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# POTENTIAL OF AGRICULTURAL BIOMASS VALORIZATION FOR CIRCULAR BIOECONOMY

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***Abstract***

*This paper assesses the role that cereal crop byproducts could play in a circular economy context in Romania. The study focuses on the quantification of biomass availability using Residue-to-Product Ratio (RPR) and estimating the bioenergy potentials by means of Lower Heating Value (LHV) calculations for a variety of byproducts of vegetal crops. Results show that cereal crop side products an important source of biomass and hence offer opportunities for bioenergy and circular agricultural systems. However, in an effort to balance the approach of biomass utilization, sustainability issues related to soil health and food security are also discussed. This work emphasizes the importance of considering environmental and economic advantages in contributing to a circular bioeconomy.*

***Key words***: *bioeconomy, biomass availability, bioenergy, circular agriculture, Romania*

## INTRODUCTION

Integration of agricultural biomass into the bioeconomy sector is a key step toward achieving sustainability and renewable resources [6, 27]. Biomass that can be resulted from agriculture sector is being increasingly regarded as one of the significant feed stocks in the transition process from a fossil-based economy to a bio-based one [24].
The EU has been at the forefront in this transition; agricultural biomass contributes about 68% of the total biomass supply in the region [4]. It is coupled with the EU Bioeconomy Strategy that focuses on mobilization of biomass resources for economic growth, sustainable development, and societal progress [18,8]. This takes the form of cascading biomass use, where agricultural by-products are converted into high-value products like biofuels, bioplastics, and bio-based chemicals [8]. The cascading concept ensures, the highest level of efficiency in the use of resources before its final recycling or return to the soil in organic form, as far as possible. By prioritizing uses of biomass that would create most economic and environmental value, could reduce material waste, while adding value to the sustainability of agricultural systems by creating new sources of income for farmers, efficient use of resources, and reduction in the carbon footprint of agricultural production [5, 6, 7].
Agricultural biomass that is including dedicated crops, crop residues (straw, stoovers, husks), manure, pruning, processing waste such as fruits and vegetable waste, bagasse and chaffs (Figure 1). The dedicated crops are those grown for the sole intention of producing biofuels and energy. These include classical sources of biofuel such as corn and sugarcane, rapeseed, oil palm, jatropha, sorghum, and cassava and energy grasses like miscanthus and switchgrass [19,14]. The remainder needed energy sector is filled by short rotation forests and more dedicated crops. Besides the primary products, a number of postharvest by-products and leftovers are utilized for bioenergy. Herbaceous by-products come from straw derived from cereals, rice, and corn [23, 22]. Also from bagasse and empty fruit bunches from oil palm; and from pruning derived from stover and empty cobs of corn.
Wood biomass comes from the regeneration of orchard wood, vineyards, olive, and oil palm plantations. Other processing residues include kernels, sunflower shells, rice husks. These represent a different variety of source material

able to be converted into energy in support of sustainability efforts .

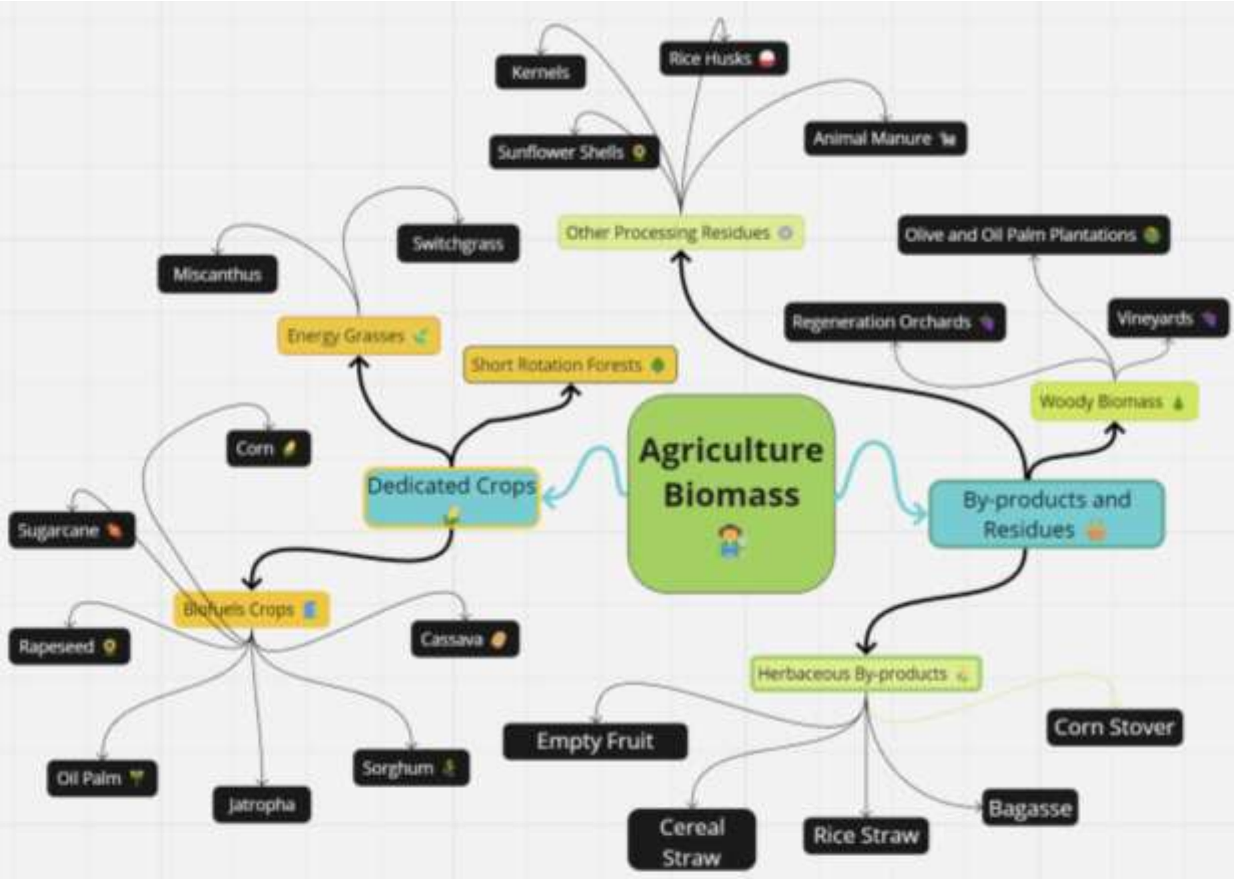


Fig. 1. Sources of biomass from agriculture [2, 11, 28]
Source: Author's own elaboration.

In this context, the aim of this paper is to explore the opportunity and challenges of agricultural biomass inclusion into the bioeconomy by means of its utilization in the circular agriculture system. For this, three objectives were set, as follows:
(i)quantification of biomass availability from major cereal crops in Romania, such as wheat, maize, barley, oats, rice, and sorghum
(ii)estimation of bioenergy potential of the selected cereal crops. For this, the energy output was obtained by applying LHV values.
(iii)highlight the sustainability implications by further discuss the wider implications of diverting agricultural harvest by-products for the purpose of bioenergy production on soil health, food security, and circular agricultural practices.

## MATERIALS AND METHODS

The study design incorporates a quantitative approach, utilizing statistical data and mathematical calculations to derive insights into the role of biomass in circular agriculture. The statistical data were extracted from open data of National institute of Statistics Romania. To determine the amount of crop Harvest by-products produced relative to the primary production this study utilized the Residue-to-Product Ratio (RPR) as a primary index metric. The equation for calculating the biomass available from agricultural residues using primary production and the Residue-to-Product Ratio (RPR**)** was:

Biomass Available = Production×RPR (1)

where:

-Biomass Available is the amount of agricultural residue biomass available.

-Production refers to the total yield or production of a primary crop (tons).

-RPR (Residue-to-Product Ratio) is the ratio of crop residue generated per unit of primary crop (e.g., straw per ton of wheat).

Potential energy was calculated by using the following equation:

Potential Energy (GJ) = Biomass Available (tons) × Lower Heating Value (LHV) (GJ/ton) (2)

where:

-Potential Energy (GJ) is the total energy that can be produced from the biomass.

-Biomass Available (tons) is the amount of biomass derived from agricultural residues (calculated using the production and RPR).

-Lower Heating Value (LHV) (GJ/ton) is the energy content of the biomass, usually given in gigajoules per ton (GJ/ton), and varies by biomass type (e.g., wheat straw, corn stover).

## RESULTS AND DISCUSSIONS

***Agriculture biomass as a raw source for circular economy***

According to Eurostat, biomass is an essential source of renewable energy, especially for heating, electricity, and transport.

Biomass energy accounted for about 59% of all renewable energy consumption in the EU in 2021, making it the centerpiece of energy production across the region [9].

In circular agriculture, biomass can be effectively recycled and utilized to produce biofuels, fertilizers, and animal feed [16].

Within vegetal production, cereal crop Harvest by-products are foreseen to contribute significantly in a circular economy. The residue can be used in the production of bioenergy through various methods, such as direct combustion, gasification, and anaerobic digestion of post harvest by-products like wheat straw and rice husk. This, therefore, reduces over-dependence on fossil fuel.

Besides, these post harvest by-products play a critical role as soil amendments. Mulching or composting improves the structure of the soil and increases the water retention and fertility.

Besides energy and agriculture, cereal crop post harvest by-products are also being employed in industries for the production of various biocomposites like paper.

These uses of crop post harvest by-products prove to be indicative of the potentials in economic and environmental sustainability within a circular economy (Table 1).

Table 1. Potential Uses of Cereal Crop Residues

| Harvest by-products | Primary Use | Secondary Use | Examples |
|---|---|---|---|
| Wheat Straw | Bioenergy (Combustion) | Mulch, Animal Bedding | Power generation, soil cover |
| Rice Husk | Biogas, Biochar | Industrial Raw Material | Fertilizer, packing material |
| Maize Stover | Bioenergy (Ethanol) | Compost, Animal Feed | Ethanol production, soil cover |
| Barley Straw | Soil Amendment | Animal Bedding, Bioenergy | Livestock feed, combustion |
| Sorghum Stalk | Bioenergy (Ethanol) | Animal Feed, Mulch | Fuel, livestock feed |

Source: Authors' own elaboration based on [2, 4, 10, 16, 23, 27].

Production of corn and wheat in Romania is shown in Fig. 2, while in Fig.3 it is presented total production for selected crops: barley, oats, sorghum and rice.

***Biomass production in Romania***

Romania occupies a top position in the EU production of grain and oil seed, accounting for 10% of EU production [20].

This insight is very relevant in terms of the development of biomass production in circular agriculture, since an increase in Romanian cereals and oilseed production can make a positive contribution to the assured supply of agricultural post harvest by-products in the frame of bioenergy, while the transition of the feedstock supply chain may result in circular agriculture.

Analyzing the detailed data on primary production of the last decade, from 2012 to 2021, there were significant fluctuations in cereal production within Romania (Figures 2 and 3).

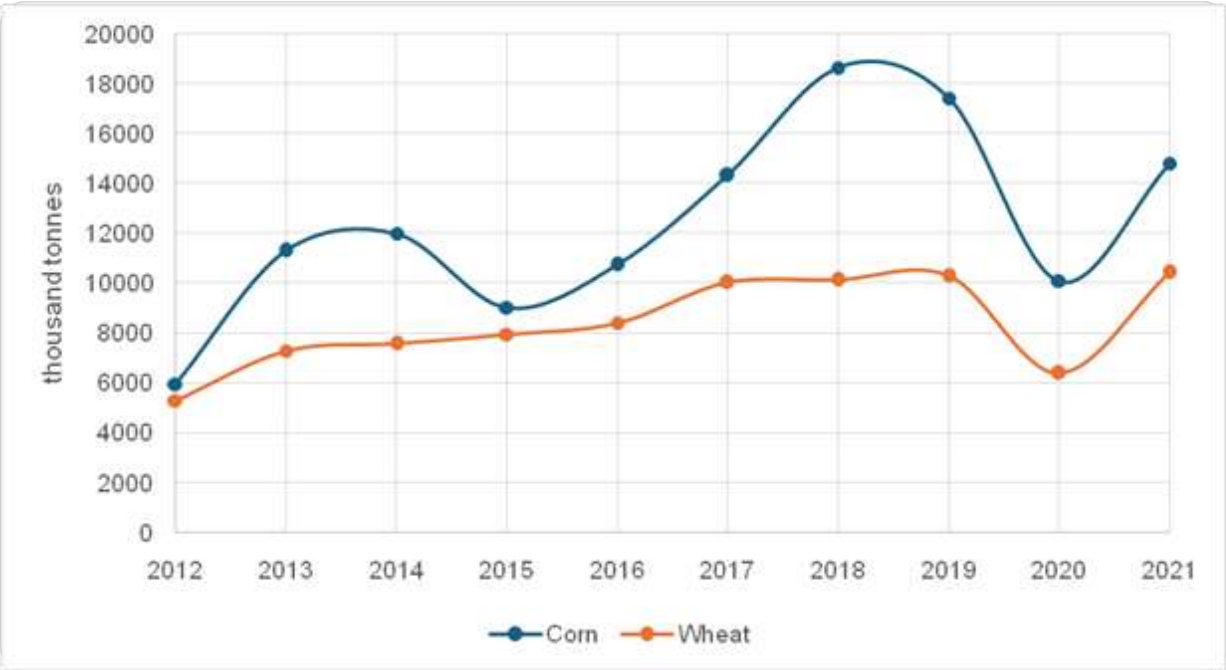


Fig. 2. Production of corn and wheat, Romania
Source: Author's representation based on NIS data [17].

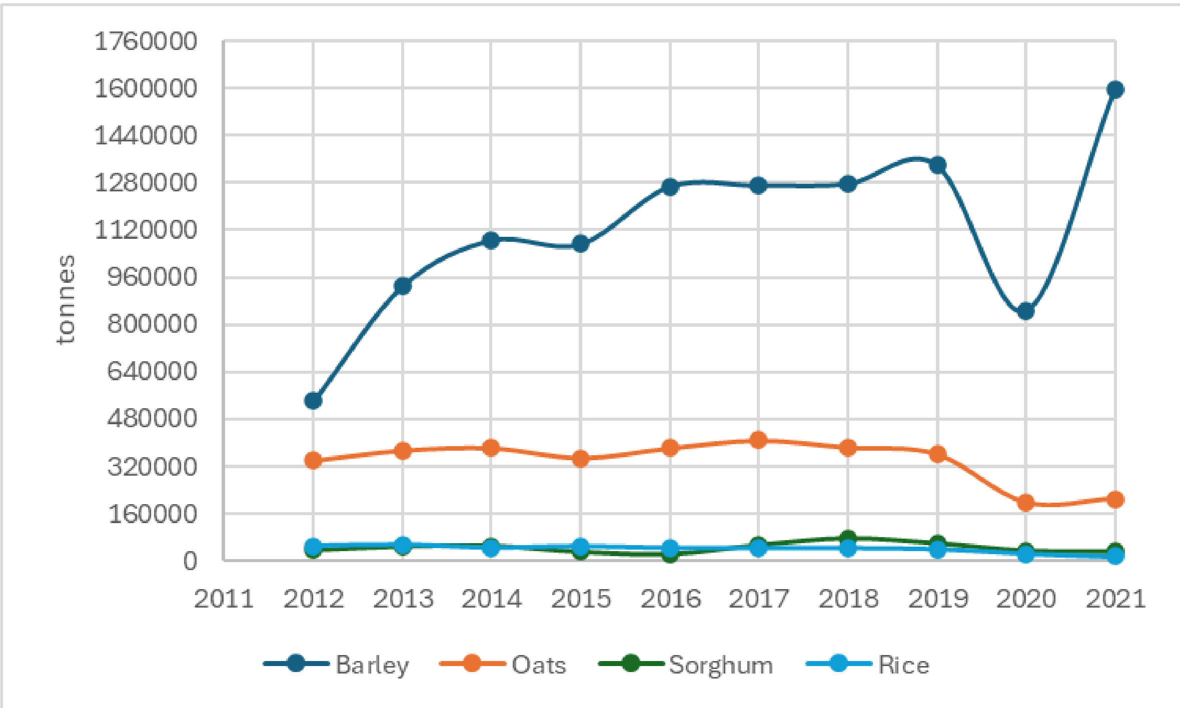


Fig. 3. Total production for selected crops In Romania
Source: Author's representation based on NIS data [17].

Analyzing the detailed data on primary production of the last decade, from 2012 to 2021, there were significant fluctuations in cereal production within Romania (Figures 2 and 3).

The production of corn began an upward trend from about 5.95 million tons in 2012 to a peak in 2018 with 18.66 million tons, reflecting an increase in agricultural output. At the same time, wheat production also increased gradually from 5.29 million tons in 2012 to more than 10 million tons by 2019. However, both crops show a sharp decline in the year 2020, probably due to external factors like bad weather conditions or economic disruptions, but their recovery could be seen by 2021.

Overall, barley and oats were observed to be important crops as well, with substantial fluctuations, especially in 2020. Sorghum and rice remain smaller contributors to Romania's agricultural output, with rice experiencing a continual decline. These trends may have implications for future crop management strategies, especially regarding the integration of these crops into Romania's bioenergy or food security plans.

Analyzing the cereal production trends data, it becomes evident the potential for utilizing agricultural post harvest by-products as biomass for bioenergy. Biomass post harvest by-products are directly related to agricultural production because higher crop yields translate into an equivalent amount of post harvest by-products since post harvest by-products are a set percentage of the crop.

Biomass residues are organic materials produced after a crop has been harvested. Examples include those emanating from cutting or pruning, like stems, straw, stalks, leaves, and branches. In most cases, if these parameters are known, it is possible to estimate the energy potential of biomass.

Furthermore, by applying the Residue-to-Product Ratio (RPR) we have calculated the potential biomass available resources. The RPR values was considered after a brief literature review as described in Table 2.

Table 2. Residue-to-Product Ratios (RPR) for Major Cereal Crops

| Cereal Crop | Average RPR | Range of RPR | Primary Post harvest by-products Types |
|---|---|---|---|
| **Wheat** | 1.3 | 1.0 - 1.6 | Straw, Chaff |
| **Rice** | 1.5 | 1.2 - 1.8 | Straw, Husk |
| **Maize (Corn)** | 1.5 | 1.0 - 1.6 | Stover (stalk, leaves, husks) |
| **Barley** | 1.4 | 1.1 - 1.6 | Straw, Chaff |
| **Sorghum** | 1.2 | 1.0 - 1.4 | Stalk, Leaves |
| **Oats** | 1.5 | 1.3 - 1.7 | Straw, Chaff |

Source: Author's own findings after [10, 21, 11].

RPR quantifies the amount of crop residue that is produced for each unit of the primary product produced, such as grain.

This is one of the most important measures when accounting for biomass availability for various uses such as bioenergy, enrichment of soil and biobased products [25].

The actual ratios may vary depending on local conditions and specific crop varieties.

Corn typically has an RPR of around 1.5, meaning for every ton of corn produced, 1.5 tons of post harvest by-products (stalks, leaves, cobs) are available.

With corn production peaking at 18.66 million tons in 2018, Romania could potentially generate around 28 million tons of corn biomass.

Similarly, wheat straw, with an RPR of approximately 1.3, can add significant biomass resources to the circular economy. These agricultural post harvest by-products, which might otherwise be wasted, can be repurposed into bioenergy or organic fertilizers (Figure 4).

The analysis has further advanced by calculating the energy potential by using Lower Heating Value (LHV) (Table 3).

LHV is defined as the quantity of useable energy that releases the combustion of a unit of fuel with the exclusion of the latent heat of vaporization of water [1].

In other words, this value is regarded as fundamental to any bioenergy assessment, as it offers an estimation for the energy potentials contained in varied types of biomass, including agricultural residues. Indeed, cereal crop post harvest by-products like wheat straw, maize stover, and rice husks have been generally observed with LHV values of about 12 to 17 GJ per ton [1, 3].

Of course, these values vary due to a set of factors that relate to moisture content and the specific biomass type.

In applications related to bioenergy systems, LHV has been estimated to account for the amount of energy producible from available biomass in Romania.

For the developed model, it was used a median value for each selected crop, based on literature review.

Among the selected vegetal species, corn and wheat are the dominant contributors to Romania's bioenergy potential, providing the most significant quantity of agricultural post harvest by-products that could be diverted into bioenergy.

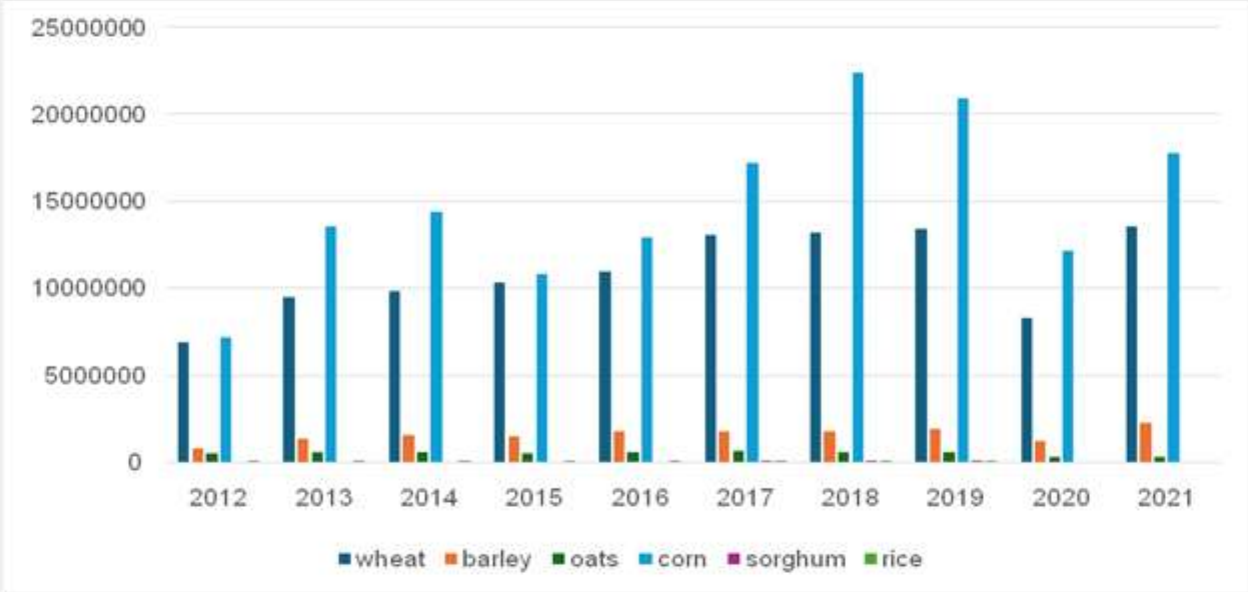


Fig. 4. Yearly biomass available for the selected crops
Source: Author's calculations

Table 3. LHV Values For Cereal Crop Residues (JRC, FAO, IRRI), Biomass Energy Resource Center

| Cereal Crop | LHV (GJ/ton) |
|---|---|
| Wheat Straw | 13-15 GJ/ton |
| Maize (Corn) Stover | 15-17 GJ/ton |
| Barley Straw | 13-15 GJ/ton |
| Rice Husk | 12-14 GJ/ton |
| Rice Straw | 12-14 GJ/ton |
| Oat Straw | 13-15 GJ/ton |
| Barley | 13-15 GJ/ton |
| Sorghum | 14-16 GJ/ton |

Source: Author's own elaboration.

Poor growth conditions may have contributed to a potential decline in both corn and wheat in 2020, but both rebounded in 2021 (Figure 5).
The other relevant contributions come from barley and oats even if their values are lower. This bioenergy carrier has been regularly raised from 10,602 thousand GJ in the year 2012 up to 31,239 thousand GJ in 2021 (Figure 6).

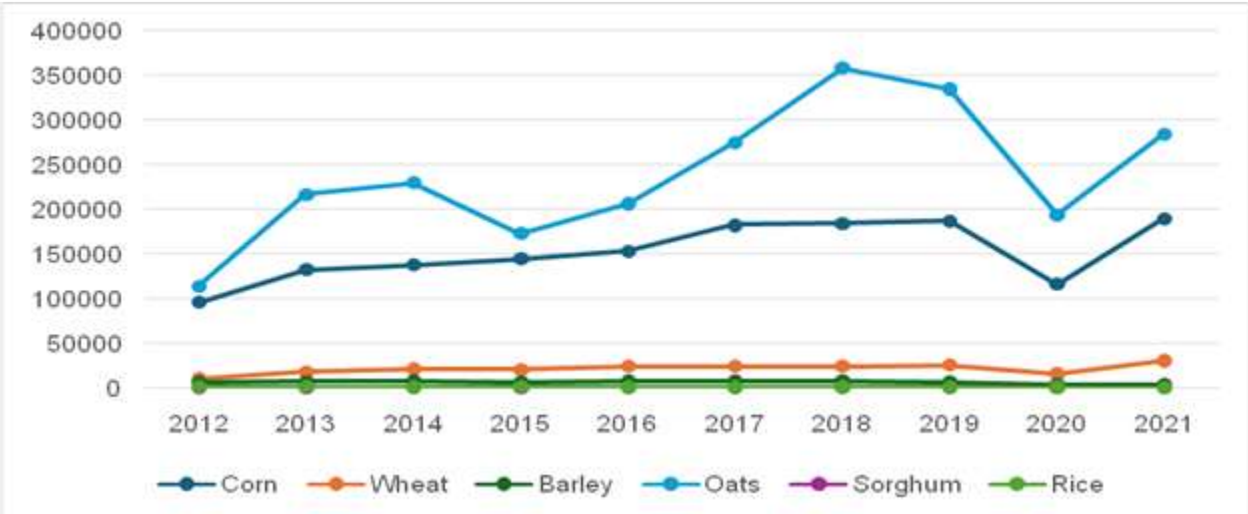


Fig. 5. Dynamics of the potential energy value for the selected crops (GJ)
Source: Author's calculations.

Oats have represented quite stable values, with some ups and downs in their oscillations.

Sorghum and rice are minor biomass feedstocks, although sweet sorghum has a huge potential for biofuels. The availability of such feedstocks is particularly relevant with a view to bioenergy production for diversifying energy sources within circular agriculture.

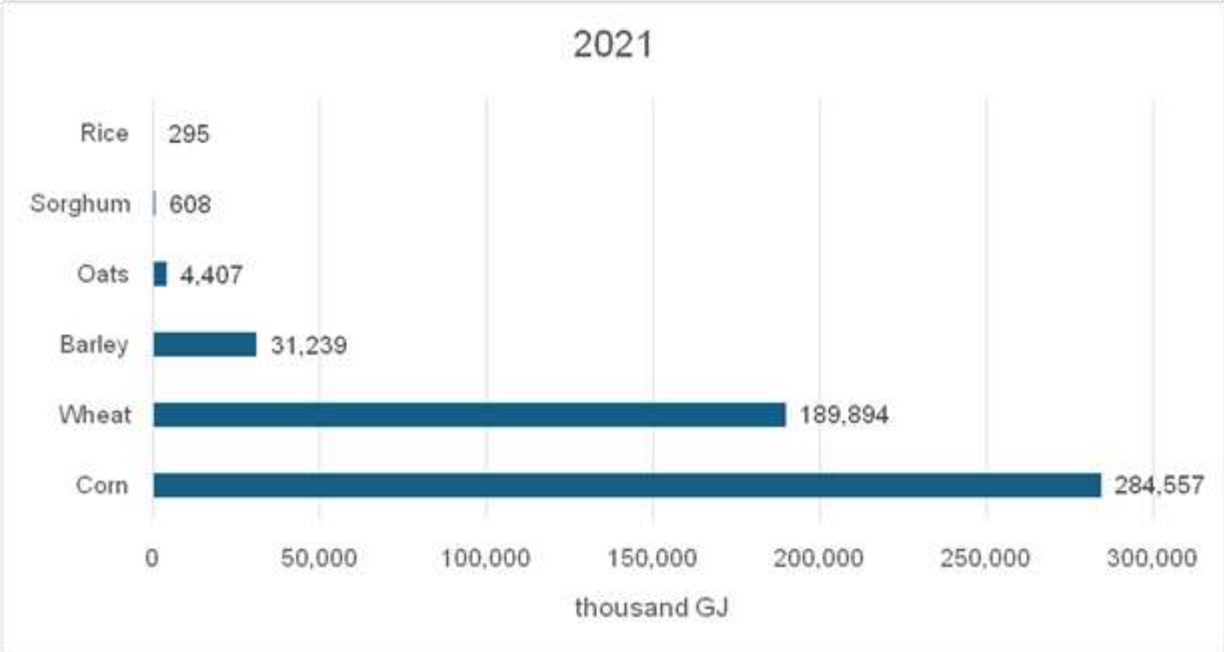


Fig. 6. Potential Energy for the selected crops for the year 2021 (GJ)
Source: Author's calculations.

It is important to take into consideration that in the same time with the increasing demand for biomass in the bioeconomy, there is concern for its supply in a sustainable manner. In this light, [15] says that a balance needs to be maintained with much care. Other strategies that have been put forth to help address these challenges and ensure that growth in the bioeconomy does not come at the expense of other important agricultural functions include the sustainable intensification of agriculture and utilization of marginal lands.

However, we highlight that the calculated potential for bioenergy in an absolute maximum since all agricultural post harvest by-products were considered to be used exclusively for the production of bioenergy. In reality, these vegetal wastes already have a number of other important uses in practical agricultural systems that are critical for sustainable farming and environmental conservation.

The most critical uses of crop post harvest by-products involve soil conservation. Leaving a portion of the biomass in the field after harvest is necessary for the replenishment of organic matter in the soil. Organic matter in the soil is important for maintaining appropriate soil structure and fertility. Crops leftovers incorporated in the soil will add to the water retention of the soil, reduces erosion, and enhances microbial activities-all critical factors for the long-term maintenance of soil health. Also, integrating post harvest by-products within the soil contributes to the sequestration of carbon, therefore reducing greenhouse gas emissions [26,12,13].

Vegetal waste also contributes much in animal husbandry, by providing the bedding material. Straw and other crop post harvest by-products contribute to clean and absorbent beddings for animals, thus contributing to animal welfare for comfortable and hygienic living. This bedding can later be composted and returned to the fields, creating a nutrient loop that supplies organic fertilizer toward soil fertility without total dependence on chemical inputs.

These valorizations of vegetal waste are essential in maintaining a balanced and circular agricultural system.

Excessive shifting of this post harvest by-products for bioenergy purposes, without these functions, may lead to a loss of soil quality and increased dependence on synthetic fertilizers, therefore acting against the goals of sustainability that bioenergy is supposed to promote.

Thus, as promising this bioenergy potential might be, it calls for a reasonable approach in which enough post harvest by-products are left behind for the maintenance of soil health and bedding of livestock, so as to strike a balance in ensuring overall sustainability in agricultural practices.

Another issue that needs to be addressed is the technological challenges. For example, due to inefficient conversion of biomass ethanol and methane during fermentation present limitations. More technological inventions are required to make the energy sources derived from biomass more competitive with those from fossil fuels [16].

Last, but not least, there are the financial challenges that need to be taken into account. While biomass is generally procured at low costs, the energy production from biomass remains relatively expensive due to the logistical issues of transportation costs and seasonal feedstock availability.

## CONCLUSIONS

Biomass utilization for bioenergy, fertilizers and bio-based products is considered a green alternative for transition to circular bioeconomy.

However, it may cause a disruption in natural ecosystems by the appropriation of net primary production. Cascade use of biomass, a concept in which biomass is used sequentially for different uses before finally getting combusted for energy-can reduce environmental impacts and increase resource efficiency.

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