

Article

# Reduction in Operating Costs and Environmental Impact Consisting in the Modernization of the Low-Power Cylindrical Wood Chipper Power Unit by Using Alternative Fuel

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**Abstract:** Alternative fuel within the meaning of Directive 2014/94/EU is, among others, LPG (liquefied petroleum gas), characterized by a lower purchase cost and lower emissions of toxic exhaust compounds in comparison to the combustion of classic gasoline. In wood chippers, intended for chopping branches, with low-power internal combustion engines that meet the emission standards in force in 2019 in the European Union, in accordance with Regulation 2016/1628/EU, carburetor fuel supply systems are commonly used. Innovative trends in the development of these drives are: electronic fuel injection, systems supporting the adaptation of the working elements to the conditions of use and the use of alternative fuels. The first two solutions significantly affect the cost of purchasing a power unit or modernizing it. The authors of this article indicate, as a beneficial alternative, a cheap (EUR 105) possibility of modernizing the carburetor fuel supply system. It is based on a modification that will allow for the use of LPG instead of gasoline to drive the working system of the wood chipper. This article presents the results of tests on the fuel consumption of a wood chipper powered with gasoline ( $3.04 \text{ L h}^{-1}$ ) and LPG ( $3.65 \text{ L h}^{-1}$ ) during continuous chipping. The cost of an hour of chipping related to fuel consumption was determined, which was equal to  $3.89 \text{ € h}^{-1}$  while using gasoline, and  $2.19 \text{ € h}^{-1}$  when using LPG. The mass flow rate ( $0.66 \text{ t h}^{-1}$ ) and volumetric flow rate ( $3.5 \text{ m}^3 \text{ h}^{-1}$ ) of a wood chipper powered by a low-power (9.5 kW) internal combustion engine with spark ignition were determined. In addition, we determined the cost of producing  $1 \text{ m}^3$  of biomass from chipping freshly cut oak branches (*Quercus robur* L. Sp. Pl. 996 1753) with a maximum diameter of 80 mm and a humidity of 25%. The branches were selected earlier in such a way that their dimensions as as similar as possible. This amounted to EUR 1.11 for a gasoline-powered drive and EUR 0.63 for a LPG powered one. The benefits of using an alternative fuel supply system, the installation of which increases the cost of the machine by 8.4%, have been confirmed.

**Keywords:** wood chipper; mass flow rate; volumetric flow rate; fuel consumption; non-road small engine; alternative fuels; LPG

## 1. Introduction

Mobile wood chippers, powered by non-road small engines, are usually intended for chipping branches with a maximum diameter of around 100 mm. The engines of such machines are subject to legal regulations in the European Union (Regulation 2016/1628/EU) regarding the emission of toxic exhaust compounds [1]. These provisions are permissive in comparison with the emission requirements for vehicles, for example [2,3]. This contributes to the low technical sophistication of

the design of the fuel supply systems for these power units [4,5]. From a review by Warguła et al., in 2018, it appears that 78% of commercially available engines were powered by gasoline, and in this group 89% were equipped with a carburetor fuel supply system [6]. Currently, work is underway to develop these power units towards the use of injection fuels [7–10], systems adapting the drive to the conditions of use [11,12], improving durability [13] and alternative fuels (LPG [14–18], ethanol [19,20] and methanol [21]). However, there are no regulations limiting the use of outdated technologies, and the relatively high cost of drives with the injection system is the result of their low popularity in the industry [4]. The authors of this article, noticing this problem, indicate a solution introducing innovation in this engine group through the use of alternative fuel. Construction, which has been tested in this study, has a low cost of implementation and can be used in both new solutions as well as those that are already being used.

The application of alternative fuel, which is LPG (Liquefied Petroleum Gas), according to Directive 2014/94/EU [22], allows for the reduction in the toxicity of exhaust gases [23–25]. The reduction of pollution emissions is necessary due to its direct impact on humans [26,27]. Research is conducted around the world on the level of the emissions of toxic exhaust compounds generated by internal combustion engines powering non-road mobile equipment and their impact on the environment and operators [28–33]. In this context they also relate to wood chippers [34]. Research conducted in China in 2016 showed that the PM<sub>2.5</sub> dust emission from road vehicles amounted to 123,000 t, and non-road equipment drives generated 38,000 t [35]. Despite the passage of several years, researchers from China still estimated a similar value of this emission at 38,800 t in 2019 [36]. This value includes emissions related to low-power wood chippers, which are the subject of this paper. They are not suitable for biomass production on a large scale; however, they are very popular, especially in cleaning works in urban areas. Guo et al. predict a further increase of 6% in 2020 and 9% in 2025. The reason for this phenomenon is the increase in the mechanization of agriculture and the dynamic development of the construction industry [36]. The results of research conducted in the USA in 2006 testify to the fact that operators of machines powered by classic construction engines may be exposed to much higher levels of CO gases and PM<sub>2.5</sub> dusts during their work [37]. This means that the emissions generated by this type of equipment cannot be ignored, because they are not only a part of global emissions, but are also locally significant as a real threat to people's lives and health in the workplace.

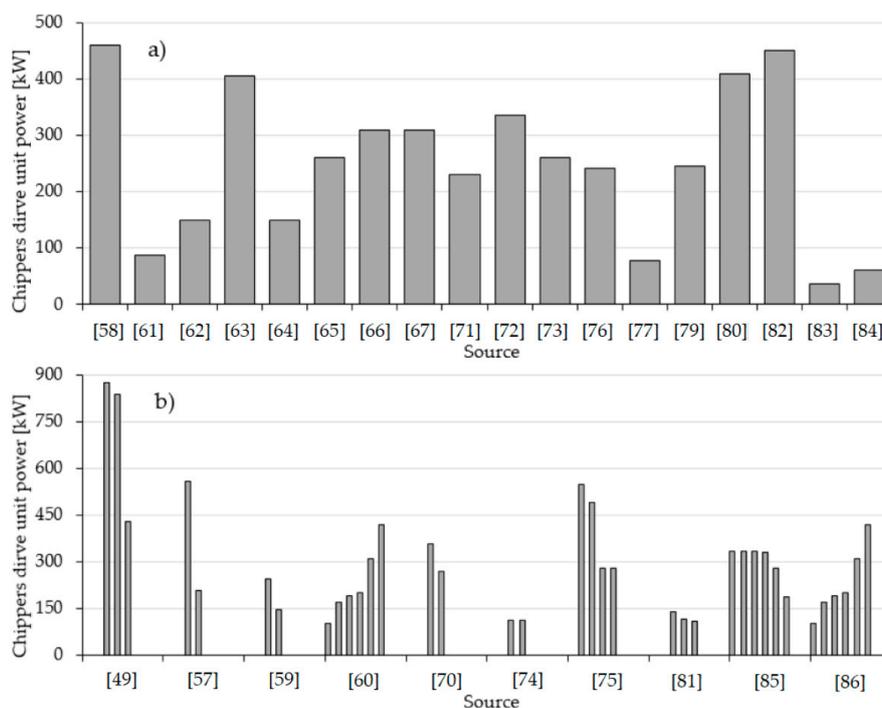
Air pollution concentrations in urban areas around the world are important and actual problems. The standards of air quality are exceeded in most major cities on all continents: Australia [38], South America [39], North America [40], Asia [41], Africa [42] and Europe [43]. This situation is one of the reasons for dysphoria [44,45], loss of physical-motion capacity [46], loss of health [47,48] but also contributes to the development of oncological diseases [49] and premature death [50,51]. Scientists are increasingly recognizing the relationship between human health and air pollution. Research is also being conducted among professional groups in which the nature of work is related to being in an environment polluted by exhaust gases from machine drives. Such research concerns various industries: agriculture (e.g., tractor operators) [52]; forestry (e.g., chainsaw operators) [33]; people working in the mining industry [53]; people working in the vicinity of power generators [54]. All of these studies indicate that people working in these conditions are subjected to elevated concentrations of pollutants, which may translate into increased pathogenic tendencies [55]. Limiting the quantitative emission of exhaust gases and limiting the toxic exhaust compounds within them is beneficial for the environment and the people surrounding the machinery emitting pollutants. It also presents benefits for industry and state organs whose employees and citizens, exposed to lower emissions, may be characterized by better health and psychophysical status, and thus would be more efficient at work.

Most of the available tests for fuel consumption and the efficiency of wood chipping processes are carried out on high-power machines with compression-ignition (CI) engines, as shown in Figure 1 [56–84]. The term “small engines” applies only to spark ignition engines when they are used in chipping machines (due to operating conditions) of power lower than 19 kW [1]. Provisions regarding non-road mobile equipment with compression-ignition (CI) engines apply to engines without

defined restrictions regarding the power of the power unit. Instead, they introduce a division into different research cycles, depending on the power of the engine [1]. However, in the literature there are available research results for wood chippers that are defined as low power (209 kW) and medium power (559 kW) [85]. The analyses related to these machines mainly concern the impact of:

- material
- part of a tree (trunk or branches) [64,65,67,70,72,77,80,82,84]
- tree species (soft or hard wood) [60,62,64–67,72,78,79,86]
- wood humidity (fresh or dry) [64,70,72,87]
- machine
- type of working element [58,67,68,80,84]
- power unit (high power or low power, industrial) [67,73,84,85]
- wear of knife blades [58,59,61,65–68,76,79,88]
- size of the sieves [65,69,77,85,86]
- average productivity [56,63,66,70,71,73,74,80,81,89,90]
- wood chips
- size of wood chips [56,63–65,71,72,76,80,86,90,91]
- method and frequency of feeding of chipped material
- feeding system (feeder [62,80] or operator [11])
- space and terrain topology during the works on chipping processes [75].

There is a lack of analysis of the impact of power unit selection on wood chopping processes. The authors are also not familiar with research related to the average productivity and fuel consumption of low-power chipping machines powered by spark ignition engines. The vast majority of tests are carried out on drum chippers [57–63,65–67,69–75,77,79,80,84], disc chippers [56,67,68,74,76,80,81,83,84,92], hammer chippers [80,84] or spiral chippers [74]. There is a lack of analysis of cylindrical chippers. A small number of studies related to cylindrical chippers can also be noted.



**Figure 1.** Power of wood chipper power units tested in scientific papers; (a) papers referring to one chipper, (b) papers referring to more than one chipper.

The purpose of the paper is to compare the fuel consumption of a cylindrical chipper with a low-power engine powered classically by gasoline and—after modernization—by alternative fuel. The authors indicate a relatively cheap way of modernizing the machine, bringing ecological and economic benefits. The paper presents current research on the machines, representing the current state of technology and the industry, dealing with the green infrastructure of urban areas. In the future, these results will be a reference for the development of innovative solutions.

LPG installations are not applicable in all mobile machines, among others, due to the mass and size of gas tanks. The difficult applicability of LPG installations for small drives is characterized by their limited use. The authors used LPG installations in the low-power engine of a mobile machine, in which there were no significant difficulties in operation. This contributes to the widespread use of alternative fuels that are more environmentally friendly. This is the only such solution known to the authors in machines of this kind. The presented research results have an additional advantage; they are the answer to one of the problems of low-power wood chipper users. Based on the literature, there was a lack of knowledge regarding the operational parameters of these machines independent of their manufacturers.

This article presents the results of tests on a cylindrical chipper powered by a low-power motor (9.5 kW). During the experiments, fuel consumption during the chipping process was determined, depending on the fuel supply system used. In the first stage of research, the fuel consumption of the chipper powered by gasoline engine, equipped with carburetor power supply system, was determined. In the second stage, a chipper, equipped with an LPG supply system, was tested. During the experiments, the average productivity of the tested machine was determined. For this purpose, the mass and volumetric flow rate values were determined in order to evaluate this parameter. Operating costs were also included, taking fuel prices into account.

## 2. Materials and Methods

The subject of performed research was a Red Dragon RS-100 wood chipper [93], its unmodified version presented in Figure 2a, driven by a German GX 390 OHV (9.5 kW) four-stroke spark-ignition engine [94], its unmodified version depicted in Figure 2b, and engine specification presented in Table 1. The factory configuration version (A) uses a carburetor fuel feed system, and is intended for processing wood waste and branches with a diameter of up to 80 mm [93]. The unmodified gasoline-powered carburetor is shown in Figure 2c. Then, the original design (A) was modernized to the second version (B). In version (B) the carburetor powered by gasoline was replaced by a carburetor system adapted to use a mixture of propane and butane as fuel. The modified carburetor powered by LPG is presented in Figure 3b [95]. A cylindrical chipper with a drive equipped with an LPG system is shown in Figure 3a.

The engine in configuration A was supplied with petrol and the engine in configuration B with LPG, the selected physicochemical properties of which are shown in Table 2 [96]. The provided data refer to the International Standard Metric Conditions for natural gas and similar fluids (ISO 13443:1996) and are defined for 288.15 K (15 °C) and 101.325 kPa.

**Table 1.** Technical specification of German GX390 engine.

Parameter	Characteristic
Swept volume	389 cm <sup>3</sup>
Engine maximal power at 3600 rpm	9.56 kW/13 HP
Engine maximal torque at 2500 rpm	26.5 Nm
Bore/Stroke	88 mm /64 mm
Engine Type	Four-stroke, OHV (Over Head Valve)
Number of cylinders	1
Ignition	Electronic, without ignition timing adjustment [97]
Weight	31 kg
Average cost	EUR 270

**Table 2.** Properties of tested fuels, where MON = motor octane number; RON = research octane number [96].

Fuel	Gasoline 95	Liquefied Petroleum Gas Propane–Butane 50%/50%
Density under reference conditions (liquid phase) [kg (m <sup>3</sup> ) <sup>-1</sup> ]	720–775	520
Fuel calorific value [MJ kg <sup>-1</sup> ]	42.6	46
Boiling temperature [°C]	40–210	–30
Excess air coefficient $\lambda$ up to the ignitability boundaries	0.4–1.4	0.4–1.7
Octane number MON (RON)	85 (95)	95 (100)
Air fuel ratio (AFR) for stoichiometric mix	14.7:1	15.5:1

The research was carried out on freshly cut branches of oak (*Quercus robur* L. Sp. Pl. 996 1753) with a diameter in the largest cross-section amounting to approximately 80 mm and a humidity at around 25%. The specimens that underwent the tests are a representative of hard wood species in accordance with Janka classification [98].

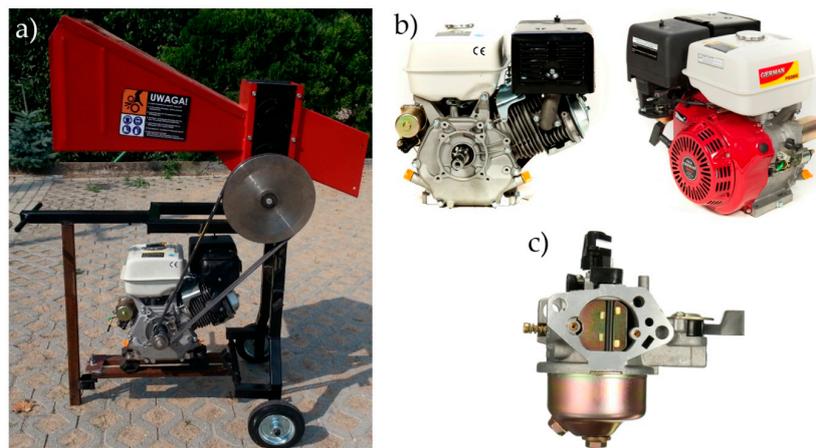
The measurement of actual fuel consumption was taken using the mass method [99,100]. The measurement consisted of measuring the weight of the tank with fuel  $m_e$ , performing work under the predefined operating conditions and then reading the level of fuel consumption, which yielded an accuracy of  $\pm 0.001$  kg.

The tests were carried out in two stages. During the first stage, it was carried out in set exploitation conditions:

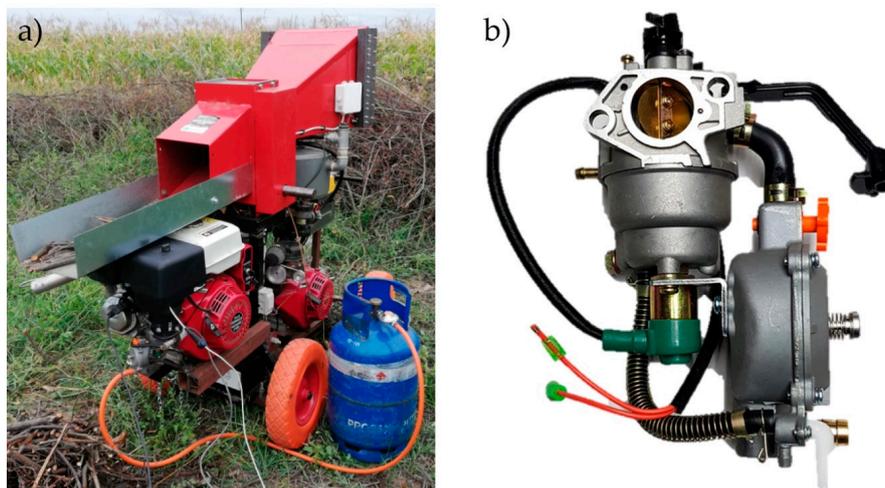
- idling at low speed;
- idling with maximum torque;
- operation through a continuous chipping process.

The carried out statistical analysis consisted of performing the distribution normality test using the Shapiro–Wilk method, rejecting excessive errors using the Chauwenet method and determining the standard deviation for the mean of the measurements. For the measurement tests results, the mean value was calculated, taking into account the corrections according to Student's t distribution for the 95% confidence level, as shown in Tables 1 and 2 [101–104].

The efficiency of wood chip production (in terms of capacity) was measured using two methods. The first method was based on measuring the time of  $t$  filling the container with a volume of  $V = 120$  L, while the other involved measuring the weight of  $m$  filled containers. This way, the results of the volumetric  $Q$  and mass  $Q_m$  flow rates of the tested cylindrical chipper were obtained. The tests were carried out in 10 replications. Statistical analysis was performed at the significance level set at  $\alpha = 0.05$ . The Anderson–Darling test was used to determine the normality of the distribution of measured data.



**Figure 2.** View of the unmodified Red Dragon RS-100-type cylindrical chipper and its components: (a) chipper with German GX 390 type engine attached, (b) unmodified German GX 390 type engine, (c) unmodified gasoline-powered carburetor.



**Figure 3.** View of the modified Red Dragon RS-100 type cylindrical chipper and its components: (a) chipper with German GX 390 type engine after fuel supply system modification, (b) modified carburetor powered by LPG (in the “a” picture, two engines are mounted in the wood chipper, but only the one connected to the cylinder took part in the tests).

### 3. Results

#### 3.1. Fuel Consumption

The results of the fuel consumption test for the cylindrical chipper powered by a gasoline and LPG combustion engines are presented in Table 3.

**Table 3.** The fuel consumption of the cylindrical chipper: A—with a gasoline powered engine; B—with an LPG powered engine. AVG, arithmetic average; SD, standard deviation of the mean; I, incertitude limits by Student’s t distribution for a 95% confidence level.

Test No.	Idle Work with Low Rotational Speed [kg h <sup>-1</sup> ]		Idle Work with High Rotational Speed [kg h <sup>-1</sup> ]		Continuous Chipping [kg h <sup>-1</sup> ]	
	A	B	A	B	A	B
1	0.455	0.375	0.887	0.752	2.319	1.823
2	0.470	0.345	0.875	0.782	2.521	1.945
3	0.432	0.331	0.929	0.811	2.287	2.011
4	0.443	0.389	0.921	0.862	2.312	1.954
5	0.454	0.353	0.892	0.798	2.274	1.887
6	0.443	0.412	0.935	0.743	2.509	1.898
7	0.466	0.375	0.859	0.815	2.292	1.789
8	0.481	0.385	0.923	0.832	2.141	1.873
9	0.429	0.394	0.935	0.843	2.648	1.923
10	0.431	0.388	0.944	0.773	2.251	1.902
AVG	0.450	0.375	0.914	0.801	2.311	1.901
SD	0.0056	0.0078	0.0092	0.0123	0.0485	0.0203
I	0.013	0.017	0.021	0.027	0.108	0.045

### 3.2. Average Productivity of the Chipping Process

The results of the average productivity test of the branch chipping process using the cylindrical wood chipper are presented in Table 4. The tested power units were characterized by a similar power value, and the type of fuel burned did not affect the waste cutting process. For this reason, the results are not broken down into the type of fuel used to power the chipper.

**Table 4.** Values obtained as a result of measurements and statistical data. AVG, arithmetic mean; SD, standard deviation of the arithmetic mean;  $p_{val}$ , test probability for the Anderson–Darling test.

Test No.	Mass $m$ [kg]	Time $t$ [h]
1	24.50	0.0220
2	19.50	0.0233
3	21.50	0.0380
4	27.50	0.0405
5	21.00	0.0382
6	21.50	0.0425
7	20.00	0.0428
8	22.50	0.0350
9	26.10	0.0258
10	22.40	0.0350
AVG	22.65	0.0343
SD	2.61	0.0078
$p_{val}$	0.32	0.1124

The volumetric  $Q$  and mass  $Q_m$  flow rates of wood chip production during the experiment were determined using the relationship:

$$Q = \frac{V}{t} \cdot [\text{m}^3 \cdot \text{h}^{-1}] \quad (1)$$

$$Q_m = \frac{m}{t} \cdot [\text{kg} \cdot \text{h}^{-1}] \quad (2)$$

The recorded results were obtained for the continuous operation of the chipper (the chipping process continued uninterrupted). Based on the obtained data, after using relationships (1) and (2), it was determined that, in the considered process, the volumetric flow rate was  $Q \approx 3.5 \text{ m}^3 \text{ h}^{-1}$ , while the mass flow rate was at a level of  $Q_m \approx 660 \text{ kg h}^{-1}$ . Therefore, the density of the content of the wood

chip container was  $\rho = 188.78 \text{ [kg (m}^3\text{)}^{-1}]$ . This is apparent density because it takes into account the volume of voids in the container filled with air.

#### 4. Discussion

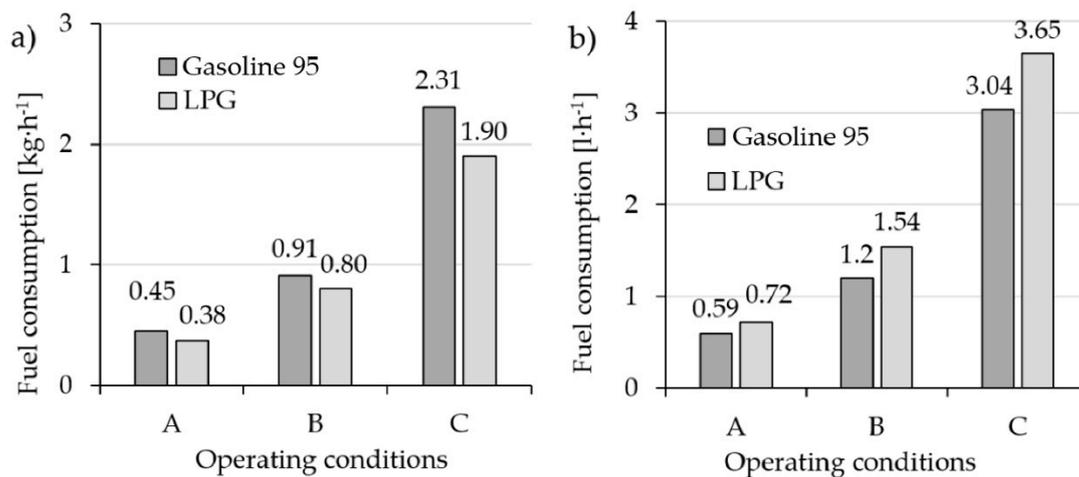
The fuel consumption per hour of machine operation can be expressed in mass (3) or volume (4), as described by the correlations:

$$G_e = \frac{V_p \cdot \rho_p}{t} = \frac{m_p}{t} \cdot [\text{kg} \cdot \text{h}^{-1}] \quad (3)$$

$$G_e = \frac{m_p}{\rho_p} \cdot \frac{1}{t} \cdot [\text{m}^3 \cdot \text{h}^{-1}] \quad (4)$$

where:  $V_p$  is the volume of fuel consumed during the measurement in  $[\text{m}^3]$ ,  $\rho_p$  is the density of the fuel under the measurement conditions in  $[\text{kg (m}^3\text{)}^{-1}]$ ,  $t$  is the fuel consumption time during the measurement in  $[\text{h}]$ , and  $m_p$  is the mass of fuel consumed during the measurement in  $[\text{kg}]$ .

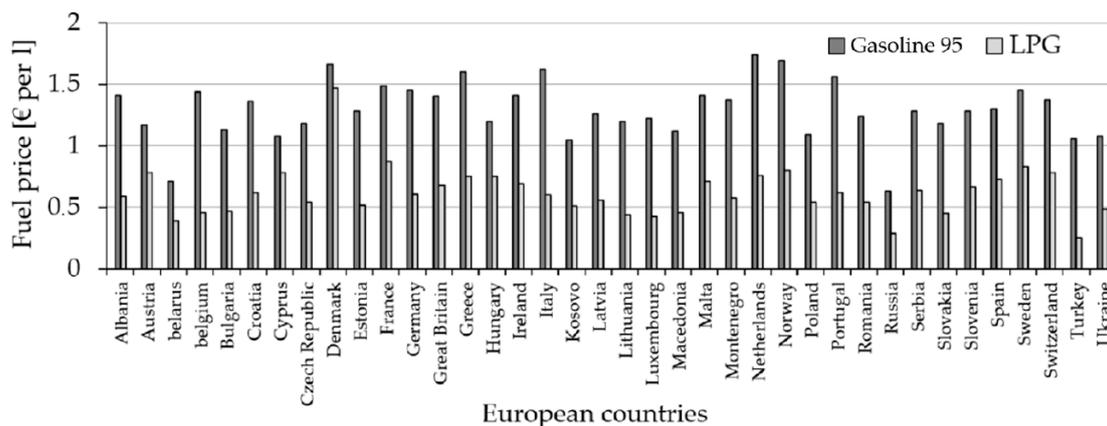
It is easier to estimate operating costs by using volumetric fuel consumption, as the tested fuels (gasoline and LPG) are widely sold in liters in the EU. A liter of 95 lead-free petrol at  $15 \text{ }^\circ\text{C}$  weighs an average of 0.76 kg (measurement in compliance with PN-EN ISO 12185 and PE-EN ISO 3675). Whereas 1 L of LPG in the liquid phase under the same conditions weighs 0.52 kg, in accordance with PN-EN 589:2019-04. The values of fuel consumption during the working hours of the chipper are shown in Figure 4.



**Figure 4.** Consumption: (a) fuel mass per hour of operation, (b) fuel volume per hour of operation. A—Idling with low rotational speed of the drive, B—Idling with high rotational speed of the drive, C—chipping process.

The volumetric fuel consumption during LPG combustion increased by an average of approximately 23%. This is consistent with the results of other research teams, whose test results showed an increase in fuel consumption when powering the LPG engine, relative to gasoline [105–107].

Fuel prices depend on many variables and change every day. In addition, these prices change differently, depending on the country and even region [108–110]. The authors set the average price in EUR for 1 L of fuel in Europe as of 10 January 2020, as shown in Figure 5. The average price of gasoline was  $1.28 \text{ € L}^{-1}$  and the price of LPG was  $0.60 \text{ € L}^{-1}$ . This indicates that, during this period, gasoline was more than twice as expensive as LPG (about 113%). These values were adopted for further analysis. The cost of an hour of chipping with a cylindrical chipper associated with fuel consumption was  $3.89 \text{ € h}^{-1}$  while combusting gasoline and  $2.19 \text{ € h}^{-1}$  when burning LPG. The conclusion is that, despite the higher fuel consumption, an hour of operation on the LPG powered chipping machine (continuous chipping) is about 44% cheaper. Machine operation in other states outside of the chipping process will also have a lower cost of use.



**Figure 5.** The price of gasoline and LPG in selected European countries, as of 10 January 2020.

The use of an installation enabling LPG combustion in small engines requires expenditures on the modernization of the construction. The cost of such modernization, according to the Table 5, amounts to EUR 105. The published data show that it can be expected that the expenditure incurred will pay for itself after about 65 h of operation, taking into only fuel costs into account. The cost of the cylindrical chipper presented in the study is EUR 1250, and modernization with an LPG system increases the cost of the machine by 8.4%.

**Table 5.** Cost of components and services for modernizing a small engine to be powered by LPG.

System Components and Service	Cost
Carburetor	46 €
LPG gas reducer with pressure gauge	7 €
Installation hose	6 €
11 kg gas tank	23 €
Working time spent on the modernization of the structure and system regulation 1 h	23 €

Chipping machine performance is strongly dependent on raw material, size of chips, type of working element and its settings, wear of knife blades, size of sieves and feeding system [74]. However, regardless of the factors mentioned, the hourly performance during the operation of such a machine, excluding all delays associated with the supply of material for a machine with a power in the range 205–430 kW, is equal to 20–115 m<sup>3</sup>·h<sup>-1</sup>, and the arithmetic average is about 70 m<sup>3</sup>·h<sup>-1</sup> [56,70,73]. The volumetric flow rate of a small cylindrical chipper (9.5 kW) when chipping branches with dimensions constituting a heavy load is equal to 3.5 m<sup>3</sup>·h<sup>-1</sup>. However, the mass flow rate of a cylindrical chipper with a low-power engine is equal to 0.66 t h<sup>-1</sup> and, compared to the performance of an industrial chipper with a power of 335 kW and a mass flow rate of 43.8 t h<sup>-1</sup> [81], is lower by about 98.5%. It should be noted, however, that this is not a machine intended for the mass production of biomass.

The production cost of 1 m<sup>3</sup> of biomass with a gasoline powered chipper is EUR 1.11, and for an LPG powered chipper it is EUR 0.63. For comparison, the production cost of 1 m<sup>3</sup> of wood chips with high power chippers (205–407 kW) is between EUR 1.03 and EUR 2.38 [73]. The analysis indicates that chipping branches with low-power wood chippers does not generate increased costs of wood chip production. It is worth pointing out that the use of these machines can provide benefits during cleaning works, reducing the need to transport branches to large chipping machines.

The introduced change significance can be demonstrated on the basis of the recorded results. The relatively cheap and uncomplicated modification of the low-power chipper allows for an increase in the efficiency of its work in terms of fuel costs. The use of this solution in home gardens and other individual cases is characterized by a rather long investment return time. In this case, it would be more reasonable to purchase a chipper equipped with such a modification when the need arises. However,

such a modification on a larger scale—for example, in a company serving urban green areas—will allow measurable economic benefits to be achieved within a reasonable period of time.

In addition, this research is part of the modern scientific trend related to powering the same machines with different fuels, showing the positive effects of using alternative fuels [111–114].

## 5. Conclusions

The presented study is currently the only one known to the authors offering empirical research results regarding chipping machines with low-power internal combustion engines. Data obtained from the test results of a cylindrical chipper powered by various types of fuel, along with the presentation of the costs of modernization, can support the process of estimating expenses in the forestry and fruit industries and industries dealing with the green infrastructure of urban areas. The results regarding fuel consumption and costs clearly indicate that the operating costs of low-power chipping machines can be reduced at a relatively low cost (cost of modernization is about EUR 105). For a new machine, the cost of installing alternative fuels increases its price by about 8.4%. The introduced modernization utilizes the combustion of LPG fuel, the consumption of which is higher during the machine's hour of work by about 20% compared to the combustion of gasoline (Gasoline 95–3.04 L h<sup>-1</sup> vs. LPG 3.65 L h<sup>-1</sup>). However, the price of one liter of LPG is, on average, more than half that of combustible gasoline in Europe. For example, in January 2020 it was about 113% (Gasoline 95, 1.28 € L<sup>-1</sup> vs. LPG, 0.60 € L<sup>-1</sup>). This contributes to lower costs, while chipping branches with the use of machines whose drive is powered by LPG, by about 44% (Gasoline 95, 3.89 € h<sup>-1</sup> vs. LPG, 2.19 € h<sup>-1</sup>). The determination of mass flow rate (0.66 t h<sup>-1</sup>) and volumetric flow rate (3.5 m<sup>3</sup>·h<sup>-1</sup>) of the examined machine made it possible to determine the production costs of 1 m<sup>3</sup> and 1 t biomass with a chipper equipped with a 9.5 kW combustion engine. The cost of producing 1 m<sup>3</sup> of biomass with a gasoline driven chipper is EUR 1.11, and for the LPG driven chipper it is EUR 0.63, while the cost of producing 1 t of biomass with a gasoline powered drive is EUR 1.94, and for a chipper powered with LPG it is EUR 0.91. In addition, modernization reduces the negative impact on the natural environment and is part of the trend of the innovative powering of internal combustion engines with alternative fuels. The test results revealed that the mass and volumetric capacity of this type of wood chippers is relatively low. However, the main purpose of these machines is not the industrial production of shredded biomass, but the support of the clearing of wooded areas. Their task is to facilitate transport and, as a result, storage and composting and, ultimately, energy acquisition. Chipping in such conditions with tested machines does not generate higher production costs of wood chips. Development activities in the field of small machines and devices are important because these machines can have a great impact on the human body, the environment and the functioning of enterprises. Further research should be conducted in the field of exhaust emissions, the testing of developed constructions and their development into electronic control systems. In addition, the published results can be used to assess the costs of tree farming processes in urban areas.

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