STRUCTURAL MODELS OF AGROECOSYSTEMS AND CALCULATION OF THEIR ENERGY AUTONOMY

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Abstract. The results of the research in structural models with complete energy autonomy of agroecosystems (electricity and heat energy of own production) are presented. The aim of the work is to show the opportunities of complete energy autonomy of agroecosystems by producing and using their own electrical and thermal energy with observance of humus balance. Structural models of functioning of agroecosystems with organic and intensive production are presented. The models include growing of winter wheat, corn for silage, grain, winter rape, barley, sugar beet, and perennial grasses, sugar and honey production, mushroom and fish cultivation, and compost production. The model with organic production additionally provides for the production of pork, beef, chicken, milk, eggs, and oil. In addition, the proposed models provide for the production of diesel biofuels and bioethanol in the amount necessary to ensure the operation of mobile equipment, as well as biogas and generator gas for heat and electricity. The criterion of ecological stability of the proposed models of agroecosystems is the observance of humus balance. The analysis of the presented models allows asserting that complete energy autonomy of agroecosystems with a positive humus balance in the soil is possible. In agroecosystems with organic production the most heat energy – up to 50 % can be obtained by using straw pellets. Biogas can provide up to 20 % of the needs thermal energy, diesel biofuels – up to 16 %. 14 % of heat energy can be obtained from burning straw rolls. The production of electricity from wood gas produced from straw pellets provides 54 % of all electricity needs. Due to the use of biogas, up to 29 % of electric energy is provided, and through the use of diesel biofuels – up to 17 %. All the needs for heat energy for agroecosystems with intensive production can be provided by 80 % through the use of biogas and by 20 % – due to straw briquettes and pellets. All electricity costs for agroecosystems with intensive production can be provided through the use of biogas. The electric energy obtained through the use of wood gas resulting from gasification of straw pellets or briquettes can be sold at a green rate.

Keywords: energy, straw, biodiesel, biogas, gasproduction.

Introduction

Modern agricultural production provides humanity with food, that is, it solves the food problem [1]. Agricultural enterprises can also produce energy products: gaseous fuel – biogas; liquid fuel – diesel biofuel, bioethanol; solid fuel – straw in bales, fuel pellets and briquettes [2].

The use of fuel obtained during agricultural activities allows partial solving of the energy problem of mankind. For example, the article [3] states, that electricity from biogas is a promising direction of energetics and is an additional source of income in rural areas. In particular, biogas production from plant biomass is widespread [4]. In addition, vegetable raw materials are used for production of fuel pellets [5] and bioethanol [6].

Agriculture should be considered as an agroecosystem based on crop rotation with crop and livestock production. Such production is a natural complex, which is transformed by human agrarian activity [7;8]. The using of vegetable biomass in agroecosystems is a concern for scientists, regarding the reduction of food production and the negative impact on balance of humus in the soil [9]. On the basis of this there is a violation of agroecosystems stability. Accordingly, there is a threat of stable food production [10]. Stability of agroecosystems depends on the preservation of economic, biological and physical system components. The high level of integration of these components implies that any assessment of agroecosystem stability should take into account the dynamics of all its components [11]. It is possible to avoid negative impact by using agroecosystems with a high level of biological diversity [12] or agroecosystems with clear monitoring and system planning of environmental sustainability [13]. For example, we propose a model with a diversified production of agricultural products and biofuels [1], where environmental sustainability is ensured by maintaining the necessary balance of humus in the soil.

However, in these models, ensuring environmental safety, it was not possible to ensure the energy autonomy of agroecosystems. Thus, studies [14] have shown that it is possible to fully provide the agroecosystem with thermal energy and only 20 % of electric energy. Therefore, it is necessary to

search for additional sources of energy, especially for agroecosystems with intensive production. The basis of the energy autonomy of the agroecosystem can be the use in scientifically justified limits of the non-grain part of the harvest for heat in the form of rolls, bales, pellets, briquettes and the production of generator gas on this basis. [15]. But to assess the possibility of safe use of biofuels of own production, an analysis of structural models of agroecosystems is required.

Materials and methods

To study the ecological and energy efficiency of agroecosystems, we propose structural models of organic and intensive production, based on the models presented in [1;2;14].

Structural models of agroecosystems of organic (Fig. 1) and intensive production (Fig. 2) contain: crop rotation for cultivation of major crops; provision for the production of oil, sugar, honey and mushrooms, production of diesel biofuels and bioethanol in the amount necessary to ensure the operation of mobile equipment.

The models also provide that biogas is used to generate electricity and heat, and part of the plant biomass in the form of rolls or straw chaff is used to produce heat. Part of the plant biomass can be used for production of pellets, followed by production of wood gas from them. It is proposed to use wood gas for electric energy production. The models provide for implementation of all agrotechnical processes at the expense of their own energy resources. Models of agroecosystems provide environmental sustainability by maintaining the balance of humus and economic sustainability by maximizing the profits.
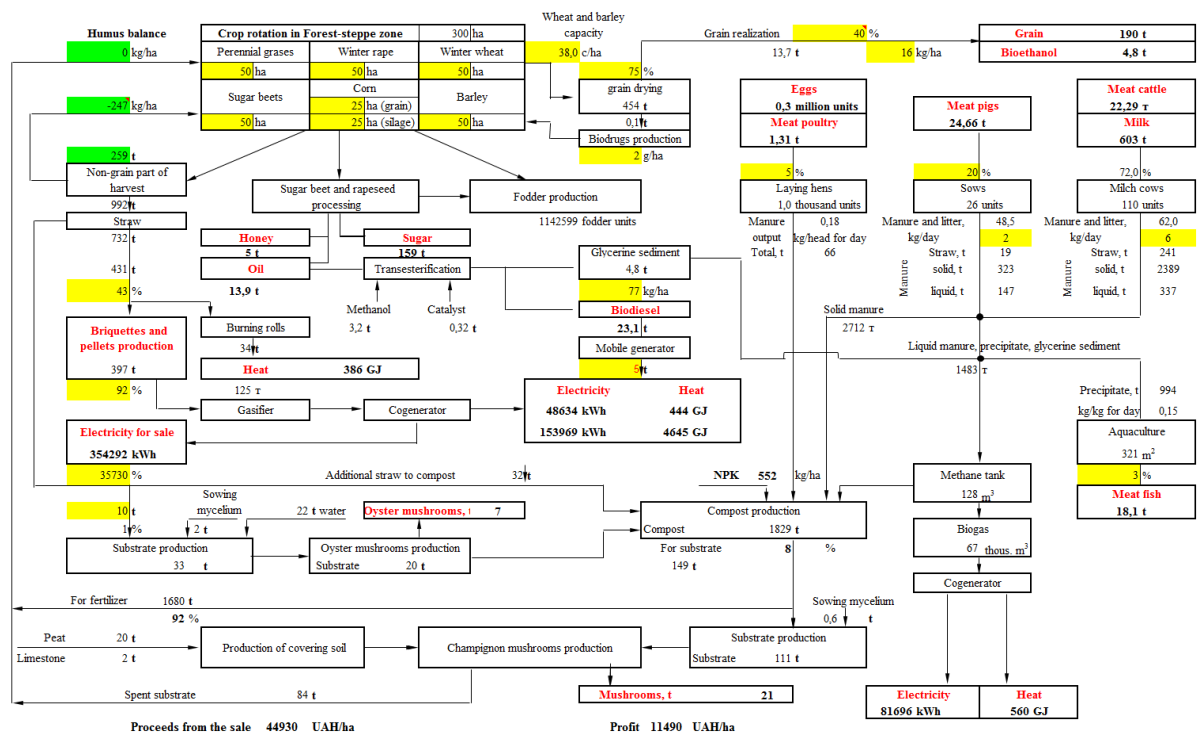

Fig. 1. **Model of energy autonomous agroecosystem with organic production**

The difference between the models is that the model for organic production includes production of pork, beef, fish, chicken, milk, and eggs. At the same time, the model for intensive production involves production of fish only.

On the basis of the developed structural models of functioning of agroecosystems with organic and intensive agricultural production, the main indicators of their efficiency were established.
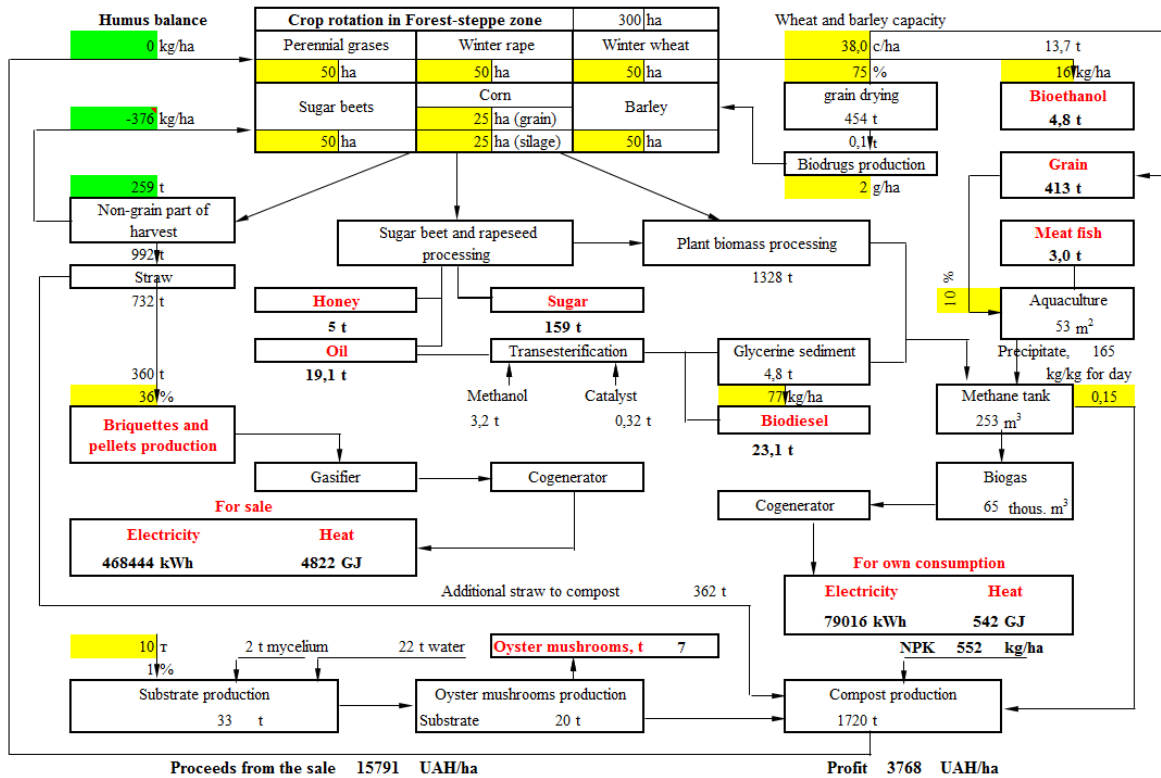
Fig. 2. **Model of energy autonomous agroecosystem with intensive production**

Results and discussion

The analysis of indicators of the efficiency of agroecosystems functioning shows that the observance of balance of thermal and electric energy is possible for agroecosystems with organic production (Table 1, Table 2).

Table 1

Balance of thermal energy in agroecosystem with organic production

Process	Requirement		
	Unit		Total, GJ
Grain drying	0.55	GJ·t^{-1}	250
Egg production	0.007	GJ per thousand PCs	1.7
Poultry production	0.61	GJ·t^{-1}	0.8
Pork production	3.7	GJ·t^{-1}	91.2
Beef production	4.5	GJ·t^{-1}	100.3
Milk production	2.8	GJ·t^{-1}	1688.3
Mushroom production	3	GJ·t^{-1}	82
Fish production	10	GJ·t^{-1}	181.5
Biogas production	5.5	MJ·m^{-3}	373
Bio-diesel production	0.7	GJ·t^{-1}	28.9
Totally			2798
Production of heat from biogas			560
Production of heat from bio-diesel			444
Production of heat from straw briquettes and pellets			1407
Production of heat from straw rolls			386
Deficit (-). surplus (+)			0

After analyzing the data given in Table 2, we can state that most of the heat energy is spent on milk production – up to 60 %, for biofuel production up to 14 % of the heat energy including 13 % for biogas production.

The resulting biogas provides up to 20 % of the heat energy needs. Up to 16 % of the heat energy is provided by the heat generated by use of diesel biofuels. 14 % of thermal energy is obtained from burning of straw rolls. Most of the heat energy, up to 50 %, can be obtained by using straw pellets and briquettes.

Table 2 shows that the largest consumption of electrical energy (up to 68 %) is required in milk production. Up to 23 % of the electricity is spent on biofuel production, 15 % – on production of fuel pellets and briquettes.

The production of electricity from the wood gas obtained from straw pellets provides 54 % of all agroecosystem needs in electricity. Due to use of biogas, up to 29 % of electric energy is provided. The use of diesel biofuels provides up to 17 % of the electricity demand.

The calculations show that the balance of heat and electricity is also possible for agroecosystems with intensive production (Table 3, Table 4).

In the agroecosystem with intensive production, more heat energy is used to ensure the operation of the biogas plant – 53 %. Grain drying requires up to 37 % of thermal energy.

All needs in thermal energy for such agroecosystem can be provided at the expense of biogas use – 80 %, and straw briquettes and pellets – 20 %.

Table 2

Balance of electric energy in agroecosystem with organic production

Process	Requirement		
		Unit	Total, thousand kWh
Grain cleaning	0.8	$kWh \cdot t^{-1}$	0.4
Grain drying	3	$kWh \cdot t^{-1}$	1.4
Egg production	0.31	KWh per thousand PCs	0.1
Poultry production	28.1	$kWh \cdot t^{-1}$	0.04
Pork production	185	$kWh \cdot t^{-1}$	4.6
Beef production	233	$kWh \cdot t^{-1}$	5.2
Milk production	310	$kWh \cdot t^{-1}$	186.9
Mushroom production	326	$kWh \cdot t^{-1}$	8.9
Fish production	420	$kWh \cdot t^{-1}$	7.6
Biogas production	0.3	$kWh \cdot m^{-3}$	20.4
Bio-diesel production	125	$kWh \cdot t^{-1}$	5.2
Production of briquettes and pellets	110	$kWh \cdot t^{-1}$	43.7
Totally			284.3
Generation of electricity from biogas			82
Generation of electricity from bio-diesel			49
Generation of electricity from straw briquettes and pellets			154
Deficit (-). surplus (+)			0

In the agroecosystem with intensive production, most energy is consumed for production of fuel briquettes and pellets – up to 59 %. Up to 29 % is used for biogas production.

All electricity costs can be provided through the use of biogas. The electric energy obtained through the use of generator gas resulting from gasification of straw pellets or briquettes can be sold at a green rate.

For the agroecosystem with organic production and ensuring the balance of humus, the largest share was the profit from livestock production – 64 % (Fig. 3). Due to the production of biofuels there was received up to 15 % of the profits, 11 % of which was due to the production of electricity based on its own biological resources. Crop production accounts for 13 % of financial revenues.

Table 3

Balance of thermal energy in agroecosystem with intensive production

Process	Requirement		
		Unit	Total, GJ
Grain drying	0.55	GJ·t⁻¹	250
Mushroom production	3	GJ·t⁻¹	20
Fish production	10	GJ·t⁻¹	30.1
Biogas production	5.5	MJ·m⁻³	361
Bio-diesel production	0.7	GJ·t⁻¹	16.2
Totally			676
Production of heat from biogas			542
Production of heat from straw briquettes and pellets			135
Deficit (-). surplus (+)			0

Table 4

Balance of electrical energy in agroecosystem with intensive production

Process	Requirement		
		Unit	Total, thousand kWh
Grain cleaning	0.8	kWh·t⁻¹	0.4
Grain drying	3	kWh·t⁻¹	1.4
Mushroom production	326	kWh·t⁻¹	2.1
Fish production	420	kWh·t⁻¹	1.3
Biogas production	0.3	kWh·m⁻³	19.8
Bio-diesel production	125	kWh·t⁻¹	2.9
Production of briquettes and pellets	110	kWh·t⁻¹	39.6
Totally			67.4
Generation of electricity from biogas			67.4
Deficit (-). surplus (+)			0

In the agroecosystem with intensive production and ensuring of humus balance, the largest share had revenues from crop production – up to 52 % (Fig. 4). And the production of biofuels provides up to 31 % of financial revenues.

Thus, the production of biofuels can ensure the energy autonomy of agricultural enterprises and become a significant source of income. At the same time, it is possible to meet the needs in the production of food products and get a positive balance of humus.
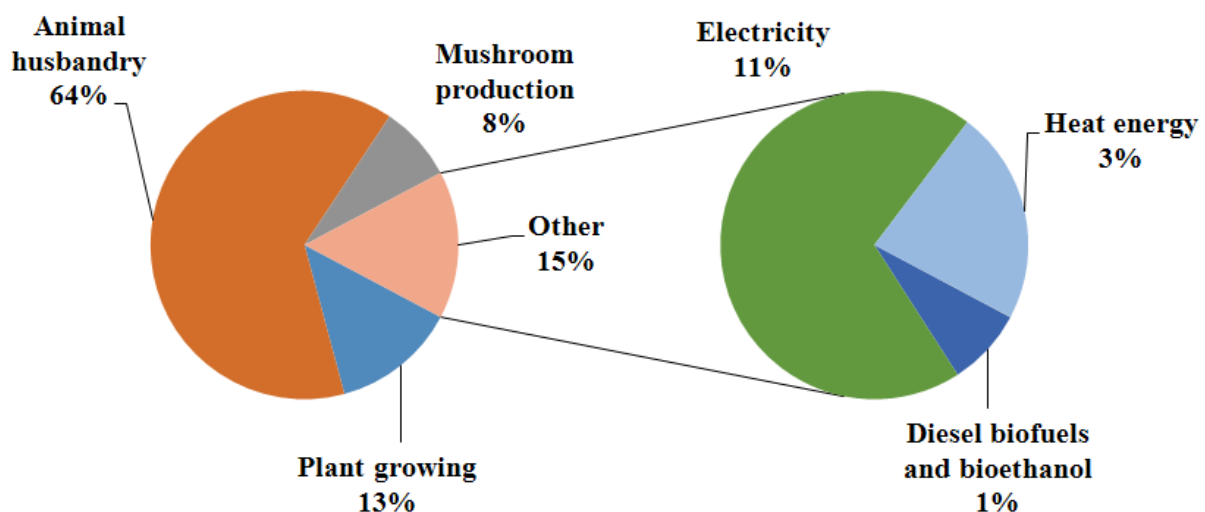

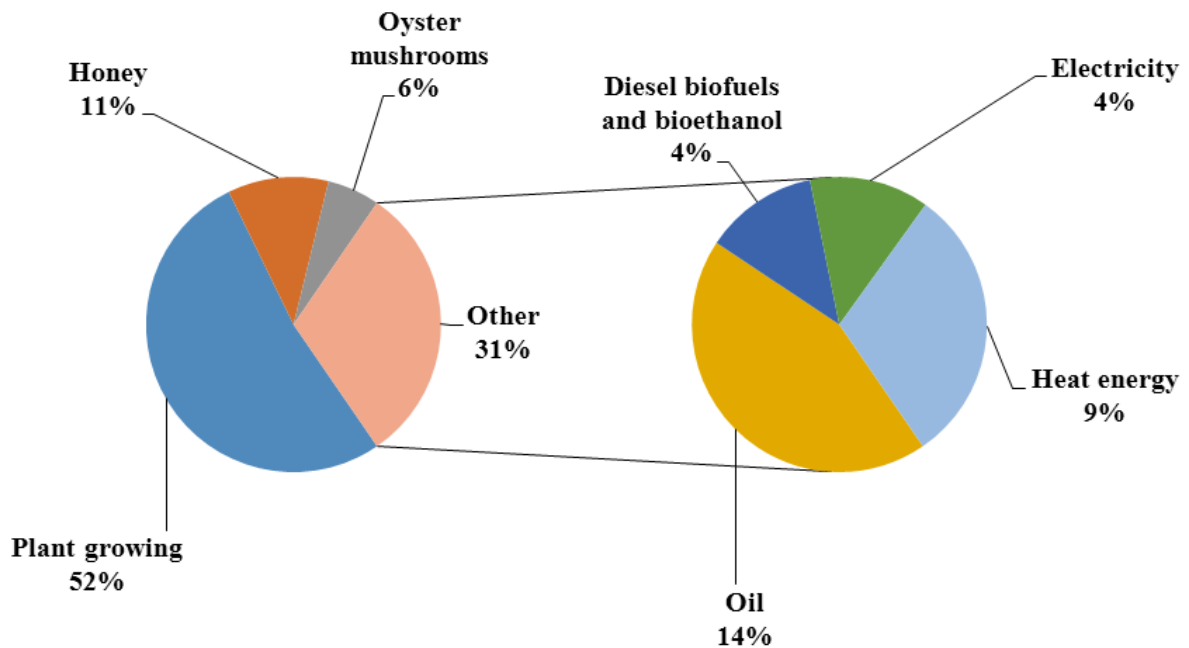Fig. 3. **Structure of profits in agroecosystem with production of organic goods and biofuels**

Fig. 4. **Structure of profits in agroecosystem with intensive production of goods and biofuels**

At present, there are no data available in open publications on the possibility of providing energy autonomy of agroecosystems in the aspect the complete electric autonomy of agricultural enterprises with providing of humus balance in the soil [10;11]. Scientific discussions on the feasibility of using biofuels in agricultural production are being conducted [9;12;16]. The basis of these discussions is that maintaining the balance of humus, when using plant biomass as biofuels, is impossible. However, the models of agroecosystems presented by us demonstrate the possibility of achieving energy autonomy while preserving the humus balance in agroecosystems. The presented agroecosystem models can be applied to agrarian enterprises, regardless of their size, and can also be used to modeling agricultural production of individual countries.

Conclusions

1. In agroecosystems with organic production the most heat energy – up to 50 % can be obtained by using straw pellets. Biogas can provide up to 20 % of the needs for thermal energy, diesel biofuels – up to 16 %. 14 % of the heat energy can be obtained from burning straw rolls. The production of electricity from wood gas produced from straw pellets provides 54 % of all electricity needs. Due to the use of biogas, up to 29 % of electric energy is provided, and through the use of diesel biofuels – up to 17 %.
2. All the needs for heat energy for agroecosystems with intensive production can be provided by 80 % through the use of biogas and by 20 % – due to straw briquettes and pellets. All electricity costs for agroecosystems with intensive production can be provided through the use of biogas. The electric energy obtained through the use of wood gas resulting from gasification of straw pellets or briquettes can be sold at a green rate.
3. The results of agroecosystems modeling show that agricultural enterprises can achieve energy autonomy. In this case, a positive balance of humus in the soil will be observed.

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