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WASTE MANAGEMENT AND PROSPECTS FOR THE DEVELOPMENT OF CIRCULAR ECONOMY TECHNOLOGIES

Abstract. In the context of the transition from a linear model of the economy to circular issues of waste management and prospects for the development of circular economy, technologies are relevant and require further study.

The article explores the necessity and advantages of introducing a circular economy model for further efficient development of the national economy. The trend in the volume of education and waste management in the territory of Ukraine for the period 2010—2019 was analyzed. The negative trends in the growth of generated waste over the study period by 4,49 % and the decrease in waste disposal by 25,86 % have been identified. An analysis was made of the development of the volumes of waste generation according to hazard classes in the territory of Ukraine for the period 2010—2019. which led to the conclusion that there was a positive trend of 2.51 times less generation of such wastes. The trend in waste generation by type of economic activity of enterprises and in households for the period 2010—2019 was analyzed. The most significant increase in waste generation by 12,41% was found in the mining industry and quarrying.

The trend in environmental protection expenditure in Ukraine by type of economic activity for the period 2010—2019 was analyzed. This has made it possible to identify the most cost-effective economic activities. A classification of technologies of circular economy is proposed, which distinguishes technologies aimed at recycling already accumulated industrial and household waste, technologies aimed at reducing the toxic load on the environment, and eco-design technologies. Based on the situation of waste management prevailing in the territory of Ukraine, it is proposed that priority be given to the development and introduction of technology aimed at the recycling of already accumulated industrial and household waste.

Keywords: waste management, linear economy, circular economy, waste-free technologies, state, development, prospects.

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ПОВОДЖЕННЯ З ВІДХОДАМИ І ПЕРСПЕКТИВИ РОЗВИТКУ ТЕХНОЛОГІЙ ЦИРКУЛЯРНОЇ ЕКОНОМІКИ

Анотація. В умовах переходу від лінійної моделі економіки до циркулярної питання поводження з відходами і перспектив розвитку технологій циркулярної економіки є актуальним і потребує додаткового вивчення.

Досліджено необхідність і переваги впровадження моделі циркулярної економіки для подальшого ефективного розвитку національної економіки. Проаналізовано динаміку обсягів утворення і поводження з відходами на території України за період 2010—2019 рр. Виявлено негативні тенденції зростання утворених відходів за досліджуваній період на 4,49 % і зниження обсягів утилізації відходів на 25,86 %. Проведено аналіз динаміки обсягів утворення відходів за класами небезпеки на території України за період 2010—2019 рр., який дозволив зробити висновок про позитивну тенденцію зменшення обсягів утворення таких відходів у 2,51 раза. Проаналізовано динаміку обсягів утворення відходів за видами економічної діяльності підприємств і в домогосподарствах за період 2010—2019 рр. Зроблено висновок, що найбільш суттєве зростання обсягів утворення відходів на 12,41 % відбулось у добувній промисловості та розробленні кар'єрів. Проаналізовано динаміку витрат на охорону навколишнього природного середовища в Україні за видами економічної діяльності за період 2010—2019 рр., що надало можливість виділити найбільш витратні види економічної діяльності. Запропоновано класифікацію технологій циркулярної економіки, у межах якої виділено технології, які націлені на переробку вже накопичених промислових і побутових відходів, технології, які націлені на зменшення токсичного навантаження на навколишнє середовище та технології екодизайну. Виходячи із ситуації поводження з відходами, яка склалася на території України, запропоновано першочергову увагу приділити розробленню та впровадженню технології, які націлені на переробку вже накопичених промислових і побутових відходів.

Ключові слова: поводження з відходами, лінійна економіка, циркулярна економіка, безвідхідні технології, стан, розвиток, перспективи.

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Introduction. The circular economy is recognized as a modern progressive model of development of the world and national economies. The transition from a linear to a circular economy will be facilitated by the development and dissemination of waste-free or low-waste technologies, or in a broader sense, circular economy technologies. The most progressive way of a wide introduction of such technologies into modern production is investment of technological innovations and development of technologies with a high level of efficiency of using resources,

environmentally friendly production and use of waste as raw materials for other types of productions. Technologies for processing already accumulated industrial and household waste are important for Ukraine in the field of investing in the development and implementation of technological innovations. A significant amount of industrial and household waste has been accumulated on the territory of Ukraine; their landfills occupy large areas of agricultural land and have a negative impact on the environment. The issue of the development and implementation of circular economy technologies for the effective development of the national economy of Ukraine is relevant. There is no unambiguous definition of «circular economy technology» in modern scientific research; systematization of circular economy technologies and classification of such technologies according to the degree of priority of their introduction into the national economy in order to accelerate the transition from linear to circular development model has not been carried out. Therefore, this issue is relevant for research.

Analysis of the research and tasks' setting. The development of the circular economy, its advantages are widely represented in scientific publications (Ellen MacArthur Foundation, 2012; Ghisellini et al., 2016, p. 11—32; Murray et al., 2017, p. 369—380) [1—3]. The need to develop and implement technological innovation and waste-free technologies as a key stimulus for growth is emphasized in the works of Stahel W. R. (2016, p. 435—435), Geng et al. (2012, p. 216—224) and Jawahir & Bradley (2016, p. 103—108) [4—6]. The proposition of classifying modern technologies into technologies of circular economy and other technologies is stated in the work of J. Banioniene, L. Dagiliene (2017) [7].

The achievements of those scholars have theoretical and practical significance in this area and have become the basis for conducting research on waste management in Ukraine and prospects for the development of circular economy technologies. Given the changes in the world economy, the outlined topic requires further comprehensive research and coverage.

The purpose of the article is the analysis of waste management on the territory of Ukraine, generalization of the concept of «circular economy technologies», classification of these technologies and determining perspective areas of the development of such technologies in the economy of Ukraine.

Achievement of this purpose was realized by solving the **problem** of conducting a comprehensive analysis of waste management in Ukraine for the period 2010—2019, generalizing the definitions of «circular economy» and «circular economy technologies» in the scientific works of scholars and developing author's conceptual provisions in regard to perspective directions of development of circular economy technologies in the economy of Ukraine.

Results of the research. Current tendencies in population growth, global increase in consumer demand, the rapid development of scientific and technological progress, the rapid development of innovation have contributed to more intensive use of natural resources and the accumulation of industrial and household waste. Understanding the need to address the challenges posed by globalization, modern technology and the slowdown in economic development has necessitated the transition from the existing linear economic model to a circular economy. The content of the concept of «circular economy» in different scientific sources differs. This fact confirms that the very concept of «circular economy» is transformed depending on the development of the system of circular economy. In studies conducted by scholars at the request of the Club of Rome, the «circular economy» is understood as an industrial system that is restorative [8]. The main idea of the circular economy is the fullest use of raw materials in the production, i.e. the introduction of low-waste and non-waste technologies. Ukrainian scholars who study the origin and phenomenon of the circular economy also emphasize the development and implementation of non-waste and low-waste technologies, but also emphasize the need to process already accumulated industrial and household waste in Ukraine, which occupies large areas of land [9—20]. Polish scholars, who also focus on circular economy issues in their research, study circular economy as «an economic development strategy with appropriate legal and economic instruments and monitoring indicators, and its implementation is based on the latest IT solutions» [21]. Foreign scholars in their research on topical issues of circular economy in European countries emphasize

both changes in the production and changes in consumption, adjustment of consumer behavior, which is no less important than production processes [22—24]. The concept of circular economy is based on the 3R principles: reduce, reuse, recycle — reduction of consumption, reuse, recycling [8].

Significant advantages of introducing the circular economy model are the use of closed-loop technologies or waste-free and low-waste technologies, optimization of waste disposal processes, reduction of the negative impact of accumulated waste on the environment, rational consumption. The concept of a circular economy has become a strategic concept for planning the economic development of the United States, European countries, Japan, South Korea and China. Ukraine also joins the concept of circular economic development.

According to the conducted analysis of the dynamics of waste generation and management in Ukraine for the period 2010—2019, the authors have made the following conclusions (Table 1).

Table 1

**Dynamics of amounts of waste generation and management on the territory of Ukraine
for the period 2010—2019**

Indicator	2010	2014	2015	2016	2017	2018	2019	Relative deviation of the data of 2019 from the data of 2010, %
Waste generated, thousand tons	422549,9	350000,4	312267,6	295870,1	366054,0	352333,9	441516,5	4,49
The amount of waste collected from households, thousand tons	6367,7	6314,3	6053,3	6346,5	5858,0	5543,5	5896,7	-7,39
The share of waste received from households in the total amount generated, %	1,51	1,80	1,94	2,15	1,60	1,57	1,34	-0,17
Disposed, thousand tons	145710,7	109280,1	92463,7	84630,3	100056,3	92463,7	108024,0	-25,86
The share of recycled waste in the total amount generated, %	34,48	31,22	29,61	28,60	27,33	29,61	24,47	-10,01
Growth (decrease) of emissions of pollutants into the atmosphere from mobile sources of pollution	—	—	83,7	80,7	102,7	98,7	102,7	22,70

Source: compiled by the authors of the article according to the data of the State Statistics Committee of Ukraine [25].

The amounts of waste generated on the territory of Ukraine for the period 2010—2019 decreased by 4.49%, which can be considered as a positive tendency from the point of view of the circular economy. However, it should be noted that a significant reduction in the amount of waste generated in Ukraine began in 2014, the amount of waste generated is less by 21.39% in 2014 than the amount of waste generated in 2013. We can assume that such a significant reduction in waste generation in 2014 occurred due to the lack of the data from the annexed territory of Crimea, and later from part of the territories of Donetsk and Luhansk regions. The amount of waste collected and received from households in Ukraine for the period 2010—2019 decreased by 7.39%. It is certainly a positive tendency, but it should be noted that Ukrainian households are not the most polluting factor in the environment (the share of waste received from households is very small and in 2019 amounted to only 1.34% of total waste generated). The negative tendencies in waste management in Ukraine include the fact that the amount of recycling decreased during the period 2010—2019 by 25.86%. At the beginning of 2020, 15.4 billion tons of waste was accumulated on

the territory of Ukraine, including 12.3 million tons (0.08%) of I—III hazard classes. The amount of accumulated waste on the territory of Ukraine has increased by 16.48% over the last 10 years. The rate of emissions of pollutants into the atmosphere from mobile sources of pollution increased during the period 2015—2019 by 22.70%, which is a negative phenomenon.

The conducted analysis of the dynamics of the amounts of waste generation by hazard classes in Ukraine for the period 2010—2019 (*Table 2*) provided an opportunity to draw the following conclusions.

Table 2

**Dynamics of waste generation by hazard classes on the territory of Ukraine
for the period 2010—2019**

Indicator	2010	2018	2019	Relevant deviation of the data of 2019 from the data of 2018, %	Relevant deviation of the data of 2019 from the data of 2010, %
Total, thousand tons	422549,9	352333,9	441516,5	25,31	4,49
Including: Total amount of generated waste of I—III hazard class, thousand tons	1389,1	627,4	553,0	-11,86	Decreased by 2,51 times
The share of waste generated of I—III hazard class on the territory of Ukraine in the total amount of generated waste, %	0,33	0,18	0,13	-0,05	- 0,20

Source: compiled by the authors of the article according to the data of the State Statistics Committee of Ukraine [25].

Analysis of the dynamics of generation of particularly harmful waste of I—III hazard class demonstrated that there was the decrease by 11.86% in 2019, which indicated a positive tendency in the management of particularly hazardous waste in Ukraine. The amount of waste of the first class of danger decreased by 0.2 thousand tons or 10%, in 2019, of the second class — by 1.7 thousand tons or 5.65%, of the third class — by 32.4 thousand tons or 5.84% and there was the increase in the amount of waste of the IV hazard class by 129283 thousand tons or 41.48%.

The conducted analysis of the dynamics of waste accumulated on the territory of Ukraine by hazard classes for the period 2010—2019 (*Table 3*) made it possible to draw the following conclusions.

Table 3

**Dynamics of waste accumulation during operation in waste disposal sites
by hazard classes in 2010—2019**

Indicator	2010	2018	2019	Relevant deviation of the data of 2019 from the data of 2018, %	Relevant deviation of the data of 2019 from the data of 2010, %
Total, thousand tons	13219983,9	12505915,8	15398649,4	23,13	16,48
Including: Total amount of accumulated waste of I—III hazard class on the territory of Ukraine, thousand tons	14335,4	12217,2	12305,1	0,72	-14,16
The share of waste accumulated of I — III hazard class on the territory of Ukraine in the total amount of generated waste, %	0,11	0,09	0,08	- 0,01	- 0,03

Source: compiled by the authors of the article according to the data of the State Statistics Committee of Ukraine [25].

Analysis of the dynamics of accumulation of particularly harmful waste of I—III hazard class demonstrated the decrease of particularly hazardous waste by 16.48% in 2019 compared to 2018. There was the decrease in emissions during the operation of hazard class I by 0.1 thousand tons or by 0.68% in 2019, of class II — by 0.8 thousand tons or 0.29%, of class III — by 99751 thousand tons or 89.25% and of class IV — there was the increase of 2892484 thousand tons or by 23.15%.

The *Table 4* presents the results of the analysis for the dynamics of waste generation according to the type of economic activity of enterprises and households of Ukraine for the period 2010—2019.

Table 4

**Dynamics of waste generation according to the types of economic activity
of enterprises and households of Ukraine for the period 2010—2019**

Indicator	2010	2014	2015	2016	2017	2018	2019	Relevant deviation of the data of 2019 from the data of 2010, %
Generated waste — all types of economic activity, thousand tons	422549,9	350000,4	312267,6	295870,1	366054,0	352333,9	441516,5	4,49
Agriculture, forestry and fisheries, thousand tons	8304,5	8451,4	8736,8	8715,5	6188,2	5968,1	6750,5	- 18,71
Mining industry and quarrying, thousand tons	347442,3	297290	257861,9	237461,4	313738,2	301448,9	390563,8	12,41
Manufacturing, thousand tons	47676,5	34796,7	31000,5	34093	32176,7	31523,2	30751,8	- 35,49
Supply of electricity, gas, steam and air conditioning, thousand tons	8636,4	5972,7	6597,5	7511,5	6191,7	6322,7	5959,2	- 30,99
Construction sector, thousand tons	326,7	306,4	376,2	300,2	493,8	378,8	188,7	- 42,24
Other types of economic activity, thousand tons	3795,8	1868,9	1641,4	1442	1407,4	1148,7	1405,8	- 62,96
Households, thousand tons	6367,7	6314,3	6053,3	6346,5	5858,0	5543,5	5896,7	- 7,39
Amounts of generated waste per unit of GDP, kg / 1000 U.S. dollars	1159,6	983,6	957,5	883,8	1073	999,7	1152,7	- 0,59

Source: compiled by the authors of the article according to the data of the State Statistics Committee of Ukraine [25].

Data analysis in the *Table 4* provided an opportunity to draw a conclusion about the growth of waste generation in all types of economic activity by 4.49% for the period 2010—2019. The most significant increase in waste generation for the period 2010—2019 occurred in the mining industry and quarrying by 12.41%. There was the decrease in waste generation by various amounts

in other types of economic activity. The most significant decrease in waste generation occurred in construction sector (42.24%) and other activities (62.96%). The amount of waste generated per unit of GDP during the period of research decreased slightly (0.59%).

The conducted analysis of the dynamics of environmental expenditures in Ukraine according to the type of economic activity provided an opportunity to draw the following conclusions (Table 5).

Table 5

Dynamics of expenditures for environmental protection according to the types of activity in Ukraine for the period 2017—2019

Indicator	2017	2018	2019	Relevant deviation of the data of 2019 from the data of 2017, %
Total in Ukraine, thousand tons	31491958,5	34392270,3	43735862,1	38,88
Including:				
Agriculture, thousand UAH, The share in the total costs, %	428932,6 1,36	418078,7 1,22	440696,9 1,00	2,74 -0,36
Mining industry and quarrying, thousand UAH, The share in the total costs, %	5968063,1 18,95	7780234,5 22,62	9371091,9 21,42	57,02 2,47
Manufacturing, thousand UAH, The share in the total costs, %	8004738,4 25,42	10323781,2 30,02	11677710,4 26,70	45,88 1,28
Supply of electricity, gas, steam and air conditioning, thousand UAH, The share in the total costs, %	6148762,3 19,52	4423931,5 12,86	9458167,9 21,63	53,82 2,11
Water supply; sewerage, waste management, thousand UAH, The share in the total costs, %	6523328,2 20,71	8212450,7 23,88	9697644,4 22,17	48,66 1,46
Other types of activities, thousand UAH, The share in the total costs, %	4418133,9 14,04	3233793,7 9,40	3090550,6 7,08	-30,05 -6,96

Source: compiled by the authors according to the data of the State Statistics Committee of Ukraine [25].

During the researched period 2017—2019, the amount of expenditures on environmental protection increased by 38.88% in Ukraine. The largest increase in environmental protection expenditures was made in: mining industry and quarrying by 57.02%; supply of electricity, gas, steam and air conditioning by 53.82%; water supply, sewerage, waste management by 48.66%; recycling industry by 45.88%. The most significant types of economic activity in terms of expenditures on environmental protection are the recycling industry, the share of which in 2019 amounted to 26.70%, water supply; sewerage, waste management (share 22.17%), mining industry and quarrying (share — 21.42%), other activities (share — 7.08%).

Analysis of waste management in Ukraine makes it possible to draw a conclusion about the significant amount of accumulated waste in Ukraine, which requires the development of technologies for their recycling. The largest amount of waste is generated at enterprises belonging to the mining industry and part of the recycling industry: metallurgical, chemical, paper and pulp enterprises. Along with the development and implementation of technologies for recycling of already accumulated industrial waste, it is advisable to improve and implement technologies that would help to prevent pollution and toxic effects on the environment. The experience of the development and application of waste-free and low-waste technologies in the developed countries proves their economic efficiency.

Summarizing the accumulated practical experience of waste management, the experience of waste management of the electronics industry, which is growing every year, attracts attention. According to estimates made by Microsoft, the amount of waste from the electronics industry or as it is now called «e-waste» is more than 53 million tons worldwide [26; 27]. The suggested algorithm for waste management is as follows: waste sorting, selection of a partner for waste disposal, pricing, implementation of the principles of environmentally friendly production.

Electronic device manufacturers are developing and implementing technologies that will further extend the life of those devices (for example, the technology «right to repair» of electronic gadgets, i.e. providing consumers with information about electronic gadgets that will help them to repair the devices themselves).

The issue of defining the concept of «circular economy technologies» and classification of such technologies according to different classification criteria is being discussed in the scientific literature. Li R.H., & Su C.H. have offered in their scientific work to classify technologies in accordance with five features: economic development, resource use, pollution reduction, environmental efficiency and development potential [28]. The scientific work of Ghisellini P., Cialani C. & Ulgiati S. includes technologies that help to reduce the toxic impact on the environment into the technologies of circular economy [2]. Banioniene J., Dagiliene L. in their study developed a classification of technologies that are divided into other technologies and technologies aimed at the hierarchy of circularity, which in turn are divided into tangible and intangible technologies. [7]. The definition of «circular economy technologies» can be based on a combination of the concepts of «technologies» and «circular economy». The definition of «circular economy technologies» was presented for the first time at the conference «Sustainable Innovation 2016» [7]. Circular economy technologies are understood as technologies that contribute to the establishment of the circular economy principles: reducing waste amounts, reducing the load in the form of emissions and water pollution, technologies that save energy and non-renewable resources, waste recycling technologies.

Based on the purpose of our research and the situation with accumulated industrial waste, which has developed in Ukraine, it is advisable to offer such a classification of circular economy technologies, which involve the use of innovations of various kinds (Table 6).

Table 6

Classification of circular economy technologies

Classification group	Types of technologies
Technologies that are aimed at recycling already accumulated industrial and household waste	Technologies of solid industrial waste recycling
	Technologies for recycling liquid industrial waste
	Technologies for recycling hazardous waste
	Technologies of household waste processing
	Waste utilization technologies that cannot be recycled at the current level of STP
Technologies aimed at reducing the toxic load on the environment	Technologies for water purification, which is involved in the technological cycle
	Technologies to prevent emissions of polluted air
	Wastewater treatment technologies
	Polluted air purification technologies
	Land reclamation technologies
Eco-design technologies	Technologies aimed at reducing all types of waste
	Technologies of products' extended life cycle
	Non-waste or low-waste technologies
	Technologies aimed at replacing natural materials with artificial ones
	Energy saving technologies
	Technologies for reuse of components
	Technologies for using recycled raw materials

Source: offered by the authors of the article.

The current level of equipment and technology does not allow to reuse the waste of certain enterprises of as raw materials. These are wastes of nuclear energy, certain enterprises of chemical and pharmacological industry, medical wastes. The waste of these economic activities can currently be utilized. Therefore, the urgent issue is to improve technologies that minimize the amount of such waste and to improve the methods of their utilization or disposal.

The issue of development and implementation of technologies aimed at recycling already accumulated industrial and household waste is especially important for Ukraine.

Conclusions. The amount of accumulated industrial and household waste on the territory of Ukraine necessitates faster implementation of technologies for their processing or safe utilization and development and implementation of low-waste or non-waste technologies in all sectors of the

national economy of Ukraine. The creation and implementation of circular economy technologies will promote the optimal use of non-renewable and other resources, will reduce resource costs and waste generation, will ensure a more rational use of resources in industrial sectors. Modern classifications of technologies are developed according to various classification features. The transition from a linear to a circular model of the economy necessitates the classification of technologies on the basis of their compliance with the principles of the circular economy. The authors have suggested the classification of technologies of circular economy, which allowed to allocate separate groups of technologies that were directed on processing of already saved up industrial and household waste, technologies which were aimed at reducing toxic load on environment and technologies of eco-design. 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.

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