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EVALUATION OF THE BIOMASS ENERGY PRODUCTION POTENTIAL IN AGRICULTURAL HOLDINGS IN RELATION TO THEIR SIZE. CASE STUDY FOR COP FARMS IN ROMANIA

Elena Cofas[1] and Cristina Teodora Bălăceanu[2*]

[1]Faculty of Management and Rural Development, University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Mărăşti Blvd, District 1, Bucharest, Romania

[2]Faculty of Marketing, Dimitrie Cantemir Christian University, 176 Splaiul Unirii, Bucharest, Romania

[*]Corresponding author. E-mail: cristina.balaceanu@research.gov.ro

ABSTRACT

Biomass energy production is a priority for the global economy in terms of ensuring the premises for sustainable development. The current context, determined by increases in energy costs, involves the identification of applicable and eco-intensive measures by which the use of biomass in productive activities will reduce the level of pollution and, implicitly, global warming. Progress of the bioeconomy is intercorrelated with the dimension of agriculture, which is the major provider of biomass for food, feed, and other bio-based industries. The agricultural sector in the last decades is characterized by an increase in energy production and consumption, with direct consequences on the environment.

Biomass is for Romania, a renewable energy source, particularly valuable, both in terms of potential and in terms of future use, through complementarity with the sustainable development programs of the state that aim to develop the capacity of production and the creation of well-being. This research aims to estimate the energy efficiency of three types of COP farms (which cultivate cereals, oilseeds, and protein crops) of different physical sizes, and the analysis of the potential energy generated by energetical cultures, with emphasis on biomass energy. The energy balance at the farm level remains a very important method to determine the efficiency of agricultural systems and for the assessment of potential energy from biomass. With this study, we emphasize the need to support a more sustainable demand for biomass and to make the bioeconomy market more competitive.

Keywords: COP, energy potential, biomass, efficiency, bioenergy.

INTRODUCTION

One of the most current problems of the contemporary world economy is the energy problem, still dominated by fossil fuels but with clear prospects of replacing non-renewable energy as a dramatic result of climate change and the reduction of conventional energy sources. Energy has become the means of payment of political and economic power, the value that dominates the hierarchy of nations, even an indicator of material success and progress. Access to energy has become the supreme imperative of the 21st century. Global energy trends, such as higher energy demand and prices, big differences across regions, structural changes in the oil and gas industry, the prospect of irreversible climate change, as well as the need to ensure energy security, highlight the need for a rapid transition to a low-carbon, efficient and environmentally benign energy system. The search for energy alternatives involving locally available and renewable resources is one of the main concerns of governments, scientists, and business people worldwide. The gradual depletion of fossil fuel resources, alongside the global warming, caused by the increase in greenhouse gas emissions, has led to the imperious need to discover new renewable energy resources, biomass, obtained from energy crops, could be the solution (Popp et al., 2021).

The evolution of agriculture is becoming more and more interrelated with the bioeconomy's dynamics because the main agriculture-based resource, biomass, is specially intended for feed and food usage. The bioeconomy development is

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intercorrelated with the changes in agriculture supply and the quantity of biomass, which can be produced by this sector. Moreover, it can be observed that in the last decade, this development has led to the creation of new roles in agriculture, so that the demand for biomass has increased and the sources of biomass from agriculture have become diversified (Islas et al., 2019). Biomass - the fourth energy source after coal, oil, and natural gas – is the largest and most important renewable energy option at present and can be used as a primary energy source worldwide, being used since ancient times, to produce different forms of energy - heat, biofuels, electricity, etc.

Biomass is an organic component of nature, which includes agricultural products, waste from agriculture, or the processing of crops, including cereal straw, residues from the production of sugar, starch, beer, etc. Practically, agriculture contributes to bioeconomy formation, especially with energy crops, residues, and secondary production. Crop residues are estimated to be formed in a proportion of 41% of wheat straw, 21% of sugar beet residues, 14% barley straw, 10% of maize stover, 4% rye residues, and 10% other agricultural residues. However, scientific literature indicates that the main sources of residues remain straw and stover from grain crops (wheat, barley, and maize), but also that around 70% of crops residues are not used in the economy as biomass and those unused residues are composed of 71% of cereal residues and 16% of oilseeds residues (Ronzon et al., 2015). Renewability and versatility are, among many other aspects, important advantages of biomass as an energy source.

In the last decades, due to the implementation of latest technologies for increasing the yields, the consumption of energy related to fertilizers, pesticides, fuel, and machinery increased. In this context, the energy assessment of agricultural production systems becomes more important in farm management systems. It is considered that: the energy consumed through inputs and generated by outputs are measures of agricultural effectiveness; the input-output analysis of energy in agricultural systems is used to determine the efficiency; the method of energy analysis of farms is relevant for the assessment of the sustainability of agricultural process (Hrčková et al., 2016). In 2011, the Directorate-General for Agriculture and Rural Development (DG-AGRI) calculated the renewable energy balances in the agriculture sector by emphasizing "primary (biomass including energy crops, wood, waste, manure, etc.), intermediate (biogas produced on the farm) and final energy (mostly electricity and heat generated on the farm)" (Pedroli and Langeveld, 2011). Their research revealed an orientation especially towards the production of electricity from biomass and that "most energy is produced by wind turbines, plus solid biomass for heating", but the main conclusion was that after 2020 "agricultural waste will surpass first-generation energy crops as a supplier of primary energy". Other researches are focused on the implications of incorporating the biomass generated by cover crops into the soil in increasing the carbon and nitrogen content of the soil, in order to reduce the inputs used in agriculture (Petcu et al., 2022).

In the majority of cereals, oilseeds, and protein crops (COP) farms, conventional energy is essential in the technological flux, especially fuel energy. If we consider this, the energy criteria become a viable instrument to analyze efficiency based on consumed energy, transformation indexes, and specific indicators. This type of analysis can characterize the agricultural production systems in terms of efficiency and in this way complement other economic assessments. In agricultural production, the profitability of a farm is dependent on the combination of direct and indirect consumed energy, an efficient technology requiring a low level of energy consumption. In this way, the energy analysis allows the transformation of all consumption and obtained production into a common energy equivalent and, at the same time, has the advantage that it is not subject to fluctuation or inflation. Therefore, energy production and consumption are compatible in time and space regardless of where and when the production process takes place (Cofas and Toma, 2014).

The production of biomass is growing rapidly due to the increasing price of fossil fuels, growing environmental concerns, and considerations regarding the security and diversification of energy supply, track decreasing the greenhouse gases (GHG) and, consequently, global warming (GW). According to recent findings in the European Green Pact, the transition to climate neutrality will generate important opportunities, such as job creation, and technological development. Therefore, the new business models will take into account the results of the research in the energy field, the use of biomass being the solution for obtaining cheap energy by reusing natural elements and their residues (Petcu et al., 2011).

MATERIAL AND METHODS

The methodology for analyzing the energy production potential

In this paper, the criterion of energy analysis of agricultural production (both for primary production and for secondary production - biomass) was used for several energy crops that are more productive for biomass. In order to perform energy analysis, it is necessary to adopt a unitary methodology for each level of analysis, taking into account elements such as the classification of energy consumed and obtained, the coefficients of transformation of different energies into a single energy equivalent, calculation methods and energy analysis indicators.

The energy criterion allows the transformation of all consumption and production obtained into a common energy equivalent and, therefore, energy consumption and production can be subjected to an energetic analysis, based on indicators specific to this analysis criterion. It may be considered that any material means, including the biological ones, have incorporated into them, in one form or another, a certain amount of energy (Helbig et al., 2008). To quantify the different forms of energy used in the production process of COP technologies in a common energy equivalent are used the specific coefficients for labor, various materials, and fixed assets. These coefficients are presented in Table 1.

Table 1. Energy equivalent for labor, materials, and fixed assets

Specification	U.M.	Energy equivalent in kWh (10^3Wh)
Labor - net energy produced	human-hours	0,074
Electricity	kWh	1,000
Diesel	liters	12,153
Gasoline	liters	12,211
Nitrogenous - N active substance	kg	25,700
Phosphates - P_2O_5 active substance	kg	5,650
Potassium - K_2O active substance	kg	4,125
Manure	kg	0,190
Pesticides and herbicides	kg	30,000 -116,300
Rope	kg	7,792
Tractors, trucks, combines	kg	20,000
Agricultural machinery, medium complexity	kg	17,000
Agricultural machinery, small complexity	kg	15,120
Irrigation	kWh	10,32

Source: Ursu and Nicolescu, 2008

There is a wide diversity of units for quantifying the energy consumed and produced in agricultural processes, and, as such, different units of measurement are used - calorie, Joule, kWh, etc. - their correspondence is presented in Table 2. To evaluate the amount of energy obtained in the form of vegetable products, all products have to be expressed in the same energy units as the energy consumption. It should be noted that agricultural products contain potential or raw energy, forms in which they are harvested and consumed either directly in their natural state, or as a result of physical or even chemical processing.

Table 2. Correspondence between different energy units

The energy units	Symbol	MJ	Mcal	kWh	CPh
MegaJoule (10^6 Joule)	MJ	1	0,239	0,278	**0,373**
Megacalorie (10^6 calories)	Mcal	4,186	1	1,163	**1,580**
KiloWatt hour (10^3 Watt hours)	kWh	3,602	0,860	1	**1,359**
Horsepower hour	**CPh**	**2,651**	**0,633**	**0,736**	1

Source: https://www.physics.uci.edu/~silverma/units.html .

In this paper, the energy efficiency tools are applied to assess the energy demand and the efficiency of the main production (q_p) and secondary (biomass) production (q_s) for the following energy crops: wheat, maize, sunflower, beans, sugar beet, barley, and rape. The energy potential analysis was performed in three scenarios for different types of mechanized agricultural systems, practically for three classes of COP farms of different sizes (20, 200 or 1000 hectares), with an optimum crop rotation for plain areas (Table 3).

Table 3. Crop rotation (ha)

Classes of COP farms	Wheat	Maize	Sunflower	Beans	Sugar beet	Barley	Rape	Total (ha)
Scenario I (a farm with a size of 20 hectares)	5	6	4	1	2	2	-	20
Scenario II (a farm with a size of 200 hectares)	60	54	30	10	10	10	26	200
Scenario III (a farm with a size 1000 hectares)	320	250	150	50	50	50	130	1000
Main production (kg) - q_p	4796	7644	3041	1477	38031	5090	2546	-
Secondary production (biomass) (kg) - q_s	1200	2000	800	1200	7200	2000	1000	-

Source: Ursu and Nicolescu, 2008.

The analysis of a single crop and a single technological variant provides sufficient information on the main aspects: energy production, energy consumption, balance, and energy efficiency. The technological sheet offers information regarding manual labor (loading hours with chemical fertilizers, loading/ unloading of seed bags, preparation of herbicide solutions and phytosanitary treatments, etc.), mechanized hours (starting from different types of operation and tillage), quantities of consumed inputs (fuel, fertilizers, pesticides, seeds, etc.) (Boclaci and Cremeneac, 2013).

Indicators for the analysis of the energy potential of the COP

In our energy analysis, we took into account the fact that the energies consumed are classified into two types of energies: active energies (direct and indirect) and passive energies.

Direct active energy is the energy used to produce the force (mechanical work) in order to operate various machines (human resources, fuel, electricity, thermal energy, solar energy, wind energy, etc.).

Indirect active energy is the energy used to extract or manufacture different materials in order to increase production or avoid crop losses (fertilizers, pesticides, herbicides, trace elements, etc.). This group includes natural fertilizers, whose energy was equivalent to the energy required for the manufacture of nitrogen, phosphorus, and chemical potassium contained in them.

Passive energy is the energy spent on the use of fixed assets (tractors, cars, buildings, etc.) and one manufacture of inert materials, such as wire, twine, etc.

For the determination of these types of energy, calculations shall be made based on the consumption expected in the technology of obtaining the product and the coefficients for converting those materials into energy units. To assess the energy efficiency of COP technologies, we started with the consumption data regarding applied inputs per unit area.

In our analysis, we considered that the following energetic indicators could be used, by applying the specific calculate formulas (Rusu, 2014):

- **produced energy** (kWh):

$$E_O = \sum E_{O_y} = \sum(E_{O_{yp}} + E_{O_{ys}}) = \sum(q_{yp} \times k_{yp}) + \sum(q_{ys} \times k_{ys}) \quad (1)$$

where:

E_O - total energy output;

E_{Oy} - energy output for crop “y”;

q_{yp} - main production for crop “y”;

q_{ys} - secondary production for crop “y” (biomass);

k_y - energy transformation coefficient for crop “y”.

- **total consumption of energy** (kWh):

$$E_I = \sum E_{I_y} = \left(\sum E_{A_{Dy}} + \sum E_{A_{Iy}}\right) + \sum E_{P_y} \quad (2)$$

where:

E_I - total energy input;

E_{Iy} - energy input for crop “y”;

E_{ADy} - direct active energy for crop “y”;

E_{AIy} - indirect active energy for crop “y”;

E_{Py} - passive energy for crop “y”.

- **specific consumption of energy** (kWh):

$$E_{A_{Dy}} = \sum ES_{Di} = \sum I \times k_i \quad (3)$$

where:

ES_{Di} - specific direct energy of input “i” for crop “y”;

I - input quantity for crop “y” (hours for manual activities, fuel) from crop technology;

k_i - input coefficient of input “i” for crop “y”.

$$E_{A_{Iy}} = \sum ES_{Ii} = \sum I \times k_i \quad (4)$$

where:

ES_{Ii} - specific indirect energy of input “i” for crop “y”;

I - input quantity for crop “y” (nitrogen, phosphorus, potassium, pesticide, seed) from crop technology;

k_i - input coefficient of input “i” for crop “y”.

$$E_{A_{Py}} = \sum ES_{Pi} = \sum I \times k_i \quad (5)$$

where:

ES_{Pi} - specific passive energy of input “i” for crop “y”;

I - input quantity for crop “y” (manure, rope, hours for mechanized activities) from crop technology;

k_i - input coefficient of input “i” for crop “y”.

- **energy intensity**:

$$E_{qy} = \frac{E_{Iy}}{q_y} \quad (6)$$

- **energy productivity**:

$$E_{wy} = \frac{q_y}{E_{Iy}} \quad (7)$$

- **energy efficiency per farm** (**energy yield**) (E_R): this indicator is expressed as a percentage and reflects how many energy units are obtained per unit of energy consumed.

$$E_R = \frac{E_O}{E_I} \quad (8)$$

- **net energy gain per farm** (E_G) (kWh):

$$E_G = E_O - E_I \quad (9)$$

Table 4 presents the energy coefficients for the main production (K_P**),** the secondary production (Ks), and the farm inputs established for crops cultivated in the soil, climate and technology conditions for Romanian region (Ki, with i from 1 to 9).

Table 4. Energy coefficients

Y (crop)	Wheat	Maize	Sunflower	Beans	Sugar beet	Barley	Rape
Main Production Coefficient (K_P)	4.46	4.56	6.58	4.54	1.14	4.44	7.3
Secondary Production Coefficient (Biomass) (Ks)	4.24	4.25	4.25	4.28	0.66	4.27	4.24
Manual and mechanized hours coefficient (K_1)	0.074	0.074	0.074	0.074	0.074	0.074	0.074
Fuel coefficient (K_2)	12.15	12.15	12.15	12.15	12.15	12.15	12.15
Nitrogen coefficient (K_3)	25.7	25.7	25.7	25.7	25.7	25.7	25.7
Phosphorus coefficient (K_4)	5.65	5.65	5.65	5.65	5.65	5.65	5.65
Potassium coefficient (K_5)	4.125	4.125	4.125	4.125	4.125	4.125	4.125
Manure coefficient (K_6)	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Pesticide coefficient (K_7)	73	73	73	73	73	73	73
Rope coefficient (K_8)	7.792	7.792	7.792	7.792	7.792	7.792	7.792
Seed coefficient (K_9)	4.46	4.56	6.58	4.54	1.14	4.44	7.3

Source: Rusu, 2014.

RESULTS AND DISCUSSION

Energy consumption in agricultural production of COP

In the first part of our analysis, starting from the technological flow of crops, we calculated the contribution of all inputs to the total energy consumption (per hectare).

In the crop production technologies (Hermeziu, 2021), the corresponding works are highlighted for each aggregate used, the consumption of human energy in man-hours, the consumption of diesel or electricity, and all the required elements for the calculation of direct active energy. Moreover, the consumed materials are also detailed, more specifically, the elements necessary to determine the consumption of indirect active energy.

Starting from the technological flux of crops, in Table 5 was estimated the direct active energy (consumption of fuel or electricity and energy consumption of human man-hours) and the indirect active energy (consumption of fertilizers, pesticides, and seeds) using the calculation formulas of the specific indicators for analyzing the energetic potential of the COP.

Table 5. Input participation in direct (E_{AD}), indirect active (E_{AI}) and passive (E_P) energy consumption (per hectare)

Input participations at energy balance	UM	Wheat	Maize	Sunflower	Beans	Sugar beet	Barley	Rape
Manual hours energy	kWh/ha	2	9	5	3	14	2	2
Fuel energy	kWh/ha	822	806	854	1,129	1,466	864	915
E_{AD}	kWh/ha	824	815	859	1,132	1,481	866	916
Share in total energy	**%**	**13.73**	**17.86**	**21.15**	**30.93**	**24.33**	**17.21**	**18.46**
Fertilizers energy	kWh/ha	3,809	2,966	2,966	1,367	3,022	3,022	3,701
Share in total direct active energy	*%*	*74.70*	*79.84*	*94.25*	*56.75*	*67.32*	*73.98*	*93.91*
Pesticides energy	kWh/ha	175	635	161	529	1,460	175	152
Share in total direct active energy	*%*	*3.43*	*17.09*	*5.12*	*21.96*	*32.52*	*4.28*	*3.86*
Seed energy	kWh/ha	1,115	114	21	514	7	888	88
Share in total direct active energy	*%*	*21.87*	*3.07*	*0.67*	*21.34*	*0.16*	*21.74*	*2.23*
E_{AI}	kWh/ha	5,099	3,715	3,147	2,409	4,489	4,085	3,941
Share in total energy	**%**	**85.08**	**81.40**	**77.49**	**65.82**	**73.74**	**81.18**	**79.44**
Materials energy	kWh/ha	16	0	0	16	12	26	13
Share in total passive energy	*%*	*22.54*	*0.00*	*0.00*	*13.45*	*10.17*	*32.10*	*12.50*
Mechanized hours energy	kWh/ha	55	34	55	103	106	55	91
Share in total passive energy	*%*	*77.46*	*100.00*	*100.00*	*86.55*	*89.83*	*67.90*	*87.50*
E_P	kWh/ha	71	34	55	119	118	81	104
Share in total energy	**%**	**1.18**	**0.74**	**1.35**	**3.25**	**1.94**	**1.61**	**2.10**

Source: own calculation

From the analysis of the data obtained in Table 5, we can see that in the structure of total energy consumption/ha, per total farm, the largest share had indirect active energy consumption, followed by direct active energy consumption, and passive energy consumption. Within direct active energy, the main energy consumption is that of fuels - 98%, with human energy consumption being only 2%. In the consumption of indirect active energy/ha, the greatest influence is exerted by chemical fertilizers (fertilizers and pesticides) - 83% of this total consumption. Similarly, by using the technological flux of crops, there were calculated the passive energy for each crop, starting from the type of agricultural equipment, the physical wear, and the working time of each unit per flux of activities. For the calculation of the passive energy consumption, the weight of the machine, the agricultural equipment, the service life, in years, the working time per year, and the hours performed in a technological process for each crop were taken into account. Appreciating equal working time for all machines is a brief method, given that, for example, the tractor does not work the same number of hours as the seeder, or combine, whose annual working period is much more limited.

The total input of energy was obtained from active and passive energy estimation based on crop's specific technological flow (Table 6). The estimates indicate that sugar beet needs the highest amount of energy to obtain an optimal yield (over 6 thousand kWh) and that beans are in the last place with an energy demand more than half of the level of sugar beet.

Table 6. Input participation in total energy consumption (per hectare)

Energy balance for biomass	UM	Wheat	Maize	Sunflower	Beans	Sugar beet	Barley	Rape
E_I	kWh/ha	5,993	4,564	4,061	3,660	6,088	5,032	4,961
Energy intensity (Eq)	kWh/kg	1.25	0.60	1.34	2.22	0.16	0.99	1.95
- biomass	kWh/kg	4.99	2.28	5.08	2.73	0.85	2.52	4.96
Energy productivity (EW)	kg/kWh	0.22	0.22	0.15	0.17	0.88	0.23	0.14
- biomass	kg/kWh	0.24	0.24	0.24	0.31	1.52	0.23	0.24

Source: own calculation

The different shares in total energy demand are a result of different values of total consumption in each crop. The results reveal, for all analyzed crops, that fertilizers have the largest share in crop energy consumption, between 50-75% depending especially on the quantity of applied nitrogen (more than 58% of total consumption). The shares of pesticides differ between crops, with the highest energy consumption being registered for sugar beet. Regarding seeds, the difference in energy levels is due to the different quantities of material used, the wheat and barley having higher technological necessities. Regarding the equipment used, measured by mechanized hours, the energy demand has the smallest share of total energy consumption. Nevertheless, the fuel energy (calculated separately) has a large share of the total energy demand (between 13% and 31%), depending on crops' mechanized activities and needed operational steps.

The energy efficiency tools are applied to assess the energy demand and the efficiency of main production and secondary (biomass) production. Reporting on the yield, we observe that the energy intensity is higher for beans, wheat, and sunflower. That means a higher quantity of input energy is needed to produce a kg of these crops. Regarding biomass, the energy needed to produce a unit of biomass is higher in the case of wheat, and sunflower (around 5 kWh/kg). In the case of sugar beet, we observe the lowest consumption of energy input per kg of biomass (only 0.16 kWh/kg).

Analysis of energy potential in agricultural farms of different sizes

In the second part of our analysis, starting from these calculations per crop and hectare we estimated the energy balances for three types of farms with an economical optimum crop rotation. The energy potential analysis was performed in three scenarios for different types of mechanized agricultural systems, practically for three classes of COP farms (Table 3).

- scenario I - a farm with a size of 20 hectares;
- scenario II - a farm with a size of 200 hectares;
- scenario III - a farm with a size of 1000 hectares.

Table 7. Energy balance (in kWh) in the scenario I with an optimum crop rotation

Energy balance	Wheat	Maize	Sunflower	Beans	Sugar beet	Barley	Rape	Total
Crop rotation - 20 ha	5	6	4	1	2	2	-	20
E_{AD}	4115	4890	3436	1132	2962	1732	-	*18267*
E_{AI}	25495	22290	12588	2409	8978	8170	-	*79930*
E_P	358	199	218	119	234	162	-	*1290*
E_I	29,968	27,379	16,242	3,660	12,174	10,064	-	*99,488*
E_O, from which:	132,391	260,14	93,639	11,842	96,215	62,279	-	*656,505*
E_{Op} (main production)	106,951	209,140	80,039	6,706	86,711	45,199	-	*534,745*
E_{Os} (biomass)	25,440	51,000	13,600	5,136	9,504	17,080	-	*121,760*
Net energy gain (E_G)	557,017							
- net energy gain from biomass	103,852							

Source: own calculation

Thus, for the farm included in scenario I, due to the lack of information, only 6 of the 7 crops were analyzed and a total energy production per farm of 656.505 kWh was obtained, in terms of total energy consumption, per holding, of 99.488 kWh (Table 7). In addition, the energy balance shows us that at the farm level, additional energy equivalent to almost 557 thousand kWh can be obtained, and the energy efficiency, which reflects how many energy units are obtained per unit consumed, is 6.59. In farms with 20 ha, the biomass reaches a level of 534,000 kWh for energy output and an energy gain of approximately 104,000 kWh. In the structure of total energy consumption per farm, the largest share was indirect active energy consumption - 80%, followed by direct active energy consumption - 19% and passive energy consumption of 1%. Passive energy consumption, which has a very small percentage, is mainly explained by the lack of a coordinated irrigation system.

Table 8. Energy balance (in kWh) in scenario II with an optimum crop rotation

Energy balance	Wheat	Maize	Sunflower	Beans	Sugar beet	Barley	Rape	Total
Crop rotation - 200 ha	60	54	30	10	10	10	26	200
E_{AD}	49,380	44,010	25,770	11,320	14,810	8,660	23,816	177,766
E_{AI}	305,940	200,610	94,410	24,090	44,890	40,850	102,466	813,256
E_P	4,294	1,795	1,637	1,193	1,171	811	2,721	13,622
E_I	359,614	246,415	121,817	36,603	60,871	50,321	129,003	1,004,644
E_O, from which:	1,588,690	2,341,259	702,293	118,416	481,073	311,396	593,471	6,136,598
E_{Op} (main production)	1,283,410	1,882,259	600,293	67,056	433,553	225,996	483,231	4,975,798
E_{Os} (biomass)	305,280	459,000	102,000	51,360	47,520	85,400	110,240	1,160,800
Net energy gain (E_G)	5,131,954							
- net energy gain from biomass	979,964							

Source: own calculation

For the farm included in scenario II, all crops that were the basis of this study were analyzed and a total energy production per farm of 6,136,598 kWh was obtained, under the conditions of a total energy consumption per farm of 1,004,644 kWh (Table 8). The analysis revealed a net energy gain of approximately 5,132 thousand kWh where the biomass reaches a level of 1,161 thousand kWh for energy output and an energy gain of 980 thousand kWh. In the structure of total energy consumption per farm, the largest share was indirect active energy consumption - 81%, followed by direct active energy consumption - 18% and passive energy consumption of 1%. In addition, the energy balance shows us that the ratio between the energy produced and the consumed one, i.e. energy efficiency at the level of the 200 ha farm, is 6.1.

Table 9. Energy balance (in kWh) in scenario III with an optimum crop rotation

Energy balance	Wheat	Maize	Sunflower	Beans	Sugar beet	Barley	Rape	Total
Crop rotation - 1000 ha	320	250	150	50	50	50	130	1000
E_{AD}	263,360	203,750	128,850	38,950	74,050	43,300	119,080	871,340
E_{AI}	1,631,680	928,750	472,050	121,700	224,450	204,250	512,330	4,095,210
E_P	22,902	8,309	8,184	3,272	5,857	4,053	13,605	66,182
E_I	1,917,942	1,140,809	609,084	163,922	304,357	251,603	645,015	5,032,732
E_O, from which:	8,473,011	10,839,160	3,511,467	619,453	2,405,367	1,556,980	2,967,354	30,372,792
E_{Op} (main production)	6,844,851	8,714,160	3,001,467	426,853	2,167,767	1,129,980	2,416,154	24,701,232
E_{Os} (biomass)	1,628,160	2,125,000	510,000	192,600	237,600	427,000	551,200	5,671,560
Net energy gain (E_G)	25,340,060							
- net energy gain from biomass	4,765,668							

Source: own calculation

In scenario III, all crops that were the basis of this study were analyzed and a total energy production per farm of 30,372,792 kWh was obtained, under the conditions of a total energy consumption per farm of 5,032,732 kWh (Table 9). In addition, the energy balance shows that at the level of the farm can be obtained additional energies equivalent to approximately 25,340 thousand kWh, obtaining in the case of these farms an energy efficiency of 6.03. The biomass reaches a level of 5,671 thousand kWh for energy output and an energy gain of 4,766 thousand kWh in farms with 1000 ha.

Analyzing the total energy consumption per farm, in its structure, the highest share had the indirect active energy consumption - 82%, followed by the direct active energy consumption - 17% and the passive energy consumption of 1%.

As shown in Table 10, if we take into consideration that in Romania there are around 60 thousand farms with 20 ha, around 8 thousand farms with 200 ha, and 850 farms with 1000 ha (Eurostat Report, 2019) we have the ability to estimate that the COP sector can produce around 96,016 million kWh (net energy gain). From this, around 18,122 million kWh are due to the biomass resources of the analyzed crops.

Table 10. The energy potential of biomass (in million kWh) in the COP sector (energy potential)

Energy balance	60000 farms 20 h*	8000 farms 200 ha*	850 farms 1000 ha*	Estimate COP sector
E_I	5,969.3	8,037.2	4,277.8	18,284.3
E_{Ip} (main production)	4,894.8	6,590.5	3,507.8	14,993.1
E_{Is} (biomass)	1,074.5	1,446.7	770.0	3,291.2
E_O, from which:	39,390.3	49,092.8	25,816.9	114,300.0
E_{Op} (main production)	32,084.7	39,806.4	20,996.0	92,887.1
E_{Os} (biomass)	7,305.6	9,286.4	4,820.8	21,412.8
Net energy gain (E_G)	33,421.0	41,055.6	21,539.1	96,015.7
- net energy gain from biomass	6,231.1	7,839.7	4,050.8	18,121.6

*Notes (legend): the numbers of farms are established based on the Eurostat Report.
Source: own calculation.

From the presented analysis, we can observe that biomass represents a promising renewable and sustainable energy source for Romania, both in terms of its energetically potential and possibilities. In fact, Romania has developed a biomass and biofuel production strategy for 2020-2030 having the energy security as its main objective. The potential of biomass energy, estimated at approximately 7.6 million tons/year or 318,000 TJ/year, represents approximately 19% of the total consumption from primary sources in Romania (Rodino et al., 2019).

The area used for energy crops has increased in the last years, and there is a large consensus that the demand for energy crops will further increase rapidly and, as such, it is going to cover several million hectares in the near future. Information about rotational systems and, therefore, the effects of energy crops should be given top priority. Literature is poor and fragmentary on this topic, especially about rotations in which all crops are exclusively dedicated to energy end uses. Well-planned crop rotations as compared to continuous monoculture systems can be expected to reduce the dependence on external inputs through promoting nutrient cycling efficiency, effective use of natural resources, especially water, maintenance of the long-term productivity of the land, control of diseases and pests, and consequently increasing crop yields and sustainability of production systems (Zegada-Lizarazu and Monti, 2011). The result of all these advantages is widely known as the crop sequencing effect, which is due to the additional and positive consequences on soil's physical-chemical, and biological properties arising from specific crops grown in the same field year after year (Cociu and Cizmaș, 2013).

Our study highlights that the energy balance at a farm level remains an important method to determine the efficiency of agricultural systems and for the assessment of energetically potential of biomass. The demand for energy in the production process and the volume of energy accumulated in biomass are two important components of the energy balance. Energy output and net energy output are crucial parameters when the demand for plant products cannot be met because of the limited area for growing crops (Sakin et al., 2015). Energy intensity and energy output/input ratio are integrative indicators of the environmental effects of crop production, which can be used to formulate recommendations for fertilization, which are optimum as far as the environment is concerned. Nitrogen fertilizers have a large share of energy inputs due to the high value of energy stored in chemical bonds (Gollner et al., 2016). For this reason, efficient nitrogen use not only increases agricultural profits, but also reduces local pollutant emissions and greenhouse gas emissions, and improves global food security.

CONCLUSIONS

The vegetable biomass production is an efficient source of energy, and the ratio between the energy introduced in the production process in the form of fuels, fertilizers, and machines (input) and the energy resulting from the products obtained (output) presents a net surplus.

Our study analyzed some of the main types of crops COP and the first observation refers to the fact that energy consumption per hectare is directly influenced by the level of the main production, but also by the level of secondary production (biomass) represented by wheat straw, corn cocoons, pasta, pasta, pasta, pasta, pasta remains of stems and leaves, etc. The analysis of the three types of farms proved that, within indirect active energy consumption/ha, the chemical fertilizers have the greatest impact over the productivity. Within direct active energy, the main energy consumption is caused by fuels - 98%, human energy consumption being only at 2%. At the same time, the passive energy represents about 1% of the total energy consumption within the farm, this consumption being low due to the lack of irrigation systems. The energy balance shows us that at the level of the farm you can obtain additional energy equivalent to almost 557,000 kWh, for farms with a size of 20 ha, 5,132,000 kWh for farms with a size of 200 ha, respectively, 25,340,000 kWh for farms with a size of 1000 ha. Energy efficiency indicates a ratio of at least 6 times higher between the energy obtained and the energy consumed, in each of the 3 scenarios. It can be noticed that both the energy balance and the energy efficiency obtained have high values, which is explained by the fact that the energy that is consumed is very low.

As such, we can achieve this, not only by rationalizing fuel consumption, but also by getting the maximum effect from the used fertilizers, herbicides, and pesticides. At the same time, proper soil preparation and maintenance, a right plan for crop rotation, and a reduction of diseases, pests, and weeds, can help the farmers to minimize the previously mentioned aspects. In agricultural production is consumed both direct and indirect active energy, as well as passive energy, and there is always fierce competition between fuels and fertilizers/pesticides. A balanced technology requires low energy consumption for its operations, so any disturbances in the application of different agrotechnical links will increase the energy consumption from outside. As such, the energy consumption of the whole agricultural domain has increased due to the introduction and use of more and more chemicals, which are generally energy-intensive products.

It is important to mention that the agricultural production systems, characterized by higher energy efficiency, are more environmentally friendly. Thus, biomass contributes to increasing the saving potential by capitalizing on renewable resources taken from nature. Concurrently, the attraction of clean technologies in the innovation-research process will increase the energy production capacity, and, implicitly, will contribute to a certain and long-lasting worldwide economic growth.

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