

The by-products of grain production are an ecological and economic solution to the energy crisis

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Abstract. The study substantiates that effective handling of by-products of grain production will contribute to ensuring the energy and environmental security of Ukraine. The main methods of crop waste management by Ukrainian farmers are considered, where preference is given to burning straw and stubble in the field. This method of disposal of by-products of grain production is environmentally hazardous, exacerbating the climate crisis. It is determined that Ukraine has a powerful energy potential of by-products of grain production because it is leading in the crop industry. It is proposed that by-products of grain production be used for energy purposes, namely direct combustion, to obtain thermal energy. Based on the use of the linear model, the production of by-products from the main grain crops in Ukraine from 2022 to 2050 is predicted. The ecological and economic benefits from the use of by-products of grain production as an alternative source of energy at the level of territorial communities of Ukraine are substantiated.

1 Introduction

In the 21st century, there is a climate crisis, as an «excessively rapid climate change» due to an increase in the global average temperature. Humanity significantly changes the concentration of greenhouse gases in the atmosphere by burning fossil fuels, etc. During their burning, carbon is released, which combines with oxygen in the air and forms CO₂. Over the past 150 years, the concentration of CO₂ increased from 280 ppm (parts per million) to more than 400 ppm» [1]. Various factors influence climate change, but human activity is the most influential, first of all, due to emissions of CO₂ into the atmosphere due to the burning of fossil fuels. Every year, the environmental crisis in the world becomes more dramatic. This requires maximum attention from each country until climate neutrality is achieved. Because of the environmental dangers of climate change, world leaders are actively cooperating in sustainable development and achieving climate neutrality. This question has also been actively investigated in the scientific space. According to scientists, the product's environmental friendliness affects the level of competitiveness [2], and the stimulation of environmental awareness among agricultural producers and consumers will contribute to the greening of resource consumption [3].

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Nowadays, the world is increasingly turning to green technologies. The reuse of resources and the issue of effective waste management are actively considered by ecologists and economists [4-6].

One of the mechanisms for improving the ecology of the environment, preserving natural resources, and reducing air emissions is the refusal to use fossil fuels and the search for alternative energy sources. This is provided for in the Paris Climate Agreement and 2015. In the agreement, the goal of maintenance of global growth temperatures on Earth within 2°C by 2100. Active in this direction is developing branch green energy is wind or sunny. However, the weather's variability and unpredictability doo allow forward supply to be set up during the year. Moreover, spent solar panels and wind turbines have a service life of up to 20 years and must be disposed of. Implementing the bioenergy development strategy for Ukraine is extremely important because "Ukraine has international obligations to reduce greenhouse gas emissions by the Paris climate agreement of 2015 - the fulfilment of the so-called "nationally determined contributions". To fulfil this new goal, Ukraine must transition to a low-carbon economy, significantly reduce fossil fuel consumption, actively develop energy efficiency, and introduce renewable energy sources. At the same time, the equipment of most of the capacities of coal-fired thermal power plants in Ukraine is on the verge of physical wear and tear, because these power plants were put into operation in the 1960s [7].

The second problem that aggravates the environmental situation is the waste of production and consumption. Their volume is growing and has catastrophic consequences. Any production is associated with waste, but a significant part of it today is generated in the fields of agriculture, forestry, and fishing.

Effective management of bio-waste can solve these problems for Ukraine because biomass is an alternative source of energy, the use of which does not cause environmental damage, and is much cheaper, compared to traditional energy resources. Ukraine can provide itself with such alternative sources of energy. To do this, we will analyze the energy potential of grain production in Ukraine and substantiate the environmental and economic benefits of using by-products of grain production as an alternative source of energy.

2 Methods

Base research became information in the direction of trends and changes in climate [1, 17-18]. Questions regarding the strategy for developing bioenergy in the world, particularly in Ukraine, were studied based on the data from analytical reports [7, 9]. For study questions, domestic and foreign scientists used ecological safety and effective waste handling [2-6, 10, 11]. Statistical information from the State Statistics Service of Ukraine was used to analyze the bioenergy potential of Ukraine [8]. To forecast the gross production of wheat, barley, and corn in Ukraine, a linear model.

3 Theory

In terms of the level of negative impact on the environment, biological waste can already be compared with industrial waste. Ukraine is not an exception, because in the period from 1995-2020, excessive generation of waste can be traced (Fig. 1).

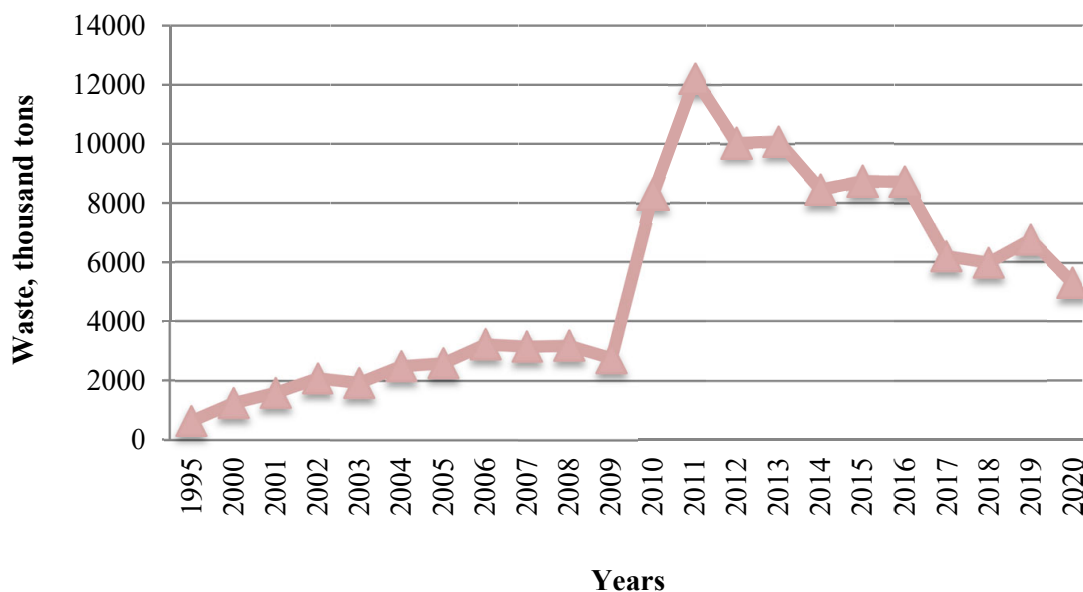


Fig. 1. Waste generation in Ukraine in agriculture, forestry, and fisheries, thousand tons [8].

The growth dynamics of waste generation in Ukraine are caused by several obstacles. Among them, it is worth highlighting technological, organizational, and legislative, as well as economic ones. Technological obstacles are caused by the lack of machinery for the production of by-products for energy needs among producers of agricultural products; the complexity of the organization of the "procurement-delivery" chain; and the difficulty of using biomass as fuel. Organizational and legislative obstacles are caused by the underdevelopment of the biofuel market in Ukraine; the difficulty of prosecuting the burning of plant remains; the absence of a state policy regarding the energy use of biomass; and the low level of popularization of successful examples of energy use of biomass. Economic obstacles are caused, first of all, by the difficulty of attracting financing for bioenergy projects using agrobiomass [9].

The problem of the generation of agricultural waste is getting worse every year, because Ukraine is an agrarian country that exports mainly grain and technical products. That is why Ukrainian farmers specialize in the production of relevant types of agricultural products. In grain production, the by-products are straw and corn stalks, which can be used as litter and feed for animals, as organic fertilizers or for obtaining thermal energy (Fig. 2).

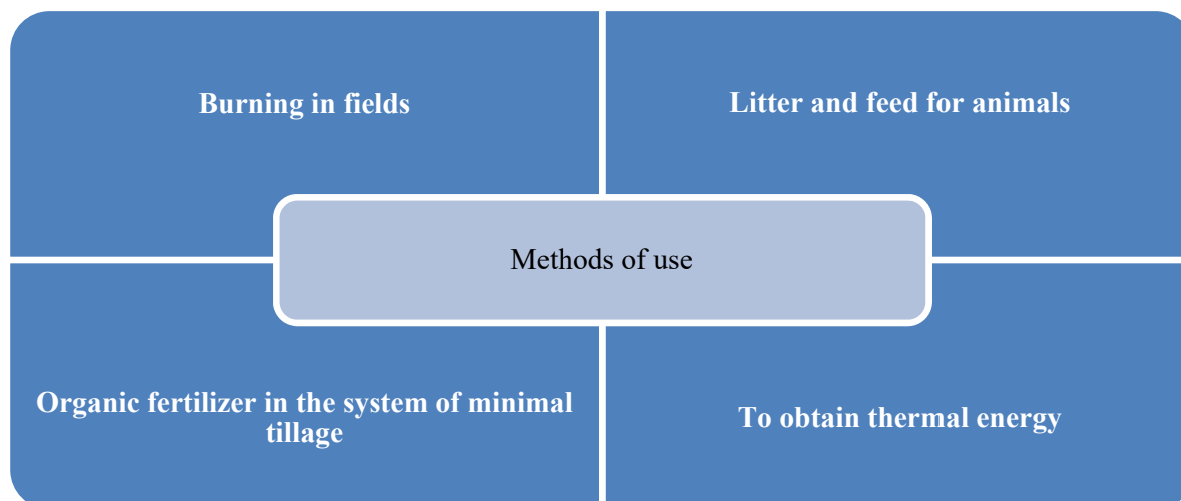


Fig. 2. Ways of using crop production by-products.

Today, the majority of Ukrainian agricultural producers - especially in the south of Ukraine, burn by-products of grain production right at the roots. Animal husbandry in these regions is not common everywhere. It is quite expensive to transport grain by-products to other regions of Ukraine. There are also certain problems with logistics. This treatment of the by-products of grain production is the worst. Burning straw and stubble in the fields leads to losses of humus (800 kg/ha). The soil loses its resistance to erosion processes, and the microflora completely dies. These processes are ecologically dangerous for the environment and only intensify the process of climate change [10].

Given the global nature of the environmental crisis, implementation business activity in countries must meet the requirements of ecological security, other ecological regulations and limits on the use of natural resources. At the level of each country, appropriate programs are implemented to support the environment and investments are made for its restoration. In Ukraine, in the period from 2006 to 2020, the number of capital investments for environmental protection increased (Fig. 3). The largest amount was invested in environmental protection measures in 2019 (1,625,671.8 thousand hryvnias), in particular, in the direction of waste management - 5,754,260.9 thousand hryvnias.

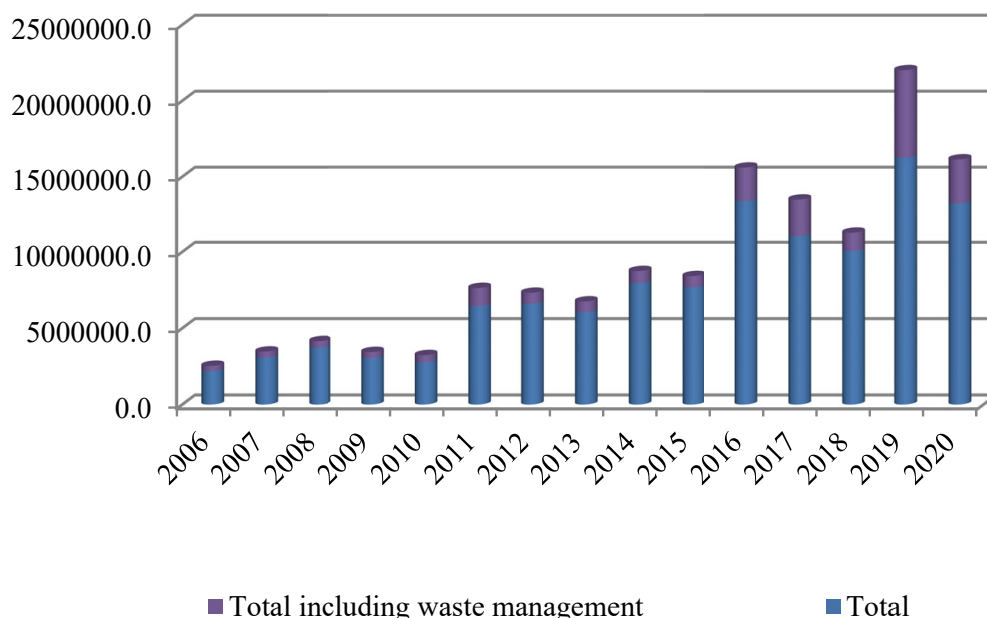


Fig. 3. Capital investments for environmental protection in Ukraine, thousand hryvnias [8].

Traditional ways of using by-products of cereals for organic fertilizer and roughage for animals or litter are rational and ecologically safe [11, 12]. However the majority of farmers focus on the production of plant products. They are not interested in by-products of crop production. Farmers use a cost-free method of disposal - burning in the field, losing potential income [13].

The by-products of grain production are an alternative environmentally safe source of energy. The products of CO₂ combustion when using straw and stubble for energy purposes will be used for the process of photosynthesis during the growth of cereals in the next period. The content of CO₂ in the atmosphere will not increase, and the greenhouse effect will not increase [14].

Biomass is one of the most flexible alternative types of raw materials for energy production, can be implemented in the electric network or heat network, and used for the company's own needs or related production processes (Table 1).

Table 1. Fuel characteristics of different types of biomass [9].

Indexes	Fresh straw ("yellow")	Straw that was stored in the field ("gray")	Corn stalks *	Sunflower stalks *	Cod wood (for comparison)
Humidity, %	10-20	10-20	45-60 ^{**} 15-18 ^{***}	40-50 ^{**} ~20 ^{***}	40
Lower heat of combustion, MJ/kg	14.4	15	5-8 (W 45-60%) 15-17 (W 15-18%)	16 (W<16%)	10,4
Content of volatile substances, %	>70	>70	>60-70	>70	>70
Ash content, %	4	3	5-9	10-12	0.6-1.5
Elemental composition, %					
carbon	42	43	45.5	44.1	50
hydrogen	5	5.2	5.5	5.0	6
oxygen	37	38	41.5	39.4	43
chlorine	0.75	0.2	0.2	0.7-0.8	0.02
potassium	1.18	0.22	6.1 mg/ kg s.r.	5.0	0.13-0.35
nitrogen	0.35	0.41	0.3-0.7	0.7	0.3
sulfur	0.16	0.13	0.04	0.1	0.05
The melting point of ash, °C	800-1000	950-1100	1100-1200	800-1270	1000-1400

Denmark is the world leader in the energy use of by-products of grain production. In the structure consumption renewable energy sources by-products of grain production make up 7%; in the structure consumption biomass - about 13%. Experience this one country is useful and interesting for Ukraine. In Denmark, by-products of grain production are mainly used as fuel in individual farm installations, stations with centralized heat supply and large power plants [15]. Ukraine has a powerful energy potential of by-products of grain production because grain production is a leader in the crop industry. Grain production continues even in war conditions. Undoubtedly, in the pre-war period, the production of the main products of grain and legumes in Ukraine increased its volumes (Fig. 4). In general, during this period, the gross harvest of grain in the country increased by 3.51 times, in particular, it increased by 3.49 times in agricultural enterprises. With the beginning of the war, this trend changed somewhat, primarily due to the difficult conditions under the occupation and mining of significant territories in the South and East of Ukraine.

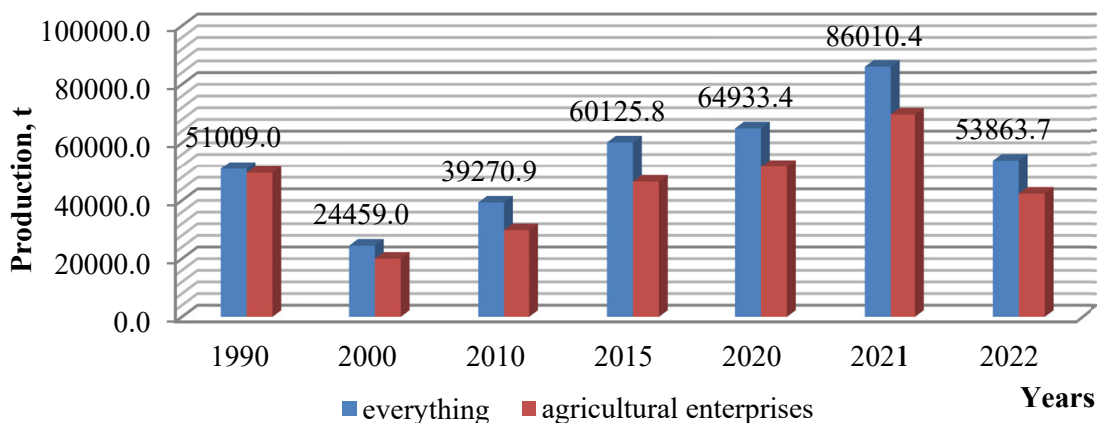


Fig. 4. Production of cereals and legumes in Ukraine, thousand tons [8].

Analysis of the dynamics of grain production by crop shows that the main area of grain and leguminous crops in Ukraine is allocated to wheat, barley and corn for grain (Fig. 5). In 1990, in the sown area of cereals and legumes, the specific weight of these cereals amounted to 78.9% and gradually increased. In 2022, the share of crops increased to 95.6%. This is by 16.7 percentage points. more compared to 1990.

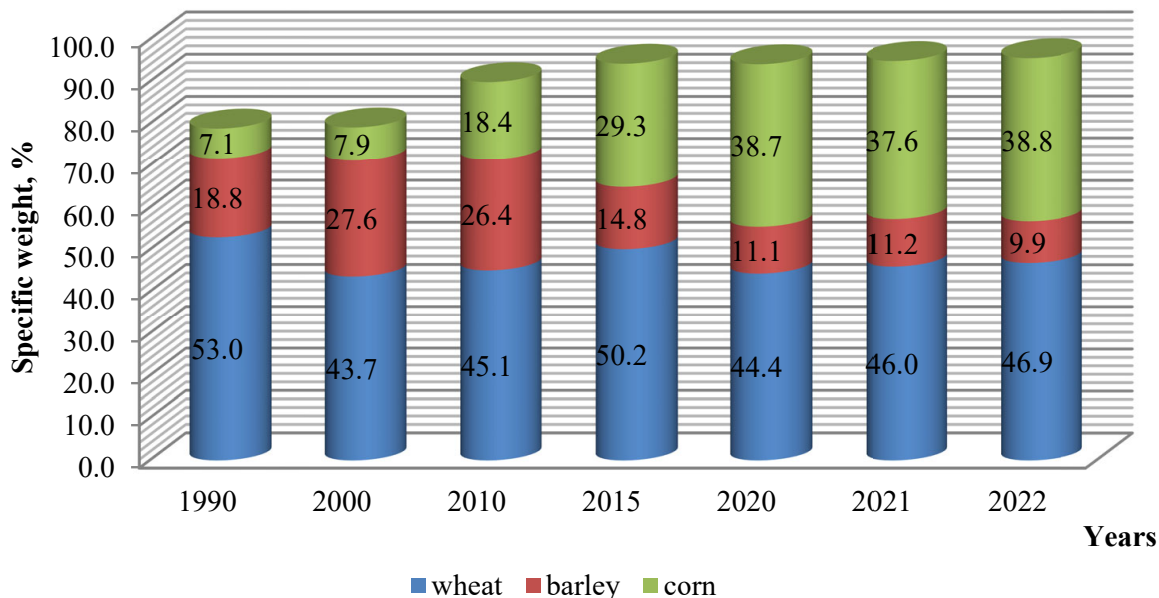


Fig. 5. The share of wheat, barley and corn sown area in the structure of grain and leguminous crops in agricultural enterprises in Ukraine, % [8]

The growth of the sown areas of the main grain crops for the period 2000-2022 with a simultaneous increase in productivity led to a steady increase in the production of grain products (Fig. 6). The production of the main grain products in the agricultural enterprises of Ukraine for the years 2000-2021 increased significantly, more in terms of wheat and corn per grain.

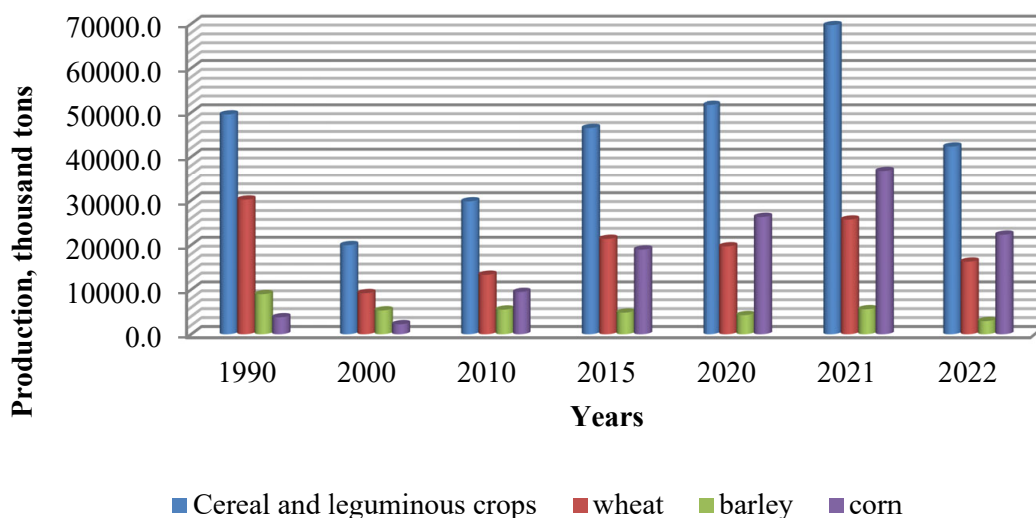


Fig. 6. Production of the main grain products in rural areas. enterprises in Ukraine, thousand tons
 Source: Agriculture of Ukraine [8].

The annual production of grain products ensures the receipt of by-products in significant volumes, where the largest volume is given by corn for grain and wheat (Fig. 7). Unfortunately, today this by-product does not find further rational use.

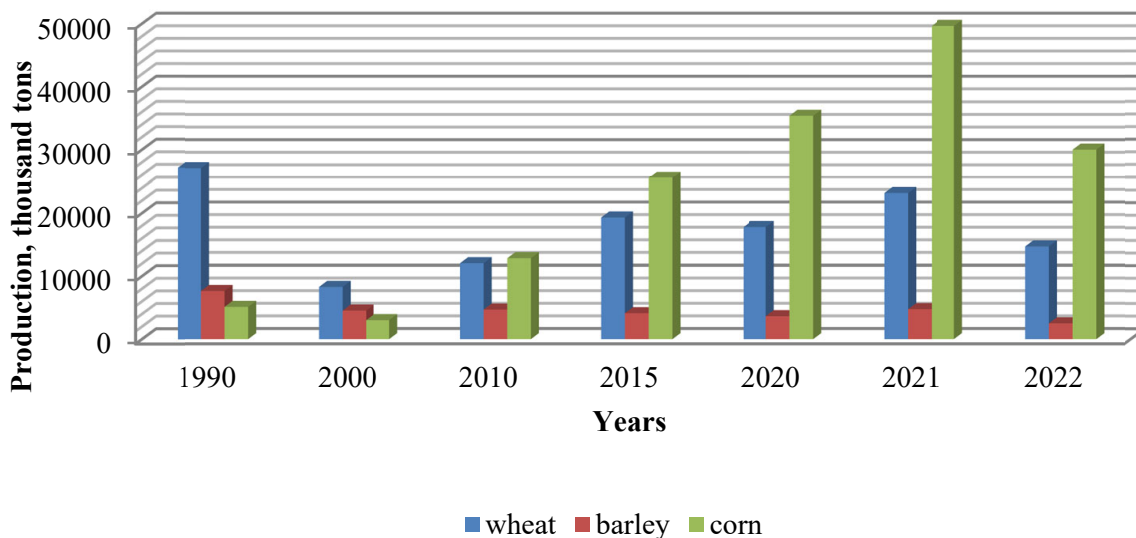


Fig. 7. Production of straw and corn stalks from the main grain crops in rural areas. enterprises in Ukraine, thousand tons [8].

Today, the problem of the energy crisis is aggravated by the war. Prices for traditional energy carriers are constantly rising. Natural gas and fossil resources are gradually being depleted. Commissioning of new wells and deposits requires large investments. Compared to this, obtaining heat and energy from the use of by-products of grain production is cheaper and environmentally safe. Unfortunately, this method of obtaining energy in Ukraine is significantly underestimated. Therefore, in this direction, we will carry out appropriate calculations regarding the economic benefit from the use of energy obtained from the by-products of grain production at the level of territorial communities.

4 Results

To substantiate the proposal to use the by-products of grain production as an alternative energy source, we will conduct calculations on the dynamics of changes in the production of the main grain products. [1 6]. For this, we will use a linear model, which will be applied to extrapolate the levels of the series (forecasting the gross production of wheat, barley and corn) for the next three years.

For analytical alignment according to the straight-line equation, we will use the gross collection indicator (Y_t) and the parameter that will indicate the serial number of the year (t). To do this, let's substitute the serial number of the year for which the forecast was made into the dynamics model. Therefore, the straight-line equation that characterizes the dynamics of gross grain collection will have the following form, in particular:

$$\text{Wheat } Y_t = 21.308 * t + 18417 \tag{1}$$

$$\text{Barley } Y_t = -620.5 * t + 8949.1 \tag{2}$$

$$\text{Corn } Y_t = 4002 * t - 5937.2 \tag{3}$$

By substituting the values of the corresponding year into the equation one by one, we obtain the leveled (theoretical) values of the levels of the gross harvest of grain crops, in particular, wheat:

$$\text{For 2023 } t = 10 \tag{4}$$

$$\text{For 2024 } t = 11 \tag{5}$$

$$\text{For 2025 } t = 12 \tag{6}$$

$$Y_{t2023} = 21.308 * 10 + 18417 = 18630.1 \text{ h} \tag{7}$$

$$Y_{t2024} = 21.308 * 11 + 18417 = 18651.4 \text{ h} \tag{8}$$

$$Y_{t2025} = 21.308 * 12 + 18417 = 18672.7 \text{ h} \tag{9}$$

Table 2. Calculation of gross grain collection trends for the period 2023-2025.

Years	Coefficient t	Cultures		
		Wheat	Barley	Corn
2023	10	18630.1	2744.1	34082.8
2024	11	18651.4	2123.6	38084.8
2025	12	18672.7	1503.1	42086.8

Thus, the gross harvest of wheat has positive dynamics. By 2025, the expected level of the indicator may change to 18,672.7 thousand tons. In the future, the gross production of corn may increase to 42,086.8 thousand tons. A general trend towards a decrease in production volumes for the cultivation of barley (Fig. 8).

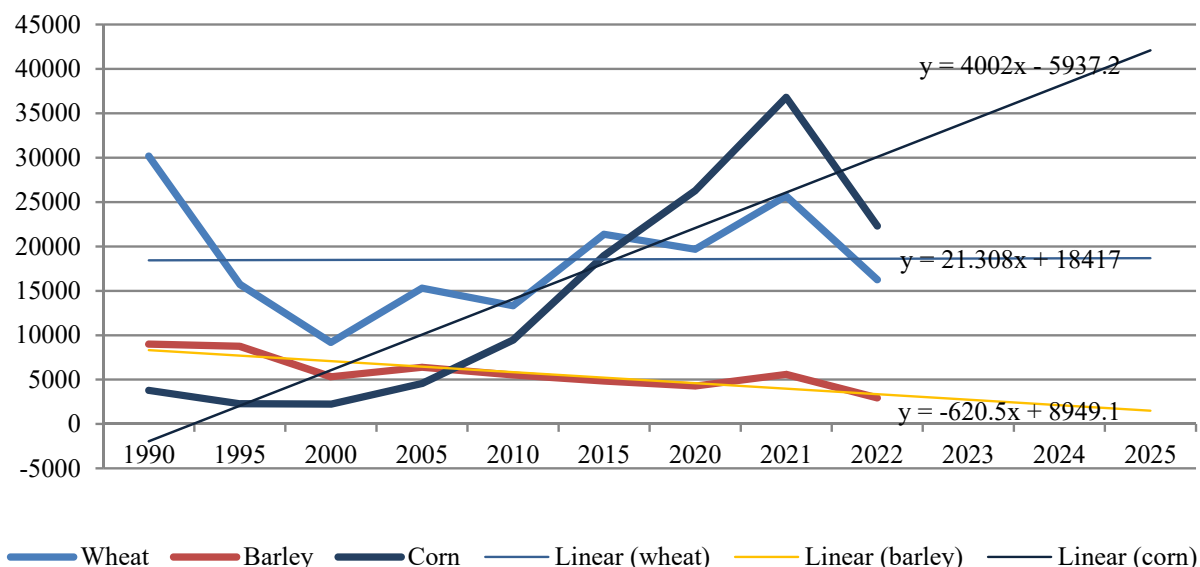


Fig. 8. Trends of gross grain collection in agricultural enterprises of Ukraine for the period 1990-2025.

The conducted calculations indicate a possible increase in the production of the specified grain crops, and therefore also by-products. However, military aggression by the Russian Federation significantly affected the actual indicators for 2022 and the prospects of grain production in Ukraine. A large part of arable land is under occupation or is not suitable for use due to military operations or the presence of mines and ammunition remnants. In addition, it negatively affected the financial condition of agricultural producers, and as a result, reduced investment in production. Which led to a decrease in the yield of grain crops in 2022 (Fig. 9).

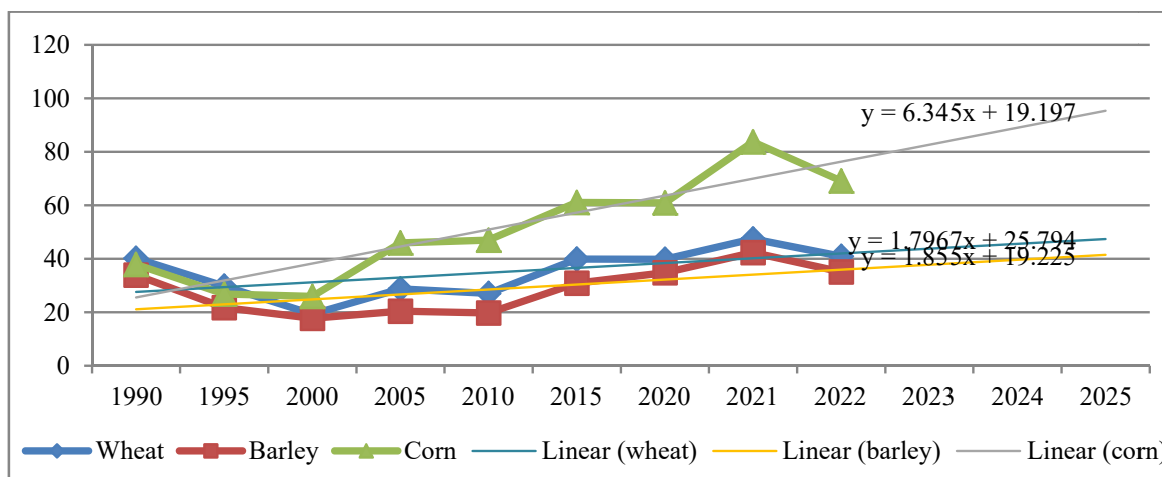


Fig. 9. Grain yield trends in agricultural enterprises of Ukraine for the period 1990-2025.

At the same time, it should be noted that, in general, the productivity of production of the main grain crops in Ukraine, according to the studies conducted since 2000, has a steady upward trend. Therefore, taking into account the high global demand for grain products, and the high adaptability and efficiency of domestic agricultural producers, in the coming years we can expect the restoration of high levels of productivity in the territories that were not affected by military actions. The conducted calculations indicate the growth of productivity in terms of grain crops in the period from 2023-2025 (Table 3). By 2025, the expected level of the indicator for wheat may change to 47.35 t/ha, for barley 41.49 t/ha, and for corn 95.34 t/ha.

Table 3. Calculation of grain yield trends for the period 2023-2025.

Years	Coefficient t	Cultures		
		Wheat	Barley	Corn
2023	10	43.76	37.78	82.65
2024	11	45,56	39.63	88.99
2025	12	47.35	41,49	95.34

This will ensure the growth of by-products shortly. A forecast of the production of by-products from the main grain crops in agricultural enterprises in Ukraine for the year 2050 is given according to Figure 10.

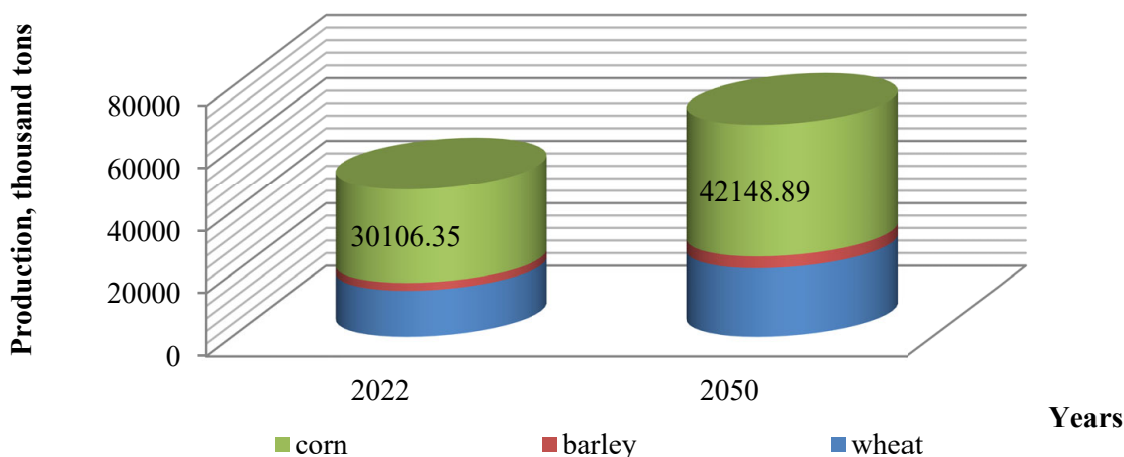


Fig. 10. Forecast of the production of straw and corn stalks from the main grain crops in rural areas. enterprises in Ukraine, thousand tons.

The expected increase in the volume of by-products from the main grain crops in Ukraine as a whole from 2022 to 2050 will amount to 42,148.89 thousand tons. This is a good alternative to energy resources because pressed straws can be used as stove fuel. " Straw, like husks, is a source of thermal energy, the technology of obtaining it has already been well developed, as well as the technology of using it for burning fuel, coal, wood, briquettes, etc. But energy use of straw in Ukraine is less than one percent, and the use of waste corn and sunflower in general is considered insignificant - the fuel resource is approximately worth 3-4 billion dollars in energy-dependent It is simply not used in Ukraine " [17].

Calculations obtained during the implementation of projects in the field of straw heat generation (Vinnytsia, Odesa, Zaporizhzhya regions, etc.) show that the production cost of 1 gigacalorie of heat produced in a straw boiler house is almost twice lower than the cost of the same gigacalorie. obtained from the burning of natural gas (especially considering its constant price increase). The possibilities of obtaining energy from the burning of straw in heat generators compared to other resources are presented in Figure 11.

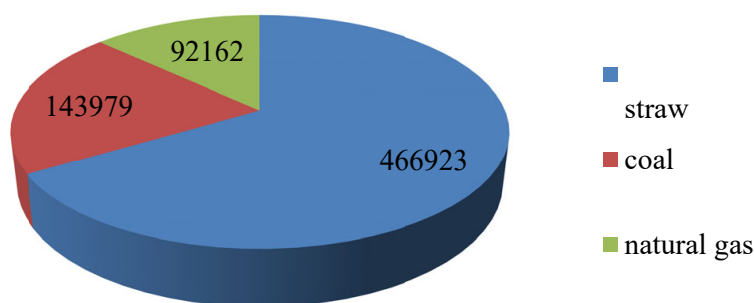


Fig. 11. The approximate amount of energy that can be obtained for 1000 euros, MJ [17].

Thanks to the production of biofuel using available resources, Ukrainians can get energy at much lower costs. The manufacturers of heat generators on straw are the following companies: UTEM – ZMK, MetalERG Ukraine. Such generators have unique environmental and technical characteristics. The power of such generators ranges from 100 to 1000 kW (Table 4). Technical parameters and economic benefits of using the UTEM-ZMK heat generator are presented according to Table 4.

Table 4. Technical and economic indicators of straw heat generators of domestic production [18].

Parameters	Power of heat generators				
	100	300	400	700	1000
Productivity, Watts	100	300	400	700	1000
Heat generator efficiency, %	Until 85				
One-time loading of straw, pcs	4 bars 40x45x80 cm	1 round bale ø 125x120 cm	1 round bale ø 125-150x150 cm	1 round bale ø 125-180x150 cm or 2 bales 180x80x120 cm	2 round bales ø 125-130x150 cm or 2 bales 250x120x80 cm
Use of straw at maximum capacity, kg/g	32	96	128	224	320
The cost of the heat generator, EUR	40,690.00 - 84,955.00				
Payback	Up to 3 years				

5 Discussion and conclusions

In the conditions of the strengthening of the energy crisis in Ukraine, the majority of territorial communities are looking for alternative sources of heating. To solve this problem, we suggest using heat generators on straw. In addition, a side benefit of using straw boilers is the production of environmentally friendly ash - the most valuable source of potassium and a whole set of trace elements. Quite a lot of ash is formed - about 5% of the volume of burnt straw - almost ten times more than that of wood. Sifted ash can be applied to fields, and added to manure. This will contribute to improving the quality of the soil.

The task of the leadership of territorial communities is to provide quality services to its residents. In conditions of dependence on gas suppliers and an increase in energy prices, the management is forced to change the vector towards alternative energy sources that will satisfy the needs for energy efficiency and energy saving, energy independence and financial savings. Thus, the transfer of schools and kindergartens to heat generators on straw gives savings on resources in the heating period twice. The implementation of the project of installing heat generators on straw in territorial communities should be systemic in nature, that is, have support from self-government, the population, business and the state.

Grain production will comply with the principles of environmental safety. Farmers will receive income that was previously neglected.

Creating a community heat supply system using biomass from grain production is possible under the following conditions:

- popularization of bioenergy projects among entrepreneurs and the population;
- use of local raw materials, to avoid additional costs for transportation, which is economically beneficial;
- promotion of the development of the local economy through the redistribution of cash flow from the purchase of energy carriers to the use of renewable resources;
- state support for the implementation of energy saving and energy independence of OTG through the provision of preferential lending;
- implementation of joint projects with other communities, which will reduce the cost of such a project and be more effective, for example, in the matter of organizing the production of straw fuel briquettes and their supply for heating a larger number of objects.

Therefore, the use of by-products of grain production will help to solve the following key problems:

- will contribute achievement of European energy and climate goals;
- solving the energy crisis, which is aggravated by the consequences of the war in Ukraine;
- preservation of the planet's resources: using agricultural waste as biofuel, thermal energy is obtained without fossil carbohydrates, which is regenerated over millennia;
- economic benefit — agricultural waste as fuel is twice as cheap as fossil hydrocarbons.

The effect of using alternative fuel from grain production waste for Ukraine is as follows:

- the creation of ecologically clean, waste-free production that corresponds to the principles of circular economy;
- obtaining potential income by agrarians;
- savings of budget funds allocated for the purchase of natural gas and fossil fuels;
- solving the energy problem at the level of social and industrial development of territorial communities.

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