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FEATURES OF MUNICIPAL WASTE MANAGEMENT IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT IN THE COUNTRIES WITH HIGH GNI PER CAPITA AND LOWER MIDDLE GNI PER CAPITA ON THE EXAMPLE OF FINLAND AND UKRAINE

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Abstract
The paper discusses ways to implement in Ukraine one of the important tasks of the sustainable development strategy - minimization and rational use of waste. The concept of a circular economy is analyzed in terms of using the material and energy potential of waste on the example of countries with high Gross National Income (GNI) per capita (Finland) and countries with lower middle GNI per capita (Ukraine). The features of the municipal solid waste management optimization in Finland and Ukraine are highlighted. It is noted that the concerns about the municipal solid waste management have reached the state level and are provided with targeted national programs and action plans. The dynamics of generation and treatment of solid municipal waste in Finland in 2009–2018 and Ukraine in 2013–2019 is analyzed. The main attention in Ukraine is paid to the implementation of the European system of municipal waste management. The paper emphasizes that an important condition for the implementation of state and municipal programs for waste recycling is the study of the socio-economic potential of the population and the contribution fractions of waste for the organization of the separate collection of waste components and creation an appropriate infrastructure. Under current situation, sensitization work with the population to increase the level of their environmental awareness and promote active participation in the implementation of municipal waste management programs is shown to be of great importance for Ukraine.

Keywords: **Sustainable Development; Municipal Solid Waste; Separate Collection; Recycling; Energy Recovery; Disposal.**

1. INTRODUCTION

One of the impetuses to the search for a new paradigm for the society development, named the concept of "sustainable development", was the dramatic degradation of the environment quality in the world in the second half of the twentieth century. The most noticeable reason for the deterioration of the environment on a global scale is the rapid accumulation of wastes, causing pollution of air, waters and soils. The level of pollution often makes it impossible or difficult for living organisms to survive in contaminated areas. Environmental pollution significantly worsens the quality of human life in a number of regions of the Earth, being a serious threat for civilization. The source of global environmental pollution was the rapid development of industry in the second half of the twentieth century, resulting in the depletion of natural resources and the accumulation of waste, which

occupy large areas and cause irreparable harm to the environment. "At the turn of the XX–XXI centuries the civilization found itself at that point of the world historical process, which determines the dynamics and direction of civilization development in the long term perspective. At different times this turning point was called differently: "revolution" by the German philosopher K. Marx; "moment" by the French historian H. Taine; "breakdowns" by the English philosopher of history A. Toynbee; "knots" by the Russian writer A. Solzhenitsyn, the transition to which means either the introduction of efficient mechanisms of production, economic and socio-cultural activities by the world society, or the completion of its natural history cycle of development, if it cannot meet the historical challenge" [1]. Humanity faces a difficult dilemma – satisfaction of the material and spiritual needs of the growing world population requires the development of production, and the development of production in its modern form leads to the increase in the volume of waste generated to alarming volumes. Solving the problem of waste reduction, recycling and disposal of accumulated waste has become vital for the world's population.

These factors have forced humanity to make decisions on changing the paradigm of its development for the transition from the "consumer society" to the "sustainable society". The concept of sustainable development was adopted at the UN Conference on Development and Environment in Rio de Janeiro in 1992 [2]. Sustainable development (SD) "meets the needs of the present without compromising the ability of future generations to meet their own needs" [3].

On September 25, 2015, 193 UN member states adopted Resolution 70/1 "Transforming Our World: The 2030 Agenda for Sustainable Development", which defines and approves 17 Sustainable Development Goals for the period up to 2030, aimed to eradicate poverty, preserve the planet's resources and ensure prosperity [4]. The goals and objectives set should ensure the balance of all three components of sustainable development: economic, environmental and social through the transition to a circular economy (CE). A circular economy is based on maximum efficiency in the use of resources, recycling of almost any product, zero waste generation while minimizing harmful emissions into the environment. Under the CE, the material and energy potential of waste will be returned to the economy, which will save natural resources. Therefore, the CE assumes Zero Waste due to the return of resources to the economy [5].

Waste management plays a central role in the circular economy [6]. The return of the material and energy potential of waste to the economy will save natural resources, slow down the growth of the volume of municipal waste in relation to GNI. CE assumes the gradual transformation of waste into production resources. The circular economy should not only make production less energy and resource-intensive, but also resolve the issue of processing the huge amount of already accumulated waste. In a circular economy production waste from one branch should be converted into resources for other branches of the economy, or into sources of energy. Thus, the CE contributes to the implementation of the 12 goals of sustainable development: ensuring the transition to rational patterns of consumption and production. Minimization and rational use of waste will limit the use of natural resources; solve the acute and complex problem of municipal waste.

The paradigm of human development, defined as a "consumer society" dominant especially in developed countries in the second half of the twentieth century, has led to the increased environmental pollution. The reason is the avalanche-like growth of municipal solid waste, which in terms of volumes is close to the level of industrial waste generation.

According to the World Bank estimates, 2.01 billion tons of municipal solid waste (MSW) was generated in 2016 [7]. By 2030, the world is expected to generate 2.59 billion tons of waste annually, and this number will grow to 3.40 billion tons by 2050 under the "business-as-usual" scenario. The world generates 0.74 kg of waste per capita per day, but national waste generation rates vary widely from 0.11 kg (Sub-Saharan Africa) to 4.54 kg (North America) per capita per day [7]. Waste generation usually correlates with income levels and the rate of urbanization. At the same time, due to its diversity, multiple sources, municipal waste is more difficult to recycle than industrial waste.

The profitability of the recycling industry is determined by the waste composition, which, according to the World Bank, depends on the level of income of the population (Table 1).

Analysis of Table 1 confirms that the content of resource-valuable components in municipal waste is much higher in the countries with High GNI per capita, than the same parameters in the countries with Lower middle GNI per capita and Low GNI per capita. In rich countries, waste separation works effectively. Finland is an example of efficient municipal waste management among countries with High GNI

Table 1.
Waste Composition by Income Level [7]

Rated according to World Bank estimates of 2015 GNI per capita, PPP	Waste Composition by Income Level, %							
	Food and scraps	Paper and cardboard	Plastic	Glass	Rubber and leather	Wood	Metal	Other
High ($12,476 or more)	32	25	13	5	4	4	6	11
Upper middle ($4,036-$12,475)	54	12	11	4	1	1	2	15
Lower middle ($1,026-$4,035)	53	12,5	11	3	1	1	2	17
Low ($1,025 or less)	56	7	6.4	1	-	1	2	17

per capita.

The experience of Finland is of great interest for Ukraine as a standard for solving the problem of waste management and turning them into an additional resource for economic development. In Finland, the highly efficient organization of separate collection, recycling and disposal of municipal waste over 10 years (from 2009 to 2018) has reduced 50-fold the amount of waste disposed to landfills. In 2018, 0.7% of municipal waste was send landfill in Finland.

Until recently, Ukraine had a simplified municipal waste management system, in which more than 94% of municipal waste was sent to landfills annually.

There for the problem of waste management requires an urgent solution – both for the implementation of the 12 goals of sustainable development, and for improving the environmental situation in the country. Ukraine is one of the countries with a high amount of waste accumulation at landfills and at the same time its economy is in unstable state. The country needs to adopt the successful experience of effective economic restructuring, in particular, the municipal waste management sector. The use of the resource and energy potential of municipal waste is of particular importance for the implementation of sustainable development objectives.

Studying the Finnish experience will contribute to the restructuring of the municipal waste management system in Ukraine.

2. THE PURPOSE AND RESEARCH METHODS

The aim of this article is to analyze the experience of Finland in the use of the material and energy resource of municipal waste in order to consider the forms and methods of Ukraine's transition to the circular economy in accordance with the 12th goal of sustainable development – to ensure the transition to rational models of consumption and production. In this context the focus is on the development of regional waste management plans. For this purpose, Ukraine's approaches to the management of solid municipal waste and solutions for their processing at the level of individual settlements, in particular Kyiv city are analyzed.

To implement the set tasks, the general scientific methods are used to analyze the possibilities of implementing the goals of the sustainable development strategy in Ukraine in the field of waste management and the transition to the circular economy. To determine the current situation in the sector, an analytical method is used, in particular, the method of statistical analysis of real data. The method of comparative analysis is also used when constructing tables reflecting the dynamics of changes in the field of municipal waste management. The method of system analysis is used to interpret the forms of the 12th goal of sustainable development implementation in Ukraine.

3. RESEARCH FIELD CHARACTERISTICS

For many years, a simplified municipal waste management system operated in Ukraine, which was actually reduced to waste collection and disposal to landfills. This led to the accumulation of more than 223 million tons of solid waste at landfills covering the area of more than 85 km^2. Most of the landfills do not comply with environmental safety standards, that is, they pose threat to the environment and the population. There was one incinerator without energy recovery in the country.

The accumulation of municipal solid waste (MSW) in Ukraine has become a state problem. The National Report "The Sustainable Development Goals: Ukraine" and the Decree of the President of Ukraine No. 722/2019 "On the Sustainable Development Goals of Ukraine for the period up to 2030" identified the need for the transition to rational consump-

Table 2.
Tasks and indicators of the 12th goal "Responsible Consumption and Production" for the Sustainable Development of Ukraine [10]

Target	Indicator	Target values			
		2015	2020	2025	2030
12.4. Reduce the amount of waste generation, and increase recycling and reuse through innovative technologies and production	12.4.1. Volume of waste generated by all economic activities per unit of GDP, kg USD 1,000 PPP in 2011	977.4	950.0	880.0	800.0
	12.4.2. Share of burned and recycled waste in the total waste generated, %	30	35	45	55

Table 3.
Dynamics of the generation of municipal solid waste in Ukraine in 2013–2019 [18, 19]

Years →	2013	2014	2015	2016	2017	2018	2019
Population, million people[1]	43.1	42.9	42.8	42.6	42.4	42.2	41.9
The amount of municipal waste, million tons	11.6	9.7	9.2	10.9	9.9	9.1	10.4
Specific amount, kg / person	270.1	226.0	215.7	255.7	233.7	215.3	248.6

[1] excluding the temporarily occupied territories of Crimea and eastern Ukraine

tion and production patterns for Ukraine to achieve SD goals [8, 9]. The tasks and indicators of the 12th goal of the Sustainable Development of Ukraine are given in Table 2. Benchmarking indicators of the achievement of the 12th goal by 2030 were established on the basis of computational and forecast work using scenario approaches to determine the long term trends of the country's development [10].

According to the indicators of achieving the 12th SD goal, 55% of the generated waste should be incinerated and utilized in Ukraine by 2030. This goal is fixed in the National Waste Management Strategy of Ukraine until 2030, according to which, by 2030, 20 Waste-to-Energy Plants should be built in the country [11] and in the National Waste Management Plan until 2030 years [12].

To achieve 12th SD goal, as well as the implementation of Directive 2008/98/EC on waste [13] into Ukrainian legislation, the Verkhovna Rada of Ukraine adopted a number of documents: Draft Law of Ukraine "On Waste Management" (2207-1-d dated 04.06.2020) [14], the Actions Program of the Cabinet of Ministers of Ukraine [15], which formulates the State Policy Concept of achieving the goal of the Actions Program of the Cabinet of Ministers of Ukraine and the Plan for its Implementation [16].

4. RESULTS AND DISCUSSION

The goals for the improvement of the waste management, included into the Action Program of the Cabinet of Ministers of Ukraine demonstrate, that the problem of household waste was recognized and emphasized at the state level, and, what is more important, the specific measures were identified to address it. Prior to the signing of the Association Agreement with the European Union [17], municipal waste management in Ukraine was limited to the disposal of waste to landfills.

The dynamics of the municipal solid waste generation in Ukraine in 2013–2019, given in Table 3 according to the official statistics, reflects the social trends in the country [18, 19]. Thus, 2013 was chosen as the base year due to reduction in the number of population and subsequent decrease in the total amount and per capita ratio of municipal waste, caused by the political and economic crisis of 2013–2014. It is highly probable, that after overcoming the crisis, the country's waste generation indicators will return to the levels of 2013.

In 2013, more than 11 million tons of municipal solid waste was produced in Ukraine. This amounted to about 270 kg of waste per capita (Table 3). According to the authors' considerations, the decrease in the amount of waste after 2016 is explained by labour emigration from Ukraine. The increase in the amount of waste in 2019 is conditioned by the improvement of living standard of the population.

As the analysis carried out by the World Bank [7] shows, an increase in the standard of living of the population is accompanied by an increase in the amount of household waste. Finland is an example of this.

As in other high-income economies, there is a noticeable increase in household waste in Finland: if in 2008 the amount of household waste was about 500 kg per capita, in 2018 it increased to about 550 kg per person [20]. At the same time, Finland belongs to the countries with safe environment. Since the last third

Table 4.
Recycling of mixed waste and separately collected waste in Finland in 2018 [22]

Parameters	Total waste treatment	Material recovery (w/o aerobic and anaerobic digestion)	Aerobic and anaerobic digestion	Energy recovery	Incineration without energy recovery	Landfilling
Mixed Waste, %	48.2	0.9	1.0	97.2	0.0	0.9
Separately collected waste total, of which:	47.1					
– Paper and cardboard waste, %		92.9	0.0	7.1	0.0	0.0
– Biodegradable waste		3.2%	86.5%	9.9%	0.0%	0.4%
– Glass waste		88.7%	0.0%	5.5%	5.2%	1.3%
– Metal waste		100.0%	0.0%	0.0%	0.0%	0.0%
– Wood waste		49.2%	0.1%	50.6%	0.0%	0.0%
– Plastic waste		63.1%	0.0%	36.0%	0.0%	0.8%
– Electrical and electronic waste		100.0%	0.0%	0.0%	0.0%	0.0%
– Other separately collected fractions		10.6%	35.6%	43.8%	2.7%	7.4%
Other and unspecified waste	4.8	1.1%	1.6%	7.2%	2.0%	15.3%

Table 5.
Municipal waste recycling and treatment in Finland [24]

Parameters	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Recycling, ths tons a year	919	827	948	912	873	856	1108	1163	1140	1286
Incineration and energy recovery, ths tons a year	463	556	678	925	1137	1316	1315	1515	1646	1733
landfill and other, ths tons a year	1180	1136	1093	901	672	458	315	90	26	22

of the twentieth century, the country consistently – from the state to the municipal level – works on involvement of municipal waste in the economy. In order to comply with the provisions of the Directive 2008/98 / EC "On Waste" [13], on April 10, 2008, the country adopted the National Waste Plan for 2016 [21]. Thanks to timely measures taken, a high level of municipal waste separation has been achieved in the country. In 2010, selectively collected waste made up 39.7%, and mixed waste total was 60.3%. In 2018, the level of the municipal waste segregation was 42% [21–24]. Selectively collected waste in Finland in 2018: Paper and cardboard (34%), Biodegradable waste (30%), Glass (6%), Metal (11%), Wood (8%), Plastic (5%), Electrical and electronic (WEEE) (4%), other separately collected fractions (2%) (Table 4).

As evidenced by the data in Table 4, in 2018 the recycling rate of mixed waste was 48% in Finland, and selectively collected waste amounted 47%. The main direction for processing mixed waste is Energy recovery (97%), and the main direction for the processing of separated waste is Material recovery (about 60%) and aerobic and anaerobic processing (about 27%). About 13% of separated waste is subject to energy recovery. For selectively collected waste, the recycling rate of cardboard, paper and paperboard is 53%, Metal waste – 18%, Glass waste – 9%, Wood waste and Plastic waste – by 5... 6%.

The share of energy recovery of waste grew, being 57%. Landfill disposal of waste has ceased almost completely: its share was only around 0.7% in 2018 (Tabl. 5).

Analysis of the data from Table 4, 5 shows that waste energy recovery is a priority direction for waste recycling in Finland. Over 9 years waste energy recovery has increased by 39%, and waste recycling has increased by 6%. While in 2009 the energy recovery reached 18%, in 2018 it increased to 57%. Recycling percentage increased from 36% in 2009 to 42% in 2018. The disposal of waste to landfills has stopped almost completely: in 2018, its share was only about 0.71%. This is partly due to the ban on landfilling of organic waste, introduced in 2016, aimed at waste recycling enhancement.

In 2009, there were 2 waste incineration plants in Finland, where about 300 thousand tons of municipal waste were incinerated. In 2013, there were 6 waste

Table 6.
Development dynamics of the municipal waste treatment [18]

Parameters	Years						
	2013	2014	2015	2016	2017	2018	2019
The number of settlements in which separately collection of municipal waste is organized, settlement	503	496	398	575	822	1181	1462
Number of semi-automatic waste recycling machines , pcs.	21	21	20	22	25	26	34
Number of waste-to-energy plants with heat recovery, pcs.	1	1	1	1	1	1	1
Number of waste incineration plants without energy recovery, pcs.	3	3	3	3	3	3	3

incineration plants with a capacity of over 700 thousand tons in the country in the cities of Turku, Riihimäki, Oulu, Kotka, Vantaa and Tampere. In addition, some good quality waste (SRF) went co-incineration in conventional power plants as a supplementary fuel [25]. In 2017, there were nine waste incineration plants in Finland, with a combined annual incineration capacity of approximately 1,595 thousand tons [26]. Waste incineration in Finland is based on cogeneration of electricity and heat, and heat, in particular, is recovered in district heating networks. The recovered energy yield to heat and electricity varies according to the combustion technique. In addition to municipal waste, incinerators also incinerate approximately 10–20% of commercial and industrial energy waste, but without commercial waste, the current incineration capacity would be sufficient to handle all of Finland's mixed waste. Finland has managed to achieve a large-scale reduction in waste disposal due to the optimal organization of the extensive system of municipal waste separation and waste energy recovery. The implementation of these tasks is also ensured by the high level of environmental awareness of the population.

In accordance with "From recycling to a circular economy National Waste Plan to 2023", it is planned to increase the share of waste recycling and reduce the use of the energy potential of municipal waste [26]. According to the National Waste Management Plan until 2023, recycling should account for 55% of waste, and the use of the energy potential of waste should be reduced to 40%. The implementation of the 2023 National Plan contributes to the achievement of the targets of the Directive (EU) 2018/851 [27].

Finland is an example of successful municipal waste management. Ukraine needs to adopt that successful experience of effective restructuring municipal waste management sector.

Its experience shows that task of reducing the amount of household waste and their recycling cannot be solved only at the international and state level.

In the implementation of the task of recovery municipal waste into re-use materials or energy, two parties should be involved – state and municipal authorities that provide technical capabilities for returning waste to industry and energy for further use as resources and the population with the knowledge and skills of resource-saving waste management.

The solution of this problem requires clear programs at the municipal level and appropriate environmental education of the population and information on waste management methods to ensure their maximum processing and neutralization.

When Ukraine committed itself to adapting its legislation to the EU legislation, waste management began to be brought in line with the European practice. The country is currently introducing the waste hierarchy to reduce the amount of waste, disposed at landfills.

The dynamics of the development of the municipal waste treatment industry is presented in Table 6.

The analysis of the data from Table 6 confirms the beginning of the reform of the waste management system, being implemented at the level of settlements, primarily by local authorities. The most optimal method for ensuring the high level of utilization of municipal waste is their separate collection. Therefore, since 2015, separate collection of municipal waste has been actively introduced in settlements. During the year, the number of settlements, where separate collection of waste components was organized, increased by 44%; such dynamics is seen until 2018. This led to the fact that by 2019 number of settlements, practicing separate waste collection, had quadrupled.

The organization of separate collection of municipal waste is most efficiently carried out in those cities where local governments not only organize sites with containers for separate collection of waste, but also conduct sensitization of the population, starting with schoolchildren. While the solution of the industrial waste problem depends mainly on the legislative and

Table 7.
Dynamics of municipal solid waste treatment [18]

Parameters	Years						
	2013	2014	2015	2016	2017	2018	2019
Secondary raw material collection points, %	1.0	1.5	1.4	1.2	1.5	1.6	1.2
Waste recycling facilities, %	1.7	0.8	1.4	1.3	2.6	2.9	2.9
Composting areas, %	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Waste incineration plants, %	1.3	1.5	2.8	2.4	2.5	2.3	1.9
Solid waste disposal sites (SWDS) %	96.0	96.4	94.2	95.2	93.4	93.2	94.2

Table 8.
Contribution fractions of municipal waste in the major cities of Ukraine [29]

Parameters	Kyiv	Kharkiv	Dnipro
Population, people [19]	2,950,819	1,450,082	1,002,944
Paper Cardboard waste, %	13.5	13.3	9
Biodegradable waste	44.0	50.8	46.5
Glass waste	9.5	10.5	9.2
Metal waste	1.4	0.9	1.3
Wood waste	2.3	1.3	0.4
Plastic waste	21.5	11.6	20.4
Other fractions	7.8	11.6	13.2

tax policy of the state, the environmental awareness and actions of each citizen play the key role in solving the problem of municipal (household) waste. Local authorities should create conditions for the responsible management of household waste by the population: the installation of easily accessible and numerous containers for separate waste collection, their timely removal, formation of economically substantiated tariffs for the removal of household waste, and established waste collection service. The semi-automatic waste recycling machines are also actively introduced: 1.7 times more waste recycling facilities operated in the country in 2019, as compared to 2015. The available recovery capacities are described in [28].

Organization of separate collection of waste components has led to the increase by 28% in the number of secondary raw materials collection points. However, the introduction of the waste hierarchy has not yet led to significant changes in waste streams (Table 7).

The data in Table 7 show that about 1.5% of municipal waste is collected at the secondary raw materials points, and less than 3% of waste is recycled at semi-automatic waste recycling machine and waste processing plants. Municipal solid waste is not sent to composting at all. However, as it was shown by the study of the contribution fractions of municipal waste in Kyiv, Kharkov and the Dnipro, carried out by the Japan International Cooperation Agency (JICA) [29] (Table 8), in the largest cities of Ukraine, the predominant component of municipal waste is Biodegradable (food) waste (about 50%). Therefore, the selectively collection of Biodegradable waste in accordance with the Directive (EU) 2018/851 [27] followed by Aerobic and Anaerobic digestion has great potential in Ukraine.

As it is seen from Table 8, plastic waste is about 20%, paper & board and glass – 9…13%. Other resource-containing components make up insignificant share of the waste due to low purchasing power of the Country's population. The studies of municipal waste composition provided by other authors seem to be related [30–32]. This explains the complexity of the development of recycling in the Country.

In the Draft Law of Ukraine "On Waste Management" [14], the following targets are set for the preparation for reuse and recycling of municipal waste:

1) until 2025 at least 10% of the mass;

2) by 2030 at least 20% of the mass.

The change of waste streams in Ukraine is possible only with the developed recycling infrastructure – enterprises for processing municipal solid waste and secondary materials production (paper, metal, plastics, fertilizers, etc.) – and Ukraine currently lacks it. The creation of such enterprises is not profitable in the current crisis conditions, and therefore, they can be created only within the framework of a long-term state strategy for the implementation of the sustain-

Table 9.
Dynamics of the reduction in the number of landfills and dumps of municipal waste [18]

Parameters	Years						
	2013	2014	2015	2016	2017	2018	2019
Number of landfills, ths. facilities	6.70	5.98	6.06	5.47	5.43	6.11	6.07
Number of unauthorized dumps, ths. facilities	30	24	28	27.5	30	26.6	26.9
Area of landfills, km^2	100	93.8	90.8	90.1	85.8	91.7	88.4
Area of unauthorized dumps, km^2	20	15	10	12	8	7.5	5.8

able development goals or local authorities and communities through participation in the EU programs for the implementation of the circular economy principles in regional economies.

The model of effective municipal solid waste management at the regional level should be based on baseline conditions: waste composition and available recovery capacity.

The first steps of formation of an effective municipal waste management and treatment system in Ukraine are present in papers [32–35].

For example, the cluster structure in the sphere of municipal solid waste treatment in Odessa and Kherson regions should developed [33]. The paper illustrates the organization of secondary material resources recycling with a modular-quarterly principle of Odessa agglomeration.

Qualitative leap ahead took place in 2015. In accordance with the principles of the waste hierarchy, the Kiev incineration plant JV "Plant "Energy" KP "KYIVTEPLOENERGO" began operating with heat recovery. It generated heat energy from municipal waste and transferred to the city's district heating network.

The study of the heat of combustion of mixed waste in Kyiv was carried out by the Institute of Engineering Ecology, in 2016 under the conditions similar to those of the Kyiv waste incineration plant "Energy". The experiment was carried out at the experimental boiler and involved burning of mixed waste with moisture corresponding to different seasons of the year. The boiler was loaded with up to 5 kg of mixed waste of real moisture. The heat of combustion of municipal waste in Kyiv was set within the range of 1500... 1700 kcal/kg by the experimental study and calculation method [36, 37].

Currently, the plant burns about 25% of the city's mixed municipal waste per year. This allows the plant to transfer about 250 thousand Gcal of thermal energy to the heating network of the Kyiv district heating system for heating and hot water supply of the residents. There are also 3 low-capacity waste incineration plants without energy recovery in Ukraine.

The authors have made an analysis of the energy potential of municipal solid waste based on their composition and calorific capacity of some large cities of Ukraine and the Russian Federation for the thermal treatment technology [38–39]. They come to a conclusion that municipal waste in its composition and heating value of both countries differs significantly from municipal waste in other countries. Some technologies and plants for processing and utilization of MSW, as well as their separate components, developed by SE "UkrRTC "Energostal" (Kharkiv, Ukraine) and applied in production practice are presented in paper [38].

To solve the problem of reducing the disposal of municipal waste at landfills, in accordance with the National Waste Management Strategy, it is planned to build 20 waste energy recovery plants by 2030 [11].

It should be noted that the implementation of the waste management program, especially in the case of municipal solid waste, is currently in its infancy in Ukraine. Although separate waste collection initiatives are being introduced quite successfully, construction of incineration plants is underway, but still about 94% of waste is removed for disposal at 6 thousand landfills and dumps (Table 9).

According to these data, landfills occupy about 90 km^2 of the country's territory. Unfortunately, part of the waste ends their life cycle at unauthorized landfills, which are not isolated from the environment. There are about 27 thousand of them. In 2014, unauthorized landfills occupied 15 km^2. Consistent work on their elimination had led to the decrease in the area of unauthorized landfills by a factor of 2.5 by 2019.

All landfills and dumps being the sources of methane CH_4 emissions, the greenhouse effect of which is 28 times higher than the carbon dioxide CO_2 cause an ecological problem [40]. Landfills and dumps are harmful to the environment. The analysis of greenhouse gas emissions dictated by different methods of solid waste management (waste disposal, compost-

ing, complex recovery) is represented in the study [41]. The emission of greenhouse gases while solid waste disposing is shown to be prolonged, whereas solid waste composting reduces the time of emissions sizeably what should be included into analysis of prospects for solid waste problem solution.

The estimation of carbon redistribution during generation and decomposition of organic component of municipal solid waste for different ways of treatment is presented in paper [42]. The study of the transformation and distribution of carbon compounds during treatment options of organic component of municipal solid waste is implemented on the example of Odessa region and Odessa in particular. Such options as disposal and complex recovery of organic wastes are considered.

Unauthorized landfills have turned into a serious problem. It has become economically viable to send waste to unauthorized landfills without paying for disposal. The solution to this problem can be facilitated both by a flexible legislative policy in the field of environment protection, in particular, by encouraging enterprises to manage their waste efficiently or minimize their generation, and by scientific development and implementation of programs for municipal waste management, taking into account the specific traits of settlements.

But as mentioned above measures are being taken at the state and municipal level to organize recycling in according to the waste hierarchy [13].

According to the provisions of the National Strategy for Waste Management in Ukraine until 2030, Regional Waste Management Plans should be developed by the end of 2020 [11]. The plans should be based on the analysis of the existing waste management system in a region, demographic and social situation, long-term plans for the development of a region [43]. Some of the studies carried out, used in the development of plans, are presented in papers [44–47].

A public movement is actively working in the country to popularize Zero Waste among the population. In 2018, the NGO Zero Waste Lviv and No Waste Ukraine were registered [48, 49]. At the beginning of 2019, in order to strengthen the zero waste movement in Ukraine, PO Zero Waste Lviv, PA O.ZERO (Kyiv) and Kharkiv Zero Waste created NGO Zero Waste Alliance Ukraine [50]. As representatives from Ukraine, Zero Waste Alliance Ukraine is part of the European organization Zero Waste Europe. A new project has now begun to introduce the Zero Waste concept at the city level. In 2020 Lviv signed an agreement to join the network of municipalities Zero Waste Europe [51]. Participation in the project will enable Lviv to implement the Zero Waste Cities certification and extend the experience of Zero Waste Citi to other cities of Ukraine [52].

The example of Ukraine shows that in the context of the economic crisis, an important field for the implementation of the tasks of minimizing and rational use of waste is working with municipal waste. The creation of infrastructure for the disposal of municipal waste, combined with the increase in environmental awareness of the population, their involvement into the programs on the reduction of the volume of waste generation, and sorting promotion allows taking specific steps towards the efficient management of municipal waste even under the conditions of limited economic resources. A special place is occupied by the creation of legislative and organizational basis for the implementation of the tasks set.

5. CONCLUSIONS

1. To apply the approaches of circular economy while implementing the 12th principle of sustainable development, Ukraine needs to improve the efficiency of resource use, organize the processing of industrial and municipal waste to maximize the use of their material and energy potential.
2. The Analysis of the municipal waste management system in Finland, a country with High GNI per capita, proves the prospects of waste recycling. For Ukraine, a country with Lower Middle GNI per capita (PPP), the most relevant is the introduction of Aerobic and Anaerobic Digestion. The possibility of waste recycling will reach 10% of the mass of waste by 2025, and it will reach 20% by 2030. It is advisable to burn the rest of the waste with the transfer of heat energy to the district heating network to replace natural gas.
3. Finland recycles 57% of the collected municipal waste at the Waste-to-Energy Plants using the generated heat and electricity for the needs of the population. Ukraine, as an energy-deficient country, needs to implement Finland's experience in the energy use of municipal waste.
4. Analysis of the municipal waste management system in Ukraine shows how the problem of municipal waste management is being solved step by step in Ukraine under the conditions of the economic crisis. The main focus is on: creating landfills and reducing the area of unauthorized dumps; organization of separate waste collection; construction of

incinerators for the production of thermal energy. State and municipal waste management programs are being created.

5. Experience shows that the system is evolving, but for the successful implementation of such sustainable development task as the implementation of resource-saving CE with secondary and tertiary waste use, significant legislative, financial and organizational efforts are required at the state and municipal levels.
6. To increase the efficiency of state and municipal programs of waste disposal, it is necessary to: develop recycling infrastructure to provide efficient management of waste; conduct information campaigns among the population in order to increase the level of environmental awareness and distribute knowledge about modern methods of reducing the volume of household waste generation and about their separate collection.

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