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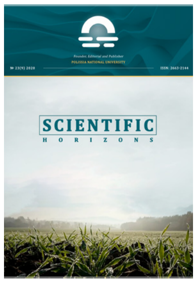

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Environmental Efficiency of Post-Harvest Grain Processing in Combined Photovoltaic/Wind Power Systems

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Abstract. In the context of increasing production of grain and leguminous crops, the amount of energy used during their post-harvest processing also increases, and, consequently, greenhouse gas emissions from the consumption and production of such energy increase. Since the post-harvest grain processing is one of the energy-intensive processes in the production of agricultural products, and the largest use of energy in this process falls on the drying of grain, the purpose of this study was to reduce greenhouse gas emissions from electricity consumption upon post-harvest grain processing by using hybrid photovoltaic/wind power systems to meet the needs of low-temperature grain drying. Installations that use this process are aerated bins. Power supply of such systems from the power grid accompanies indirect carbon dioxide emissions from electricity consumption. It was established that one of the ways to reduce the emission of such gases, as well as to ensure reliability and energy efficiency for low-temperature grain drying in aerated bins is the use of wind and solar radiation energy. To compare environmental efficiency, it was determined that the criterion for the efficiency of using hybrid photovoltaic/wind power systems to improve low-temperature grain drying is a direct environmental criterion for reducing greenhouse gas emissions from electricity consumption. It was established that the environmental effect of reducing carbon dioxide emissions depends on the levels of autonomy of the use of hybrid photovoltaic/wind power systems and the amount of electricity consumed during low-temperature grain drying. It is theoretically calculated that the use of such systems to power active ventilation bunkers can reduce greenhouse gas emissions from 122.7 to 16,564.5 CO^2 kg for low-temperature drying of grain from 25 to 225 tonnes of grain per year. The practical value of this study was to reduce greenhouse gas emissions during low-temperature grain drying by using combined photovoltaic/wind power systems

Keywords: renewable energy sources, low-temperature grain drying, agricultural production, environmental criteria

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INTRODUCTION

An increase in acreage, which according to the State Statistics Service of Ukraine [1] amounted to 27.97 million hectares at the end of 2020, has a great anthropogenic impact on the environment. Thus, according to the source [2], agriculture accounts for 23% of the world's total anthropogenic greenhouse gas emissions. Apart from this, there are direct and indirect carbon dioxide emissions upon energy consumption in agricultural production processes. Indirect greenhouse gas emissions into the atmosphere occur during electricity consumption by installations that are used in various agricultural processes. Thus, referring to the Law of Ukraine "On the Fundamental Principles (Strategy) of the National Environmental Policy of Ukraine for the period up to 2030", it is necessary to use renewable energy sources to reduce carbon dioxide emissions. Electricity consumption from such sources should provide 17% of total electricity consumption in 2030 [3].

One of the most important processes in agricultural production is post-harvest grain processing. The main component of this process is grain drying. Grain drying, for its part, is one of the most energy-intensive post-harvest processes. It accounts for up to 70% of operating costs in the current lines of post-harvest grain processing [4; 5].

The use of a low-temperature grain drying process reduces the use of energy for drying grain. This drying method is used in aerated bins. In agriculture of Ukraine, active ventilation bunkers are used at complexes and post-harvest grain processing points. They are designed for pre-drying and storage of freshly picked grain before the main drying, cooling of grain after high-temperature drying, temporary and long-term storage. In aerated bins, the grain is dried with air. At the same time, the air in the bins is heated by an electric heater. Today, various types of aerated bins are used in agriculture. Such bunkers use electric heaters with a capacity from 2.3 to 49 kW. The capacity of the bins ranges from 1.5 to 50 tonnes of grain, depending on the type of bins [6; 7].

To reduce carbon dioxide emissions into the atmosphere, it is necessary to solve the issue of using alternative energy-saving technical and technological solutions upon post-harvest grain processing. Thus, the use of solar and wind energy is a possible way to reduce greenhouse gas emissions, as well as increase the reliability and energy saving for grain drying in active ventilation units. The use of technical means that convert such energy into electricity is rational, since the period of post-harvest grain processing in the territorial and time interval coincides with a considerable intensity of solar radiation and wind speed. In addition, the use of these types of energy combined to meet the needs of low-temperature drying increases the reliability of such a process and increases the economic efficiency of agricultural production. Thus, it is advisable to use hybrid photovoltaic/wind power systems to power aerated bins. The use of these systems reduces greenhouse gas emissions into the atmosphere, thereby increasing the environmental efficiency of post-harvest grain processing.

The purpose of this study was the efficiency improvement of the post-harvest grain processing through the use of hybrid photovoltaic-wind power systems.

MATERIALS AND METHODS

To preserve the high quality of agricultural products with minimal greenhouse gas emissions into the environment, modern environmental conditions of the post-harvest grain processing were selected. Therefore, pursuant to the Law of Ukraine "On the Fundamental Principles (Strategy) of the National Environmental Policy of Ukraine for the period up to 2030", reduction of the load on the environment, reliability of power supply (autonomy) and reducing its cost should be carried out using hybrid photovoltaic/wind power systems for powering active ventilation bunkers. The selection of hybrid photovoltaic/wind power systems for typical active ventilation installations is based on the calculated parameters of energy flow, stochastic characteristics of meteorological conditions for a given territory, as well as their absence; zoning and cost of electricity, cost of equipment and duration of low-temperature grain drying. Statistical meteorological data on solar and wind energy receipts in the Kyivska Oblast were collected in the branch State Archive of the Hydrometeorological Service of Ukraine for 11 years. The duration of the low-temperature grain drying process was determined by the Hakkila calculation method.

Next, to ensure an increase in the efficiency of post-harvest grain processing, namely low-temperature drying in aerated bins, it is necessary to determine the efficiency criteria based on which the use of hybrid photovoltaic/wind power systems will be compared. Based on sources [3; 8], the main efficiency criterion is the environmental criterion. This criterion quantitatively reflects the amount of greenhouse gases released into the environment, which decreases upon the use hybrid photovoltaic/wind power systems (HPWPS) during low-temperature grain drying. This criterion acts as a direct environmental effect, which indicates the amount of CO^2 emissions, that can be eliminated in case of electricity consumption not from the electric grid, but from a hybrid photovoltaic/wind power installation. The calculation of the direct environmental effect of reducing greenhouse gas emissions from electricity consumption is calculated as follows:

$$E_{ec} = (R_{CO^2} \cdot W_{gen} \cdot K) - (R_{CO^2} \cdot W_{gen}) \quad (1)$$

where W_{gen} is the total electricity consumed for grain drying, kWh; K is the coefficient of used power of aerated bins from the network (K<1); R_{CO^2} is the national coefficient for CO^2 emissions for the production of 1 kWh of electricity, kg (R_{CO^2} = 1,227 kg CO^2/kWh) [9].

Thus, to calculate the direct environmental effect, it is necessary to determine the total electricity consumed for low-temperature grain drying and determine the required level of autonomy. In addition, along with the direct environmental criterion, one can also indicate an indirect environmental effect. It is based on the absence of any costs for preventing morbidity of the population as a result of a decrease in the quality characteristics of air and the cost of compensating for the consequences of global warming [10].

RESULTS AND DISCUSSION

The environmental effect is determined by comparing the basic version of the heat energy source – a mains-operated electric air heater, as well as a new version – an HPWPS and mains-operated electric air heater. For the basic version, the BV-25 aerated bin was chosen, which is equipped with a 25-kW electric air heater, and for the new version – the same bin with the same power of the electric air heater, but operated by an HPWPS.

To determine the environmental efficiency criterion for reducing greenhouse gas emissions during electricity consumption, the authors calculated the amount of electricity consumed during low-temperature grain drying. To determine the amount of energy consumed by active ventilation during low-temperature grain drying, it is necessary to identify the duration of aeration and the total power consumption of installations [11-13]:

$$W = \sum P_{inst} \cdot t \quad (2)$$

where ΣP_{inst} is the total power consumption of installations, kW; t is the duration of aeration, h.

The total power consumption is calculated as the sum of the power consumption of all electrical installations. Thus, if one bin (with one three-phase asynchronous electric motor) is used for aerated-bin low-temperature grain drying, then its power consumption is defined as follows [14; 15]:

$$\sum P_{inst} = \sqrt{3} \cdot U \cdot I \cdot cos\varphi = \sqrt{3} \cdot P \cdot cos\varphi \quad (3)$$

where R is the electric motor power, kW.

Calculated data on the amount of electricity consumption during low-temperature grain drying in aerated bins are presented in Table 1.

***Table 1**. Power consumption during low-temperature drying, kW*

Number of bin loads	Duration of low-temperature drying, h			
	0	20	40	60
1	0	500	1,000	1,500
3	0	1,500	3,000	4,500
6	0	3,000	6,000	9,000
9	0	4,500	9,000	13,500

Analysing the results of calculating electricity consumption during post-harvest grain processing, it is evident that the amount of electricity consumed directly depends on the amount of grain and the duration of aeration itself. One bin load equates to 25 tonnes of grain. Thus, upon drying 225 tonnes of grain, which equates to 9 bin loads and the duration of low-temperature grain drying is 60 hours, which is added for each bin load, the amount of energy consumed will equate to 13,500 kWh.

Equation 1 is used to calculate the direct environmental effect of reducing greenhouse gas emissions during electricity consumption. Table 2 presents the results of the amount of greenhouse gas emissions into the atmosphere from electricity consumption at different levels of autonomy of the hybrid photovoltaic/wind power system. These data are the result of calculating the first half of Equation 1.

Table 2. The amount of carbon dioxide emissions into the atmosphere from electricity consumption at different levels of autonomy, kg

Autonomy level	Number of bin loads	Duration of low-temperature drying, h				Autonomy level	Duration of low-temperature drying, h			
		0	20	40	60		0	20	40	60
Without HPWPS	0	0	0	0	0	K=0.2	0	0	0	0
	1	0	613.5	1,227	1,840.5		0	490.8	981.6	1,472.4
	3	0	1,840.5	3,681	5,521.5		0	1,472.4	2,944.8	4,417.2
	6	0	3,681	7,362	11,043		0	2,944.8	5,889.6	8,834.4
	9	0	5,521.5	11,043	16,564.5		0	4,417.2	8,834.4	13,251.6
K=0.4	0	0	0	0	0	K=0.6	0	0	0	0
	1	0	368.1	736.2	1,104.3		0	245.4	490.8	736.2
	3	0	1,104.3	2,208.6	3,312.9		0	736.2	1,472.4	2,208.6
	6	0	2,208.6	4,417.2	6,625.8		0	1,472.4	2,944.8	4,417.2
	9	0	3,312.9	6,625.8	9,938.7		0	2,208.6	4,417.2	6,625.8
K=0.8	0	0	0	0	0	K=1	0	0	0	0
	1	0	122.7	245.4	368.1		0	0	0	0
	3	0	368.1	736.2	1,104.3		0	0	0	0
	6	0	736.2	1,472.4	2,208.6		0	0	0	0
	9	0	1,104.3	2,208.6	3,312.9		0	0	0	0

The table 2 demonstrates that during the increase in the autonomy of using hybrid photovoltaic/wind power systems to power low-temperature grain drying in aerated bins, the amount of CO^2 emissions is substantially reduced. According to calculations, the volume of emissions amounts to 16,564.5 CO^2 kg when the aerated bin is powered from the mains and 3,312.9 CO^2 kg at 20%, the bunkers are powered from the grid and 80% are powered from a hybrid photovoltaic/wind power system. Under the condition of full autonomy, i.e., 100% powered by HPWPS, emissions amount to 0.

Table 3 presents the theoretical calculation of the reduction of greenhouse gas emissions depending on the duration of low-temperature aeration, the amount of dried grain (bin loads) and the levels of power supply autonomy from the hybrid photovoltaic/wind power system.

Table 3. Reduction of CO^2 emissions depending on the autonomy level, the amount of dried grain, and the duration of low-temperature grain drying

Autonomy level	Number of bin loads	Duration of low-temperature drying, h		
		20	40	60
K=0.2	1	-122.7	-245.4	-368.1
	3	-368.1	-736.2	-1,104.3
	6	-736.2	-1,472.4	-2208.6
	9	-1,104.3	-2208.6	-3,312.9
K=0.4	1	-245.4	-490.8	-736.2
	3	-736.2	-1,472.4	-2208.6
	6	-1,472.4	-2,944.8	-4,417.2
	9	-2208.6	-4,417.2	-6,625.8

Table 3, Continued

Autonomy level	Number of bin loads	Duration of low-temperature drying, h		
		20	40	60
K=0.6	1	-368.1	-736.2	-1,104.3
	3	-1,104.3	-2208.6	-3,312.9
	6	-2208.6	-4,417.2	-6,625.8
	9	-3,312.9	-6,625.8	-9,938.7
K=0.8	1	-490.8	-981.6	-1,472.4
	3	-1,472.4	-2,944.8	-4,417.2
	6	-2,944.8	-5,889.6	-8,834.4
	9	-4,417.2	-8,834.4	-13,251.6
K=1	1	-613.5	-1,227	-1,840.5
	3	-1,840.5	-3,681	-5,521.5
	6	-3,681	-7,362	-11,043
	9	-5,521.5	-11,043	-16,564.5

Results of reduction of CO^2 emissions depending on the autonomy levels of the aerated bin power supply from the hybrid photovoltaic/wind power system indicate that the use of such systems in post-harvest grain processing reduces greenhouse gas emissions from -122.7 to -16,564.5 CO^2 kg. Figure 1 demonstrates the dynamics of reducing emissions with a duration of 60 hours and different amounts of aerated bin loads.

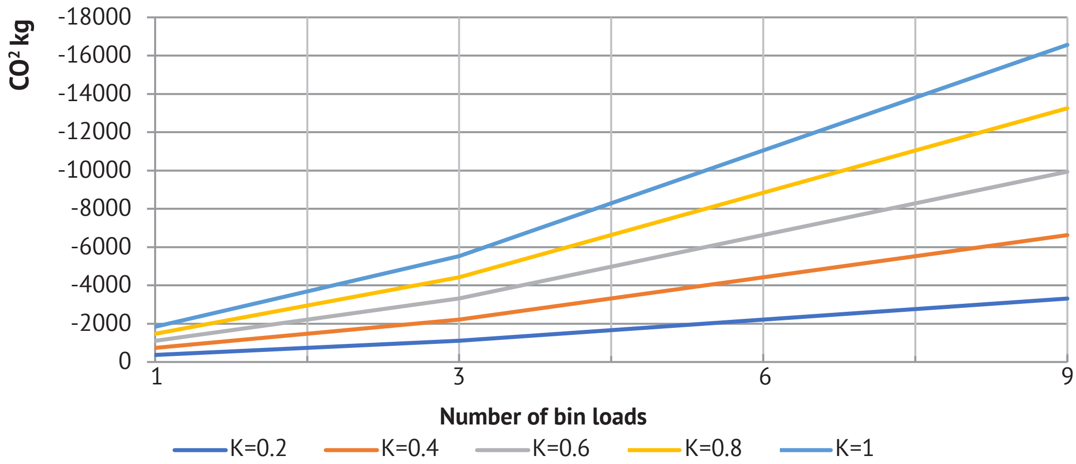

***Figure 1**. Dynamics of reducing greenhouse gas emissions with a low temperature grain drying time of 60 hours and different amounts of aerated bin loads*

The above dynamics graphically illustrate that the more grain is dried, the less greenhouse gas emissions are produced during post-harvest grain processing, and, as a result, its efficiency increases. in addition, the reduction of these emissions depends on the autonomous power supply of aerated bins.

CONCLUSIONS

An increase in grain production leads to an increase in the energy consumed upon post-harvest grain processing. At the same time, such energy includes electricity. The consumption of electricity leads to indirect emissions of carbon dioxide into the atmosphere. Thus, to reduce these emissions, it is rational to use hybrid photovoltaic/wind power systems for powering aerated bins upon post-harvest grain processing, namely low-temperature grain drying.

To compare environmental efficiency, it was determined that the criterion for the efficiency of using hybrid photovoltaic/wind power systems to improve low-temperature grain drying is a direct environmental criterion for reducing greenhouse gas emissions upon electricity consumption. It was established that the environmental effect of reducing carbon dioxide emissions depends on the levels of autonomy of the use of hybrid photovoltaic/wind power systems and the amount of electricity consumed during low-temperature grain drying. It is theoretically calculated that the use of such systems to power active ventilation bunkers can reduce greenhouse gas emissions from 122.7 to 16,564.5 CO^2 kg for low-temperature drying of grain from 25 to 225 tonnes of grain per year.

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Екологічна ефективність процесу післязбиральної обробки зерна під час застосування комбінованих фотовіроенергетичних систем

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Анотація. В умовах збільшення виробництва зернових і зернобобових культур зростає й кількість енергії, використаної під час їхньої післязбиральної обробки, а, отже, збільшуються викиди парникових газів за споживання та виробництва такої енергії. Оскільки процес післязбиральної обробки зерна є одним з енергоємних процесів у виробництві сільськогосподарської продукції, а найбільше використання енергії в цьому процесі припадає на сушіння зерна, то метою даної роботи є зменшення викидів парникових газів при споживанні електроенергії в процесі післязбиральної обробки зерна шляхом застосування комбінованих фотовітроенергетичних систем для забезпечення потреб процесу низькотемпературного сушіння зерна. Установками, які використовують такий процес, є бункери активного вентилювання. Живлення таких систем від електромережі супроводжує непрямі викиди вуглекислого газу від споживання електричної енергії. Встановлено, що одним із шляхів зниження викиду таких газів, а також забезпечення надійності та енергоефективності на низькотемпературну сушку зерна в установках активного вентилювання є використання енергії вітру та сонячного випромінювання. Для порівняння екологічної ефективності було визначено, що критерієм ефективності застосування комбінованих фотовітроенергетичних систем для підвищення процесу низькотемпературного сушіння зерна є прямий екологічний критерій зниження рівня викидів парникових газів при споживанні електроенергії. Встановлено, що екологічний ефект від зменшення викидів вуглекислого газу залежить від рівнів автономності застосування комбінованих фотовітроенергетичних систем і кількості спожитої електроенергії в процесі низькотемпературного сушіння зерна. Теоретично розраховано, що для живлення бункерів активного вентилювання застосування таких систем може зменшити викиди парникових газів від 122,7 до 16564,5 кг CO^2 за низькотемпературного сушіння зерна від 25 до 225 т зерна в рік. Практична цінність даної роботи полягає у зменшені викидів парникових газів під час низькотемпературного сушіння зерна шляхом застосування комбінованих фотовітроенергетичних систем

Ключові слова: відновлювальні джерела енергії, низькотемпературне сушіння зерна сільськогосподарське виробництво, екологічний критерій