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The Potential of Sunflower Crop By-products for Bioenergy Production in Romania

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ABSTRACT

Circular economy principles applied to agriculture sector enhances efficiency by closing production loops, where agricultural byproducts or waste are transformed into valuable inputs for new processes. Transforming byproducts into energy or raw materials can substantially reduce the reliance on natural resources, decrease greenhouse gas emissions, and foster a more sustainable economy that balances environmental well-being with economic stability. In this context, this study is focused on assessing the energy potential of sunflower residues in Romania. The analysis highlighted the regional variability of cultivated area, production and yield in sunflower crops. The maximum biomass potential of the sunflower crop residues at national level was 6,221 kilotonnes, and the maximum energy potential was 102,958 TJ.

Keywords: biomass, circular economy, energy potential, sunflower.

INTRODUCTION

Circular economy is crucial for fostering sustainable development as it emphasizes the efficient use of resources and the reduction of waste. This system enhances efficiency by closing production loops, where agricultural byproducts or waste are transformed into valuable inputs for new processes. By repurposing the byproducts into energy or raw materials, we can significantly reduce exploitation of natural resources, lower greenhouse gas emissions, and create a more resilient economy that supports both environmental health and economic viability. The agricultural sector generates high amounts of waste, raising concerns about its sustainability. Every year the agricultural sector generates over 140 billion metric tons of biomass, the daily production being over 2 tons in rural areas, according to the FAO report (Duque-Acevedo et al., 2020). Of this large amount of agricultural residues, 66% come from grain crops. Europe produces about 23 million tons of dry biomass annually in the form of cereal straws (Shah et al., 2021). However, there are methods by which the agricultural waste can be reused and recycled, being utilized ecologically and sustainably, the purpose being to reduce the impact on the environment. The conversion of agricultural waste into compost, biofuel or other value-added materials helps to promote a circular economy and reduce negative environmental impacts (Duque-Acevedo et al., 2022; Haque et al., 2023).

In recent years, scientific research has been focused on the recovery of agricultural residues with the aim of identifying methods for reconversion and estimating the amount of available waste. It was highlighted the need to transform agricultural waste into useful resources, thus minimizing negative environmental effects and supporting sustainable development (Hamelin et al., 2019; Berevoianu, 2022).

Sunflower is the fourth most valuable oilseed crop in the world. The reason for the value of sunflower lies in its utility and variety of uses, being an extremely good source of antioxidants, unsaturated fatty acids, and essential vitamins. Sunflower crop performs under various climatic regimes and types of soils. Additionally, the sunflower

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byproducts, such as seed hulls and stalks, can be used biofuels production or as animal feed, thus increasing its economic and environmental importance (Mathias et al., 2015; Brumă et al., 2021; Joiţa-Păcureanu et al., 2023; Puttha et al., 2023).

Studies focused on the recovery of the residues of the flower - sunflower, are aimed at the effective realization of various parts of the plant after harvesting and processing. Research aims to convert residues into valuable products, thus contributing to reducing the ecological impact and promoting sustainable agriculture (Puttha et al., 2023). The results indicate that sunflower culture has high potential as a source of raw materials with industrial and eco-logical applications (Horak et al., 2023). Residues in sunflower crops, particularly peels, have significant energy production potential (Bazaluk et al., 2021; Dankevych et al., 2021). Sunflower husk burning leads to ash below 3%, being energy efficient, indicating high potential as an alternative energy source (Horák et al., 2023).

In this context, research questions of this study were as follows:

i) what is the theoretical potential of biomass and energy obtained from sunflower crop residues at national and regional level in Romania for a ten years period?

ii) how does agricultural residue production and energy potential vary between different regions of Romania?

For answering the above mentiones research questions, this study highlights the importance of an effective recovery of sunflower crop residues and the benefits for bioenergy production and environmental sustainability. The manuscript is organized into three main sections. The first section focuses on analyzing the areas cultivated with sunflowers, alongside their production and yields, both at the national and regional levels. The second section explores the results derived from calculating the quantity of biomass residues generated by sunflower cultivation. Finally, the third section includes an assessment of the energy potential of sunflower residues, including their theoretical potential and the available energy potential.

MATERIAL AND METHODS

This research examines the theoretical potential of biomass from agricultural residues and the theoretical and available energy potential at national level for the period 2013-2022, for sunflower crop. The statistical data used in this study were official open source data available on National Statistics Institute website, from Romania. Estimation of the total amount of sunflower waste generated was done by applying statistical and empirical methods, using mathematical models that correlate the yield of the main crop with that of residues.

Production Residue (RP)

Production Residue (RP) is a parameter that indicates the volume of agricultural waste or residual biomass generated in a given area. It is useful for estimating the total waste generated during crop production. RP represents the total amount of residue or by-products produced after the harvest of a crop. It was calculated as follows:

$$RP = RPR \times Y \times A$$

where:

RPR - Residue to Product Ratio,

Y - Crop Yield (tons/ha),

A - Crop Area (ha).

RPR accounts for the residue generated per unit of yield. Data for RPR were retrieved from previous studies found in literature. Y indicates the crop production efficiency per hectare and A captures the extent of the land used. Therefore, this equation allows estimating the amount of residue available for use based on residue yield, cultivated area and availability factor.

The biomass from the residue (BR)

The biomass from the residue (BR) quantifies the amount of residue biomass per unit area, providing a standardized measure to evaluate residue production. The biomass from the residue (BR) was calculated with the formula below:

$$BR = AR / A$$

where:

AR - Available Residue,

A - Crop Area (ha).

AR refers to the total quantity of crop residue generated after harvesting, which is typically determined by measuring or estimating the remaining stalks, leaves, or other plant material left in the field.

The theoretical potential of biomass (TPB)

The theoretical potential of biomass (TPB) indicates the total annual amount of biomass obtained from agricultural residues, without considering economic, technical, or environmental constraints. It provides an upper limit for evaluating the availability of these residues for various applications, such as bioenergy production, bio-based materials, or soil fertility enhancement. This potential was calculated based on the total crop production, the crop-specific residue-to-product ratio (RPR), and moisture content (Avcioğlu et al., 2019) as per formula below:

$$\text{TBP} = \sum_{i=1}^{n} CP(i) * RPR(i) * \left[\frac{100 - M(i)}{100}\right]$$

where:

CP(i): Crop Production for crop *i*, is representing the annual production (in tons) of a specific crop *i*, in a given area,

RPR(i): accounts for the residue (e.g., straw, husks) generated per unit of yield of the main crop. Data for RPR were retrieved from previous studies found in literature,

M(i): Moisture Content of the residue from crop *i* is the percentage of water present in the residue,

n: Number of crops considered.

The theoretical energy potential (TEP)

The theoretical energy potential (TEP) represents the total annual production of energy produced by dry residues. Calculation of the theoretical energy potential (TEP) involves determining the total amount of energy that could be obtained from sunflower crops grown in Romania, over the given time interval. TEP was estimated using equation provided by Avcioğlu et al. (2019).

$$\text{TEP} = \sum_{i=1}^{n} TBP\ (i) * LHV(i)$$

where:

LHV (i) is the lower heating value of plant as MJ/kg. The value for sunflower was collected fron literature review.

Available energy potential (AEP)

Available energy potential (AEP) is defined as the energy content of biomass that can be economically and technically harvested (Licata et al., 2024).

The determination of the energy potential of agricultural biomass (AEP) requires the assessment of the amount of biomass resulting from agricultural crops and the conversion into usable energy (Avcıoğlu et al., 2019).

$$\text{AEP} = \sum_{i=1}^{n} TEP\ (i) * A(i)$$

where:

A(i) is the available residue ratio as percentage.

RESULTS AND DISCUSSION

The analysis of statistical indicators such as the cultivated area, the total production and yield of sunflower crop in Romania provides a detailed picture of the performance of the crop throughout the country. Sunflower has the ability to adapt to different types of soil and climatic conditions thus contributing to the expansion of cultivated areas, resulted in increased production and improved quality of oilseeds (Soare and Chiurciu, 2023).

The analysis of official statistical data revealed significant variations in key aspects of sunflower cultivation (Table 1). The cultivated area ranged from almost 100 thousand hectares to 1,283 thousand hectares, with an average of 1,078 thousand hectares, reflecting the diverse use of agricultural land across different regions of the country. Sunflower production varied between 1,786 thousand tons and 3,570 thousand tons, averaging 2,477 thousand tons, highlighting the crop's substantial contribution to the national agricultural sector. Additionally, the average yield ranged from 1.77 tonnes per hectare to 3.04 tonnes per hectare, with an overall average of 2.30 tonnes per hectare. This measure of agricultural efficiency is influenced by factors such as farming technologies, climatic conditions, and crop management practices.

Table 1. Statistical indicators of sunflower cultivation in the period 2013-2022

Region	Area (thousands of hectares)			Production (thousand tons)			Yield (tons/hectare)		
	Min	Max	Average	Min	Max	Average	Min	Max	Average
North-West	44.7	81.2	60.6	73.8	214.9	140.3	1.65	2.94	2.30
Center	8.	20.5	13	12.2	53.2	32.5	1.48	2.82	2.41
North-East	109.4	201.8	1,500.1	195.4	484.2	319.9	1.47	3.17	2.14
South-East	283.9	388.1	332.7	422.2	998.5	726.2	1.34	3.17	2.20
South-Muntenia	208.6	290.4	246.8	454.8	699.5	588.5	1.94	3.10	2.40
Bucharest-Ilfov	8.5	11.6	10.7	16.6	28.6	22.7	1.82	2.65	2.11
South-West Oltenia	123.4	216.7	165.7	209.7	629.9	384.4	1.62	3.15	2.30
West	55.5	169.1	97.9	101.5	584.7	262.4	1.83	3.46	2.58

Source: own calculations, INSSE.

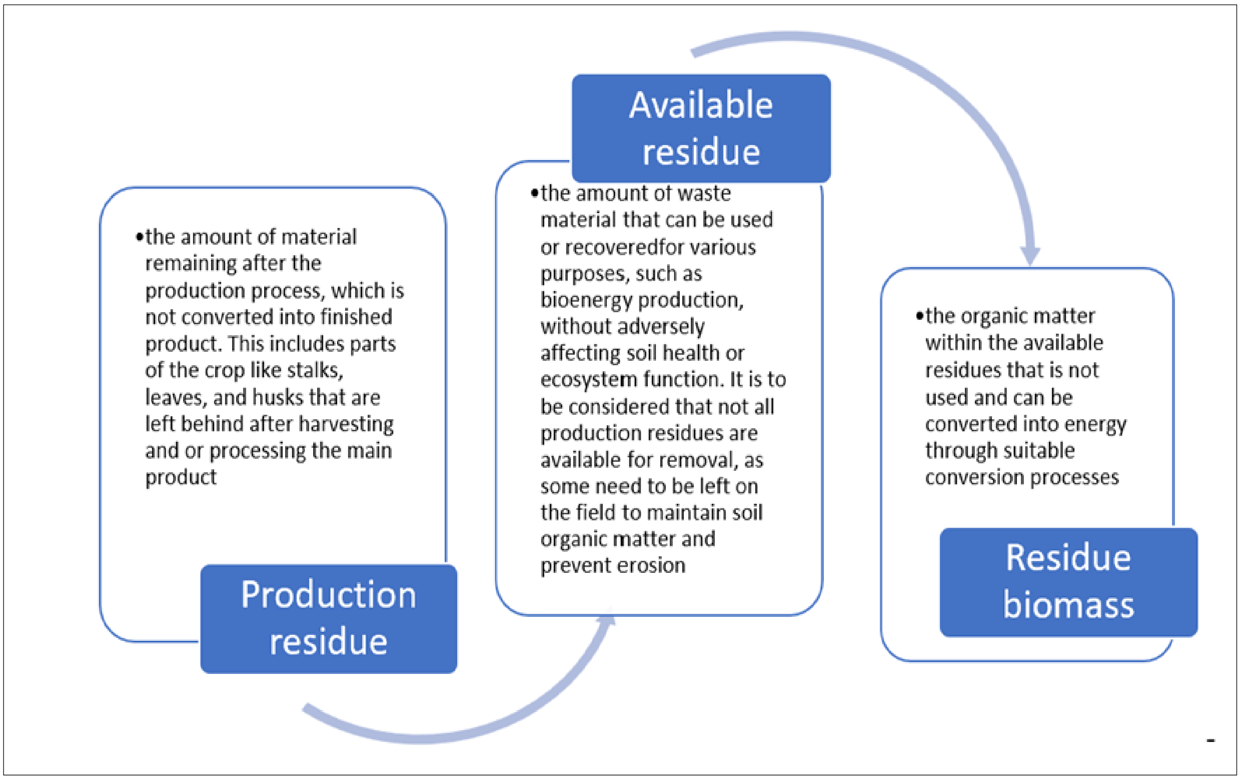
Sunflower production in Romania has experienced considerable regional variations during the ten years period analyzed. The Central and Bucharest-Ilfov regions reported the lowest production levels, with values of 12 thousand tons and 16.6 thousand tons, respectively. In contrast, the South-East Region achieved the highest production, reaching a maximum of almost 1,000 thousand tons. The Western region achieved the maximum yield of 3.46 tons/hectare, being a value higher than the maximum yield at national level, 3.04 tons/hectare. The lowest minimum yield was achieved in the South-East region, of 1.34 tons/hectare, thus observing significant variations in the efficiency of agricultural production in different regional areas.

Regions like the South-East rely on extensive cultivation to achieve high production, while regions such as West and South-Muntenia combine moderate areas with high yields, making their farming practices potentially more sustainable and resource-efficient.

This disparity underlines the substantial differences in production capacities across the country, which can be attributed to a variety of factors, such as regional climate conditions, soil fertility, agricultural practices, agricultural machinery and irrigation investment. These differences highlight the uneven distribution of sunflower cultivation potential across Romania and emphasize the importance of regional approaches to agricultural development and policy-making.

Calculation of RP, AR and BR for the sunflower crop in Romania - national and regional analysis

Next, in order to assess the biomass resources available for sunflower crop at national level, three main indicators were calculated as detailed below.



According to literature data, the agricultural residues from sunflower, specifically the stems and leaves, contain a humidity content ranging between 14% and 20% (Sun et al., 2013). The ratio of residue produced, which quantifies the ratio of residue produced relative to the primary crop, varies from 0.7 to 1. The Lower Heating Value (LHV) of these residues was reported to range between 13.2 MJ/kg and 17.9 MJ/kg, indicating their potential for energy production. Additionally, the availability of these residues was estimated of around 60%, reflecting the portion of the total residues that can be practically collected and utilized (Matin et al., 2019; Havrysh et al., 2023).

At national level, the average amount of available residues is 2417.6 kilotons, which is about half of the total waste production, which is 4029.4 kilotons. This relationship suggests that much of the waste generated is recoverable and can be used for various purposes, such as power generation, composting or other industrial applications.

The South-East and South-Muntenia regions are noted with significant amounts of available residues, of 715.4 kilotons and 578.6 kilotons, respectively, they are known for their intensive farming practices and large areas grown with sunflowers. The smallest amounts of waste available are recorded in the Bucharest-Ilfov and Centru regions, with 22.1 kiloton and 30.7 kilotons, respectively (Figure 1).

At national level, the biomass residue is 2.24 tons per hectare, indicating an average of the residues generated per unit of agricultural area. West Region is distinguished by a residual biomass per hectare of 2.52 tons, significantly above the national average (Figure 1).

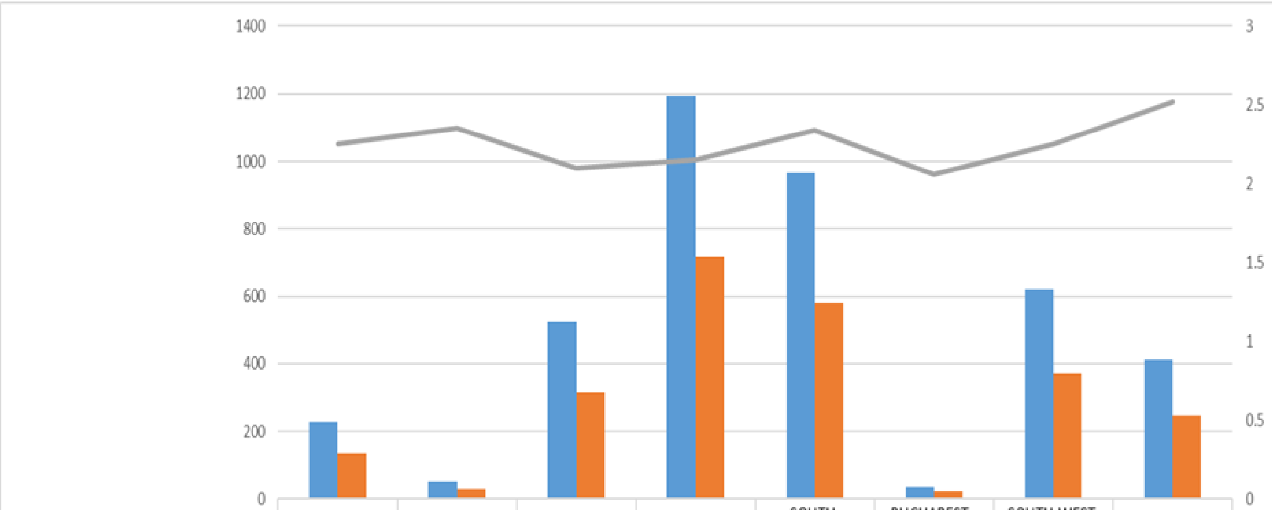
By analysing the quantities of available residues and biomass of residues for sunflower growing, significant regional variations can be observed. Differences between the areas studied are influenced by a number of factors, such as the type of crop, the variety used, agricultural practices and investments in technology and infrastructure.

Calculation of TPB, TEP and AEP for the sunflower crop in Romania - national and regional analysis

Agricultural residues at EU level are a valuable resource for bioenergy production, with an estimated annual value of PJ 1 530. Romania has a high potential for agricultural biomass, due to diversified crops. The conversion of agricultural residues into bioenergy can contribute to the sustainable development of the sector, but also brings environmental benefits (Bădan and Dumitru, 2020).

Using the calculation methodology described above, the value of the theoretical biomass potential (TPB), the theoretical energy potential (TEP) and the available energy potential (AEP) for sunflower crop residues (stems and leaves) were calculated, by region.

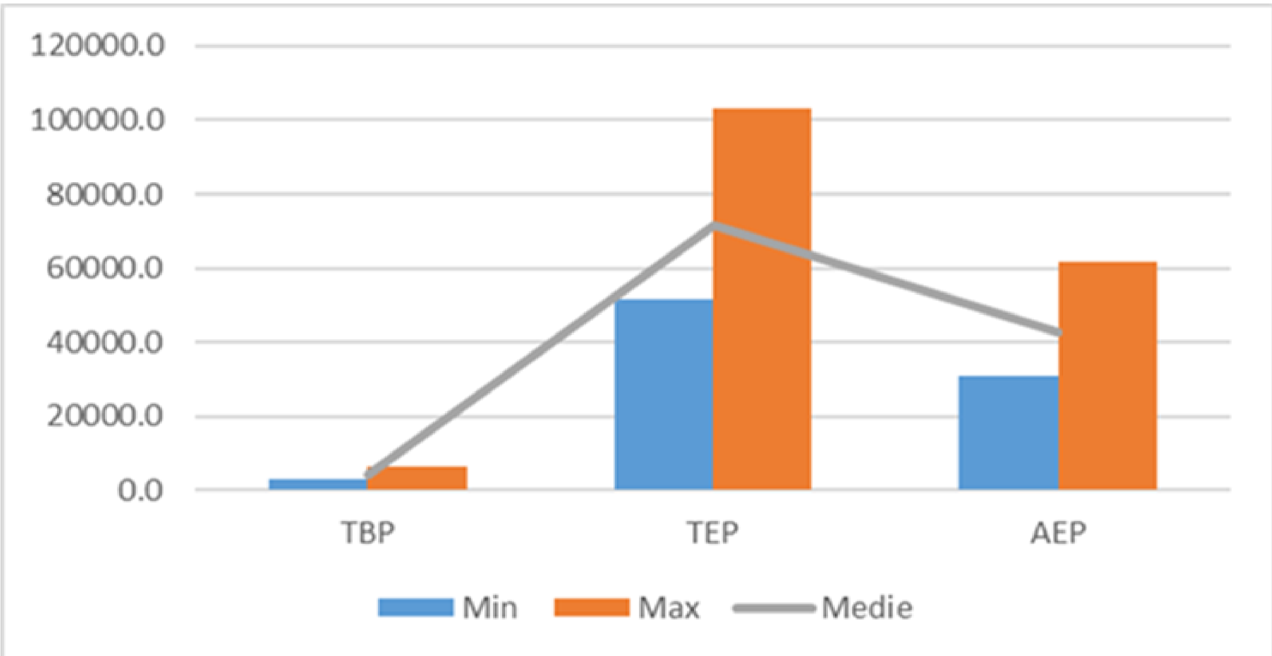
At national level, the theoretical potential of biomass reached a maximum calculated value of 6,221 kilotons, and the average value of 4,316 kilotons (Figure 2).



	NORTH-WEST	CENTER	NORTH-EAST	SOUTH-EAST	SOUTH-Muntenia	BUCHAREST - ILFOV	SOUTH-WEST OLTENIA	WEST
Production residue RP (kilotons)	227.4	51.2	524.1	1192.3	964.4	36.9	621.3	411.2
Available residue AR (kilotons)	136.5	30.7	314.4	715.4	578.6	22.1	372.8	246.7
Residue biomass BR (tons/ha)	2.25	2.35	2.1	2.15	2.34	2.06	2.25	2.52

Source: own calculations

Figure 1. Calculation of residual availability indicators at national and regional level for the sunflower crop (average value of the period 2013-2022)



Source: own calculations

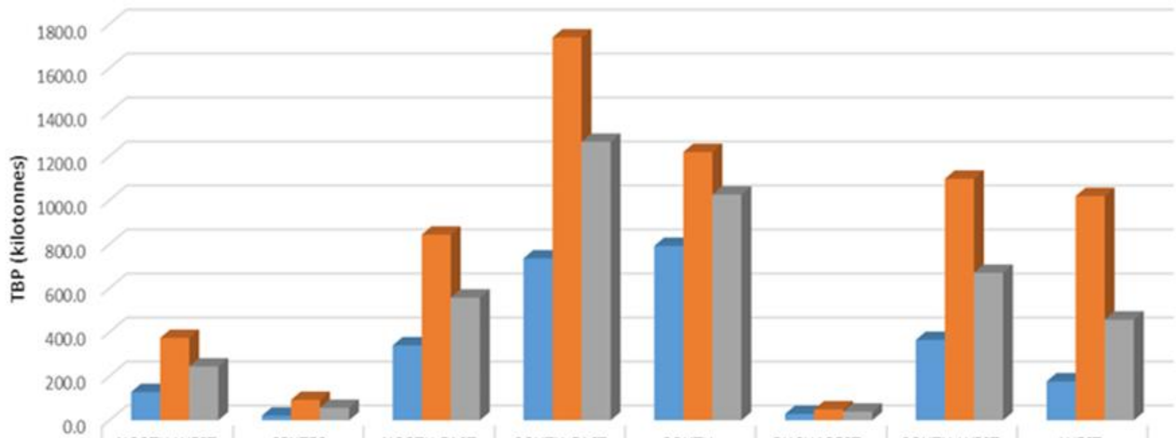
Figure 2. Theoretical biomass potential (TPB), theoretical energy potential (TEP) and available energy potential (AEP) at the national level for the sunflower crop

Determining the theoretical potential of dry biomass for sunflower cultivation, it can be seen in figure 3 that the South-East Region recorded the maximum amount of the period of 1,740 kilotons, followed by the South-Muntenia Region with a value of 1,219 kilotons. The minimum amount of biomass resulting from the calculations in the Bucharest-Ilfov Region (29.9 kilotons), a fact due to the industrialization of the area, but also in the Central Region (21.2 kilotons), the geographical area that does not present optimal conditions for sunflower cultivation (Figure 3).

The theoretical energy potential estimated at the national level recorded a maximum value of 102,958 TJ. It shows considerable differences between regions. The South-East and South-Muntenia regions show the highest values, with maximum values of the period of 28,804 TJ and 20,179 TJ respectively. The two development regions recorded a share of approximately 60% of the average theoretical energy potential at the national level for the period 2013-2022.

The Bucharest-Ilfov, Center and North-West regions show the lowest average values of the theoretical energy potential, of 654 TJ, 936 TJ and 4,046 TJ, respectively (Figure 4).

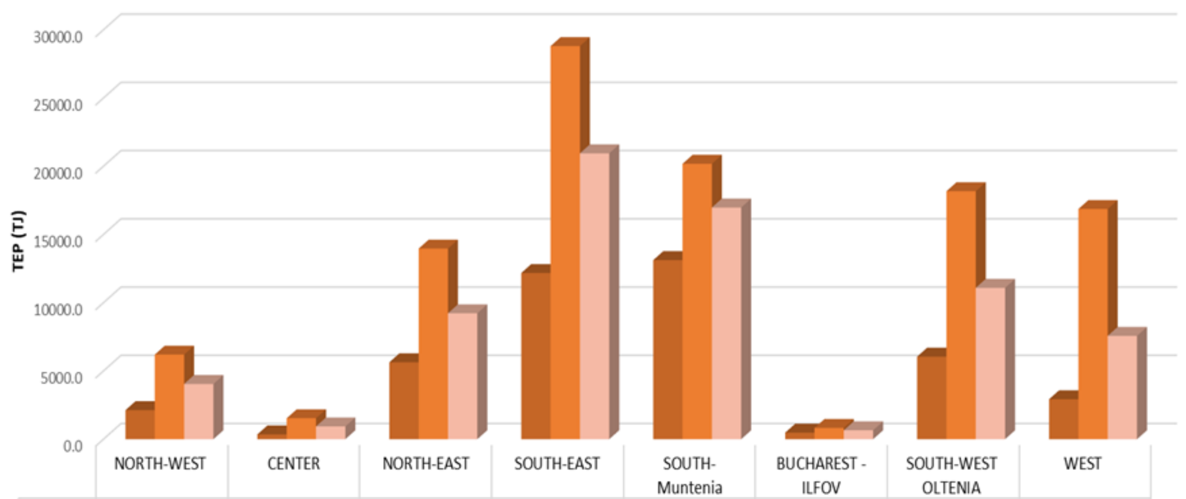
The available energy potential can represent the energy stock that we can have followed the utilization of agricultural residues. Analyzing the results obtained at the regional level, the highest value of the available energy potential was held by the South-East Region, with a maximum of the period of 17,282 TJ and an average value of 12,568 TJ, which represents 30% of the average potential of energy available nationally (42,866 TJ). The Bucharest-Ilfov and Center regions represented approximately 17% of the available average energy potential, recording the lowest values during the analyzed period (Figure 5).



	NORTH-WEST	CENTER	NORTH-EAST	SOUTH-EAST	SOUTH-Muntenia	BUCHAREST - ILFOV	SOUTH-WEST OLTENIA	WEST
Min	128.6	21.2	340.5	735.8	792.8	28.9	365.4	176.9
Max	374.5	92.8	843.9	1740.4	1219.3	49.8	1097.9	1019.1
Average	244.5	56.6	557.5	1265.7	1025.7	39.5	670.0	457.4

Source: own processed data

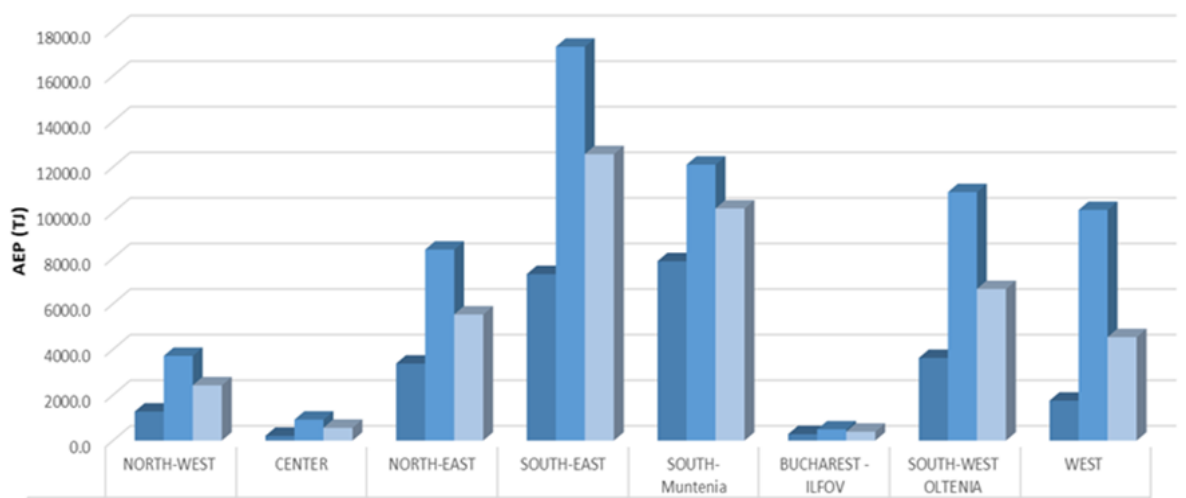
Figure 3. Theoretical biomass potential (TBP) at regional level (Kilotons)



	NORTH-WEST	CENTER	NORTH-EAST	SOUTH-EAST	SOUTH-Muntenia	BUCHAREST - ILFOV	SOUTH-WEST OLTENIA	WEST
Min	2127.6	351.2	5635.4	12178.2	13120.4	477.7	6048.2	2927.2
Max	6198.0	1535.8	13966.6	28804.1	20179.2	824.9	18169.9	16866.9
Average	4046.4	936.8	9226.6	20947.0	16975.1	654.1	11088.8	7569.8

Source: own processed data

Figure 4. Theoretical energy potential (TEP) at regional level (TJ)



	NORTH-WEST	CENTER	NORTH-EAST	SOUTH-EAST	SOUTH-Muntenia	BUCHAREST - ILFOV	SOUTH-WEST OLTENIA	WEST
Min	1276.5	210.7	3381.2	7306.9	7872.2	286.6	3628.9	1756.3
Max	3718.8	921.5	8380.0	17282.5	12107.5	494.9	10901.9	10120.1
Average	2427.9	562.1	5536.0	12568.2	10185.1	392.5	6653.3	4541.9

Source: own processed data

Figure 5. Available energy potential (AEP) at regional level (TJ)

Romania has a high biomass potential resulting from agricultural residues. Agricultural residues from sunflower crop are an important energy resource with high energy potential. Based on the real-world calculations, it was found that at national level the theoretical potential of biomass from the re-walls from the studied culture was estimated at a maximum amount of 6,221 kilotons, re-marking at regional level South-Muntenia and South-East Region with quantities of 1,219 kiloton and 1,740 kilotons, respectively.

Knowing the theoretical energy potential and the available energy potential is a necessity in assessing renewable energy sources. The values obtained reveal that at regional level the South-East Region has the highest values of MET and AEP, of 28,804 TJ and 17,282 TJ, respectively.

The constant improvement of conversion methods and the development of efficient biomass collection and processing methods is a method of maximizing the available energy potential.

A important aspect related to agricultural biomass residues importance for circular bioeconomy is the amount in which they are available. This directly depends on agricultural production. Thus, the higher the crop production, the higher the residue yields. Knowing the potential availability of biomass in a given area is essential for promoting renewable energy initiatives and facilitating planning based on the potential of biomass residues. At farm level, estimating the potential availability of biomasses would be useful in making decisions regarding their energy use. Numerous studies conducted in various countries have evaluated the energy potential of these residues (Riva et al., 2014; Karan and Hamelin, 2020), covering large geographical regions to highlight the diversity of crop types in terms of available biomass quantities and energy potential. Most of these studies emphasize that agricultural biomass residues can be successfully used for energy purposes, thus contributing to the sustainability and efficiency of agricultural resources.

CONCLUSIONS

In view of advancing renewable energy targets, theoretical biomass potential, theoretical energy potential, and available energy potential were estimated, to highlight the role that waste or byproducts from the agriculture sector can play in the bioeconomy. Specifically, this paper investigated the energy potential of sunflower crop by-products from Romania. Therefore, the energy and biomass potential were estimated at regional and national level. The results showed that there are significant regional differences in sunflower cultivation across Romanian regions. In terms of energy potential, the South-East and South-Muntenia regions have the highest theoretical and available energy potentials. The lowest values were from Bucharest-Ilfov and the Central regions, reflecting the role of infrastructural and geographical disparities in biomass supply.

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