Bioenergy Potential of Ukrainian Agriculture

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Abstract- The study of the possibility of transition of agricultural production to self-sufficiency in energy resources based on renewable energy sources is an urgent issue and was conducted based on statistical data for Ukraine in 2019. It was found that the biological yield of plant biomass is 64.3 million t, and ensuring a zero humus balance can be achieved by using straw in the amount of 11.7 million t. At the same time, the excess amount of straw that can be used for energy needs may amount to 7.5 million t, which is about 12% of the total biological yield of plant biomass. The maximum amount of straw for energy needs cannot exceed 19.2 million t with a deficit-free humus balance in crop rotation due to the need to use straw for other priority needs, which is 29.8% of the biological yield of plant biomass of field crops. This is possible only if at least 40% of the sown area in the crop rotation will be under green manure. Calculations have shown that the potential production of biomethane based on organic biomass of manure, droppings and glycerol can reach about 1 billion m3, which is 4 times higher than the consumption of natural gas in agricultural production in Ukraine. Electricity generated from generator gas and biomethane in the amount of 5,464 million kWh is by 932 million kWh less than the total demand for agricultural and food production, but by 3059 million kWh greater than the needs of agricultural production.

Keywords Plant biomass, humus, diesel biofuel, bioethanol, biomethane, generator gas.

1. Introduction

Agricultural production has a significant impact on increasing greenhouse gas emissions due to greenhouse gas emissions in animal husbandry and partly due to the use of fossil fuels and electricity generated based on fossil fuels. The bioenergy potential of different countries and regions agriculture is widely covered in scientific works in recent years. It is also important to study the possibility of switching agricultural production to self-sufficiency in energy resources based on renewable energy sources [1, 2].

The first problem that arises in relation to the production of biofuels is to provide for the food needs of the population. For the each state the ensuring the food and energy independence very important element of domestic policy. The role of the ensuring the food and energy independence will increase in the future due to the growing welfare of the population. [3]. For the 13 European countries authors has examine the influence of the bioenergy production from the energy renewable sources on the food independence. It was founded that in those countries the agricultural bioenergy sector did not influence on the indices of the food independence. In the Czech Republic, Norway, Poland, Spain, and Germany, the correlations were found, but they was direct. It means that with the increasing of the bioenergy production from the renewable sources, indices of food independence also increase. In the review [4] says that EU support of biofuel production has result to the increasing of world food prices. The increasing of biofuel production have led to decrease stocks of food stock in the world. The EU biofuel policy is directed to the increasing of the palm oil demand. The increasing of the palm oil production for the EU export has stimulated the increasing of palm plantations. In this connection, the EU biofuel policy is directed on the increasing biofuel production for reduction of the greenhouse gas emission compared to the fossil fuels and on the limiting the use of food crops for biofuel production.

The next problem that arises in relation to the production of biofuels is to provide for the preservation of soil organic carbon. The studying of bioenergy potential of the biomass crop residue in India has shown that the estimated annual bioenergy potential of the biomass of the crop residue is 4.15 EJ, that equivalent to 17% of total India's energy consumption [5]. It was studied the biomass potential and the development of the bioenergy technologies in Sweden, Estonia, Norway, Denmark, Germany, Poland, Finland, Lithuania, and Latvia. The study found that bioenergy have an important role in the renewable energy production and Baltic Sea countries have the large diversity of biomass and bioenergy technologies depending from the geographical location, crop rotation, and population size. The studding of bioenergy potential of Baltic Sea countries is a good example to follow that can help of the bioenergy development in other countries and regions of the world [6]. During the studding of bioenergy potential of Japan was shown an important role of the energy supply strategy and that Japan's domestic bioenergy supply capacity is limited [7]. In the article has estimated Japan's technical and economically feasible bioenergy potential with used an integrated assessment with a gridded high-resolution land-use model and consideration of changes in the population and the crop rotation. It was installed that Japan's technical bioenergy could be from 3.43 to 3.78 EJ/year. The results of the study also showed that the Emilia-Romagna region (Italy) has a large availability of agricultural residues. They can used for bioenergy production, thus expanding opportunities of an agricultural production. The opportunity using 25% of total crop residues for renewable energy production was identified without competing for the agricultural land [8]. The analysis greenhouse gas emission reduction potential and of bioenergy production in Canadian province British Columbia has shown that existing biomass resources could yield from 110 to 176 PJ per year and reducing greenhouse gas emissions by from 13 to 15.7%. The authors consider it necessary develop both technological improvement and using external cost adjustment through measures like carbon taxation. [9]. The authors of the paper [10] made a preliminary assessment of the technical bioenergy potential of Russia which makes up 2225.4 PJ, crop residues makes up 42% of the total bioenergy potential, municipal solid waste 25%, forest residues 23%, livestock waste 9%, and sewage sludge biogas 1%. Only 12% of the Russian bioenergy potential is being currently utilized at the technical bioenergy potential 30% of the total heat and electricity consumption. In the some Russian regions, the technical bioenergy potential more than the existing heat and electricity consumption. This brief analysis of literature sources showed that the assessment of the bioenergy potential of individual countries and regions is an important element of further development of techniques for renewable bioenergy. A characteristic feature of the assessment of the bioenergy potential of individual countries and regions is also that the assessment of organic carbon into the soil is carried out based on established standards for the return of plant residues to the soil.

Chinese scientists are paying attention that most studies on agricultural residue estimations ignored the loss of soil humus and many authors research overestimated its resource potential. The study was conducted to estimate the resource potential of using agricultural residues for China bioenergy with considering soil humus conservation. The results showed that 226 Mt of residues could be collected annually with maintaining the current soil humus at a mean of 1.1%. To achieve of soil humus level of land in China above 2%, the agricultural residues would be reduced to 24 Mt. This indicates on the differences of bioenergy potential for various type of soils and natural climatic zones [11]. However, this study takes into account the predicted rather than the actual value of the level of return of humus in the soil. In general, there is a need for a more comprehensive assessment of the bioenergy potential of agricultural production.

The aim of this study was the determining the bioenergy potential of Ukrainian agriculture, taking into account the actual crop rotation and providing a balance between humus mineralization and the return of organic carbon for further humus formation in soils. The study based on a simulation modelling of the functioning of the agroecosystem with the production of organic products, of the possibility of providing the agroecosystem by electric and thermal energy through the use of biofuels of its own production with ensuring the balance of humus in crop rotation [12] and many years experience in the development of technical means for the production and use of biofuels in agriculture.

2. Materials and methods

The method of assessing the bioenergy potential of agricultural production involved the sequential determination of the following values:

– shortage of humus in crop rotation of the country or region;
– volume of plant biomass;
– the amount of straw for livestock needs;
– volume of manure;
– the amount of additional straw to compensate for the loss of organic carbon;
– volumes of electricity and heat production from biomethane [13, 14] and generator gas;
– volumes of diesel biofuel [15] and bioethanol to replace fossil diesel fuel and gasoline.

For Ukraine agriculture, the analysis is based on statistical data (Table 1) on the structure of areas and gross collection of field crops in Ukraine, given in [16]

Based on data on the mineralization of humus by field crops, the relative yield of dry mass of root residues of field crops, and the relative value of humification of root residues of field crops [17, 18], it was established an imbalance of humus as the difference between the total mineralization of humus by field crops and its intake due to the humification of root residues of field crops.

The biological yield of plant biomass was calculated taking into account the relative yield of dry aboveground plant biomass for each crop [17] and taking into account its relative humidity at the level of 20%.

Table 1. Area structure and gross collection of field crops in Ukraine

Crop	Harvested area, thousand hectares	Gross collection, thousand tons	Yield, t/ha
Winter and spring wheat	6,812	28,328	4.16
Rye	115	333	2.90
Winter and spring barley	2,609	8,917	3.42
Oats	182	422	2.32
Corn for grain	4,987	35,880	7.19
Millet	93	170	1.83
Buckwheat	69	85	1.23
Rice	11	55	5.00
Legumes	347	710	2.05
Sugar beet	221	10,204	46.17
Sunflower	5,959	15,254	2.56
Rapeseed	1,279	3,280	2.56
Soybeans	1,613	3,699	2.29
Potatoes	1,309	20,269	15.48
Vegetables	452	9,688	21.43
Forage crops	1,419	16,329	11.51
Total	27,477	153,623	–

On the basis of data on the relative value of stubble quantity and plant biomass loss during field crop harvesting and the relative value of field crop biomass humification [20], the value of humus intake due to stubble and losses of plant biomass during harvesting of field crops was established.

The volume of weed biomass varies widely depending on the timing of field crops, mechanical tillage, and the use of chemical weed control agents. According to the [19] weed biomass ranges from 0.01 to 0.5 kg/m2 of area under field crops. Due to the widespread use of chemical weed control agents, in this study, the humus balance was calculated on the basis of the volume of weed biomass of 0.1 kg/m2 of the area under field crops, and the volume of green manure biomass – of the yield at the level of the yield of fodder crops on an area of 5 million ha.

The need for straw for bedding and feeding animals was determined on the basis of animal population statistics (Table 2) provided in [16].

Table 2. Livestock population and initial data for calculating the need for straw for bedding and feeding the animals

Name	Livestock, thousand heads	Stall-feeding period, days (Horodniy, 2008)	Norms of straw demand for bedding, kg/head per day (Horodniy, 2008)	Average norms of straw demand for feeding, kg/head per day
Cows	1,789	210	6	4
Young cattle	1,303	210	6	2
Pigs	5,727	365	2	–
Sheep and goats	1,205	210	1	0.4
Poultry	220,500	365	–	–

Based on table 2 data, the values of the daily yield of manure and droppings, the values of their relative humidity and the relative value of humification of manure and droppings, the value of humus intake due to manure and droppings was established.

As a result, the total annual humus balance according to [18] and the balance of plant biomass in accordance with the above structure of areas and gross harvest of field crops in Ukraine were established.

The resource base of diesel biofuel production to replace petroleum diesel fuel and bioethanol production to replace gasoline was calculated based on the actual consumption of petroleum diesel fuel in agricultural production in 2019 at the level of 1.6 million t and gasoline at the level of 111 thousand t according to the [16]. Calculations were performed at the relative yield of rapeseed and sunflower oil at 33%, the relative yield of soybean oil at 12%, and the relative yield of diesel biofuels from oil at 95%. Calculations were carried out at the relative yield of bioethanol from corn grain at the level of 333 kg/t according to [20] and the relative demand for gasoline for bioethanol denaturation at the level of 3%.

The calculation of the biomethane yield was carried out on the basis of data given in table 3, taking into account the data from Biteco (https://biteco-energy.com), concerning the indicators of biomass moisture, organic matter content, organic matter decomposition level and methane content in biogas. The efficiency factor for obtaining electricity from biomethane was assumed to be at the level of 26% according to [21], and for obtaining electricity from generator gas – at the level of 12%.

Table 3. Initial data for calculating the biomethane yield

Name	Biomass yield, million tons	Biomass moisture, %	Organic matter content, %	Organic decomposition level, %	Methane content in biogas, %
Cows	20.7	91.5	85	28	55
Young cattle	7.1	90	85	40	55
Pigs	13.6	94	85	40	60
Sheep and goats	0.7	70	80	45	55
Poultry	0.0	72	75	30	55
Glycerin precipitate	14.1	85	75	50	65

The consumption of heat and electricity by agricultural and food production was taken according to [16].

The basis for calculations on the use of biofuels in agricultural production in Ukraine was experimental studies conducted on production and the use of diesel biofuels and biogas during the last twenty years.

3. Results

It was found that for the structure of areas and gross harvest of field crops in Ukraine in 2019, the estimated humus deficit was 480 kg/ha. As a rule, the annual humus deficit in Ukraine is 500±50 kg/ha.

The estimated humus balance based on the structure of areas and gross harvest of field crops in Ukraine in 2019 is shown in table 4.

Table 4. Estimated humus balance based on the structure of areas and gross harvest of field crops in Ukraine in 2019, kg/ha

Mineralization of humus by field crops	1,312
Humus intake due to humification of root residues	832
Humus deficiency	480
Humus intake due to biomass humification of:	
stubble and straw lost during harvesting	183
weeds and green manure	93
manure and droppings	135
Total humus intake	1,244
Total humus balance	**-64**

It was also found that the biological yield of plant biomass is 64.3 million t. The structure of straw use in Ukraine based on the structure of areas and gross harvest of field crops in Ukraine in 2019 is shown in figure 1. As a result of the analysis, it was found that ensuring a positive humus balance can be achieved when using straw in the amount of 11.7 million t for humus deficiency compensation needs. At the same time, the excess amount of straw that can be used for energy needs may amount to 7.5 million t.

Thus, the amount of plant biomass that can be used for energy needs, according to the data on the structure of areas and the gross harvest of field crops in Ukraine in 2019, can be about 12% of the total biological yield of plant biomass. However, it should be noted that there is a significant relationship between the total humus balance and the amount of plant biomass that can be used for energy needs (Figure 2). So, for example, even if the negative total humus balance is 112 kg/ha, the use of plant biomass for energy needs becomes impossible due to the need to spend plant biomass to eliminate the negative humus balance.

The analysis also showed that the maximum amount of straw for energy needs cannot exceed 19.2 million t with a deficit-free humus balance in crop rotation due to the need to use straw for other priority needs, which is 29.8% of the biological yield of plant biomass of field crops.

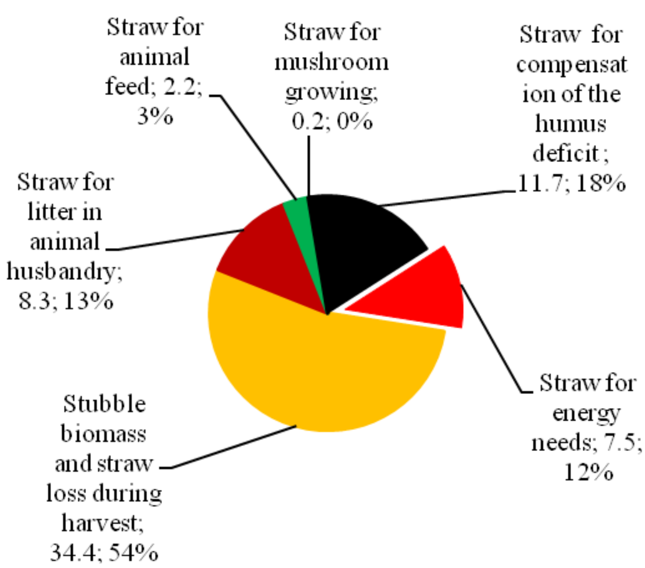

Fig 1. The structure of straw use in Ukrainian agriculture in million t

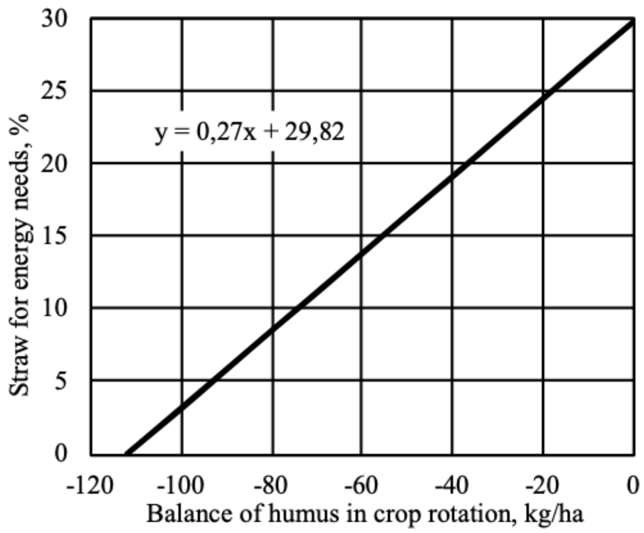

Fig. 2. Relationship between relative volumes of straw for energy needs and the general balance of humus in crop rotation

It is also established that for the areas and structure of the gross harvest of field crops in Ukraine, which has developed recently, an increase in the use of straw for energy needs can be ensured only by increasing green manure crops in crop rotation (cover crops in crop rotation).

The analysis showed (Figure 3) that only if at least 40% of the sown area in the crop rotation will be under green manure, it is possible to use the maximum amount of straw for energy needs, namely 29.8% of the biological yield of plant biomass of field crops.

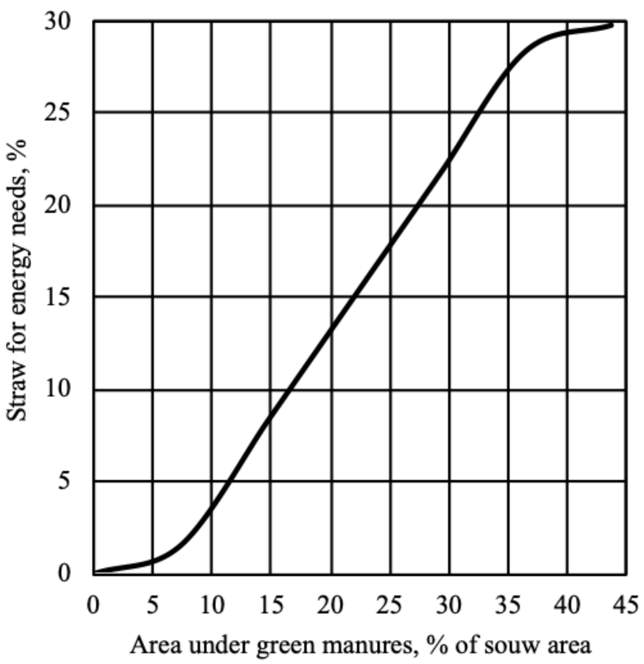

Fig 3. Relationship between relative volumes of straw for energy needs and the area under green manures in crop rotation

Analysis of the possibilities of replacing diesel fuel of petroleum origin with diesel biofuels based on renewable resources of oilseeds showed that processing of rapeseed and soybean grain will not completely replace diesel fuel of petroleum origin, which is consumed in agricultural production (Figure 4). To do this, it is necessary to additionally attract 7.8% of the total production of sunflower grain. Glycerin precipitate (glycerol), which is formed in the production of diesel biofuels, is included in the total biomass balance for the biomethane production.

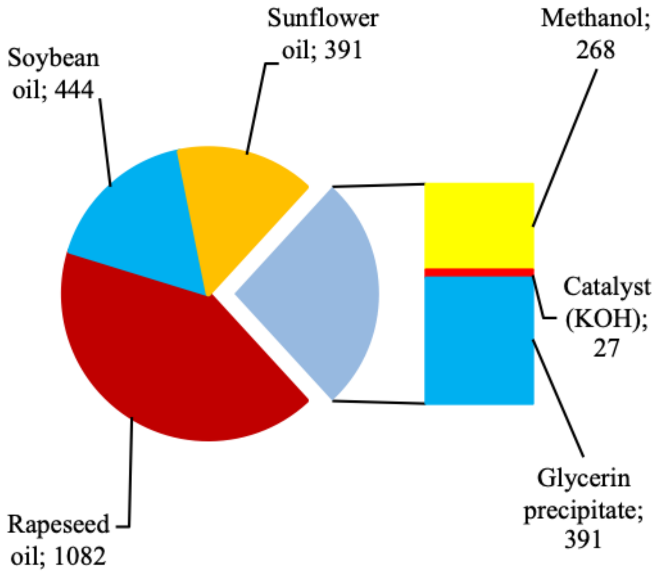

Fig 4. The potential structure of raw material flows in the production of diesel biofuels in thousands of tons

It is also established that due to the insignificant volume of gasoline consumption in agricultural production, only 1.4% of the total corn grain production is needed to replace it with bioethanol. The increase in the required volume of bioethanol production compared to the consumption of gasoline in agricultural production (Figure 5) is due to the fact that the calorific value of gasoline is 1.6 times greater than that of bioethanol. The required amount of gasoline for bioethanol denaturation, based on the relative demand of 3%, is 123 t.

Calculations have shown that the potential production of biomethane based on organic biomass of manure, droppings and glycerol can reach about 1 billion m3, which is 4 times higher than the consumption of natural gas in agricultural production in Ukraine.

The use of gasifiers to produce generator gas with the production of heat and electricity based on it in conjunction with biomethane cogeneration makes it possible to fully meet the heat needs of agricultural and food production and meet the needs of agricultural production in electricity.

According to the calculations, the total heat production during the transformation of generator gas and biomethane into electric energy amounted to 90 million GJ. On the other hand, heat consumption by agricultural and food production, according to [12], was only 39 million GJ. Excess of low-temperature heat in the amount of 51 million GJ can be used for heating domestic and social infrastructure facilities, and also encourages the need to develop more efficient methods for converting generator gas and biomethane into electricity (Figure 6).

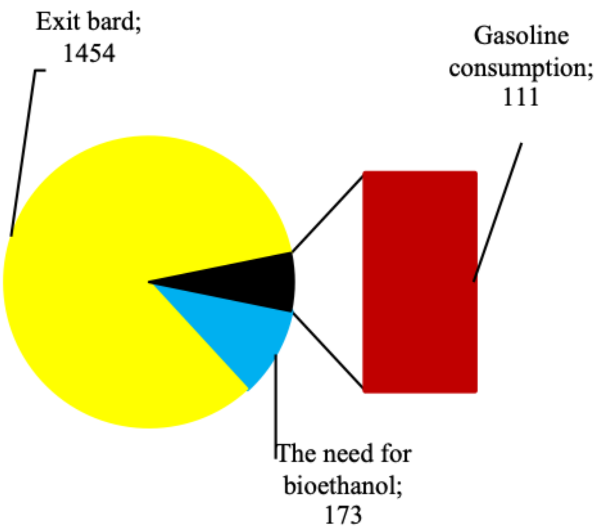

Fig 5. The potential structure of raw material flows in the production of bioethanol in thousands of tons

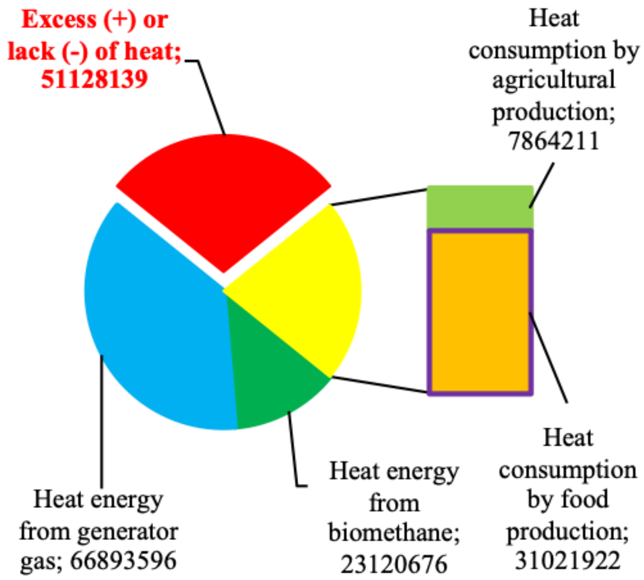

Fig 6. Potential production and consumption of heat based on biomethane and generator gas in Ukrainian agriculture in GJ

As for generating electricity from generator gas and biomethane, it can be predicted that 5,464 million kWh of the produced electricity will be by 932 million kWh less than the total demand for agricultural production (2,405 million kWh) and food production (3,991 million kWh) according to [19] (Figure 7), but by 3,059 million kWh more than the needs of agricultural production. The use of excess electricity does not create technical problems, unlike low-temperature excess thermal energy, because it can be transferred to the general electrical network.

Unlike the production of pellets and briquettes from plant biomass, which must be transported to consumers, the production of electric energy significantly simplifies the supply of electric energy to consumers through electric networks.

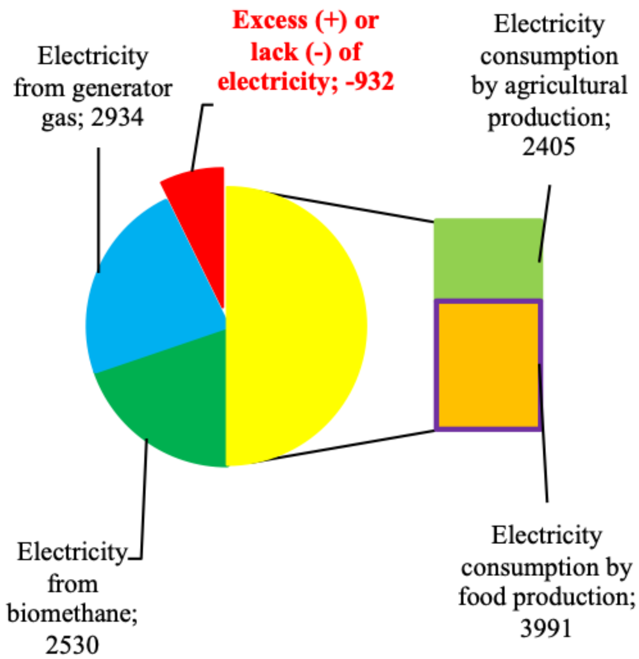

Fig 7. Potential production and consumption of electricity based on biomethane and generator gas in Ukrainian agriculture in million kWh

At the same time, there is also no need to create a number of intermediary structures for the sale of pellets and briquettes.

4. Conclusions

The peculiarity of the presented method of estimating the bioenergy potential of agriculture is taking into account the actual shortage of humus in crop rotation, the amount of straw for livestock needs, and the amount of additional straw to compensate for the loss of organic carbon. This method can be used to assess the bioenergy potential of agriculture in other countries and regions.

It is established that for the structure of areas and gross collection of field crops in Ukraine in 2019, ensuring a positive balance of humus can be achieved by using straw in the amount of 11.7 million t for humus deficiency compensation needs. At the same time, the excess amount of straw that can be used for energy needs may amount to 7.5 million t, which is about 12% of the total biological yield of plant biomass.

The maximum amount of straw for energy needs in Ukraine, based on statistics from 2019, cannot exceed 19.2 million t with a deficit-free humus balance in crop rotation due to the need to use straw for other priority needs, which is 29.8% of the biological yield of plant biomass of field crops. However, it is possible to use the maximum amount of straw for energy needs only if at least 40% of the sown area in the crop rotation will be under green manure.

Calculations have shown that the potential production of biomethane based on organic biomass of manure, droppings and glycerol can reach about 1 billion m3, which is 4 times higher than the consumption of natural gas in agricultural production in Ukraine.

Electricity generated from generator gas and biomethane in the amount of 5,464 million kWh is by 932 million kWh less than the total demand for agricultural production (2,405 million kWh) and food production (3,991 million kWh), however, is by 3,059 million kWh more than the needs of agricultural production.

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