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COMPOSTING AS ONE OF THE PROSPECTIVE METHODS OF RECYCLING THE ORGANIC COMPONENT OF MUNICIPAL SOLID WASTE

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Abstract. In the conditions of constant deterioration of the environment, municipal solid waste management (MSW) in Ukraine remains one of the most pressing challenges in environmental safety because of its significant accumulation in landfills and the lack of effective mechanisms for its disposal. Approximately 40–50 % of municipal solid waste is organic, so the removal of this part of waste from landfills through composting and conversion of waste into secondary material resources will significantly reduce the environmental load on existing and potentially planned landfills. Therefore, the choice of promising technologies for the disposal of organic waste is one of the major tasks to ensure environmental safety. One of the effective strategies for dealing with excessive amounts of organic waste and one of the best and most affordable technologies for the waste recycling system is composting.

Key words: organic waste, biological methods, composting, composting conditions, waste recycling, waste management.

1. Introduction

Proper management of waste generated as a result of human life is one of the most important problems. The lack of adequate landfills and the high cost of waste management have persuaded many municipalities to pursue a policy of integrated waste management, which includes measures such as reducing waste generation, reuse, biological recycling, and final disposal in landfills. The problem is becoming even more serious in urban areas, as mismanagement causes damage to soil, water, and the environment creates risks to public health.

Sustainable municipal solid waste management (MSW) is seen as one of the key elements in achieving urban sustainability by mitigating global climate change, resource recycling, and energy recovery. Waste management systems based on waste collection and transportation to landfills are outdated. Because of the unsatisfactory current state, namely overload, non-compliance with safety standards (no appropriate passports) the landfill is considered the least preferred method of disposal, because the accumulation of waste in landfills and dumps increases air pollution; toxic substances get into the soil, pollute it, and becoming a part of the natural cycle, seep into groundwater, creating a significant danger to consumers of drinking water, namely the functioning of ecosystems is disrupted; harms agriculture and construction (because it is accompanied by the withdrawal of land from economic circulation).

Therefore, in the conditions of constant deterioration of landfills, municipal solid waste management and implementation and improvement of existing technologies for organic waste disposal in Ukraine remains one of the most urgent tasks. Consequently, the removal of approximately 40–50 % of waste from landfills through composting and conversion of the waste into secondary material resources will significantly reduce the environmental load on landfills.

That is, there is a **scientific and applied problem** of creating new and improving existing environmentally friendly technologies for the disposal of organic waste, which will ensure the rational use of available renewable resources.

Analysis of recent research and publications

Theoretical – practical and methodological issues related to the management and disposal of organic waste and their socio-economic consequences are in the scientific interests of many domestic and foreign scientists.

Modern researchers of the composting process as an effective method of waste management are M. V. Gatsenko, G. G. Geletukha, A. A. Dolinsky, O. O. Lyashenko, O. A. Sagdeeva, V. V. Shatsky. Their works describe composting technologies, the conditions under which the process takes place, the preparation of the substrate, the composition of the substrate, and the ratio of essential nutrients in it. However, so far the problem of organic waste disposal has not been finally resolved, so the need to study the prospects for the use of environmentally friendly technology of organic waste disposal through composting is obvious.

Thus, **the aim of the study** is to analyze the biological method of organic waste disposal, with preliminary sorting, as one of the promising and rational methods of solving the problem of environmental pollution by waste. **The object of the research** is organic waste, which is formed and accumulated as a result of human life.

2. Presentation of the main material

Organic waste makes up the majority of municipal waste, so if disposed of properly, it will bring more benefits for sustainable development. Proper management of organic waste means its composting to obtain fertilizer – compost. Separate collection of such waste is important, as such waste can account for 40 to 50 % of the total. It is important that waste is considered as a resource and properly managed, namely: reduction of sources of generation, sorting, processing, composting, incineration, landfill and simple disposal. The most scientifically and technically developed countries in the world are already successfully using modern technologies to reduce the load of solid waste on the environment and dispose of them as efficiently as possible.

Decisions on the proper management of MSW must be not only environmentally sustainable, but also cost-effective and socially acceptable. In the EU, the transition to a circular waste economy is at the national level. Unlike a linear economy, generalized as “picking up, producing, consuming and disposing of”, a circular economy is defined as one in which waste is a valuable resource, i.e. what was previously considered “waste” can be converted into a valuable resource) [1]. In this context, the EU calls for waste management to be transformed into sustainable material resource management that embodies the principles of the circular economy, enhances the distribution of renewable energy, increases energy efficiency, reduces the Union’s dependence on imported resources and provides economic opportunities and long-term competitiveness [2]. The transition to a closed-loop economy requires changes in the scale of values, from product design to new business and market models, from new ways of converting waste into resources to new models of consumer behavior. This implies a complete change of system and innovation not only in technology but also in logistics, society, finance and politics [3]. EU believes that countries that have developed effective municipal waste management systems tend to do better in general waste management [4].

Organic waste causes some environmental impact when disposed in landfills (if it enters mixed waste, it can contaminate other waste and recyclable materials. When it enters landfills, it contributes to the formation of filtrates that contaminate groundwater, soil, and water bodies). CH_4 and NH_3 emissions are formed during biodegradation. Methane can be partly used for energy purposes. The compost obtained as a result of biodegradation is a substitute for fertilizers and is also used to improve soil structure. The analysis of the total environmental impact of the application of different waste management options includes many indirect consequences, so the choice of the optimal option requires an extended approach to life cycle assessment (LCA). This is shown in a simplified example in Fig. 2 [5].

Sorting is very important in waste management at the household level; sorted waste can be disposed using separate technologies. Practice shows that in the case of separate waste collection from the total amount of waste can be removed up to 70–80 % of useful resources, and in the absence of sorting – no more than 15 %. However, the most efficient separate waste collection is possible at the place of their generation, i.e., for household waste – it is sorting by the population [7]. Sorting waste in this way reduces by half the amount of waste that needs to be taken to recycling or incineration plants or landfills. The obtained solid organic material can be used in further processes by the consumer [6]. Such leaders in processing and secondary use of waste as Germany, Switzerland, Sweden, the Netherlands are showing high efficiency in separate sorting of MSW. So, for example in Germany 5 containers are used for garbage collection.

Black container – for unsorted waste, brown – for organic waste, blue – for paper, yellow – for packaging and plastic, green – for colored glass, green with a white stripe – for colorless. There are special containers for batteries. In Switzerland, processing, incineration, and composting make up 100 %. Landfills have been banned in this country since 2000. Switzerland is the world leader in the number of returned bottles – more than 90 % of glass containers are returned to glass recycling plants. Sweden recycles 99 % of its waste and additionally is importing about 700.000 tons of waste from other countries. The priority is not waste disposal in landfills, but its recycling. Newspapers, glass, metal, plastic, electrical appliances, light bulbs, and batteries are collected here separately. Food waste is collected in separate bags. Special machines collect electronics, hazardous waste, and chemicals. Unsorted waste is utilized by burning at waste incineration plants to produce heat [8].

Because of the aggravation of environmental problems, very actual are the issues of determining promising areas for the disposal of organic waste, namely the study of the prospects of biological processing of organic waste to obtain useful products – compost and biogas.

It is important to note that separate collection, reuse, recycling, and energy use of solid waste compete with each other for raw materials, but do not exclude each other. This thesis can be confirmed by Figure 3, which shows the situation with waste recycling in the member countries of the Organization of Economic Cooperation and Development (OECD). We see that countries that have significantly reduced the share of solid waste disposal in recent decades have achieved this result by combining the reuse of materials with recycling, including compost, and with heat treatment – incineration, which in most cases involves the use of energy [10].

Composting belongs to the biological methods of MSW utilization. Biological methods involve the decomposition of the organic part of solid waste by living microbes that use biodegradable organic substances as a food source for growth and reproduction. As microbes grow and reproduce, a lot of these nutrients are converted to heat, carbon dioxide, and water. This leads to a significant loss of weight during the process. There are two main types of environments (aerobic and anaerobic) in which such microbes live. Biological methods can be used to treat either mechanically separated organic waste from mixed solid waste or from sorted sources that provide a cleaner organic flow. Food and green waste are suitable raw materials for these technologies. Other biodegradable materials such as paper, cardboard, and horticultural crops can also be treated. However, such degradation takes longer [11].

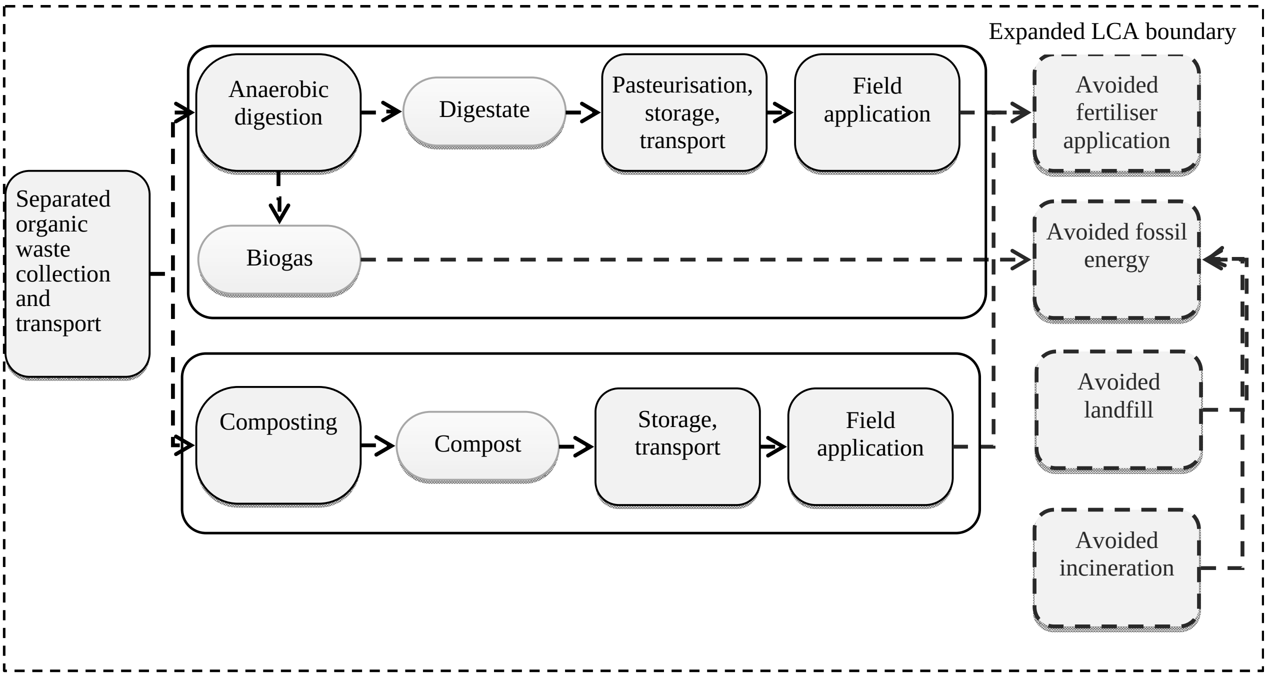

Fig. 2. Major stages and processes affecting the life-cycle balance of organic waste entering anaerobic processing or composting, in a simplified scenario involving a landfill or incineration [5]

Municipal waste disposal and recovery shares, 2013 or latest

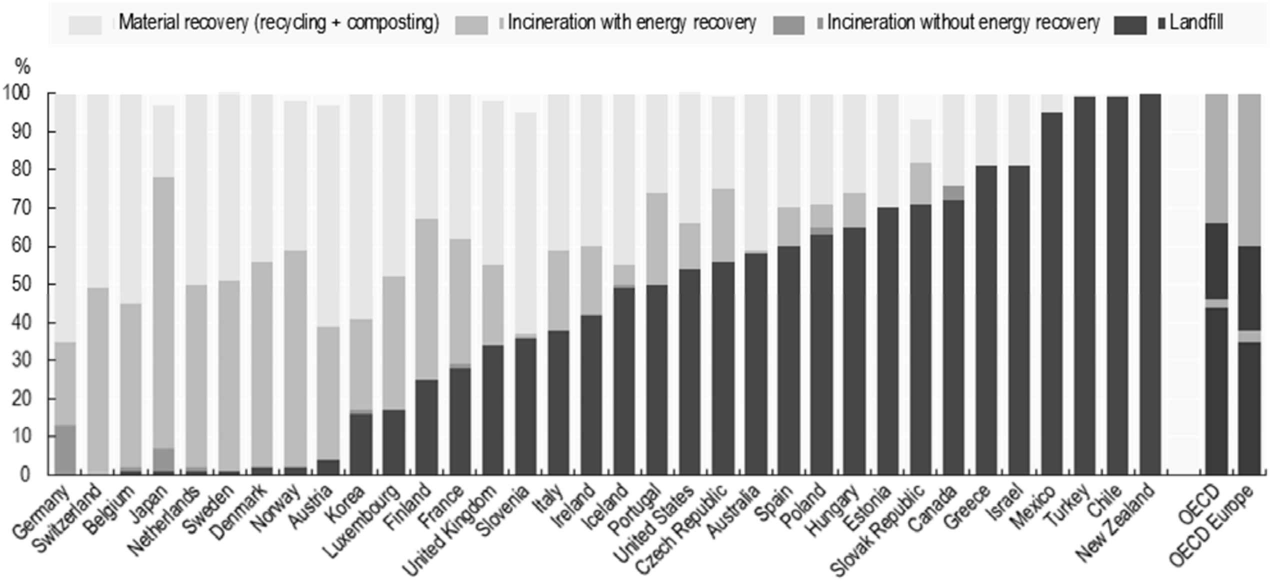

Fig. 3. Features of solid waste management in OECD countries (Source: OECD 2015) [1]

3. Composting

Composting is a method of disinfection of household, agricultural, and some industrial solid waste, based on the decomposition of organic substances by microorganisms. The final product is a hygienically pure non-toxic humic substance, which is successfully used primarily as a stimulating regeneration of soil ecosystems, and secondly, as an organic fertilizer, increases soil fertility [12].

The composting process is divided into two types depending on the process of biological decomposition of organic substances: anaerobic composting and aerobic composting. The process of anaerobic composting occurs in the absence of oxygen, or with its limited supply to the compost mixture. This method is characterized by the dominance of anaerobic microorganisms and the corresponding release (formation) of intermediates, including methane, organic acids, hydrogen sulfide and other compounds and components. In the absence of oxygen, these compounds accumulate and are not subject to further conversion during metabolism. Some of them have an unpleasant odor and negative phytotoxic effects on plants. The advantages include minimizing operating costs and lower nutrient losses.

The process of aerobic composting occurs in the presence of sufficient oxygen. The decomposition of organic substances is accompanied by the decomposition of organic compounds with the release of carbon dioxide, ammonia, water, thermal energy and the formation of stable end products (compost) with properties close to humus. The heat released accelerates the breakdown of proteins, fats and complex carbohydrates (cellulose, hemicellulose) with a corresponding reduction in the process as a whole. Controlled high-temperature processes ensure weed seed germination and disinfection of pathogenic microflora. Despite the higher loss of nutrients, this process is more efficient in terms of the use of compost in crop production and obtaining environmentally friendly products due to the expected and planned agronomic properties [13].

Microorganisms such as bacteria, fungi, and protozoa are involved in the process of biodegradation. Decomposition includes two stages of biochemical transformations – mineralization and humification. During mineralization, organic substances such as carbohydrates (sugars) and amino acids are easily fermented, degrading the metabolic activity of microorganisms, producing heat, carbon dioxide, and water. Mineralization leads to a partially stabilized organic residue. Typical ways of biochemical reactions that occur during mineralization are:

Carbohydrates → Simple sugars → Organic acids → CO_2 + H_2O + Organic matter

Proteins → Peptides → Amino acids → NH_4 compaunds → N_2 or ammonia [14]

Aerobic composting is one of the best technologies for an integrated waste management system due to the least anthropogenic impact on the environment, in accordance with the latest national and foreign developments, affordable and practical technology.

But composting is not as popular as other methods of waste disposal due to a number of its shortcomings, such as a long production cycle, and sometimes the unstable quality of the product. Because of this, many studies of solid waste processing are devoted to methods of accelerating the composting process. This can be achieved in various ways, such as the development of highly efficient compost devices and changing the biotic parameters of the process (vermicompost, the use of specialized crops and biocenoses of microorganisms) or abiotic (temperature, pH, etc.) [12].

3.1. Composting conditions

Control of parameters such as pH, bulk density, temperature, porosity, nutrient content, C/N ratio, particle size, moisture, and oxygen supply are crucial to get an accurate idea of the desired optimal process conditions (Fig. 4) [15].

It is necessary to provide two components for composting: the content of carbon and nitrogen in the raw material. Microorganisms use carbon as an energy source and nitrogen for protein synthesis. The ratio of C: N to ensure efficient decomposition is approximately 30 parts of carbon to 1 part of nitrogen by weight. Nitrogen-rich materials are called "greens" because they are mostly fresh, green substances. These include herbs and garden cuttings or vegetable cuttings. Carbon-rich materials are called "brown" because they can be dry wood, such as fallen leaves, straw and twigs [6]. Nitrogen-rich materials are called "greens" because they are mostly fresh green substances. These include herbs and garden cuttings or vegetable cuttings. Carbon-rich materials are called "brown" because they can be dry wood, such as fallen leaves, straw, and twigs [6]. The shape and size of particles are important factors in estimating the operating costs of the process. The appropriate size of the particle can be achieved by grinding the waste into smaller particles [16]. The size of the particle in the compost mass provides the level of porosity, appropriate aeration and regulates gas/water exchange [17], so it is desirable that the size of the material was small (5–20 cm) to facilitate access of microorganisms to organic substances [18].

One of the important factors is the temperature, as most microorganisms die if the temperature is above +55 °C, but some of them can withstand high temperatures and even drying. According to temperature ranges, microorganisms are divided into mesophiles, psychrophiles, and thermophiles. For psychrophiles, the optimum temperatures are below +20 °C, for mesophiles – from +20 to +40 °C and thermophiles – above +40 °C. Therefore, the composting process is conveniently divided into stages according to the temperature regime [17].

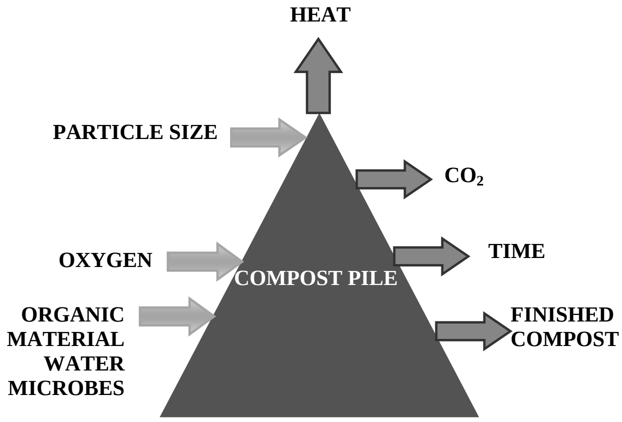

Fig. 4. Components of the composting process [15]

Mesophilic stage. At the beginning of composting, the temperature in the substrate is at the level of environmental indicators. The microorganisms that dominate the original substrate begin to multiply rapidly, and the temperature rises to +40 °C. Due to the release of organic acids by microorganisms, the environment is acidified.

Thermophilic stage (decay stage). At this stage, the temperature rises above +40 °C, which causes the death of mesophiles and the dominance of thermophilic microorganisms. When the temperature reaches + 60–70 °C, the number of destructive fungi of cellulose and lignin decreases. Instead, the composting process begins with bacillary forms of bacteria. Sometimes the temperature inside the ridge due to chemical processes can reach +90 °C, while the growth of microorganisms is inhibited. Under such conditions, the decomposition of proteins accompanied by the release of ammonia occurs and, therefore, the alkaline pH of the environment is set. During the thermophilic stage, sugars, starch, fats, and proteins decompose the fastest, after which more complex compounds begin to transform. At the same time methane, ammonia, carbon dioxide are intensively released. The duration of the stage depends on many parameters (the type of manure, the degree of grinding, humidity, aeration, ambient temperature, etc.) and ranges from 1 to 2 weeks [19].

Attenuation stage. The temperature drops to the level of the environment. At this stage, the pH decreases. Fungi and actinomycetes evolve and decompose polysaccharides, hemicellulose and cellulose into monosaccharides that can be used by other microorganisms [19].

Maturation stage. During this stage, complex processes of transformation of lignin and proteins of dead microorganisms take place, which provides the synthesis of humic acids. The duration of each of the stages of composting is different. The first three stages (mesophilic, thermophilic, and attenuation stage) pass quickly, the final stage – maturation, can last several months. Therefore, microorganisms at all stages of composting provide fermentation of organic substance. In general, more than 2.000 species of bacteria and at least 50 species of fungi are involved in composting. Therefore, the compost microbiota can be considered decisive in the fermentation of organic substance and obtaining the final product [19].

Researchers Yong, Xiao, and others show in their studies that the mesophilic stage together with the cooling and maturation stages are not necessary parts of the composting process, and accordingly, the composting period can be significantly shortened if the composting mixture is heated artificially to maintain the necessary conditions for thermophilic growth. However, heating is accompanied by significant energy consumption and, consequently, the additional load on the components of the environment, so the abandonment of the mesophilic composting regime is not a rational environmental and economic solution [20].

Because composting is an aerobic process, proper ventilation should be maintained to ensure that microorganisms that emit carbon dioxide into the atmosphere breathe, so composting aeration is necessary for efficient decomposition. Aeration, supplemented by the supply of O_2, is an important aspect that provides oxygen mainly for microbiological processes, temperature control, moisture optimization, and removal of excess carbon dioxide. Oxygen concentration in the range of 15 to 20 % is necessary for the desired composting [21]. Excessive aeration will cause a drop in temperature and a large loss of moisture by evaporation. As a result of this, the decomposition process stops. On the other hand, low aeration prevents sufficient water evaporation, generating excess moisture, and anaerobic environment [6].

Microorganisms work fastest when thin liquid films are present on the surface of compost materials. Optimal decomposition occurs when the moisture content is about 55 %. If it is less than 40 %, the microbial activity reduces, the degradation phases cannot be completed, which means that the resulting product is biologically unstable. If the moisture content exceeds 60 %, nutrients are leached and compost can be compacted. Moreover, water will saturate the pores and interrupt the oxygenation through the material. When compaction occurs, decomposition slows down, and anaerobic bacteria can become dominant in the heap, which can create unwanted GHG emissions and odors [11].

The pH value in the mixture is also an important indicator of the efficiency of the composting process. As a result of the synthesis of carboxylic acids, the pH value of the mixture to be composted varies from slightly acidic to slightly alkaline because of the formation of ammonium ions in the range from 4.5 to 8.1. Typically, these values are closely related to the activity of microorganisms involved in composting [22]. Microorganisms generate heat in the process of their vital activity. Composting begins at ambient temperature, which can rise to 65 °C without human intervention. During the maturation phase, the temperature drops to ambient temperature. It is desirable that the temperature does not fall too fast, because the higher the temperature and the longer the process, the higher the rate of decomposition and obtaining of hygienic compost. Too low temperature (below 35 °C) can be caused by insufficient moisture or nitrogen deficiency in the compost material, and too high temperature (above 70 °C) can also be caused by insufficient moisture or ventilation. Both too low and too high temperatures cause the death of the desired group of microorganisms [6].

Organic waste can be composted both individually and at the level of the local community. When separately collected organic part of the waste is composted, clean compost will is formed, which can be sold to the population and used to fertilize communal parks, gardens, greenhouses, and flower beds. The removal of organic waste from the total amount of waste will facilitate the sorting and further processing of such waste. In Europe, recycling is a disposal operation in which waste is processed into products, materials, or substances for primary or other purposes. It includes the processing of organic material, but not energy recovery or conversion into materials to be used as fuel or fillers. As a result of recycling, waste benefits by replacing other materials that would otherwise be used to perform a specific function, or waste is prepared to perform such a function at a factory or for a larger economy [23].

Conclusions

It is important that in creating and improving highly efficient MSW management systems, waste is considered as a resource and properly managed.

Biological methods of organic waste processing are environmentally effective and cost-effective methods. The peculiarity of biological methods of disposal is that they do not require significant labor and material costs.

Advancing to a cyclical economy requires active public participation in waste management and the pre-sorting of waste at home.

The processing of solid waste into compost is a modern and perfect method. The main advantages of using composting technologies in waste treatment are the return of plant nutrients available in the waste to ecosystems, the reduction of the amount of waste, and the simultaneous useful use of other organic waste in compost.

Therefore, in modern conditions, the method of processing should become an important mechanism for solving environmental and economic problems, the severity of which is growing faster than the effectiveness of measures taken to address them. Considering this, recycling should be considered as an integral part of the regional socio-economic system, which creates the conditions for improving the environmental and economic development of the regions of Ukraine.

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