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Ecological fuel obtained by recovery the biomass resulting from the pruning of Paulownia trees and plant residues. Determination of calorific value.

Combustibil ecologic obținut prin utilizarea biomasei rezultate din toaletarea arborilor Paulownia și a resturilor vegetale. Determinarea puterii calorifice.

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Abstract. *In the current climate context regarding the reduction of net greenhouse gas emissions, the article proposes the creation of an ecological fuel obtained from the trimming of Paulownia trees and plant residues (stems and leaves of Sunflower and corn), residues that are not used in other purposes. For the proposed blends (66.66% Paulownia, 16.67% Sunflower and 16.67% Corn) the calorific value was determined and compared to a sample with 100% Paulownia. The results show that for the mixtures obtained, a decrease in calorific value of 37.32% and 29.74% respectively (depending on the humidity of the mixture) was found compared to the Paulownia standard sample (20,000 J/g), but which is close or even higher than that of other commercial mixtures (sample S4-beech+oak-9,482 J/g). right.*

Key words: ecological fuel, biomass residues, recovery, calorific value

1. Introduction

The objective of achieving climate neutrality in the European Union by 2050 and reducing net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels requires an energy transition in which renewable energy (wind, solar, hydropower, ocean energy, geothermal energy, biomass and biofuels) play a fundamental role as the

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energy sector currently contributes more than 75% of Europe's total greenhouse gas emissions [1], [2].

The new climate target introduced by the 'Fit for 55' package increased the integration of renewables (RES) for Europe from 32% to 45% by 2030 [3].

As regards biomass, the Directive promoting energy from renewable sources stresses the need to apply biomass cascading principles that reduce the risk of rampant deforestation [4].

Biomass consists of two main components: one consists of biodegradable materials from products, waste and residues of biological origin from vegetal and animal substances and various sectors such as agriculture, forestry, fisheries and aquaculture, together with adjacent industries, and the other is the biodegradable part of industrial and municipal waste of biological origin.

The principles of cascading use of biomass refer to [5]:

- *Sustainability* – storage of CO2 through afforestation [3], return of material to biomass stock, reintegration of woody biomass into forests after use (reuse of wood biomass ash (rich in basic minerals, potassium and phosphorus) as forest fertiliser));

- *Resource efficiency* – efficient use of main (timber or veneer) and secondary flows (wood of thin parts of the trunk, sawdust, cutting debris, bark, tops and branches - used for wood-based panels, pulp, wood packaging and bioenergy) of woody biomass, but also of the reuse of agricultural by-products and agroforestry residues (thermal insulation boards, acoustics and anti-vibration, as well as lining material for containers and pots for transplanting plants and trees as an alternative to plastics);

- *Circularity in every stream and every step* – efficient design of the entire life cycle, encouraging collection, recycling and reuse;

- *New products and new markets* - new technologies to transform by-product and waste streams into new products;

- *Subsidiarity* - allocation of biomass at local and regional level for different uses as material and/or energy source, assessment of qualitative and quantitative biomass availability;

In this context, it was analyzed which are the main sources contributing to the supply of biomass for energy in the EU (Fig.1) [6].

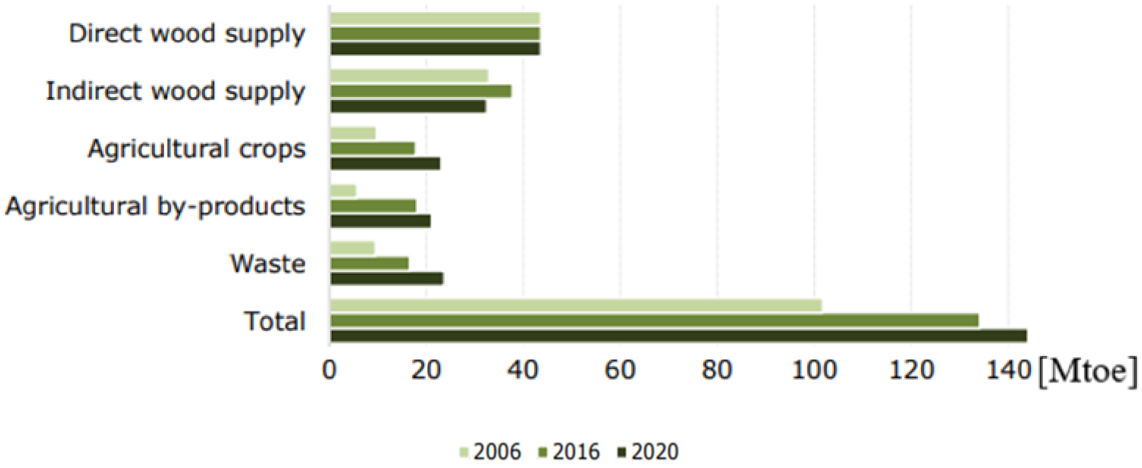

Fig.1. EU internal primary energy supply [6]

Figure 1 shows that forestry is the source that contributes most to the supply of biomass (directly and indirectly) for energy with a percentage of over 60%, followed by agriculture (about 30%), and the remaining about 10% comes from waste (municipal, industrial, etc.). As the new EU targets set by the "Fit for 55" package set more ambitious targets for carbon removals, i.e. 85 million tonnes higher by CO_2 equivalent (Fig. 2), binding targets are set for each country aimed at increasing net removals of greenhouse gases [3].

These targets are addressed in two phases: Phase I – by 2025 – introducing mandatory balance between emissions and removals and Phase II – 2026-2030 – net removals of 310 Mt.

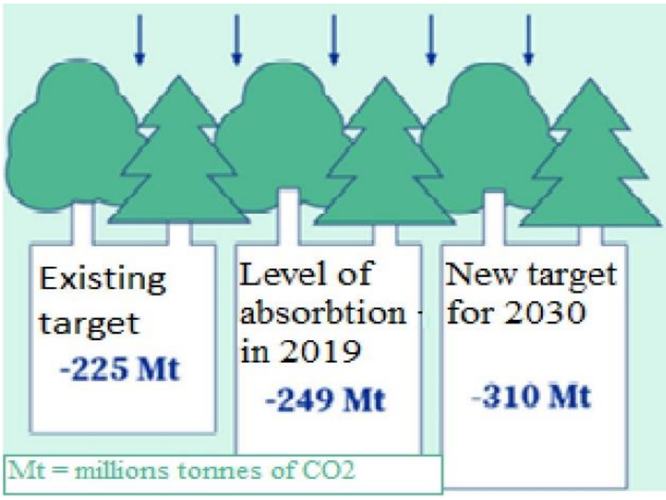

Fig. 2. Targets for carbon removal by 2030 [3]

In the current energy context, the paper proposes an analysis of the sustainable use of biomass resulting from waste from agriculture and forestry. Ignoring the use of energy plants for energy generation, we propose the production of solid biofuel from plant residues (stems, leaves and branches) from crops for food purposes (sunflower, corn) and from Paulownia crops.

The analysed crop plants have the advantage of absorbing satisfactory amounts of CO_2 from the atmosphere and generating calorific values high enough to be used as biofuel. We also propose an analysis of the carbon neutrality of the resulting material. This analysis is based on literature guidelines stating that using biomass for combustion can be carbon neutral [7] and reducing methane emissions into the atmosphere [8].

2. Current state of research

This chapter describes the plants from which solid biofuel will be made, these being:

- Princess Tree (Paulownia Tomentosa) - Paulownia has a high carbon assimilation coefficient, the rapid growth of biomass requires large amounts of CO_2 absorbing around 12.5 t / ha / year [9]. A tree absorbs about 22kg of CO_2 and exhales 6kg O_2 over the course of a year, resulting in a purification of thousands of cubic meters of air. [10] For wood production, between 550-750 trees/ha are planted [11]. The density of Paulownia wood, with a moisture content of 12%, varies from 220 to 350m-3 kg, but most often oscillates around 270 kg $^{m-3}$. [12,13,14] The calorific value of Paulownia biomass is close to that of coal, with a value of 20 MJ/kg [15].
- Sunflower (Helianthus annuus) – According to some general estimates, it is estimated that a sunflower crop can absorb about 1.5 to 2 tons of CO_2 per hectare during the growing period [16],[17]. Research shows that this agro-industrial waste has a calorific value of 17.8 MJ/kg [18]; similar to other solid biofuels currently in use. Freshly harvested sunflower plants may have a higher initial moisture content, which can generally range between 8% and 12% [19].
- Maize (Zea Mays) - Global corn production reaches 1661.25 million tons/year, which constitutes about 27.2% of total agricultural waste. The components of the corn plant consist mainly of about 34.5% stems, 32.3% leaves, 14.3% husks, 12.3% cobs and 6.6% flowers. Maize scraps, among the most abundant agricultural waste in the world, are ubiquitously found after grain harvesting, accounting for about 47-50% of the dry mass of total grain production [20]. Maize residues have a calorific value of 17 MJ/kg [21] and a moisture content below 15% [22], [23], [24], [25].

3. Methods

3.1. Preparation of samples

- Obtaining basic materials.

The raw material for the study was obtained by grinding using a Hecht 6208 shredder. The basic materials come from vegetable waste - stems and leaves from sunflower (S2), corn (S3) and plant residues resulting from pruning Paulownia Tomentosa trees (S1), materials that are shown in Fig. 2. The materials were obtained from local farmers who grow corn and sunflowers (plant residues are abandoned in the fields), and from boat and musical instrument producers who own Paulownia Tomentosa (sawdust and grooming) crops.

Fig. 1. Basic materials

Tests were also carried out for the comparative study on a mixture of beech and oak (S4) obtained from a local briquette producer. The material for analysis was represented by different types of pellets (diameter 6 mm, length 25 - 35 mm) produced in the Laboratory for fuel analysis, ecological investigations and dispersion of pollutants at the Polytechnic University of Timisoara.

- Measurement of moisture content of obtained materials (before drying).

With the help of the wood humidometer FHM 20, the humidity of the materials used was measured (Fig. 2). The measurements were made at 4 points, considering for the humidity of the samples, the arithmetic mean of the 4 readings (Table 1).


Fig 2. Humidity measurement of materials S1, S2, S3, S4.

Tabel 1

The average humidity of materials S1, S2, S3, S4.

Material	Humidity readings [%]				Medium humidity [%]
	1	2	3	4	
S1	26,9	29,8	27,4	27,3	27,8
S2	10,3	13,3	12,9	14,7	12,8
S3	12,9	13	14,8	14,4	13,7
S4	7,7	8	7	8,2	7,7

Since moisture contents below 15% (recommended by the briquette manufacturer) were obtained for samples S2, S3 and S4, only sample S1 was dried and an average moisture content of 27.8% was measured.

- Establishment of recipes for clean fuels proposed for analysis

Recipes S5 and S6 were made according to Table 2 data by mixing basic materials with proportions of 66.66% Paulownia, 16.67% Sunflower and 16.67% Maize, with different humidity of Paulownia residue.

Tabel 2

New recepies

Sample	Paulownia		Sunflower		Corn	
	Weight [g]	Humidity [%]	Weight [g]	Humidity [%]	Weight [g]	Humidity [%]
S5	4	27,8	1	12	1	13,7
S6	4	6,275	1	12	1	13,7

It can be seen that between the preparation period of the basic materials and the period of preparation of the samples, for the shredding of sample S2 the moisture content decreased and for sample S3 the humidity was kept constant.

3.2. Making samples for experimental trials

Making a biofuel with superior combustion properties requires a low moisture content. Since for samples S2, S3 and S4 humidity below 15% (value recommended by the briquette manufacturer) was obtained at both stages of work, only the material was dried for sample S1 for which an average humidity of 27.8% was measured.

To lower the humidity of Paulownia Tomentosa mince, the drying oven was used (Fig. 3) for 90 minutes, heating the base material to a temperature of 100 ^{o}C.

After preparing the raw materials, a pelletizing press was used (Fig. 4) and 2 types of samples with different composition (S5, S6) were made (Fig. 5).

Fig. 3. Drying oven

Fig. 4. Pelletizing press

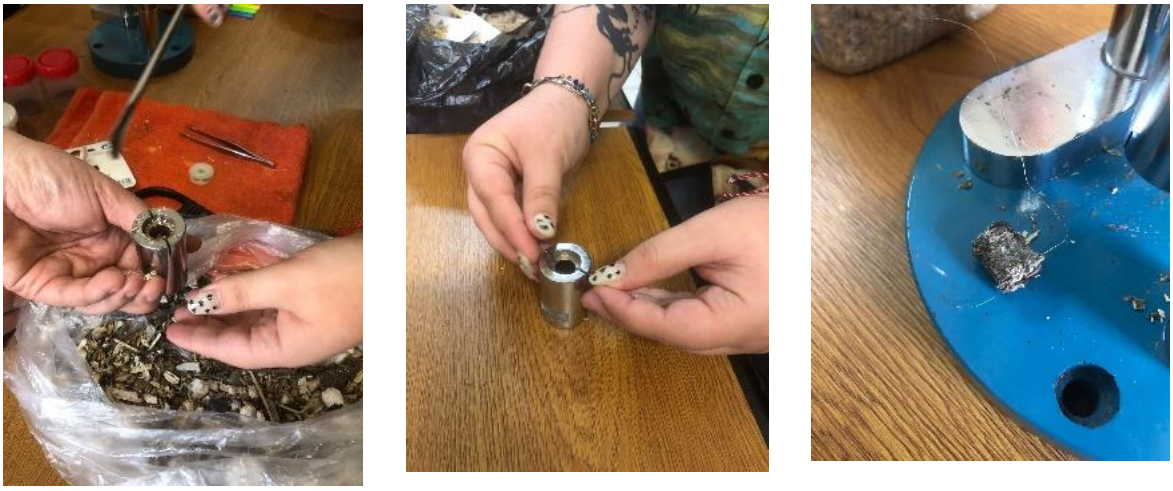

Fig 5. Pellet making process

3.3. Measurement of calorific value

Calorific value is expressed as energy released in the form of heat when a compound or material is completely burned in the presence of oxygen. A higher calorific value indicates a higher fuel energy density, meaning it would release more energy per unit of fuel burned. Therefore, in order to obtain the same amount of energy, the amount of fuel needed to be burned is lower in the case of a higher calorific fuel [26].

The calorific value measurement was carried out for samples S1, S4, S5 and S6.

The pellets obtained from pressing were weighed and then fixed with nickel-chromium wire in the calorimetric bomb (Fig. 6).

Fig. 6. Preparation of samples for testing

A calorimetric bomb (Fig. 7) is a device that measures the amount of heat generated by a chemical reaction or complete combustion of a sample of the substance. The principle of operation is based on isolating the sample of the substance in an airtight container and placing it in a container with water. The substance is then incinerated and the heat generated is transferred to the water in the outer container [27].

Fig 7. Preparation of the commissioning of the calorimetic bomb

The water system around the sample absorbs heat and heats up, allowing the amount of heat released by the combustion process to be determined. The temperature variation of the water in the outer container is measured with great precision and is used to calculate the heat energy generated by the reaction. This heat energy is expressed in units of heat, such as kilocalories or joules. Thus, the calorimetric bomb provides an accurate and sensitive method for determining the caloric content of various organic substances (Fig. 8).

Fig. 8. The process of determining calorific value.

4. Results and discussions

In addition to the samples made, a sample of Paulownia Tomentosa was again dried at 100ºC to lower the moisture content. Following the application of the second stage of drying, a humidity of 4% was obtained.

Test results are centralised in Table 3.

Table 3

Measurement results

Environmentally friendly fuel	**Calorific value [J/g]**		**Humidity [%]**		**CO_2 absorption [t/ha/an]**
	From the literature	**Measured**	**Measured before drying**	**Measured after drying**	**From the literature**
Paulownia [12]	20,000	20,000	24	15 (after first drying)	12
		20,090	24	6,275 (after second drying)	
Sunflower [16]	17,8	-	12	-	1,8
Corn [19]	17,2	-	13,7	-	-
S5 (Paulownia-sunflower-corn mixture)	-	12,536	-	13,18	-
S6 (Paulownia-sunflower-corn mixture)		14,052	-	10	-

From the analysis of Table 3 it can be seen that the highest calorific value is obtained for Paulownia Tomentosa, a value that is confirmed by the specialized literature. In addition, better results can be obtained as the base material has a lower moisture content, but for briquettes or pellets, the humidity cannot be lowered towards zero.

For the proposed mixtures, satisfactory values for calorific value have been obtained. Again, it is noted that for the same proportions of the base materials from which the mixture was made, lowering the humidity increases the calorific value.

5. Conclusions

The comparison of the calorific value obtained for the proposed mixtures (66.66% Paulownia, 16.67% Sunflower and 16.67% Corn-samples S5 and S6) with a sample with 100% Paulownia Tomentosa with humidity of 15% and 6.275% respectively indicates a decrease of 37.32% and 29.74% respectively (depending on the humidity of the mixture), but higher than that of the beech and oak mixture (commercialized briquettes – sample S4) by 32.21% (for S5) and 48.20% (for S6), respectively.

In conclusion, the newly proposed fuels (mixture of 66.66% Paulownia, 16.67% Sunflower and 16.67% Maize), even if they have lower calorific values than mixtures known in the specialized literature (Paulownia - 20MJ / kg), the fact that waste that is not recovered is integrated gives them an advantage in terms of protecting the environment by reducing deforestation.

6. Future directions

In the next stages of research, we aim to identify new unrecovered waste, which has a good energy content and which, in mixtures with biomass with high calorific value, can be recovered as fuel.

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