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Sorting, Logistics and Secondary Use of Solid Household Waste in Ukraine on the Way to European Integration

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ABSTRACT

The study is aimed at solving the problem that has arisen in Ukraine in the field of household waste management, namely the generation, accumulation, storage, processing and disposal of waste. This issue is of particular importance for the population of each country, which is explained by the extremely negative impact of waste and landfills on the health and quality of life of the population, as well as the ecological situation of the respective territories. The purpose of the study is to improve the sorting, logistics and secondary use of solid household waste in Ukraine by adapting the waste management system in Ukraine to EU requirements. As a result of the research, it was confirmed that the volumes of waste generation are quite significant in different countries, their morphological composition varies depending on the level of economic development of countries, the level of application of advanced technologies, etc. The authors' logically ordered scheme of domestic waste management in Ukraine showed a number of shortcomings: lack of deep separation of waste and practically no motivation to use solid waste for energy. As a result of the research, the authors suggested using eight containers for sorting household waste, which will become the basis for its further efficient use as a secondary resource. The authors proposed a system for improving the logistics chain of waste management, in particular, proposed vacuum transportation of sorted waste to processing lines, which will ensure the environmental friendliness of useful disposal processes. An analysis of the experience of the secondary use of solid waste in different countries showed the prevalence of energy utilization of waste, the current level of which in Ukraine is insignificant. In connection with the invasion of the Russian Federation in Ukraine, the volumes of waste generation of all types increased. There is an urgent need to use the bioenergy potential of waste in connection with the energy crisis caused by hostilities and fuel shortages. The concept of sustainable development of the field of solid waste management, which is based on economic, social, ecological and energy effects, with the interaction of which the phenomenon of synergy takes place, is substantiated.

Keywords: waste management, utilization, logistics, solid household waste, separating, containers, energy use.

INTRODUCTION

Today, the trend of excessive consumption of natural resources continues in the world. The annual growth in the use of natural resources is 1.5%. To a large extent, this is connected with the growth of the population of the planet and its various needs. Estimates indicate that during the past 30 years, almost a third of the planet's resources have been exhausted (Attenborough, 2020). The issue of restoration of natural resources, their economical and rational use, as well as secondary

processing to minimize waste generation is extremely urgent. The pollution of the natural environment, the increase in morbidity among the population, the production of greenhouse gases, the accumulation of which leads to global warming, the reduction of the area of agricultural land due to the increase in the number of spontaneous landfills and, in general, the irrational handling of waste, is a consequence of the lack of an effective mechanism that should combine theoretical aspects and practical management of household waste. A thorough state policy in the

field of household waste management is an integral component of sustainable development and, accordingly, national security in general. Such a policy will contribute to the creation of new jobs, the creation of cheap secondary resources, the production of ecologically clean agricultural products, the reduction of morbidity among the population, etc.

Every second, 3.8 kg of “environmentally harmless garbage” – food waste – is generated in the world. This is 29% of the average garbage bin of a modern person (Matukhno, 2019). However, generated waste, including households waste, is essentially not waste, but is a potential raw material that can be further used in various economic activities for the production of secondary products and energy. An important prerequisite for this is high-quality waste management which will enable its further beneficial use. Every year, 2 billion tons of household waste are generated in the world, and every year this volume continues to grow (The World Bank, 2022).

The solution to the problem of constantly growing generation of waste is its efficient management and processing. For this purpose, the governments of many countries, guided by the principles of the circular economy, are implementing a strategy of extended producer responsibility. Currently, Ukraine is lagging behind leading countries in implementing effective systems for sorting and logistics of solid household waste, while losing its useful potential.

LITERATURE REVIEW

In 2008, the European Union adopted Directive 2008/98, which implements a strategy for the transition to a circular economy model, and emphasizes the theme of the “waste management hierarchy” – a concept that shows the sequence of the most desirable ways of doing things, which ultimately ensure the reduction of volumes waste (On waste and repealing certain Directives, 2008). Concept of sustainable development is close to circular economy and also concentrates on safe environment and use of renewable resources (including for energy use and biofuels’ production). Korpaniuk et al, 2019, worked in this direction and defined the problems of resource management and ensuring the conditions for sustainable development of agricultural enterprises of Ukraine. Klymchuk et al., 2020, investigated sustainable

energy development; Lutkovska, 2020 focused on methods of the evaluation processes of the environmental sustainable system modernization.

According to the experts of the Ellen McArthur Foundation, the following factors can be defined as the advantages of the “circular economy” for the company: significant saving of materials; sustainable resource use; stimulation of innovations; the ability to meet the needs of the constantly growing population of the Earth; growth of the economy and incomes of the population (Concept, 2022). Zvarych, 2019, Varfolomeev & Churikanova, 2020, studied the problems of introducing a circular economy in Ukraine. In particular, Zvarych, 2019, in his work examines the prospects for the implementation of the EU Action Plan in Ukraine, offers specific steps to include Ukrainian industry in the circular process. Using the example of EU countries, the researchers substantiate the possibilities of the formation and development of circular business models in Ukraine. Ruda and Myrka (2020) substantiate the theoretical aspects of the closed-loop economy, the process of its formation, and provide the main proposals for its development in Ukraine. Varfolomeev & Churikanova, 2020, studied the problems and main aspects of the application of the circular economy in different countries of the world, as well as evaluate the prospects of Ukraine’s transition to the circular economy. Kaletnik et al, 2020 studied the regulation of the land circulation both in Ukraine and other countries.

Currently, the circular economy in Ukraine is beginning to form. At the same time, the introduction and implementation of the principles of circular economy in Ukraine have significant obstacles. This is due to the fact that the market of secondary raw materials is not transparent – more than 50% of it is in the shadows. At the same time, the market of secondary processing and waste-free technologies, including innovative technologies, are at the initial stage of development. In addition, the second negative factor for the development of the circular economy in Ukraine is the absence of tariffs for the processing of secondary resources. In Ukraine, there are opportunities to transform the dominant model of the linear economy into an ecologically and economically efficient circular model, but the existing economic mechanisms still orient enterprises to the use of an outdated linear model. According to the statements of Kucher et al, 2022, the very first step on the way to the development of a

circular economy in Ukraine should be a ban on subsidizing any activity that harms the environment. Investigations of Kaletnik & Lutkovska, 2020 focuses on the perspectives of system modernization environmental safety in conditions of sustainable development.

According to Loiko et al, 2021, for the development of the principles of the circular economy in Ukraine, it is advisable to pay primary attention to the development and implementation of technologies aimed at recycling already accumulated industrial and household waste that maintains the current level of scientific and technological progress. Regarding the issue of accumulation and management of waste of various types, it has been widely studied by many scientists. Nanda & Beruti, 2021 state, that composition of solid wastes varies with income: low-to-middle-income population generates mainly organic wastes, whereas high-income population produces more waste paper, metals and glasses.

The crisis brought upon by the COVID-19 pandemic has altered global waste generation dynamics and therefore has necessitated special attention. Enormous amount biomedical waste, plastic waste, and food waste have been created. Due to the use of used personal protective equipments (facemasks, gloves, and other protective stuffs) among civil citizens and hospital workers. Sharma et al. presents the study of specific cases for biomedical waste, plastic waste, and food waste management. Hantoko et al, 2021, discussed the ways the operation of waste treatment facilities must be improved to cope with the challenge of handling medical waste, as well as working around the restrictions imposed due to COVID-19. Matveev and Geletukha, 2019, made an analytical review of the prospects for energy utilization of solid household waste in Ukraine. Prysliak et al., 2020, carried out the study of the potential and current state of agricultural waste use in energy purposes in Ukraine and the awareness of the heads of the agricultural enterprise about such possibility.

Previous research of the authors (Berezyuk et al, 2019) concerned the economic and environmental benefits of using waste as a source secondary and energy resource and the potential of using waste as a part of the state's environmental and energy security. The results of the previous studies conducted by the authors (Tokarchuk et al. 2021) have shown that the potential of bioenergy production from agricultural waste (plant and

animal secondary resources) can replace 36.1% of natural gas consumption in Ukraine. At the same time, Myronenko et al. 2017 and Tokarchuk et al, 2022 confirm that the use of waste as a raw material for the production of biofuel does not call into question the feasibility of using biomass as an energy source and does not create risks to the country's food security.

However, the issues of quality sorting of waste, taking into account European experience, their logistics and effective further use remained insufficiently studied, which made it necessary to carry out research. Russia military invasion in Ukraine brought new issue regarding with waste generation and waste management in Ukraine intensified the energy and environmental crisis in Ukraine. The volume of household waste generation in Ukraine is also affected by the migration of the population from the zones of active hostilities to the western and northern regions of Ukraine. With the increase in population density in relatively "calm" areas, the volume of solid waste generation also increases, and communal services are not always ready to efficiently dispose all of it. The problem of waste has become particularly acute under the conditions of military operations that are currently ongoing in Ukraine, as large amounts of various types of wastes (military, construction, medical, industrial and agricultural) are generated. Specific wastes of hostilities also include destroyed military equipment, spills of fuel and lubricants, ammunition, hand bombs, anti-tank mines, etc.

MATERIALS AND METHODS

The study was based on secondary data obtained from official statistical sources of the EU, Ukraine, other countries and scientific literature. The field of solid waste management in Ukraine was chosen as the main object of the study. The European experience and the experience of other advanced countries were analyzed in order to improve similar processes of waste management in Ukraine. The deduction method was used to introduce the best practices of solid household waste management in Ukraine. In order to visualize static data and to visualize the composition and structure of solid waste in different countries, a tabular method was used. The graphic method was used to display and compare the existing logistics scheme of household waste management in Ukraine,

Switzerland and Germany. The principles of transition to a circular economy, ensuring sustainable development of the field of solid household waste management are taken as the basis for improving the logistics of solid household waste management and their useful utilization (including energy).

The purpose of the research is to create an effective logistical management scheme based on the analysis of Ukrainian, European and world experience in the generation and management of solid waste based on the improvement of waste separation and the introduction of vacuum transportation, which will increase the efficiency of the secondary use of waste, including the use of waste for energy purposes. In accordance with the established goal, the following research tasks were formed: (1) to analyze the formation and composition of solid household waste in Ukraine and other countries; (2) to present the dynamics and logical scheme of the existing household waste management in Ukraine, to identify the shortcomings of modern waste management in Ukraine; (3) evaluate the best logistics practices of waste management in EU countries; (4) to improve the sorting and logistics of solid waste in Ukraine based on the best European and world practices; (5) justify the feasibility of using waste for energy generation.

RESULTS AND DISCUSSIONS

According to the Law of Ukraine “On Waste”, waste is a raw material that has been used in the

production process, and has completely or partially lost its consumer properties and cannot be used in the same production in the future due to its technical features. The same legal document defines household waste as waste that is generated in the course of human life and activity in residential and non-residential buildings (solid, large-sized, repair, liquid, except for waste related to the production activities of enterprises) and is not used according to the place of their accumulation (Law of Ukraine “On waste”). According to forecasts of the World Bank, by 2030 the amount of waste in the world may increase to 2.58 billion tons, by 2050 to 3.7 billion tons.

The generation of household waste per person in the EU varies between member states (Fig. 1). On average, in 2020, the generation of municipal waste in the EU amounted to 505 kg. The largest volumes of household waste were generated in Denmark and Luxembourg – 845 and 790 kg per person, respectively, the smallest – in Romania – 287 kg per person.

Analysis of statistical data shows that more and more household and similar waste is generated in Ukraine every year (Table 1). However, the waste potential is not actually used. It is worth noting that during 2011–2020, the volume of solid household waste generation increased by 22%, and in 2020 amounted to 12,634.9 thousand tons. 40.64% of the total volume of generated waste was taken to specially equipped landfills, 1.3% was burned for energy, and 0.04% was disposed of. Household waste production per capita increased by 33.5%

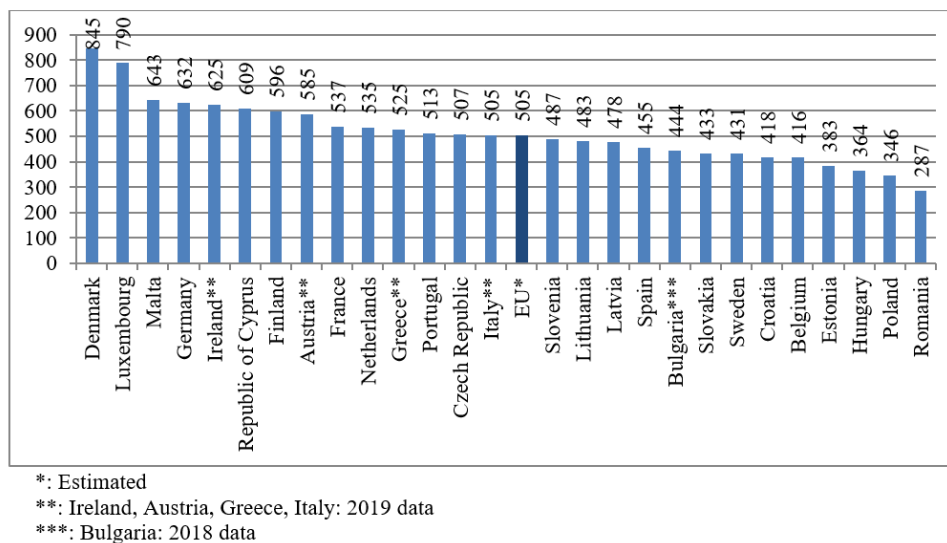


Fig. 1. Municipal waste generated in the EU, 2020 Source: formed by the authors based on the data from Eurostat, 2020

Table 1. Handling of household and similar waste in Ukraine, 2011–2020, thousand tons

Directions of waste management	Years										2020 to 2011	
	2011	2012	2013	2014*	2015*	2016*	2017*	2018*	2019*	2020*	+/-	%
Collected household waste	10356.5	13878.0	14501.0	10748.0	11491.8	11562.6	11271.2	11857.2	11792.7	12634.9	2278.4	122.0
Removed household waste	7030.0	9362.7	9504.4	5893.8	6233.0	6089.5	6469.0	7171.2	7099.0	7521.5	491.5	107.0
Including removed to specially equipped landfills	4321.5	5175.1	5178.5	3397.9	4194.3	4208.1	4417.5	4885.8	5043.6	5134.4	812.9	118.8
Burned for energy	154.0	149.9	147.6	149.0	254.3	257.3	244.4	205.5	198.5	163.7	9.7	106.3
Burned without gaining energy	98.5	78.6	2.9	3.8	2.1	2.0	1.2	1.0	1.0	0.7	-97.8	0.7
Disposed	74.5	57.4	9.4	3.8	4.0	6.5	16.5	16.7	0.1	4.5	-70.0	6.0
Including composted	3.7	0.0	0.4	0.0	8.2	7.9	0.01	-	-	-

Note: – no data available, * without taking into account the temporarily occupied territory of the Autonomous Republic of Crimea, the city of Sevastopol and part of the temporarily occupied territories in the Donetsk and Luhansk regions. Based on the data from State statistics service of Ukraine, 2020.

over the past 10 years, and amounted to 302.7 kg in 2020 (State statistics service of Ukraine, 2020). For comparison: in Belgium and Spain, the volume of solid household waste generation reaches 416–455 kg/year, in Denmark and Luxembourg – about 800 kg, however, in these countries, almost all solid waste is processed.

In total, in 2020, more than 54 million m³ of household waste (over 10 million tons) was accumulated in Ukraine, which was transported without processing to 6 thousand landfills with a total area of almost 9 thousand hectares. Currently, the situation with the accumulation of waste in Ukraine is critical – some solid waste landfills are 80–95% full (Berezyuk et al, 2019). The fee for waste disposal is very high in most EU countries. For example, in Sweden, the waste disposal fee is about 160 euros per ton, in Germany – 140 euros, in Italy – 120 euros. If household waste is separated and handed over for recycling, citizens shouldn't pay the disposal fee. The tariff for removal of solid household waste in Ukraine, on opposite, is quite low. The average tariff for household waste management in Ukraine is almost 19.8 euros per ton, including for landfill – 6.4 euros. The average tariff for handling household waste for the population is 17.0 euros per ton, including for burial – 5.8 euros.

The composition of solid household waste varies within individual regions and between countries. This is due to the difference in the level of economic development, the structure of industry, the system of sorting and disposal of waste, and the peculiarities of the population's preferences

regarding food consumption. The quantity and composition of solid household waste are crucial for determining their proper handling. Such information is important and useful for the transformation of solid household waste into energy resources on the territory of communities.

The composition and structure of waste depending on the level of countries economic development is presented in Table 2.

Different categories of countries have differences in the structure of household waste, which causes different problems in the field of handling them in the medium and long term. In developing countries, organic wastes prevail (64%). There is an accumulation of large volumes of biomass, that is not currently recycled, but can be used as a valuable source for the production of alternative energy. This leads to sanitary and hygienic problems and the spread of diseases. In countries with transition economy, a significant part of waste is paper (16%), organic matter accounts for 45%, then goes textiles and rubber (15%), plastic (12%). Significant volumes of rubber and plastic in solid waste are the result of the use of outdated technologies that are “unfriendly” to the natural environment. In the future, these countries will face the problems of disposal of this type of waste, which is quite difficult from a technological point of view. Developed countries are characterized by significant amounts of paper (34%), amount of organic waste is much lower (26%), and other waste (12%). The main problems for countries with developed economies are the depletion of natural resources, the growing anthropogenic

Table 2. Distribution of waste by category in different countries, 2019, %

Types of waste	Type of economic development of the country		
	Developed economy	Transition economy	Developing economy
Paper	34.0	16.0	1.5
Organics	26.0	45.0	64.0
Glass	11.0	1.5	4.0
Plastic	7.0	12.0	0.5
Metals	7.0	1.5	1.0
Textiles, rubber, leather	3.0	15.0	7.0
Other	12.0	9.0	22.0

Note: Based on the data from Eurostat, 2020.

impact on the environment. Some countries face a shortage of certain types of waste to ensure the capacities of waste processing plants (in particular, Sweden, which imports waste).

According to the data of the National Project “Clean City”, the morphological composition of solid household waste for the regional centers of Ukraine is given Table 3. Despite the fact that there are certain differences in the composition of solid waste in Ukraine and in EU countries, it can be noted that the calorific value of this type of waste in Ukraine corresponds to the European level. The key to effective processing of waste, including household waste, is sorting (maximum division into different groups and fractions, which involves primary and secondary sorting) and direct packaging (via vacuum pumps and underground pipelines to sorting stations for further use in production or energy purposes). The

main obstacle to the development of the secondary resources market (household waste market) in Ukraine is the difficulty of separating the components of secondary materials from the rest of solid household waste with the subsequent division of secondary materials into components. Of the existing set of technologies for separating secondary materials from the rest of solid household waste, the most expensive and the most difficult is the extraction of secondary materials from the already formed general flow of solid household waste at special enterprises.

The European experience of solid household waste separation shows differences within individual countries, however, the general tendency is to allocate a fairly significant number of containers for different types of waste. Bio-waste represents an important share of solid household waste. The following key factors play an important role

Table 3. Morphological composition of solid household waste in regional centers of Ukraine, 2019, %

Wastes components	1	2	3	4	5	Average value	Range
Food waste	30.0	35.5	43.6	45.6	29.4	36.8	30.0–45.0
Paper and cardboard	5.3	5.9	7.6	8.5	15.6	8.6	5.0–15.0
Polymers	16.0	8.7	12.3	10.7	16.6	12.9	8.0–17.0
Glass	13.6	10.9	11.3	9.1	15.2	12.0	9.0–14.0
Black metals	1.0	0.3	0.6	1.2	2.0	1.0	0–2.0
Non-ferrous metals	0.1	0.2	0.3	0.4	0.3	0.3	0–0.5
Textile	2.0	3.8	2.2	2.2	5.7	3.2	2.0–5.0
Wood	1.6	2.5	0.1	1.4	2.0	1.5	0.1–2.0
Hazardous waste	0.3	0.1	0.3	0.3	0.5	0.3	0.1–0.5
Bones, skin, rubber	0.5	1.6	0.4	0.9	0.8	0.8	0.5–1.5
Combined waste	0.5	0.9	0.4	1.0	-	0.7	0.4–1.0
Residues, incl.	29.1	29.4	20.9	18.7	11.9	22.0	12.0–30.0
Small construction waste	0.3	2.8	3.4	3.2	3.2	2.6	0.3–3.5
Street garbage, leaves	6.1	0.5	0.3	0.0	3.4	2.1	0–6.0
Hygiene products	3.1	3.7	2.6	2.8	3.6	3.2	2.3–3.5
Others	19.6	22.4	14.7	12.7	1.8	14.2	2.0–2.2
Calorific value (average, J/kg)	9.4	7.5	8.3	8.4	11.8	9.1	7.5–11.8

Note: Based on the data from (Matvieiev & Heletukha, 2019).

in the implementation of a successful system of collection and separation bio-waste in EU (Fig. 2). One of the prerequisites for the effective use of solid waste as a source of energy and secondary resources is their proper handling, which allows them to be processed more qualitatively, with less energy, time and human resource consumption and, importantly, to obtain higher quality products for secondary use at the output.

Waste disposal is divided into three types: primary, secondary and mixed. Primary recycling involves the use of waste in various sectors of the national economy without prior deep physical and chemical processing; in particular, it is construction waste or plastic. Secondary – involves the use of products of special waste processing, as a result of which products of a different composition than the original waste (waste water, wood waste) are formed. Mixed disposal includes both primary and secondary disposal (Kropivnyi et al, 2020). Table 4 presents the characteristics of the secondary use of solid waste in individual countries of the world.

In Germany, the manufacturer receives 90 euros for each ton of recycled waste. In Ukraine, there is a legal norm that such producers are entitled to funds from environmental funds of local budgets, but in practice this norm does not apply.

Waste sorting in Ukraine has a positive trend; it is stimulated at the level of individual communities and households. According to the Ministry of Development of Communities and Territories of Ukraine, in 2021, 34 waste sorting lines were operating in 29 cities of Ukraine. In addition, waste sorting complexes are being built in 11 cities. There is a leachate collection system at 54 landfills, a biogas extraction system is installed at 18, and cogeneration plants, etc. are in operation. In 2021, territorial communities of Ukraine planned to purchase about 40,000 containers for collecting household waste and more than 90 specially equipped vehicles with funds from regional and local budgets, enterprises, special funds, the UN Program and the DOBRE program (MDCTU, 2022 a). The USAID-funded DOBRE program is a five-year program implemented by the international organization Global Communities and financed by the United States Agency for International Development (USAID). It intends to help those new local governments effectively manage these new responsibilities, and support the development of stronger community cohesion through citizen engagement in these new communities.

The most common in Ukraine today is the sorting of waste into organics (wet waste) and sorting of glass, metal, paper and plastic. The

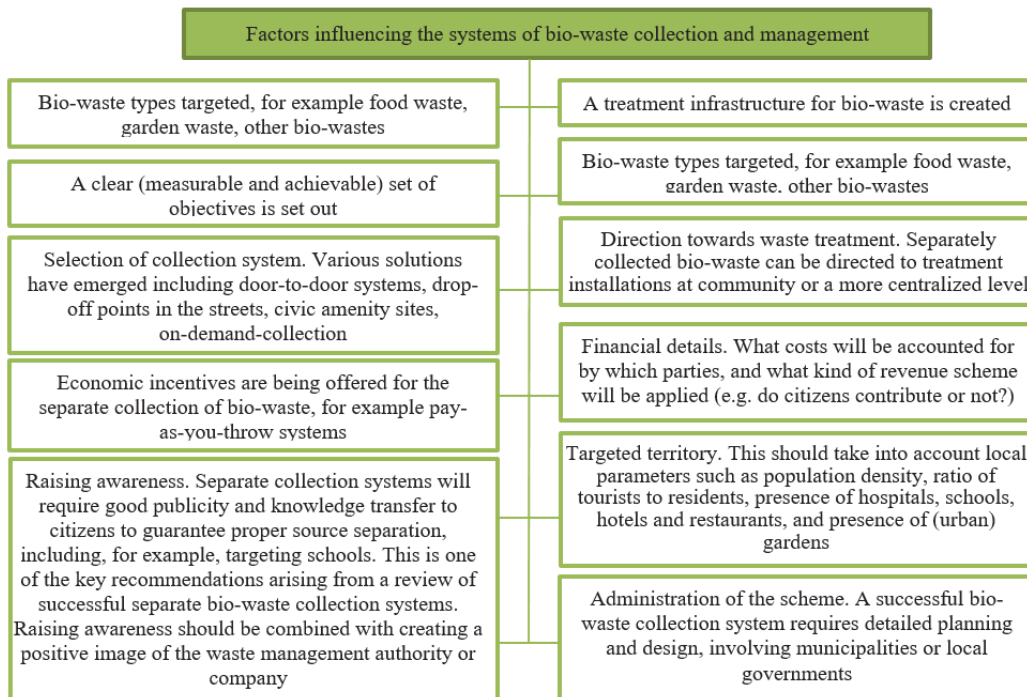


Fig. 2. Key local factors influencing the provided systems for separate bio-waste collection and management in EU countries. Based on the data from EEA Report, 2020

Table 4. Characteristics of the secondary use of solid waste in some countries of the world

Country	Characteristics of waste management
Austria	New technologies are being introduced to transform waste into a resource – when wastes become a resource for the production of new goods. Biotechnology is used to break down plastic. This is how the “plastic cycle” is ensured: waste from one product is used to create another.
United Kingdom	It is one of the world leaders in the technology of converting food waste into energy using “anaerobic digestion” – the use of bacteria to process food waste and obtain biogas and biofertilizers. Local authorities regulate the cost of separate collection by charging for the provision of containers for mixed waste, but composting and separate collection containers are provided free of charge.
Germany	Waste disposal is carried out by sorting and further processing. Waste that cannot be processed is burned to generate heat and electricity. Sanctions are not provided, garbage sorting is encouraged.
Poland	Waste is sorted into 5 fractions, which are subsequently disposed of as secondary resources. Waste that cannot be processed is buried in solid household waste landfills with a degassing system to generate heat and electricity.
France	The waste disposal system involves sorting waste into 2 fractions: secondary materials and other waste. There are bins for clothes. There are no penalties or incentives.
Finland	Residential buildings, shops and businesses have convenient waste collection points. The packaging deposit system is practiced - when the buyer also pays for the packaging when buying a product.
Sweden	99% of all waste is processed, from which fuel and secondary materials for production are obtained. The country is so successful in this area that it imports garbage from other countries.
USA	Waste management at the city level is carried out in a complex that involves municipal authorities, private businesses, and the population in accordance with existing programs.
China	Both public and private medium-sized, family companies are engaged in the secondary processing of solid waste. Sufficient funds are allocated for scientific research and implementation of innovative technologies in the field of solid waste recycling.
South Korea	Extended producer responsibility for waste management is practiced. In 2013, the government introduced mandatory processing of food waste using special biodegradable bags. 95% of food waste is currently recycled into compost, animal feed, solid fuel and methane gas (through anaerobic digestion).
India	There are significant problems in the waste management system in the form of delays in their removal and the accumulation of excess masses of waste in the places of their primary collection within settlements. Heat treatment of waste, use of plastic for road construction is practiced.
Japan	The “Law on Waste Management and Public Cleaning” and the “Guidelines for the Development of a Local Waste Management Plan” define the categories of waste and outline the main provisions of solid waste management. There are 6 product-specific regulations that reflect the concept of extended producer responsibility, the Resource Efficiency Promotion Act and the Green Procurement Act.

Note: Based on the data from (Popova, 2019; Avfall Sverige, 2022; USEPA, 2022).

existing system of responsibility for environmental pollution, including household waste, functions unsatisfactorily, as the volume of generated waste grows every year. The reason for this is the ineffective system of fines for generated waste and evasion of their payment. The formation of unauthorized landfills in fields, forests and forest strips is also a problem. The fee for sorted waste, which is a source of cheap and high-quality raw materials, can radically change the state in the field of household waste management. Wastes can be transformed from a problem into a source of income. Therefore, at the state level, the transition from the system of fines for improper handling of household waste to the system of incentives for compliance with the correct handling of waste should be approved. The system of incentives for proper waste management should be organically implemented into the existing household waste management system and over time change the

consciousness of the average Ukrainian in relation to the generation and management of waste, as well as promote their energy use (Fig. 3). In general, a larger number of specialized containers is the key to minimizing sorting costs and ensuring the most useful further use of waste. We propose to diversify the types of waste containers currently used in Ukraine. As a basis, we suggest taking the European experience of using seven unified colors of containers (green, blue, yellow, black, brown, red, orange).

We propose to divide the black container into actual black – food waste, and gray – wood raw materials, since these organic wastes have different characteristics and differences in the possibilities of further use (Table 5). The consumer value of solid household waste can be partially or completely lost due to problems in logistics (improper storage, poor-quality delivery). Among the European countries, Switzerland, Germany and the

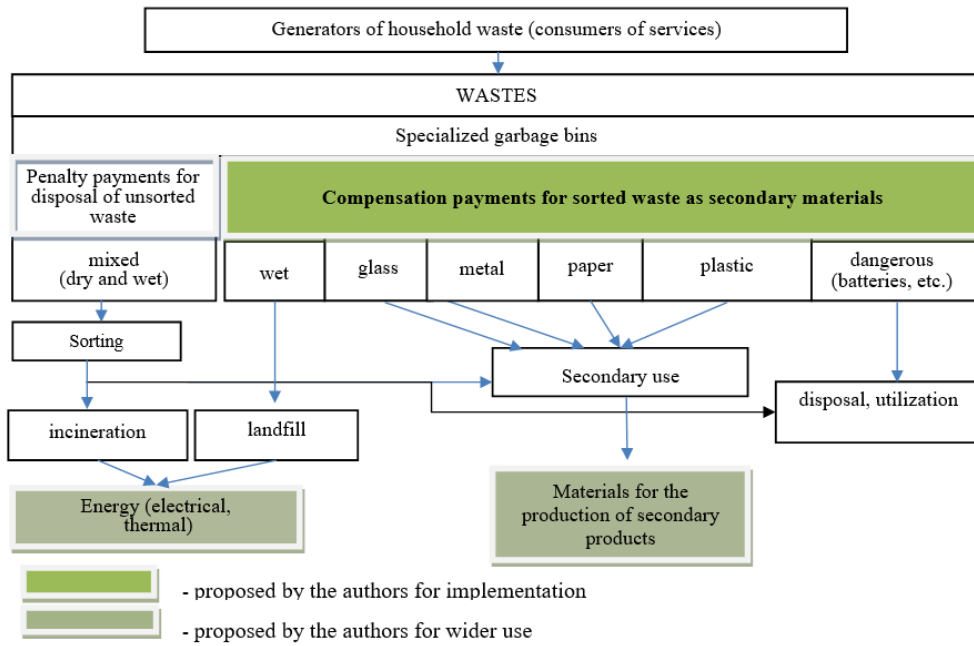


Fig. 3. Logical scheme of existing household waste management in Ukraine and proposed motivation for separate sorting and energy use of waste

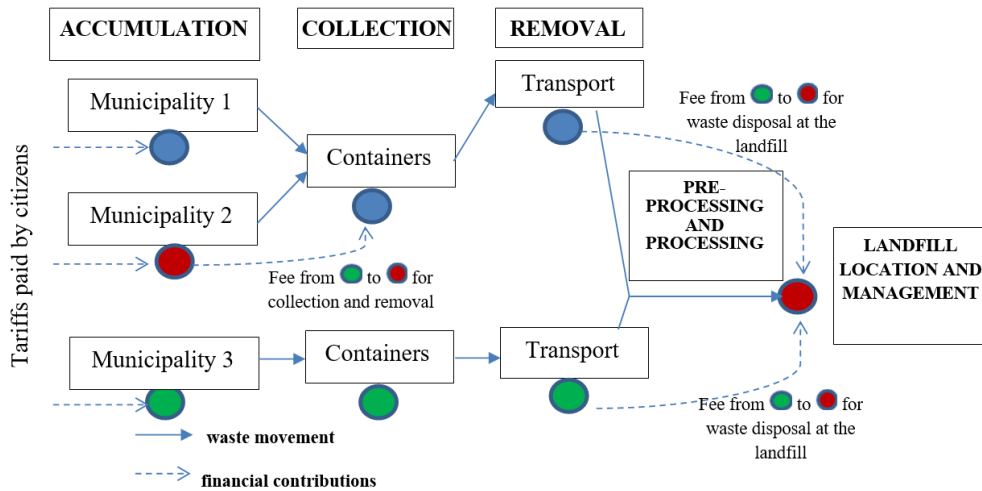


Fig. 4. Logistic scheme of solid waste management in Switzerland and Germany. Based on the data from (Matviciev & Heletukha, 2019)

United Kingdom are the leaders in implementing effective logistics schemes for the recycling of solid household waste. In the process of implementing logistics schemes for solid household waste recycling, as a rule, several municipalities cooperate, which ensure separate collection and removal of waste for sorting and further effective management of it (Fig. 4). As the practice of these countries shows, the quality of waste collection, transportation, processing and disposal services

increases in parallel with the development of the business of processing waste into secondary resources, which are further used for the production of many different goods. This directs the entire logistics system in a constructive market direction, creates competition among operating companies that sort and process waste. We see the improvement of waste logistics in Ukraine at the level of individual communities (both rural and urban) in the construction of vacuum sorting stations

for waste transportation. They require little capital investment, can change and adapt depending on the change of the community or city micro-district, and ensure the greening of the sorting process. Residents of cities can implement these communications without complex calculations, but with the active assistance of local authorities.

In general, this idea will contribute to the formation of a clean and comfortable natural environment, the receipt of income from the sale of secondary raw materials or energy resources in the local budget. This waste management system involves minimum costs of live labor, as it includes maximum automation, but still ensures the creation of jobs. As a result, primary sorting stations should be built in certain communities or areas of cities, which will transfer the received separated waste using a vacuum to the secondary sorting station. As a result, sorted materials with the potential for secondary use will be obtained.

The benefits of primary and secondary processing of solid household waste are indisputable: it is an opportunity to partially solve the problems of the limitation and availability of certain types of resources, and the replacement of primary raw materials with secondary ones, which is much cheaper and lowers the cost of finished products. Such types of sorted waste as paper, metal, plastic and glass are most often recycled. One of the key arguments in favor of waste processing is significantly lower energy costs for obtaining raw materials and reduction of negative anthropogenic impact on the natural environment. In the USA, the average cost of processing secondary raw materials is (in USD/t): newspapers – 36; mixed paper – 45; cardboard boxes – 48; mixed glass – 52; steel cans for preservation – 58; transparent glass – 65; green glass – 85; brown glass – 105; PET plastic – 180; HDPE plastic – 185 (US Environmental Protection Agency, 2022)). An effective market for household waste management involves:

- 1) establishment of environmental tax rates for waste disposal at landfills, depending on the type of waste and landfill class;
- 2) implementation of a system where generators and “owners” of waste pay only for the actual weight of waste that is not suitable for preparation for reuse and recovery, and incentives are created for separate collection of waste;
- 3) stimulation of the use of products and materials obtained as a result of recycling;
- 4) provision of fiscal and credit benefits for financial support of scientific research and implementation

of innovative waste processing and recycling technologies, etc (MDCTU, 2022 b).

Implementation of an effective waste management system in Ukraine with high-quality sorting, improved logistics and secondary use of waste for energy and non-energy sectors will have a number of effects:

a) Economic effect:

- economic benefit from the reuse of waste as a secondary material due to its cheapness (in the production of paper, glass and other products from sorted solid household waste);
- savings of primary resources in the production of products and energy due to replacement with secondary ones;
- additional funds to local budgets thanks to tax revenues and assets involved in new waste sorting and recycling operations;
- economic benefit from trading quotas for reducing greenhouse gas emissions;
- preservation of the lands of territorial communities for recreation, development of agriculture and other types of activities due to the reduction of the areas of landfills and volumes of solid waste disposal;
- implementation of low-waste and zero-waste technologies.

b) Social effect:

- creation of new jobs in the field of solid household waste management (maintenance of vacuum sorting lines, work at factories for the secondary use of waste, including RDF (refuse derived fuel) production, etc.);
- improving the health of the population, reducing the risks of diseases associated with the accumulation of solid household waste in unsuitable places;
- environmental education – formation of environmental consciousness of the population;
- improving the image of communities that carry out effective management of solid household waste;
- cleaning of community territories, development and formation of recreational zones for organized recreation of the population and tourism.

c) Ecological effect:

- cleaning of the natural environment during the reorganization of existing solid waste landfills and the introduction of the collection and energy use of landfill gas;

- contributing to the achievement of the goal of restraining the increase in the global average temperature of the Earth’s surface below the level of 2°C compared to the pre-industrial level;
- prevention of pollution, soil and groundwater due to the reduction of landfill areas;
- reduction of greenhouse gas emissions, in particular, landfill gas;
- preservation of biodiversity and environmental protection;
- formation of an eco-image for cities and regions.

d) Energy effect:

- use of the potential of the organic fraction of waste for the release of biogas at solid waste landfills;
- expansion of incineration of solid household waste with the production of energy, which will expand the energy resource at the community level;
- the possibility of production and use of RDF – fuel obtained from the remains of pre-shredded and subsequently compressed solid waste briquettes or granules;
- saving of traditional sources of energy due to the use of alternative sources based on solid waste processing.

According to the proposed concept, the interaction of four effects – economic, social, ecological and energy with effective waste management

will create a synergistic effect, which is a condition for sustainable development (Figure 5). It is worth noting that the proposed concept involves interactions of the first, second and third orders. Interactions of the first and second orders (1, 2) imply any interactions between two or three effects, however, do not give the maximum result. Only in the case of an exclusive interaction of all four effects – economic, ecological, social and economic – interaction of the third order (3) it is possible to achieve the sustainable development.

Separating the energy effect into a separate sphere is due to the fact that energy resources have a significant impact on the economy and humanity in general, and their direct use and production based on waste processing is related to the environment and its impact. In particular, municipal waste can be used for the production of RDF (Refuse-derived fuel), and the organic fraction of waste – for the production of biogas. According to expert assessments, biogas extraction systems have been installed at 26 landfills in Ukraine, and power generation plants with a capacity of 30 MW are in operation. The amount of utilized biogas in 2020 was 64.0 million m³ (50% methane). The amount of electricity produced in 2020 is 112.3 GWh (Matvieiev & Heletukha, 2019).

Speaking about the profitability of bioenergy generation from secondary resources, in the case of Ukraine, due to the shortage of fuel and a significant increase in its cost (the cost of petrol and diesel have increased by 40% since the beginning

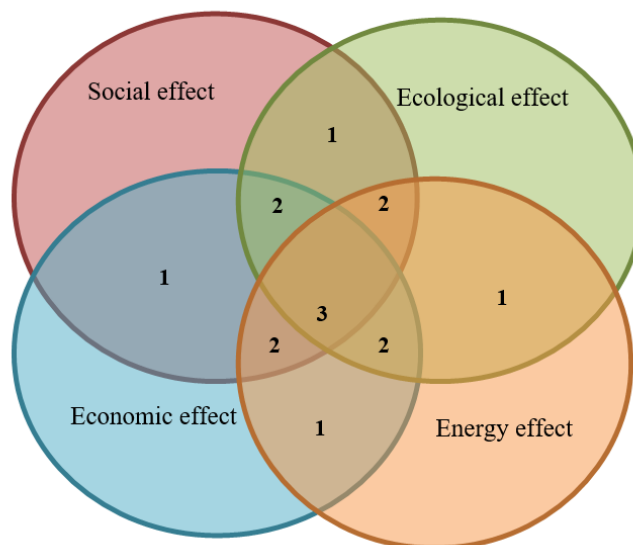


Fig. 5. The concept of sustainable development of solid waste management

of 2022), as well as need to strengthen energy security (energy dependency of Ukraine and difficulties with the import of fuel) biofuel production in Ukraine is particularly relevant. Also, biofuels production from waste does not compete with food security comparing to first generation biofuels. It is worth noting that the driving factors in the development of biofuel production in Brazil, which has long been a leader in bioethanol production, were the disruptions in oil supplies caused by World War II. In Germany, the development of biogas technologies also dates back to the war and post-war periods, when there were significant difficulties in providing the population with fuel and energy resources.

CONCLUSIONS

The generation of solid household waste in the world in general and within EU member states varies both in terms of volume per person and morphological composition and depends on various factors (level of development of the country, experience in waste sorting, introduction of advanced disposal technologies). The average volume of municipal waste generation in the EU is 505 kg per person, and the range is 287–845 kg per person; the structure of waste is dominated by food and organic waste (34.7%); the secondary use of municipal waste is encouraged. The dynamics of waste management in Ukraine is unstable. According to statistics, only a small share (0.04%) is subject to disposal. Most of the waste (40.64%) is taken to landfills, after which the probability of its secondary processing is significantly reduced due to the existing problem of the lack of proper sorting and separation of the necessary amount of secondary materials for further processing.

The experience of the EU has shown that any waste has a direct “owner”, because it is produced by someone, therefore, the entire burden of its processing or disposal must be compensated by those who directly created it. Therefore, the rational management of waste and, if possible, its use of waste as a secondary resource or for energy purposes, is the key to reducing costs for its disposal and a potential source of income. It is obvious that it is possible to build an efficient business on waste, you just need to understand the essence and peculiarities of handling it. For the successful secondary use of solid household waste, it is necessary to improve sorting and logistics facilities,

considering the best European and world experience, adapting it to the conditions of Ukraine. The implementation into practice of the eight types of containers proposed by the authors for sorting solid household waste in Ukraine and the logistics scheme, which is based on vacuum transportation of garbage for further centralized sorting are the keys to creating conditions for efficient waste management, obtaining useful secondary products and producing bioenergy.

Solid household waste produced by the population has a great potential for recycling. Bioenergetic recycling of waste with the production of biogas or electric/thermal energy, or the processing of municipal waste into refuse-derived fuel is a promising direction of effective waste management, which will contribute to the faster transition of Ukraine’s linear economy to a closed cycle economy following the example of the EU. Energy utilization of waste is especially important for Ukraine today in the conditions of hostilities, when oil depots are destroyed and there is a threat to energy security.

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