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OBJECTIVATION OF THE ECOLOGICAL AND ECONOMIC LOSSES FROM SOLID DOMESTIC WASTE AT THE HEATING ENTERPRISES

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Abstract:
The aim of this research is to study theoretical and practical aspects of the ecological and economic losses from the use of solid domestic waste (SDW) as energy resources in the heat power industry of Ukraine. The methodical approaches to evaluating the ecological and economic losses caused by solid domestic waste (SDW) comprise: the developed algorithm, which evaluates the ecological and economic losses in the SDW use as fuel and energy resources in comparison with basic and project variant; the investigated morphological composition of SDW in the Ukrainian regions, on the basis of which there is proposed a matrix for further calculations of the ecological and economic loss from atmospheric pollution as a result of the energy-intensive SDW combustion at the power plants by the Ukrainian regions. The efficiency of using SDW as secondary energy resources, which essentially depends on the conventional energy resources combustion, is proved. According to the chemical and morphological composition of SDW, the average amount of harmful substances by their element constituents of SDW is determined. The economic loss from the combusting 1 ton of SDW as energy resources is estimated. Reasonability of using SDW as energy resources, based on the optimal ratio between conventional resources and energy-intensive SDW through minimizing total production costs and possible ecological and economic loss, is grounded. It is proved that while estimating the ecological and economic losses, it is necessary to consider the SDW morphological composition and regional specific features regarding the location of heat and power enterprises and organized storage landfills. It is grounded that the obtained estimates of the ecological and economic losses may be used for identifying the ecological and economic evaluation of the SDW efficiency use in the heat power industry at the regional level.

Key words: *solid domestic waste (SDW); ecological and economic losses; fuel and energy resources; heat power industry*

INTRODUCTION

Under modern conditions of social and economic development, the amounts of the fuel and energy resources (FER) consumption is constantly growing, which leads to the non-renewable natural energy resources depletion and influences the energy independence of Ukraine and Poland [1]4]. Increasing of productivity efficiency leads to achieving the macroeconomic stability [5]. Macroeconomic stability is a key aspect of the innovation development [7], fostering investment climate [9], social progress [13] and country's marketing strategy [17]. At the same time, the long-term operation of resource and energy intensive industries and technologies, overconsumption and overconcentration of the production in the industrial regions justified the necessity of the alternative energy research. One of such directions may include the solid domestic waste (SDW) use in the heat power industry, implementation of which will save natural resources (gas, coal) at the stage of their mining, transporting and consumption, and will reduce the amounts of SDW accumulation on the organized storing landfills, which will reduce the eco-destructive impact on the environment. This objectively determines the importance and necessity to carry out systematic studies regarding the improvement of ecological and economic principles of using SDW in the heat power industry according to the State Energy Strategy of Ukraine till 2030.

LITERATURE REVIEW

A great contribution to solving the environmental and economic problems regarding the management and consumption of solid waste has been made by scientists. In fact, the development does not occur without environmental burdens, and the generation of waste is one of them. Recently,

waste has become one of the urgent topics in the scientific literature. If there are human inhabitants, waste problems will always exist. The term *solid waste* is used to denote hard rubbish. Household waste contributes to an absolute majority of municipal solid waste (MSW) sources to which most costs of municipal waste management are allocated.
Waste management is used to decrease the negative effect of waste on human health and the environment. We can relate waste management to those activities which are engaged in recovering resources from wastes. Waste management comprises waste production prevention, reduction of the amount of waste and its negative impact on the environment.
The use and forecast of solid waste in sustainable development were studied by the authors in the papers [22]. Digestion-based waste-to-energy technology can be deployed to extract useful energy from landfills, used to reduce emissions, according to [27]. The benefits and usefulness of developing the renewable energy sources, considered together with the analysis of the most economically advantageous fields of their use, are considered by [29] and [30]. The developing countries suffer greatly from problems associated with population growth, rapid development and urbanization, providing sustainable waste management. The best and most economical method to solve these problems is to minimize the generation of waste [31] In the paper [35] the authors point out viewpoints which consider theoretical and methodical approach to the innovative regulation of the waste management sector as a global system. In addition, they investigate the mechanism of relations among countries which will promote formation and innovative development of the waste management national system through the network cooperation and state-private partnership [35]. De Feo and De Gisi emphasize that the most cost-effective method to reduce household waste includes public education and citizen encouragement to participate in the design of household recycling processes. In addition to it, this author supposes that the attempts to improve solid waste management in the developing countries focus on cost-effective waste management technologies together with source reduction, separation and recycling [36].
However, the fact that citizens participate in the source separation process strongly influences the household recycling programs' success [37].
The SWM programs, which are misunderstood by some residents, can affect the SWM participation rate in a negative way [38]. Thus, gender, age, education and the individual's income level are most commonly employed variables. The works of the abovementioned authors represent the issues regarding the reasonability of using SDW at the waste reuse in the production processes. At the same time, the analysis of these works shows that problems regarding the evaluation of the ecological and economic losses caused by SDW use in the heat power industry have not been sufficiently studied today. It confirms the urgency of the topic selected.

METHODOLOGY

The methodologic approaches to estimating the ecological and economic losses from SDW use in the Ukrainian regions have been improved on the basis of the algorithm (Figure 1), which outlines the stages of the ecological and economic losses evaluation at the heating enterprises by SDW combusting and storing on the landfill.

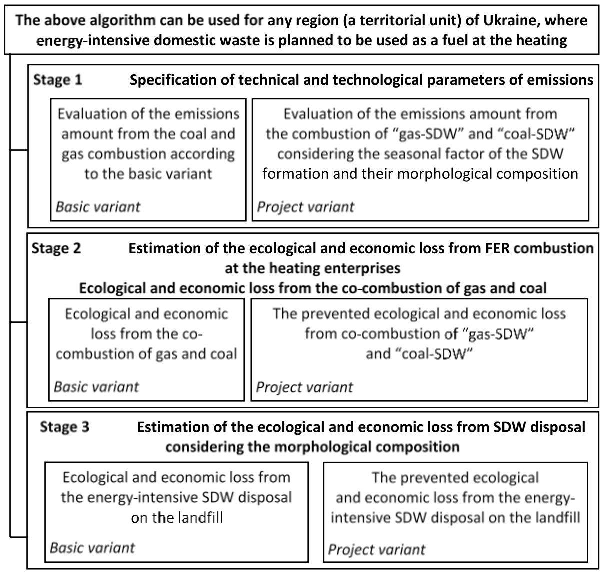

Fig. 1 The Algorithm for Evaluating the Ecological and conomic Loss from SDW Use as the Fuel and Energy Resources

The above algorithm can be used for any region (a territorial unit) of Ukraine, where energy-intensive domestic waste is planned to be used as fuel at the heating enterprises. The algorithm is based on the matrix calculations system (see Table 1).

Table 1
The Calculations Matrix of the Ecological and Economic Loss from the Atmospheric Pollution by Combusting the Energy-Intensive SDW at the Heating Enterprises by the Ukrainian regions

Regions of Ukraine j, (j = 1,…,k)	**Loss by the i- morphological constituents of SDW (i = 1,…,n)** SDW constituent 1	SDW constituent 2	…	SDW constituent n	Total in j region
Region 1	U_1	U_2	…	U_{n1}	$\sum_{i=1}^{n} U_i$
Region 2	U_1	U_2	…	U_{n2}	$\sum_{i=1}^{n} U_i$
…	…	…	…	…	…
Region k	U_1	U_2	…	U_{nk}	$\sum_{i=1}^{n} U_i$
The total loss by the i- a constituent of SDW	$\sum_{j=1}^{k} U_{1j}$	$\sum_{j=1}^{k} U_{2j}$	…	$\sum_{j=1}^{k} U_{nj}$	$\sum_{i=1}^{n}\sum_{j=1}^{k} O'_{ij}$

RESULTS

In order to construct the matrix, it is necessary to study the SDW morphological composition by the Ukrainian regions, which enables defining the polluting substances mass, which comes to the atmosphere after combusting 1 ton of every element of the SDW morphological composition. The

SDW morphological composition consists of such elements as paper, carton, food waste, wood, leaves, metals, bones, skin, rubber, textile, glass, polymeric material 16 mm. Not all these components of SDW can be used as FES at the heating enterprises. It is reasonable to use only energy-intensive waste as FES, such as paper, carton, textile, food waste. It is necessary to analyze the chemical and morphological composition of SDW by regions of Ukraine to define the amounts of energy-intensive waste. The chemical and morphological composition of SDW per 1 ton of SDW, stored on the landfills in Sumy for one year is taken as the example (Table 2). Calculations are based on the data given by the communal enterprise "Komunservice" Sumy.

Table 2
The Chemical and Morphological Composition of SDW in Sumy

Morphological constituents of SDW	Carbon (C)	Hydrogen (H)	Oxygen (O)	Nitrogen (N)	Sulfur (S)	Ap*	Bp**
Paper, carton	15.016	1.972	13.806	0.276	0.112	10.759	17.871
Food waste	4.004	0.525	3.681	0.071	0.030	2.869	4.765
Wood, leaves	2.567	0.337	2.360	0.047	0.019	1.839	3.055
Textile	2.002	0.262	1.840	0.036	0.015	1.434	2.382
Waste 16 mm	5.091	0.668	4.681	0.093	0.038	3.648	6.059

Ap* – slaggy constituent; Bp** – humidity composition

Having defined the energy-intensive composition of SDW, considering the geographical location of the Ukrainian regions, the matrix for ecological and economic loss caused by the air pollution of waste combustion by their morphological constituents, is defined. Using the information regarding the morphological composition of SDW by the Ukrainian regions, one can calculate the total ecological and economic loss from the combustion of every SDW element. It should be mentioned that the SDW storing process has various features in various Ukrainian regions, particularly in the Northern Ukraine, including Zhytomyr, Kyiv, Sumy, Chernihiv districts; the Southern Ukraine, including Odesa, Mykolaiv, Kherson districts, the Crimea with Sevastopol and Zaporizhzhia district; the Eastern Ukraine including Luhansk, Kharkiv, Donetsk districts; the Central Ukraine including Vinnytsia, Dnipropetrovsk, Kirovohrad, Poltava and Cherkasy districts; the Western Ukraine including five districts – Lviv, Ivano-Frankivsk, Ternopil, Volyn and Rivne. Uneven distribution of citizens by the administrative and territorial units forms the uneven load on the environment.

The analysis performed proves that the territories with the highest population density pollute the environment heavily with SDW (Kaufman et al. 2010). The economic loss from combusting 1 ton of SDW as energy resources in Sumy is evaluated.

Table 3
Harmful Substances Produced by Combusting 1 Ton of SDW, kg

	NO	N_2O	SO_2	CO	CO_2
Paper, carton	355.120	2.932	225.606	6.298	55002.790
Food waste	94.699	0.782	60.162	1.679	14667.411
Wood, leaves	60.731	0.501	38.582	1.077	9406.274
Textile	47.349	0.391	30.081	0.840	7333.705
Waste 16 mm	120.432	0.994	76.510	2.136	18653.120

The economic loss from polluting with harmful substances resulting from the SDW combustion at the heating enterprises in the regions is calculated by the formula:

$$Y_j^{atm} = \sum Y_i^{atm.j} \times m_i, \quad (1)$$

where:

$Y_i^{atm.j}$ is a specific ecological and economic loss, caused by the air pollution by one ton of *i*- polluting substance (*i* = 1,…,5), included to the morphological composition of SDW in j-region, UAH/tons equivalent; m_i is a mass of *i*- polluting substance in the *j*-region, *t*.

In its turn, the specific loss from air pollution with emissions of the harmful substances resulting from combusting 1 ton of SDW by the morphological composition considering the regional characteristics is calculated by the formula:

$$Y_i^{atm.j} = j_i^j \times \sigma_i^j \times f_i^j \times m_{em_i}^j, \quad (2)$$

where:

j_i^j is a specific loss of the national economy, caused by emissions of one ton of the polluting substances into the atmosphere in *j*-region.

When the methodology was investigated by the Presidium of USSR Academy of Science in 1983, the specific loss of the national economy, caused by emissions of one ton of the polluting substances into the atmosphere, was j_i^j = 2.4 rub/tons equivalent. Taking into consideration the indexation of this indicator in 2017 j_i^j = 2.4 rub/tons equivalent in the current period, we have: (1 karbovanetz = 1.37 \$ in 1983), (1 \$ = 26.15 UAH in 2017. Then, the specific economic loss caused to the environment by the emissions into the atmosphere in 2017 will be calculated 2.4·1.37·26.15 = 85.98 UAH/tons equivalent [35]; σ_i^j is a dimensionless indicator of the relative risk regarding the atmospheric pollution in j-region; f_i^j is an amendment, which considers the nature of impurities dispersion in the atmosphere in j-region; $m_{em_i}^j$ is a mass of the above emissions formed in j-region, from the combustion of 1 ton of i-substance. This parameter is calculated by the formula:

$$m_{em_i}^j = \sum A_{ik}^j \times m_{em_{ik}}^j, \quad (3)$$

where:

A_{ik}^j is an indicator of the relative aggressiveness of *k*-impurity of *i*-substance in *j*-region, tons equivalent/tons;

$m_{em_{ik}}^j$ is a mass of emissions of *k*-impurity from the combustion of one ton of *i*-polluting substance in *j*-region, tons equivalent/tons.

The combustion of conventional fuels, gas, and coal is taken as a basic variant, and harmful emissions per 1000 m^3 of gas and 1 ton of coal are determined. The ecological and economic loss is estimated by the formula (1)-(3), Table 4.

Table 4
The Basic Evaluation of the Ecological and Economic Loss Indicators from the Combustion of Conventional Fuels

Basic variant					
gas (100%)			**coal (100%)**		
Number of harmful emissions, /thousand m^3	Loss, UAH/thousand m^3	Possible loss considering 95% of purification degree, UAH/thousand m^3	Number of harmful emissions, t/t	Loss, UAH/t	Possible loss considering 95% of purification degree, UAH/thousand m^3
42.92	669.45	60.25	66.38	1035.4	51.77

The number of harmful emissions and ecological and economic loss are defined by analogy from the combustion of the fuel and energy resources in the ratio "gas (70%) – SDW (30%)", "coal (80%) – SDW (20%). Therefore, the economic loss is found in terms of 1 thousand m^3 per 1 thousand ton of fuel equivalent.

Such a difference in the ratio between "gas and SDW" and "coal and SDW" depends on the heat-generating capacity of the fuel. According to the statistic data, gas has the largest heat-generating capacity, which is 33.56 MJ/m^3, coal – 22.176 MJ/kg, and the least heat can be produced from the combustion of SDW, that is 22.176 MJ/kg.

Having analysed Tables 4-5, it may be concluded that the number of harmful emissions in the predicted variant is decreasing. It is caused by the fact that the combustion of coal with SDW is ecologically and economically beneficial.

Table 5
The Predicted Evaluation of the Specific Indicators Regarding the Ecological and Economic Loss from the Combustion of the Conventional Fuel and Energy-Intensive SDW

Predicted variant							
gas 70%	**SDW** 30%	Total		**coal** 80%	**SDW** 20%	**Total**	
Number of harmful emissions, t/thousand m^3	Number of harmful emissions, t/t	Loss, UAH/thousand m^3	Possible loss considering 95% of purification degree, UAH/thousand m^3	Number of harmful emission, t/t	Number of harmful emission, t/t	Loss, UAH/t	Possible loss considering 95% of purification degree, UAH /t
30.04	0.08	469.89	42.29	53.11	0.19	831.22	74.81

Firstly, it will enable saving funds to purchase fuel, secondly, emissions into the atmosphere will be reduced from the combustion of coal with its partial substitution by the energy-intensive SDW.

Table 6 demonstrates calculations of the ecological and economic loss at the heating enterprises from the combustion of gas and coal in the basic variant for comparison.

Table 6
The Evaluation of the Specific Indicators Regarding the Ecological and Economic Loss from the Combustion of Conventional Fuels

Basic variant					
gas (100%)			**coal (100%)**		
A quantity of harmful emissions, t/t.f.e.	Loss, UAH/t.f.e.	Possible loss considering 95% of purification degree, UAH/t.f.e.	A quantity of harmful emissions, t/t.f.e.	Loss, UAH/t.f.e.	Possible loss considering 95% of purification degree, UAH/t.f.e.
37.00	577.11	28.86	88.51	1380.55	69.03

Table 7 demonstrates the ecological and economic loss from the combustion of SDW together with conventional fuel, Table 7.

Table 7
The Predicted Variant of Calculating the Ecological and Economic Loss from the Combustion of the Conventional Fuels and Energy-Intensive SDW

Predicted variant							
Gas 70%	**SDW** 30%	**Total**		**Coal** 80%	**SDW** 20%	**Total**	
A quantity of harmful emissions, t/t.f.e.	A quantity of harmful emissions, t/t.f.e.	Loss, UAH/t.f.e.	Possible loss considering 95% of purification degree, UAH/t.f.e.	A quantity of harmful emissions, t/t.f.e.	A quantity of harmful emissions, t/t.f.e.	Loss, UAH/t.f.e.	Possible loss considering 95% of purification degree, UAH/t.f.e.
25.90	16.37	659.36	32.97	70.81	16.37	1359.82	67.99

Calculations of the ecological and economic loss from the combustion of 1 ton of SDW by their morphological composition at the heating enterprises by the Ukrainian regions, is performed by the matrix, shown in Table 8.

Table 8
The Matrix Calculating the Specific Ecological and Economic Losses from the Combustion of 1 Ton of SDW by Element Constituents at the Heating Enterprises by the Ukrainian Regions

Regions of Ukraine (j)	Morphological constituents of SDW					
	Paper, carton, UAH/t	Wood, leaves, UAH/t	Textile, UAH/t	Food waste, UAH/t	Screening to 16 mm, UAH/t	Total in the region, UAH/t
North (1)	15.878	23.162	23.396	7.487	7.954	77.88
South (2)	19.847	28.952	29.245	9.358	9.943	97.35
East (3)	16.239	23.688	23.9274	7.657	8.135	79.65
West (4)	18.765	27.373	27.649	8.848	9.400	92.04
Center (5)	16.239	23.688	23.927	7.657	8.135	79.65

DISCUSSION AND CONCLUSIONS

The performed studies enable concluding that efficiency of using solid domestic waste (SDW) as the secondary energy resources greatly depends on the combustion amount of conventional energy resources. The reasonability to use SDW as energy resources is substantiated. It is based on determining the optimal ratio between amounts of using conventional energy resources and energy-intensive SDW, based on the minimization of total production costs and possible ecological and economic loss.

It is proved that while evaluating the ecological and economic losses, there must be considered the morphological composition of SDW and regional features of the heating enterprises and landfills location. The performed complex of calculations shows that the estimated ecological and economic losses from the combustion of 100% of gas and coal account for 577.11 and 1380.55 (thousand UAH/t.f.e) correspondingly. According to the project variant in case of the conventional fuel co-combustion from SDW, losses amount to: “gas – SDW” – 659.36 UAH/t.f.e, “coal – SDW” – 1359.82 UAH/t.f.e. The obtained evaluations of the ecological and economic loss can be implemented in determining the ecological and economic evaluation regarding the efficiency of using SDW in the heat power industry at the regional level.

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