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ANALYSIS OF THE WORLD MARKET OF WASTE MANAGEMENT

This paper provides an overview of the solid waste management market, which is the object of the study, including the processes of collection, transportation, utilization and recycling, supervision and monitoring of these processes. The volume and dynamics of the global waste management market in 2023 and its forecasting until 2033 are considered. The problem solved in the article is to identify the key factors of influence and interconnection on the development of waste management market components to determine the directions of an effective sustainable development policy. The author analyzes the methods of waste management in different European countries and identifies the key factors influencing the market dynamics: the effects of urbanization, environmental regulations, waste-to-energy technologies, circular economy initiatives, smart waste management systems, increased waste recycling, and the development of green infrastructure. It is determined that the growing awareness of environmental problems and increasing public pressure are leading to an increase in government investment in the development of innovative technologies for effective waste management. It is established that the promotion of recycling infrastructure and the implementation of campaigns aimed at raising awareness among the population leads to an increase in the importance of responsible waste management, the introduction of public-private partnerships in the field of waste management and the development of green infrastructure. The market is analyzed by region, end user, and waste type. According to the regional analysis, North America has the largest market share, but Asia Pacific is showing the fastest growth. North America has a large waste management market due to its developed infrastructure and high level of environmental awareness. However, Asia-Pacific, particularly China and India, is emerging as a growth center due to rapid economic development, population growth, and rapid urbanization, indicating the potential for new waste management markets in this region. According to the analysis by waste type, industrial waste is the largest category, with the electronic segment showing dynamic growth. This analysis allows to forecast the market and trends in the waste management industry, which makes it possible to calculate costs and profits, scale global trends to Ukrainian realities, and offer promising investment opportunities, which is especially important in the times of recovery of Ukraine.

Keywords: *waste management, recycling technologies, end-user, waste type, green investment, waste market, sustainable development.*

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1. Introduction

With the development of the economy, an increase in the population and the volume of consumption, there is an increase in the negative anthropogenic impact on the environment, which is manifested in an increase in both the amount of waste and its diversity. The economic needs of society become the main factor in the formation of waste, prevailing over initiatives and measures for their prevention.

Issues related to waste management are revealed in the works of scientists from different countries of the world, however, the lack of research in this area has led to a number of problems in waste management. For example, failure to take into account risks at various stages from logistics schemes to the design of processing plants, volumes of formation and forecasting changes to volumes of accumulation, markets for the sale of generated useful products or energy after disposal. This emphasizes the need for further research in this direction. The problem of waste management becomes much more urgent in the conditions of the growth of the world population and the increase in the percentage of urban residents.

According to the forecasts of the World Bank, by 2050 the annual global production of waste may reach 3.4 billion tons [1]. This creates significant environmental and economic problems associated with their disposal and disposal. In turn, disposal of waste in landfills leads to soil, water and air pollution.

In developed countries, people do not feel the consequences of waste as much as residents of developing countries, especially in poor cities. In these countries, more than 90 % of waste is often stored in unregulated landfills or open burn. Such practices have serious consequences for health, safety and the environment. Inadequate waste disposal contributes to the spread of disease, climate change through methane emissions, and can contribute to increased urban violence.

That is why awareness of the importance of resource conservation is becoming more and more common. Waste processing reduces the need to extract new resources, which saves energy and protects the environment. It also promotes

the development of a circular economy, where waste becomes resources for new products. The waste management system is a large complex of measures, programs and legislation aimed at building a systematic approach to the management of all types of waste [2].

Thanks to scientific achievements, innovative technologies appear that allow more and more types of waste to be processed more efficiently. This makes recycling more cost-effective and stimulates market growth.

The growing demand for eco-friendly products is also a factor contributing to the growth of the market. Consumers are increasingly aware of environmental issues and are looking for green products. This encourages manufacturers to use recycled materials in their products.

A study on the Global Waste Recycling Technologies Market can help various stakeholders. Enterprises can determine promising directions of market development, assess the potential of new technologies and develop effective market entry strategies. Investors can identify the most attractive market segments and assess risks and investment opportunities. Governments can develop effective waste management policies and stimulate the development of the waste recycling market.

Therefore, the relevance of research of the world market of waste processing technologies is beyond doubt. This is a dynamic and promising market that has significant potential for development. Researching this market can help various entities make informed decisions and use the opportunities it offers.

The aim of research is to establish trends and key factors influencing the development of the waste management market in order to determine the directions of effective policy and innovative perspectives of waste management technologies in the context of sustainable development.

2. Materials and Methods

To achieve the aim of research, the following methods were used:

– monographic – to identify factors and key factors of market dynamics and improve management tools;
– method of analogies – transfer of patterns of development of the waste management market, taking into account regional characteristics, to the markets of technologies, innovations and investments;
– statistical – analysis of quantitative indicators that make it possible to draw a conclusion about the pace of development of processes in the field of waste management;
– dialectical method of cognition – for the analysis of legislative and regulatory acts and scientific works of scientists regarding the issues of assessing the waste management market to determine prospects for development and influence;
– synthesis and logical generalization – to establish conceptual foundations, dependencies and prerequisites for making rational decisions regarding waste management;
– method of comparative analysis – analysis of waste management markets according to established indicators;
abstract-logical – for theoretical generalization and formulation of conclusions.

The research information base consists of research by scientists from different countries of the world, global organizations and banks, legislative and regulatory acts, materials of own research.

3. Results and Discussions

Waste management includes the collection, transportation, treatment (including recovery and disposal), as well as the supervision and control of these processes, as well as the care of waste disposal facilities after their closure.

Fig. 1 shows the methods of waste management in different European countries. According to the data provided, it can be noted that Switzerland is the only one of these countries that has completely abandoned waste disposal, using only environmentally friendly technologies such as incineration with energy recovery. Compared to Germany, which uses methods of incineration of waste for the most part without obtaining energy, this strategy is more ecological. However, among all other countries, Germany comes closest to the strategy of Switzerland, regarding the practical refusal to bury waste in landfills.

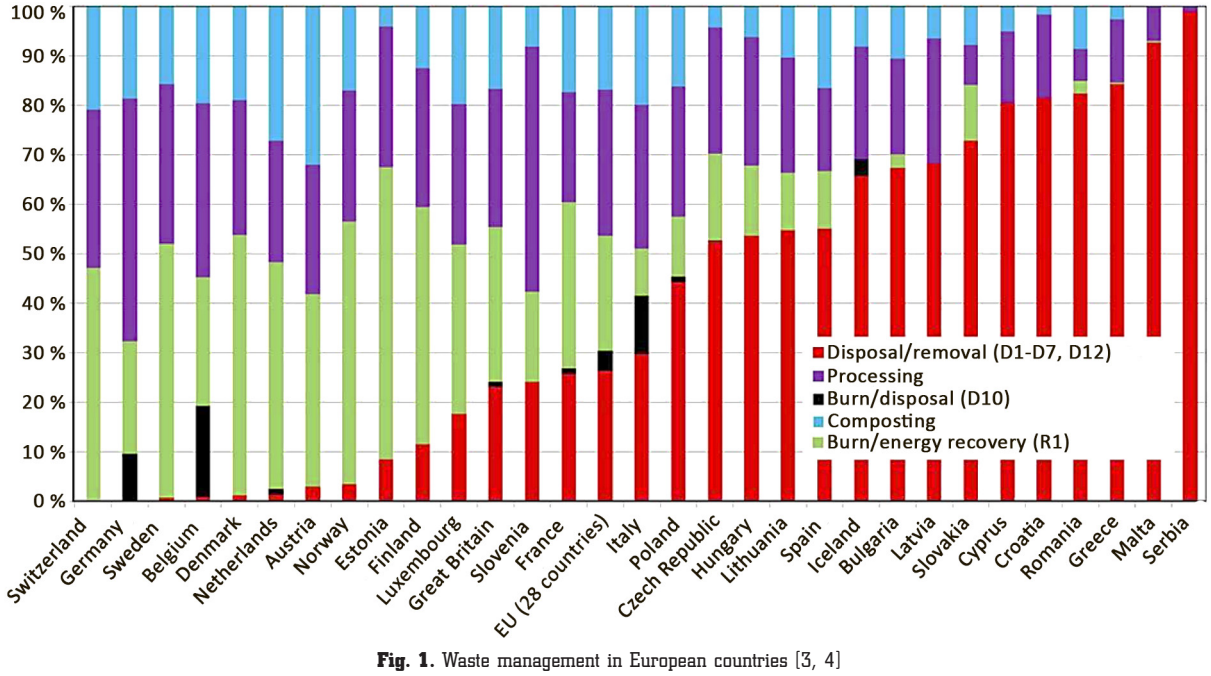

Fig. 1. Waste management in European countries [3, 4]

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Waste processing includes the process of converting various types of waste into other forms that can be used. For this, various technologies are used, such as incineration, gasification, anaerobic fermentation or pyrolysis, because otherwise the waste would be thrown into landfills or lead to environmental pollution [5–7].

Usually, this process starts with the collection and sorting of waste: unused waste such as organic materials, plastic and paper is then treated in various ways.

The global solid waste management market size reached 281.10 billion USD in 2023 and is projected to exceed approximately 420.19 billion USD by 2033, registering a CAGR of 4.15 % during the forecast period 2024 to 2033 (Fig. 2).

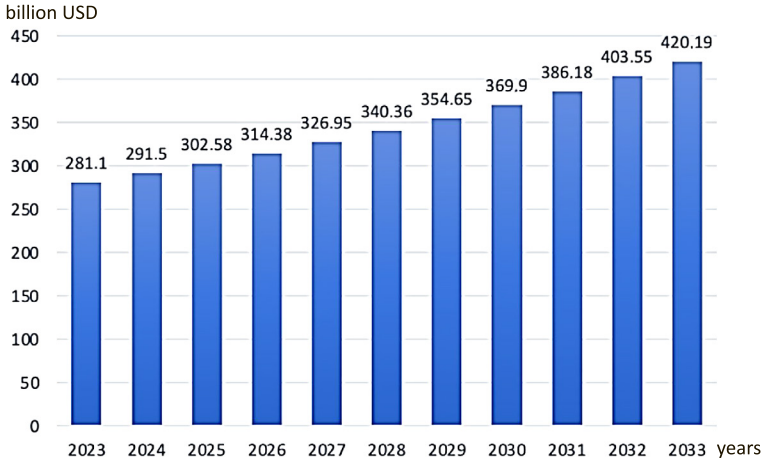

Fig. 2. Forecast of the volume of the global waste management market from 2023 to 2032, billion USD (compiled by the authors based on data from Precedence Research [8, 9])

The dynamics of this market can be explained by growth factors, which include the following:

1. *Consequences of urbanization*: rapid urbanization leads to a significant increase in the volume of solid waste in cities. Population growth and the intensive development of urban areas encourage the widespread use of advanced technologies and innovative approaches to the utilization and management of these wastes.

Already today, the global amount of solid household waste is estimated at 2 billion tons per year. There are no UN forecasts for future waste generation per capita. However, there is a general understanding that the amount of waste will increase significantly. Fig. 3 illustrates the sharp increase in the amount of waste in cities by 2050.

2. *Environmental regulations*: Global environmental standards and regulations force companies and government agencies to implement environmentally friendly and sustainable waste management practices. This requires the development and implementation of innovative technologies and methods of waste processing and disposal.

3. *Waste-to-energy technologies*: Progress in waste-to-renewable energy technologies opens up new opportunities for effectively solving the waste problem and meeting energy needs. This helps reduce the amount of waste and reduce the carbon footprint.

4. *Circular economy initiatives*: Promoting the circular economy stimulates the development of innovative approaches to recycling and using waste as secondary resources. This helps to reduce the consumption of natural resources and limit the negative impact on the environment.

5. *Smart waste management systems*: The implementation of intelligent technologies in waste management systems allows for optimization of waste collection, transportation and processing, which contributes to the efficient use of resources and reduction of losses.

6. *Increased recycling*: Increased awareness and government initiatives are helping to develop the recycling sector, which creates new business opportunities and helps reduce the negative impact on the environment.

7. *Development of «green» infrastructure*: Investments in «green» infrastructure allow cities to create more sustainable and ecologically clean conditions for waste management.

Stringent environmental standards are actively increasing demand in the solid waste management market as they force industry and municipalities to adopt advanced waste disposal methods. Governments around the world are establishing strict waste policies to reduce environmental pollution, which requires the implementation of sustainable solutions. This creates increased demand for technologies that enable efficient sorting, processing and disposal of waste, making the solid waste management market key to meeting compliance and sustainability standards.

Technological advancements in smart waste management are further increasing market demand by providing innovative tools to optimize waste collection routes and improve overall operational efficiency. The use of IoT-enabled containers, real-time monitoring systems and data analytics promotes smarter and more environmentally friendly waste management practices. The integration of such technologies not only meets the environmental goals, but also helps to solve the growing challenges of waste management in urban and industrial areas, which stimulates increased investment in the solid waste management market.

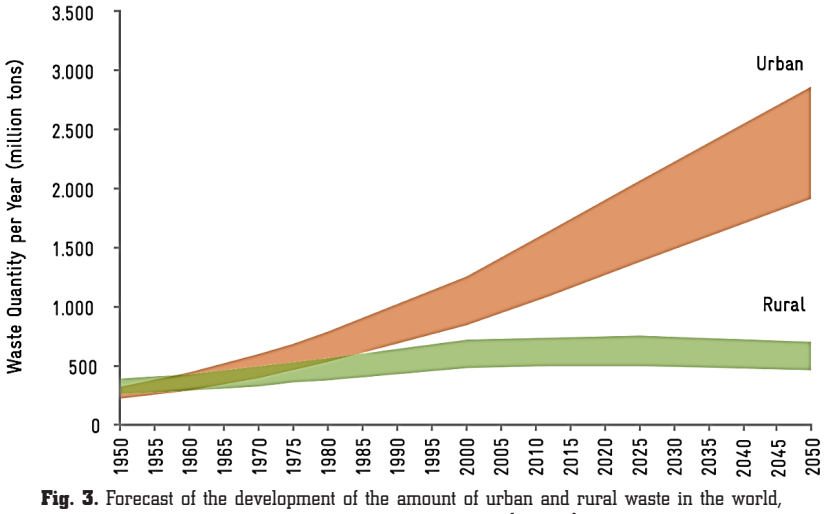

Fig. 3. Forecast of the development of the amount of urban and rural waste in the world, 1950–2050 based on UN data [10, 11]

Significant growth in demand for solid waste management services in the market is largely caused by the introduction of advanced waste-to-energy technologies. These technologies make it possible to convert solid waste into usable energy, which meets the needs of both waste reduction and energy resources. Given the importance for governments and industry of sustainable and environmentally friendly solutions, the integration of advanced waste-to-energy technologies is becoming a key factor, making the market an important player in the field of sustainable energy [4, 12].

In addition, the development of «green» infrastructure plays an important role in increasing market demand. Implementation of environmentally friendly practices in urban planning contributes to the improvement of environmental management and sustainability. Green infrastructure initiatives include waste reduction, sustainable packaging and innovative collection methods, contributing to the overall growth of the solid waste management market. As communities around the world seek holistic and environmentally conscious solutions to their waste problems.

However, there are certain limitations in the waste management market, which are determined by the availability of suitable land for landfills and infrastructure problems. The lack of land for landfills, especially in urban areas with high population density, limits the possibility of expanding waste disposal sites. This problem forces authorities to explore alternative methods, such as waste-to-energy technologies, recycling and incineration, which may prove costly at the start-up stage.

In addition, infrastructural problems such as outdated machinery, machinery and facilities for waste collection and treatment hinder effective solid waste management. Weaknesses in the infrastructure can lead to inefficiencies in the entire process. Overcoming these obstacles requires significant investment in infrastructure upgrades, the introduction of advanced technologies, and the implementation of sustainable waste disposal methods. A systematic focus on such investments is key to building sustainable and flexible waste management systems that can meet the needs of expanding urban communities and provide a cleaner and more sustainable future trajectory.

If to analyze the global waste recycling market regionally, it is possible to see that North America has the largest market share (36.50 %), followed by Europe (32.40 %) and the Asia-Pacific region (24.10 %). Other regions (Latin America, Middle East and Africa) share the remaining 7 % of the market (Fig. 4).

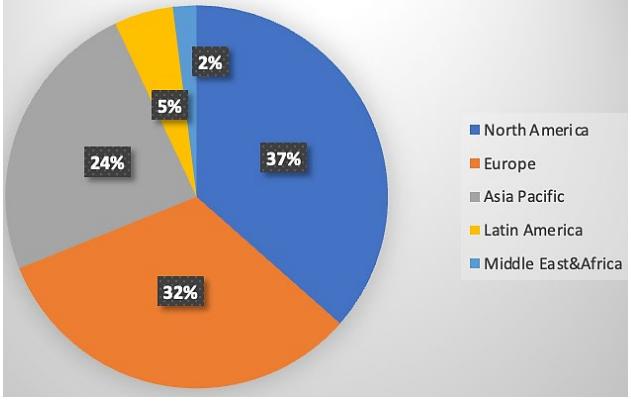

Fig. 4. Volumes of the global waste management market in 2023 by region, % (compiled by authors based on data Grand View Research [1, 6, 13])

Rapid urbanization and industrialization in North America are driving sustainable trends in solid waste management. Population growth in developing countries leads to an increase in waste volume, which emphasizes the need for efficient disposal systems. Governments are investing in smart waste management technologies, recycling infrastructure and public awareness campaigns to address environmental issues.

Europe occupies a leading position in the global waste management market, controlling an impressive 32.4 % of the global share (Fig. 4). The growing demand for waste management in Europe is due to the significant expansion of recycling capacity in the region. In the European Union, the volume of waste production in various industries, such as manufacturing, food industry, construction, electronics, textiles, etc., is growing annually. To solve this problem, numerous recycling and reuse initiatives have been introduced to reduce the depletion of valuable resources in the EU.

The possibility of reusing certain wastes arises after their repair or design change, for example in the case of clothing. In some towns in Europe, there is a practice of creating special workshops, where it is possible to turn in unnecessary things, from which craftsmen can create new products for further sale, for example, bags and other clothes from jeans.

Encouraging the implementation of the first three stages of the waste management hierarchy in Europe is carried out within the framework of the «Zero Waste» initiative and is actively supported by European cities. Zero Waste Europe has a growing membership of 31 national organizations and 400 local communities. The slogan of the «Zero Waste» initiative is No Burn! No Bury!

Today, «Zero Waste» is not considered a separate goal, but a direction of development. Participants of the initiative and local communities actively cooperate to reduce the amount of waste and implement the first steps of the waste management hierarchy in European cities (Fig. 5).

Fig. 5. Hierarchy of «Zero Waste» management [14]

A report by the European Environment Agency published in June 2023 indicates that each European citizen generates approximately 4.8 metric tons of waste annually. Due to concerns about environmental problems both at the level of individuals and at the level of companies, it is gratifying to note that 49 % of household waste is regularly recycled [15]. This positive trend in recycling is due to the growing awareness of environmental issues. Therefore, the demand for waste collection, sorting and processing services increases, which contributes to the further development and expansion of the waste management market in the region.

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In addition, the expansion of the scope of waste management in Europe is a consequence of the active approach of various European governments to the implementation of a circular economy and environmentally responsible waste management practices. In November 2022, the European Commission presented a comprehensive proposal for EU-wide packaging rules. These rules aim to improve packaging design by introducing clear labeling that promotes re-use and recycling, and supports the transition to biodegradable and compostable plastics.

In October 2022, the European Parliament approved a revision of the regulations on persistent organic pollutants. This review aims to reduce the presence of hazardous chemicals in waste and production processes. The updated rules will impose stricter restrictions, ban certain chemicals and ensure effective isolation of pollutants from recycling processes. These concerted actions by European governments underline their commitment to sustainable waste management practices and contribute to the development of the waste management industry.The Asia Pacific region, represented by countries such as Japan, China, India, South Korea, Australia, and others, is showing significant growth, which is mainly due to the large population in the region and increasing volume of e-waste. It is predicted that by 2050, more than 64% of the region's population will live in urban areas [16]. This increase in urbanization is caused by migration from rural areas and economic growth, which increases the income of the population and, consequently, the demand for waste management services.

The growing amount of e-waste and its impact on the environment has raised the general level of concern about its management. Certainly, the demand for electronics in the region has increased dramatically, making proper disposal of e-waste even more important. These factors are projected to increase the waste management market in the Asia Pacific region in the near future [17].

For example, Zhejiang, which plays a key role in e-waste dismantling in China, operates a factory that processes nearly 2 million tons of e-waste annually to extract valuable metals [18].

In addition to this, the growth of the waste management market in the Asia Pacific region is being significantly supported by the proactive actions taken by the governments. These measures include the implementation of regulations and policies aimed at solving the problems of waste management, which contributes to the expansion and development of the waste management sector in the region.

Green infrastructure development and public-private partnerships are becoming key waste management strategies, emphasizing sustainability and resource recovery. Technological advances in waste sorting and recycling also contribute to the region's leadership in responsible and sustainable solid waste management practices.

Other regions such as Latin America, the Middle East and Africa also have significant growth potential. The governments of these regions are increasingly aware of the environmental problems associated with waste and are beginning to invest in innovative solutions and infrastructure [19].

The waste management market is divided by end user into three main segments: commercial, residential and industrial [20–22]. The first covers waste management in residential buildings, apartments, family homes, apartments and other private residences. The second includes waste management in commercial facilities, such as office buildings, shops, restaurants and other businesses that provide services or sell goods. The industrial segment includes waste management at production enterprises, plants, factories and other facilities where the production process takes place.

In 2023, the residential segment turned out to be the leader in the waste management market among end users (Fig. 6). This segment covers waste that is collected from single- and apartment buildings, such as plastic bags, durable goods, consumer goods, toys, electronics, household hazardous waste and packaging materials. Rising disposable income and the popularity of e-shopping have also contributed to an increase in the volume of plastic waste in this sector.

Residents of large residential buildings, for example, multi-apartment complexes, more actively implement waste sorting before their disposal, compared to residents of individual buildings. They carefully separate paper, metal waste, cans and bottles for further recycling. Private sector recycling agencies work closely with these residents to ensure that these materials are effectively recycled by using them in production. However, due to the lack of recycling plants, only a small amount of plastic waste is recycled. Therefore, plastic that can be recycled is stored in special collection points, where it is later handed over to local authorities and companies involved in the recovery of resources.

Taking into account the increase in the level of consumption, urbanization and the increase in the income of the population, a further increase in the volume of household waste is expected. For example, more than 2.01 billion metric tons of such waste are generated annually, and this amount is expected to increase to 4.3 billion metric tons by 2050 [1].

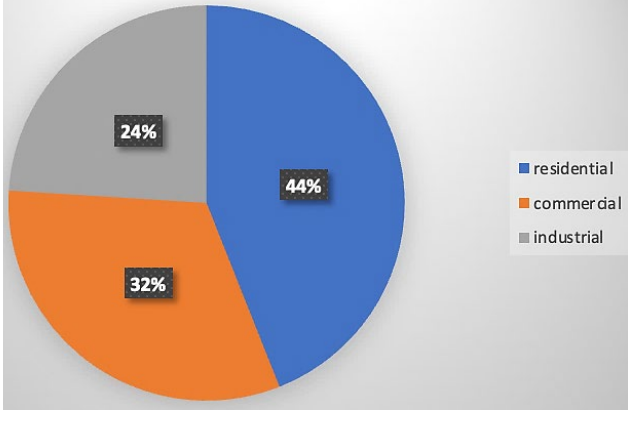

Fig. 6. Volumes of the global waste management market in 2023 by end user, % (compiled by the authors based on data from Allied Market Research [1])

The household waste market is further divided by material, paper, plastic, glass or other. A resident of a city in a developing country generates an average of 100 to 400 kg of solid waste per year (Fig. 7). The reasons for this wide range and great uncertainty lie in the different levels of economic development and consumption, as well as in determining the amount of waste generated. Some statistics use the total amount of waste generated per capita, including all recycled materials. Others consider only waste managed by the relevant local authority and thus exclude, for example, valuable materials separated and collected at source by the informal sector. Often, the separate collection of recycled materials such as glass bottles, newspapers, PET or cans is carried out before they reach the official waste stream for which the municipality is responsible.

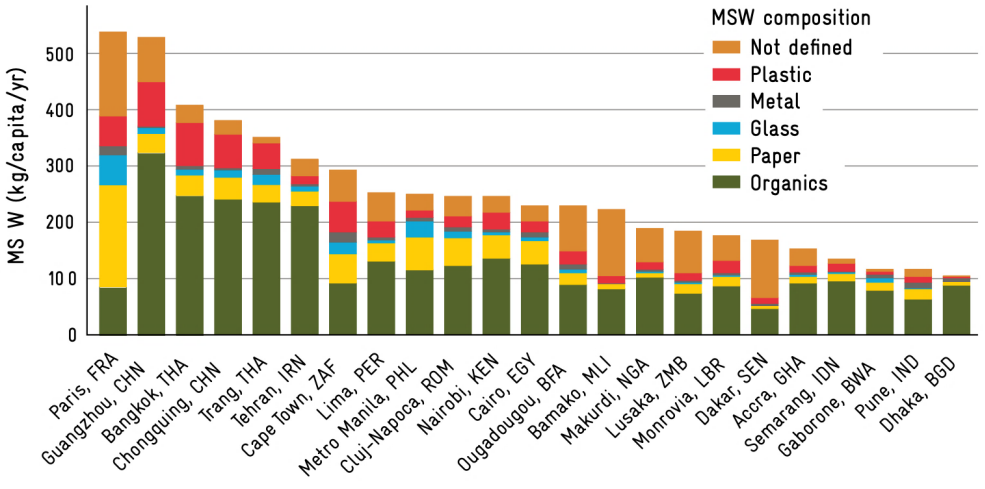

Fig. 7. Composition of MSW per capita (kg/capita/year) in different cities of the world [23, 24]

In most developing countries, organic waste with a high moisture content is the most relevant fraction entering the official waste stream and requiring treatment. In cities with high construction activity and lack of separate collection of construction and demolition waste, MSW also has a high proportion of inert material.

Plastic creates unique challenges in solid waste disposal. Trends in plastic waste management include reducing single-use plastics, supporting recycling infrastructure, and improving plastic-to-fuel technologies. Circular economy initiatives aim to minimize plastic waste through reuse and green alternatives. Regulatory measures against plastic pollution stimulate innovation in materials design and disposal processes. The market pays more attention to extended producer responsibility, which encourages them to pay attention to the management of plastic products after their use [25, 26].

The waste management industry is divided into several types, including hazardous waste, industrial waste, municipal solid waste, e-waste, plastic waste, biomedical waste, and others.

The industrial waste segment led the market and accounted for more than 76 % in 2023 (Fig. 8). Rapid urbanization and industrialization are the main factors in increasing the generation of industrial waste. Management of industrial wastes is required as improper management of these wastes can lead to pollution of lakes and groundwater and damage to wildlife and vegetation.

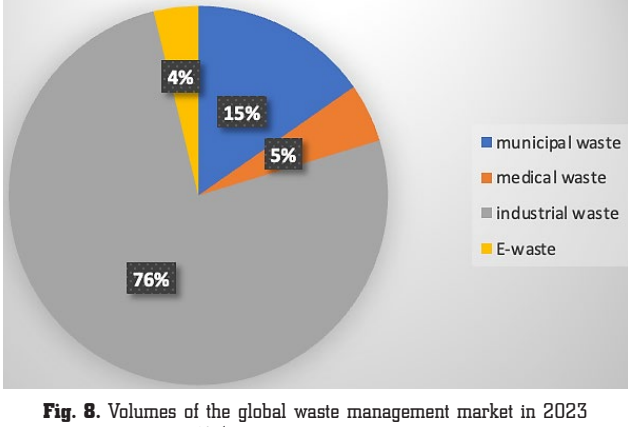

Fig. 8. Volumes of the global waste management market in 2023 by type of waste, % (compiled by the author based on data from Marketsand Markets [28])

According to global data, by 2050, about 68 % of the world's population will live in cities, which is almost 7 billion people, which is expected to increase the generation of urban waste in the near future [27]. During the 2020 COVID-19 pandemic, governments in various countries such as the US, India, and China imposed lockdowns to control the spread of the virus, forcing people to work from home, which has led to an increase in municipal waste in recent years.

The e-waste segment is projected to register the highest growth rate during the forecast period. Rapid technological progress has led to the release of new electronic products and updated versions of existing ones, which reduces their useful life and leads to an increase in the volume of e-waste. These factors are expected to fuel the growth of this segment in the future.

E-waste contains several harmful additives or hazardous substances, such as mercury, brominated flame retardants (BFRs) and chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs). The growing amount of e-waste, the low level of containers for its collection, dangerous disposal and processing of this waste pose significant threats to the environment and even to human health. Mismanagement of e-waste also contributes to global warming and the violation of climate neutrality. First, if materials in e-waste are not recycled, they cannot replace primary raw materials and reduce greenhouse gas emissions from the extraction and purification of recyclable raw materials. In addition, refrigerants contained in certain temperature control equipment produce greenhouse gases. A total of 98 million tons of CO_2 equivalent were released into the atmosphere from discarded refrigerators and air conditioners that were not disposed of in an environmentally sound manner [29, 30].

The e-waste segment is likely to grow at the fastest CAGR of 7.4 % during the forecast period. Rapid technological progress has led to the emergence of new electronic products and updated versions of existing products, thereby reducing their shelf life and, in turn, increasing the generation of e-waste.

In order to avoid the spread of infections and diseases such as pneumonia, tuberculosis, tetanus, whooping cough and diarrhea, the waste generated in hospitals, clinics and diagnostic centers must be managed with appropriate waste management practices. Between 2020 and 2021, the

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generation of biomedical waste increased due to the increase in various diagnostic activities and treatment of patients with COVID-19.

Growing awareness of environmental issues and increasing public pressure are leading governments to actively invest in the development of smart technologies for effective waste management. In addition, they contribute to the development of recycling infrastructure and the implementation of campaigns aimed at increasing public awareness of the importance of responsible waste management.

The results obtained in the course of the research can be used to forecast the market and trends in the development of the waste management industry, which will make it possible to calculate the volumes of economic indicators while minimizing environmental pollution indicators, to scale global trends to Ukrainian realities, and to offer promising ways of investing, which is especially important in times restoration of Ukraine.

However, there are certain limitations of the study, which include differences in regulatory and legislative acts, as waste management laws and regulations vary significantly between countries and regions, which may limit the applicability of the obtained data in different settings. Economic factors also have an impact, because the economic condition of countries affects the development of the waste management market. For example, developed countries have more opportunities to invest in innovative technologies, while developing countries face limited resources. Technological constraints also play a role, as the use of modern waste processing technologies may be limited in some regions due to a lack of infrastructure and necessary investment. In addition, demographic factors such as rapid urbanization and population growth in some regions put additional pressure on waste management systems, which can cause difficulties in implementing effective methods.

As for the possible vectors of research development, they include the development of innovative technologies, improvement of the regulatory framework, introduction of economic tools, education and awareness raising, as well as research into new approaches to the circular economy, where waste is considered as resources for reuse in production processes. These limitations and directions of development will help in further research and practical application of the obtained results in the field of waste management.

4. Conclusions

The study of the global solid waste management market covers the key processes of waste collection, transportation, disposal and processing. It was determined that by 2023, North America will hold the largest market share, which is due to the developed infrastructure of waste management and the high level of environmental awareness of the population. However, the most dynamic growth is shown in the Asia-Pacific region, particularly China and India, due to rapid economic development, urbanization and population growth.

Market analysis by end users showed that the household segment is the largest consumer of waste management services. This is due to the growth in the level of consumption, urbanization and an increase in the income of the population. Industrial waste, especially electronic waste, is also showing significant growth, indicating the need to develop specialized management strategies for this type of waste.

The results of the study show that North America's leading role in the waste management market is due to the presence of developed infrastructure and a high level of environmental awareness. Rapid growth in the Asia Pacific region is driven by factors such as economic development, urbanization, and population growth, which creates new opportunities for the development of the waste management market.

The high level of consumption in the household segment requires the improvement of household waste management systems, including the introduction of new technologies and approaches to disposal. The increase in the volume of industrial waste emphasizes the need to develop specialized strategies for their effective management, in particular, the implementation of sustainable policies.

The research results have both theoretical and practical value. Theoretically, they expand knowledge about global trends in waste management, which can contribute to the development of new scientific approaches and methods in this field. These results can also be the basis for further scientific research aimed at improving waste management processes and developing innovative technologies.

Practically, the research results can be used to develop regionally oriented waste management strategies. This will allow to solve environmental problems more efficiently and promote sustainable development in different parts of the world. For example, the development of household waste management strategies in cities with a high level of urbanization may include the implementation of separate waste collection, the development of infrastructure for their processing and disposal. For industrial waste, programs can be developed that will help reduce the amount of waste in production, reuse materials, and implement zero-waste technologies.

In addition, the research findings can be useful for governments and industry in developing effective policies and investment strategies. This will help support innovation in the field of waste management and the development of a circular economy, which is an important element of sustainable development. For example, investments in waste processing technologies and the development of incentives for business can significantly reduce the negative impact on the environment and improve the quality of life of the population.

In conclusion, the study demonstrates the importance of a global approach to waste management, taking into account regional characteristics and the specific needs of end users, which will allow to achieve more effective results and contribute to sustainable development at the global level.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the study and its results presented in this paper.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm they did not use artificial intelligence technologies when creating the presented work.

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