutting a locust beam (Figure 5), a similar situation was observed, and the results of cutting a locust beam with the least powerful MSA200 chainsaw were not shown because it was not possible to make all 20 cuts, with both types of batteries, using that chainsaw. The problem with the MSA200 chainsaw is that it is standardly equipped with a chain (Table 1), the basic characteristic of which is that its cutting teeth are small, and in hardwood such as dry locust beams, they do not make a wide enough cut, resulting in increased friction between the chain and the wood, and ultimately result in excessive heating of the chain and the bar and the appearance of smoke. The influence of chain sharpness [10] can be omitted because the tested chainsaws were equipped with new chains that were properly sharpened after each series of crosscutting.

The assumption before the research was that there would be a higher energy consumption as well as cutting duration on the locust beams, which have a higher wood density and lower moisture content compared to beechwood beams [16,18] (Table 2). A statistically significant difference in energy consumption was observed when cutting with the chainsaws MSA220_AP500S, MSA300E_AP300S, and MSA300E_AP500S (Table 3), while statistically significant differences in the cutting duration were observed with the mentioned chainsaws and with the chainsaw MSA300H_AP500S (Table 4).

According to the technical specifications of the batteries used (Table 1), based on their energy capacity (Wh) and the energy measured in this research, Figure 6 shows the total number of cuts (beechwood and locust beams with dimensions of 16 cm × 16 cm) that could be achieved in practice with the researched chainsaw models and used batteries. The most cuts (138) could be made in a beechwood beam with the most powerful chainsaw in eco mode and with a higher-capacity battery (MSA300E_AP500S). The fewest cuts (62) could be made with the MSA220_AP300S chainsaw in a beechwood beam, but this result should be taken with a grain of salt due to the already-mentioned anomaly observed in Figure 2. An interesting observation of the most powerful MSA300 chainsaw is that with an increase in the chain speed, the difference in the number of cuts between beechwood and locust beams decreases. In the high mode of operation where the chain rotation speed is the highest (30 m/s), it is possible to make more cuts in locust (102) rather than in beechwood (99) beams. With the aforementioned chainsaw, there is a visible negative trend in the number of cuts with an increase in the chain speed in the beechwood beam, while in the case of a locust beam, a slightly positive trend in the number of cuts is visible. Based on the obtained results, we can ask the following question: does a higher wood density with less moisture content have a favorable effect on the possible number of cuts achieved with an increase in the chain speed? With a larger-capacity battery (AP500S), it is evident that more cuts can be made, which is expected.

The longest effective cutting time (19.05 min) with one battery charge can be achieved with the least powerful chainsaw in combination with a stronger battery (MSA200_AP500S), while the shortest time (5.74 min) can be achieved with the most powerful chainsaw in high mode when cutting a beechwood beam (MSA300H_AP500S) (Figure 7). Such results are expected because the MSA300 chainsaw in a high mode of operation develops a power of over 3 kW, while the MSA200 chainsaw develops three times less power at only 1 kW (Table 1).

Battery technology and power tools are still in the development phase, and it will take some time to reach the level of efficiency that petrol-powered power tools have, especially chainsaws. The researched chainsaw Stihl MSA300, according to the manufacturer, belongs to the category of professional chainsaws for use in forestry, and based on most of its characteristics, it can be compared with the professional petrol chainsaw MS261 in regard to the power of the drive motor, high chain rotation speed, and anti-vibration system but in an increased mass, according to which we can compare it with a higher category of petrol chainsaws and especially not with the autonomy that is still insufficiently provided even by the improved Stihl AP500S battery with a higher output power (40% more compared to the Stihl AP300S). Even less researched chainsaws, which do not fall into the category of professional chainsaws, impress with their capabilities of performing work (in this research when cutting beams), especially the Stihl MSA220. Of course, battery chainsaws have their application in certain branches of the economy, primarily due to the reduced noise level and the absence of harmful exhaust gases [26] but also due to the speed of operation, which is next to petrol chainsaws [12]. For battery chainsaws to be used more in professional forestry, it is necessary to have more batteries, which require a higher financial expenditure, or at least two batteries with the possibility of charging at the worksite [14]. A significant problem that was observed during this research is the prolonged charging time of the Stihl AP500S battery, because this type of battery has a very low high-temperature tolerance, so after use, it must first be cooled down to an acceptable temperature to start the charging, which ultimately further reduces the working performance of the battery chainsaw.

5. Conclusions

Based on the obtained results and the conducted discussion, the following can be concluded:

- The smallest (least powerful) chainsaw has the highest energy consumption, while the largest tested chainsaw has the lowest energy consumption in the eco/medium operating mode;
- The smallest chainsaw, due to the low chain rotation speed, has the longest required cutting time and the lowest efficiency;
- By using a battery with a higher capacity and higher output power (Stihl AP500S), no higher efficiency was observed in all tested chainsaws;
- With a higher chain rotation speed, the cutting time is reduced;
- It cannot be confirmed with certainty that the density and moisture content of the wood significantly affects energy consumption and cutting time;
- For professional use in forestry, it is recommended to use the Stihl MSA300 chainsaw with the Stihl AP500S battery in eco/medium operating mode, as this chainsaw achieves the best results in terms of energy consumption and cutting efficiency;
- For small works, like selective cleaning operations in young forestry stands or pruning operations in urban areas, smaller chainsaws (Stihl MSA 200 and Stihl MSA 220) are very suitable because of their lightweight and satisfying cutting performance.

Cutting time on one battery charge, which according to the obtained results, is less than 6 min, is extremely short, regardless of the high technology of battery manufacturing, highly efficient brushless motors, and the perfected battery management system. Still, the energy density of the Li-Ion battery is about 70 times lower than the energy density of petrol. However, if there is a significant increase in the energy density of the batteries in the coming times, battery chainsaws will most certainly displace petrol chainsaws from use in the future.

Author Contributions: Conceptualization, Z.P. and M.B.; Data curation, B.J.; Formal analysis, M.Š. (Mario Šporčić); Investigation, Z.P. and M.B.; Methodology, Z.P. and M.B.; Resources, K.L.; Software, M.B.; Supervision, Z.P.; Validation, Z.P., M.B., M.Š. (Marijan Šušnjar) and M.L.; Visualization, M.B.; Writing—original draft, Z.P. and M.B.; Writing—review and editing, Z.P. and M.B. All authors have read and agreed to the published version of the manuscript.

Funding: The APC was funded by the Faculty of Forestry and Wood Technology of Zagreb University.

Data Availability Statement: The data supporting this study may be provided upon reasonable request to the authors of the study.

Acknowledgments: Special thanks to the company Unikomerc-uvoz Ltd. for the provided technical support.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Antonić, S.; Danilović, M.; Stojnić, D.; Dražić, S. Impact of Chainsaw Power on Fuel and Oil Consumption. *Sustainability* **2023**, *15*, 2795. [CrossRef]
2. Landekić, M.; Šporčić, M.; Bačić, M.; Pandur, Z.; Bakarić, M. Workability and Physical Wellbeing Among Chainsaw Operators in Croatia. *Croat. J. For. Eng.* **2023**, *44*, 83–94. [CrossRef]

3. Labelle, E.R.; Lemmer, K.J. Selected Environmental Impacts of Forest Harvesting Operations with Varying Degree of Mechanization. *Croat. J. For. Eng.* **2019**, *40*, 239–257. [CrossRef]
4. Haavikko, H.; Kärhä, K.; Poikela, A.; Korvenranta, M.; Palander, T. Fuel Consumption, Greenhouse Gas Emissions, and Energy Efficiency of Wood-Harvesting Operations: A Case Study of Stora Enso in Finland. *Croat. J. For. Eng.* **2022**, *43*, 79–97. [CrossRef]
5. Arnič, D.; Krč, J.; Diaci, J. Modeling of time consumption for selective and situational precommercial thinning in mountain beech forest stands. *iForest* **2021**, *14*, 137–143. [CrossRef]
6. Gulci, S.; Gulci, N.; Abbas, D.; Serin, H.; Yuksel, K. Evaluating the carbon monoxide mission from chainsaw exhaust outlet. *Sumar. List* **2023**, *147*, 121–128. [CrossRef]
7. Thaper, R.; Sesek, R.; Garnett, R.; Acosta-Sojo, Y.; Purdy, G.T. The Combined Impact of Hand-Arm Vibration and Noise Exposure on Hearing Sensitivity of Agricultural/Forestry Workers—A Systematic Literature Review. *Int. J. Environ. Res. Public Health* **2023**, *20*, 4276. [CrossRef] [PubMed]
8. Fonseca, A.; Aghazadeh, F.; de Hoop, C.; Ikuma, L.; Al-Qaisi, A. Effect of noise emitted by forestry equipment on workers' hearing capacity. *Int. J. Ind. Erg.* **2015**, *46*, 105–112. [CrossRef]
9. Poje, A.; Potočnik, I.; Mihelič, M. Comparison of Electric and Petrol Chainsaws in Terms of Efficiency and Safety When Used in Young Spruce Stands in Small-Scale Private Forests. *Small Scale For.* **2018**, *17*, 411–422. [CrossRef]
10. Maciak, A.; Kubuśka, M.; Młodzińska, E. Impact of Saw Chain Cutters Type on Cutting Efficiency and Fuel Consumption in Timber Cutting. *Ann. Warsaw Univ. Life Sci. SGGW Agric.* **2017**, *69*, 71–77. [CrossRef]
11. Bačić, M.; Landekić, M.; Šušnjar, M.; Šporčić, M.; Pandur, Z. Vibration levels and daily vibration exposure while using different tools in a forest cleaning. *Cent. Eur. For. J.* **2023**, *69*, 49–58. [CrossRef]
12. Colantoni, A.; Mazzocchi, F.; Cossio, F.; Cecchini, M.; Bedini, R.; Monarca, D. Comparisons between Battery Chainsaws and Internal Combustion Engine Chainsaws: Performance and Safety. *Contemp. Eng. Sci.* **2016**, *9*, 1315–1337. [CrossRef]
13. Pandur, Z.; Šušnjar, M.; Bačić, M. Battery Technology—Use in Forestry. *Croat. J. For. Eng.* **2021**, *42*, 135–148. [CrossRef]
14. Neri, F.; Laschi, A.; Frassinelli, N.; Fabiano, F.; Foderi, C.; Marchi, E.; Marra, E. Battery- and Petrol-Powered Chainsaws: An Investigation of Productivity in Conifer Thinning. *Forests* **2023**, *14*, 183. [CrossRef]
15. Dabrowski, A. Reducing Kickback of Portable Combustion Chain Saws and Related Injury Risks: Laboratory Tests and Deductions. *Int. J. Occup. Saf. Ergon.* **2012**, *18*, 399–417. [CrossRef]
16. Kuvik, T.; Krilek, J.; Kováč, J.; Štefánek, M.; Dvořák, J. Impact of the Selected Factors on the Cutting Force When Using a Chainsaw. *Wood Res.* **2017**, *62*, 807–814.
17. Otto, A.; Parmigiani, J. Velocity, Depth-of-Cut, and Physical Property Effects on Saw Chain Cutting. *BioResources* **2015**, *10*, 7273–7291. [CrossRef]
18. Neri, F.; Laschi, A.; Marchi, E.; Marra, E.; Fabiano, F.; Frassinelli, N.; Foderi, C. Use of Battery- vs. Petrol-Powered Chainsaws in Forestry: Comparing Performances on Cutting Time. *Forests* **2022**, *13*, 683. [CrossRef]
19. Feldmann, R. Vibrations- und Schallemissionen von Akkumotorsägen in der Jungbestandspflege. Master's Thesis, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany, 2019.
20. Blomgren, G.E. The development and future of lithium ion batteries. *J. Electrochem. Soc.* **2017**, *164*, A5019–A5025. [CrossRef]
21. Tomczak, K.; Naskrent, B. Work Efficiency of Battery-Powered Chainsaws during the Commercial Thinning in the Young Pine. *Stand. Environ. Sci. Proc.* **2022**, *22*, 18. [CrossRef]
22. Kiehne, H.A. *Battery Technology Handbook*, 2nd ed.; CRC Press: New York, NY, USA, 2003; Volume 118, ISBN 0203911857.
23. Fang, H. Challenges with the Ultimate Energy Density with Li-ion Batteries. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *781*, 042023. [CrossRef]
24. Grosjean, C.; Miranda, P.H.; Perrin, M.; Poggi, P. Assessment of World Lithium Resources and Consequences of Their Geographic Distribution on the Expected Development of the Electric Vehicle Industry. *Renew. Sustain. Energy Rev.* **2012**, *16*, 1735–1744. [CrossRef]
25. Gustafsson, T.; Johansson, A. Comparison between battery electric vehicles and internal combustion engine fueled by electrofuels—From an energy efficiency and cost perspective. Master's Thesis, Chalmers University of Technology, Gothenburg, Sweden, 2015.
26. Marchi, E.; Neri, F.; Cambi, M.; Laschi, A.; Foderi, C.; Sciarra, G.; Fabiano, F. Analysis of Dust Exposure during Chainsaw Forest Operations. *iForest* **2017**, *10*, 341–347. [CrossRef]