

THE WASTE MANAGEMENT SYSTEM IN UKRAINE AMID POST-WAR RECOVERY: CONCEPTUAL FOUNDATIONS AND STRATEGIC DEVELOPMENT DIRECTIONS*

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Abstract. The research is devoted to the analysis of the waste management system in Ukraine in the context of post-war economic recovery and the definition of strategic directions for its development. The current challenges associated with the destruction of infrastructure, the growth of construction and hazardous waste, the low level of technological support and the fragmentation of the regulatory framework are studied. Considerable attention is paid to the resource potential of waste as a source of secondary materials and energy, regional aspects of waste stream management, integration into the European market for secondary resources, as well as the role of key stakeholders – the state, business and the public. *The purpose of the research* is to form conceptual foundations and strategic guidelines for the development of the waste management system in Ukraine after the war, in particular, to identify ways to increase the efficiency of the use of secondary resources, improve infrastructure, implement digital and innovative solutions, and ensure the integration of Ukrainian practices into the European and international context. *The methodological basis of the research* is based on theoretical approaches to system analysis, categorical and conceptual modeling, as well as on the principles of sustainable development and circular economy. A comparative analysis of international experience and concepts of waste management was used, as well as a generalization of scientific approaches to strategic

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planning, standardization and integration into the European legal and economic space. Theoretical methods allow us to identify key components of the management system, assess the potential for the implementation of innovations and digital solutions, and determine strategic development guidelines in post-war conditions. *The results* obtained indicate the presence of significant resource potential of waste, especially construction and organic, which can be used for infrastructure reconstruction and energy production. Key problems of the system were identified: insufficient landfills and processing complexes, low level of implementation of modern technologies, fragmentation of legislation and weak coordination between regions. Strategic development directions were proposed: modernization of infrastructure, digitalization and implementation of innovations, integration of circular economy principles, harmonization with European standards, active involvement of stakeholders and development of partnerships, as well as creation of a long-term planning system and standards. *Practical significance.* The results of the study can be used to form national and regional waste management strategies, develop roadmaps, plan infrastructure projects, attract investments and international experience, as well as create effective partnership models for stakeholder interaction. *Value / Originality.* The research combines a systematic analysis of the resource potential of waste and management mechanisms in the post-war period with practical recommendations for strategic development and integration into the European space, making it a unique contribution to the scientific literature on circular economy and sustainable waste management in Ukraine.

1. Introduction

The waste management system is one of the key elements of sustainable development and environmental safety of any country. In the conditions of post-war reconstruction of Ukraine, the issue of effective waste management is becoming particularly relevant, since the destruction of infrastructure, the growth of construction and hazardous waste, as well as the fragmentation of the regulatory framework create significant challenges for state authorities, business and the public. The ability of the waste management system to ensure maximum use of the resource potential of secondary materials, as well as to integrate modern processing technologies and digital solutions is

critically important for accelerating economic recovery and environmental protection.

The novelty of the research topic lies in the comprehensive approach to assessing the resource and technological potential of the Ukrainian waste management system in the post-war period, the integration of international experience, the definition of strategic development priorities and the formation of conceptual foundations for long-term planning. The relevance of the work is due to the need to create an effective waste management model that would ensure a balance between the environmental, economic and social needs of society, stimulate the development of a circular economy and contribute to the integration of Ukraine into the European and international space of secondary resources.

The purpose of the study is to form conceptual foundations and strategic guidelines for the development of the waste management system in Ukraine in the post-war period. To achieve this goal, the following research tasks have been set:

1. To analyze the current state and problems of the waste management system in Ukraine, including infrastructure, technological and regulatory aspects.
2. To assess the resource and raw material potential of waste as a source of secondary materials and energy, as well as the possibilities of their integration into the recovery economy.
3. To investigate the role of state, regional and local authorities, business and the public in the development of the waste management system.
4. To identify strategic directions for the development of the system, including infrastructure modernization, implementation of digital and innovative solutions, integration of circular economy principles and harmonization with European standards.
5. To formulate recommendations for the creation of an integrated waste management system, roadmaps, scenario planning and long-term strategic development.

The methodological basis of the study is based on theoretical approaches to system analysis, categorical and conceptual modeling, as well as on the principles of sustainable development and circular economy. The work uses methods of comparative analysis of international experience, conceptual modeling and generalization of scientific approaches to strategic planning, standardization and integration into the European legal and economic space.

The logic of the presentation of the material is built on the principle of consistent coverage of key aspects: from the current state and problems of the waste management system, through the assessment of resource potential and institutional mechanisms, to strategic development guidelines and recommendations for the formation of an integrated system. This approach allows for a comprehensive assessment of existing challenges, offering effective solutions, and providing a scientifically sound basis for the further development of the waste management system in Ukraine.

2. Current status and problems of the waste management system in Ukraine

The waste management system in Ukraine is undergoing profound transformations, driven by both global challenges in the field of sustainable development and specific internal factors, among which the consequences of a full-scale war occupy a leading place. Waste is increasingly viewed not only as an environmental threat, but also as a potential resource capable of forming the basis for the development of a circular economy. At the same time, the existing infrastructure for waste collection, processing and disposal is characterized by fragmentation, low technological support and limited opportunities for integration into the European resource management space. An additional barrier is regulatory uncertainty and insufficient coordination between institutional actors – state bodies, local governments and the private sector.

In the context of a full-scale war caused by Russian aggression, the waste management system in Ukraine is experiencing large-scale upheavals. The war has significantly affected not only the volume of waste generation, in particular construction, hazardous and toxic, but also the functionality of the management chain itself: destruction of infrastructure, disruption of logistics chains and restrictions on access to processing facilities. This creates conditions of excessive environmental stress, a threat to public health and huge risks to ecosystems. In the absence of proper conditions for collection, sorting and processing, significant volumes of destructive waste enter the environment, exacerbating the crisis in the industry. Therefore, a systematic analysis of such an impact is critical as a prerequisite for identifying effective recovery strategies and sustainable management of the sector in the post-war period (Table 1).

Table 1

**Main manifestations of the impact of the war
on the waste management sector in Ukraine**

Factor	Manifestations	Potential consequences
Growing waste volumes	Generation of millions of tons of construction waste due to the destruction of cities, roads, infrastructure; debris of concrete, bricks, metals, asphalt.	Overloading of landfills, natural landfills, increasing disposal costs, danger to public health.
Hazardous waste	Spread of toxic materials (asbestos, heavy metals, fuel, ammunition remnants, explosives).	Threat of chemical contamination of soil and water, risks to the environment and public health.
Destruction of infrastructure	Destruction of waste processing plants, landfills, sorting stations, and logistics hubs.	Inability to provide centralized collection and processing, increase in local crisis zones.
Logistics disruption	Mining of territories, damage to roads and bridges, difficulty in transporting waste.	The emergence of "isolated" areas where waste accumulates without proper control.
Social dimension	Forced displacement of the population, destruction of housing and social infrastructure.	Temporary settlements without proper waste management conditions, deteriorating sanitary conditions.
Regulatory uncertainty	Lack of special mechanisms for regulating war waste (explosive remnants, toxic materials).	Legal vacuum, difficulty in attracting international assistance, risks of uncontrolled behavior.
Financial and economic constraints	Government budgets are reoriented towards military needs, and there is a lack of funds for environmental programs.	Chronic underfunding of the industry, halt in investment in processing, dependence on international donors.
Recovery options	The interest of international partners in the implementation of "green" technologies in the post-war period.	An opportunity to integrate the circular economy and mobile recycling technologies into the national system.

Source: compiled by the author based on [1; 2; 3; 4]

The war has radically changed both the quantitative and qualitative parameters of the functioning of the waste management system in Ukraine. First of all, the massive destruction of cities and infrastructure has led to the formation of unprecedented volumes of construction and mixed waste, which significantly exceed the design capacities of landfills and existing waste processing complexes. Toxic materials are of particular danger: ammunition fragments, explosives, oil residues, asbestos and other construction materials containing carcinogens. The accumulation of such waste creates risks of long-term chemical pollution of soils, water resources and the atmosphere, forming a new dimension of environmental danger.

In addition to the environmental consequences, a serious challenge is the destruction of the infrastructure base of the waste management system itself. A significant part of landfills, sorting stations and waste processing lines have suffered from hostilities or remained in temporarily occupied territories. In the conditions of a destroyed transport network and mining of certain regions, the logistics of waste collection and transportation become extremely complicated, which leads to the emergence of local crisis centers. There, waste accumulates without systematic control, provoking spontaneous landfills and worsening of the sanitary and epidemiological situation.

An additional dimension is social aspects. Mass population displacement, destroyed housing and infrastructure create conditions for an increase in the amount of mixed household waste in places of compact settlement of displaced persons. The lack of a proper collection and disposal system in such conditions increases the risk of spreading infections and reducing the quality of life of people.

Separately, it is necessary to emphasize the regulatory and financial restrictions. Ukrainian legislation did not provide for the specifics of handling war waste, and existing regulations are insufficient to solve problems with the disposal of military debris or toxic residues. Funding for the industry has sharply decreased due to the reorientation of budgets to defense needs, which makes it practically impossible to support existing programs for the modernization of recycling.

At the same time, certain opportunities are also emerging in the crisis. The high interest of international partners in supporting “green recovery” opens up a chance to integrate modern approaches to the circular economy

and introduce mobile recycling technologies directly in the regions of waste generation. In the long term, this could not only minimize environmental risks, but also lay the foundation for a more sustainable and integrated waste management system in the post-war period.

The Ukrainian waste management system, despite certain reforms, still demonstrates significant technological and infrastructural gaps. Despite the existing ambitions to transition to a circular economy, the country remains dependent on outdated landfill methods, limited in capacity and often overloaded. Modern waste processing complexes are extremely rare, and technologies for the utilization of hazardous or mixed waste are practically not implemented. This slows down the development of the secondary raw materials market and violates the environmental sustainability of the system. The unique situation caused by military aggression has further deepened this problem: the destruction of infrastructure, the shortage of specialized technological lines, the increase in recycling horizons – all this creates structural stagnation. The limited number of technological installations (biogas, sorting, thermal utilization) together with delays in financing and large-scale destruction of facilities has slowed down the possibility of implementing modern solutions (for example, bioenergy technologies or RDF combustion) [5].

In our opinion, a multi-level approach is needed to overcome this technological lag. First, it is a strategic attraction of investments in modernization, both state and international, with a clear focus on technologies for sorting, processing and disposal of hazardous waste. Second, it is necessary to integrate with reforms that provide for the implementation of the principles of the circular economy and stimulate the production of secondary raw materials. In the context of post-war recovery, this can become a catalyst for transformation – if the reforms are combined with the introduction of mobile and flexible technological solutions, as well as the creation of clusters at the regional level. Thus, existing limitations can not only be overcome, but also turned into a source of innovative development in the field of waste management.

Effective waste management in Ukraine is limited by fragmented legislation, weak coordination between central and local authorities, and the lack of effective control mechanisms and incentives for business and the public. Despite the existence of regulatory and legal acts, their

implementation often remains formal, and legal gaps lead to incoherence of government actions and low efficiency of the waste management system (Table 2).

Table 2

Main regulatory and organizational problems in Ukraine

Problem	Description	Implications for the waste management system
Fragmentation of legislation	Laws and bylaws duplicate each other, contradict each other, and are partially outdated	Coordination is becoming more difficult, legal certainty is low
Weak coordination between central and local authorities	Lack of a unified strategy, weak interaction and support of regions	Inefficient use of resources, lack of planning
Lack of incentives and control	Insufficient control over compliance with regulations, lack of financial and legal incentives for businesses and communities	Declining interest in implementing modern technologies, accumulation of problems

Source: formed by the author based on [6; 7; 8]

Analysis of regulatory and organizational problems shows that their combination forms a systemic barrier to the development of modern waste management. Fragmentation of legislation and weak coordination between levels of government lead to low efficiency of implementation of national programs and projects in the field of waste processing. Lack of incentives for business and communities limits the introduction of innovative technologies, while inconsistency of legislation complicates control over environmental safety. At the same time, post-war reconstruction creates an opportunity to review the regulatory framework and integrate effective organizational mechanisms: centralized coordination, clear regulatory requirements and financial incentives for infrastructure modernization, which will increase the sustainability and resource efficiency of the waste management system.

**3. Resource and raw material potential of waste
in the post-war period**

In the conditions of post-war reconstruction of Ukraine, the problem of waste management acquires a dual significance – as an environmental

challenge and as an economic opportunity. Significant volumes of construction, industrial and household waste generated as a result of the destruction of infrastructure can be considered not only as a threat to the environment, but also as a significant resource for ensuring sustainable development. Waste recycling and utilization can ensure the re-inclusion of valuable materials in production cycles, reduce the need for primary raw material extraction, reduce the cost of reconstruction and contribute to the formation of a "green economy". The development of a system for using the resource potential of waste opens up prospects for Ukraine's integration into the European market for secondary resources and the creation of interregional recycling clusters.

Materials from destroyed buildings – concrete, brick, metal, wood, glass, plastic, can be re-incorporated into construction processes: from the creation of new structures to the production of secondary raw materials. Smart management of this potential helps reduce dependence on imported building materials, save money on reconstruction, reduce CO₂ emissions, and stimulate the circular economy (Table 3).

Table 3

Potential of construction and industrial waste in Ukraine

Waste category	Examples of materials	Reuse possible
Concrete/brick	Destroyed concrete, brick	Processing into crushed stone/aggregate; concrete mix manufacturing; "circular concrete" on site
Metal	Reinforcement, trusses, steel elements	Overheating in metallurgy; creation of structural parts
Wood	Beams, boards, formwork	Grinding into biomass, making composites or panels
Glass	Windows, glass panels	Grinding for the production of plates, aggregates or reflective mixtures
Plastic/insulation	PVC, polystyrene foam	Raw materials for processing, innovative thermal insulation elements or building materials

Source: compiled by the author based on [9; 10; 11]

The use of construction and industrial waste as secondary resources is essential for the sustainable development of Ukraine in the post-war period.

First, the recycling of concrete, brick and metal can significantly reduce the need for primary minerals and reduce logistics costs in large-scale rough construction projects.

Secondly, the development of recycling capacities for metal, glass, wood and plastic creates additional jobs, stimulates small and medium-sized businesses and forms stable regional markets for secondary materials. Examples of such technologies are already being implemented: crushing and sorting of materials on site, recycling of glass into aggregates, wood into composites, metal into steel parts [9].

Third, the integration of such practices is a brick in the foundation of the future circular economy of Ukraine. Reducing the load on landfills, stimulating "green" industry and forming regional recycling clusters, all this strengthens environmental and economic sustainability [10; 11, p. 67]. At the same time, to realize the potential, clear strategic planning, investments in mobile technological solutions, legislative support, and creating demand for products made from secondary raw materials are necessary.

In the post-war period, Ukraine will face the need to restore the energy system and ensure energy independence. At the same time, the volume of organic and other waste is growing, which can serve not only as a burden on the environment, but also as a resource for renewable energy. Three main areas of their use – incineration in cogeneration plants (Waste-to-Energy / RDF), biogas production from organic materials, and the use of RDF fuel at local CHPs – can create additional capacities for heat and electricity, reducing dependence on external energy sources and reducing the load on landfills (Table 4).

In the context of long-term restoration of Ukraine's energy sector, the use of waste energy potential is a strategically appropriate and pragmatic solution. First, biogas from organic waste can become a significant local energy source, reducing the burden on the traditional gas supply system. At the same time, the infrastructure already partially exists, and the potential for scaling is high.

Secondly, RDF fuel from reliably operating sorting lines can provide a relatively stable energy supply for CHP or CHP plants, such as in Zhytomyr or Odessa. This allows for the simultaneous utilization of waste and the production of heat and electricity with high efficiency.

Thirdly, these solutions contribute to the environmental effect: reducing the amount of waste, gradually switching heat supply to "green" technologies, as well as energy independence. However, implementation requires support: investment financing, regulatory incentives (e.g., a "green tariff" for biogas), technical training, and active involvement of local communities in the RDF sorting and production processes.

Table 4

Component of using the energy potential of waste

Direction of use	Example / Project	Potential effect
Biogas from organic waste	By 2023, 26 biogas plants are operating in Ukraine, +30 at municipal landfills (total 28.9 MW)	Potential generation of up to 4.5 billion m ³ of biomethane by 2040, up to 20 billion m ³ by 2050
RDF fuel in bio-CHP (Zhytomyr)	Bio-CHP plans to produce 20 MW of heat from RDF + 20 MW from wood, 10 MW of electricity	Use of RDF from a local sorting complex, replacement of natural gas (~20 million m ³ /year)
CHP on RDF (Odesa)	Situation: TPP in Odessa on RDF and Waste-to-Energy technology, 12 MW of electricity + 40 MW of heat, project ~106 million USD, payback 6.5 years.	Decentralized energy supply, reduced shipments to landfills, reduced energy imports

Source: compiled by the author based on [12; 13; 14; 15; 16]

The resource potential of waste in Ukraine in the post-war period has a pronounced regional differentiation, which is due to the scale of destruction of residential and industrial buildings, the sectoral structure of the economy, population density, as well as logistical accessibility to the "Solidarity Lanes", the Danube and Black Sea routes. According to KSE estimates, more than 90% of the total damage falls on the frontline and coastal regions (with a significant share in the Dnipropetrovsk region), which directly correlates with the potential for the formation of large flows of construction scrap, scrap metal, glass and other secondary resources for processing or export. At the same time, the restoration of maritime logistics and the development of alternative EU routes have created conditions for the diversification of export channels for secondary raw materials, and the new version of the EU Regulation on cross-border shipments of waste (EU

2024/1157) defines more transparent rules for access to EU markets, subject to proper control and traceability of flows.

Table 5 shows an indicative, expert assessment based on a combination of factors: scale of destruction/dismantling (source of construction waste and scrap metal), industrial profile (ore/metal, glass, chemicals, mechanical engineering), urban population size (municipal waste), logistics/export channels (rail, EU crossing points, Danube/seaports), availability of processing facilities and risks (mine hazard, proximity to hostilities).

Analysis of the integrated resource potential of waste in the regions of Ukraine indicates a significant differentiation of their opportunities and challenges. The highest level of potential is observed in the eastern and southern regions (Donetsk, Kharkiv, Dnipropetrovsk, Zaporizhzhia, Mykolaiv regions), where large-scale destruction of infrastructure, industrial enterprises and housing generate huge volumes of construction and industrial waste. These material flows, on the one hand, constitute a significant environmental burden, but on the other hand, can serve as a key source of secondary resources for reconstruction. A special role is played by scrap metal and concrete structures, which can be used in the production of new building materials, as well as cullet and wood suitable for secondary processing.

The western regions, in particular Lviv region, have a relatively low level of waste generation, but their strategic advantage lies in their proximity to EU markets and the availability of logistics corridors for the export of secondary raw materials. This creates conditions for the development of interregional cooperation, when the western regions can become transit or processing hubs for waste generated in the eastern regions. It is worth noting separately the Sumy region, which, despite the smaller scale of destruction, has significant potential due to its agro-industrial profile and the generation of agricultural waste (straw, biomass), as well as the availability of wood and glass. Its geographical position near the EU borders opens up additional prospects for the export of secondary resources, although the limited processing capacity currently remains a key barrier.

**Integral resource potential of waste in the regions of Ukraine
in the post-war period**

№	Region	Key Drivers of Potential	Potential Waste Streams	Logistic Potential to the EU	Main Risks/ Constraints
1	Donetsk	Large-scale destruction, metallurgy	Construction debris, scrap metal	Railway routes to the West	Landmines, ongoing hostilities
2	Kharkiv	Housing destruction, machine-building base	Metals, mixed debris	Rail connections to Polish border	Shelling, damaged infrastructure
3	Dnipropetrovsk	Industrial hub, logistics center	Scrap metal, glass cullet, concrete	Transit potential to the West	Energy instability
4	Zaporizhzhia	Energy & metallurgy, infrastructure damage	Metals, concrete, insulation materials	Rail network to central and western Ukraine	Limited access due to hostilities
5	Mykolaiv	Destruction of port infrastructure	Construction debris, metals, glass, wood	Sea and rail routes	Instability of maritime corridors
6	Kherson	Flooding and destruction, water contamination	Mixed waste, hazardous debris	River logistics, transit to central/western Ukraine	Pollution, landmines
7	Kyiv Region	Urbanization, active reconstruction	Construction debris, recyclables	Developed logistics, central coordination	Landfill overload, high costs
8	Odesa	Logistics hub, ports	Glass cullet, RDF, metals	Ports, Danube corridor	Maritime security risks, port congestion
9	Sumy	Moderate destruction, agro-industrial base	Agro-waste, wood, glass, construction debris	Rail/road links to Romanian/ Polish borders	Limited recycling capacity, weak regional coordination
10	Lviv	Minimal destruction, logistics gateway to the EU	Sorted fractions, glass, paper, metals	Direct proximity to EU borders	Small local waste volumes

Source: author's own development

Effective use of the resource potential of waste requires an integrated state policy that will connect industrial centers, where the main volume of waste is generated, with western regions that can provide access to EU markets and serve as logistics hubs. This requires the creation of interregional recycling chains, the development of modern infrastructure and the active involvement of the private sector.

4. Institutional and organizational mechanisms for the development of the waste management system

The effective functioning of the waste management system in Ukraine largely depends on the coherence of institutional and organizational mechanisms that determine the order of interaction between state bodies, local governments, business and the public. In the post-war period, when the country is faced with large-scale destruction of infrastructure and an increase in the volume of construction, industrial and household waste, the role of coordination and system management becomes critical. State bodies are responsible for legislative regulation, strategic planning and monitoring compliance with standards, while local authorities and public institutions ensure the implementation of policies at the territorial level, organize separate collection and processing of waste and stimulate community activity. In this context, it is necessary to involve business structures that are able to introduce modern technologies, provide logistical support and promote interregional cooperation. The formation of an integrated waste management system is based on the interaction of all entities, which ensures a comprehensive approach to reducing the environmental load and rational use of secondary resources.

The architecture of state waste management in Ukraine is built along the vertical of “norm-making → policy and coordination → regulatory and supervision → infrastructure implementation”. The basic principles of the waste management hierarchy, planning (national/regional/local plans), as well as EPR tools (extended producer responsibility) are enshrined in Law No. 2320-IX “On Waste Management”, followed by sub-legal detailing and interdepartmental coordination. In the post-war period, it is key to link norm-making and controlling with the rapid implementation of projects: dismantling/sorting of “destruction waste”, infrastructure modernization,

launching markets for secondary raw materials and energy from waste (Table 6).

Table 6

**State (central) entities and their role in the waste management chain
(from “top” to “bottom”)**

Authority	Main Competences	Key Instruments	Practical Interaction	Post-war Priorities
Verkhovna Rada of Ukraine	Adoption of laws, EU directives transposition	Waste Management Law, eco-tax reforms	Oversight of Cabinet, legislative initiatives	Fast-track laws for recovery waste management
Cabinet of Ministers (CMU)	National policy, coordination, approval of strategies	National Waste Management Plan, CMU decrees	Delegates to ministries, donor coordination	Regulation of demolition waste, support for recycling hubs
Ministry of Environmental Protection (MinEnv)	Core policymaker, by-laws, registers, EPR	Methodologies, classification, EPR rules	Harmonises regional/local plans, drafts by-laws	EU alignment, waste flow management
Ministry for Communities & Infrastructure Development	Infrastructure, spatial planning, reconstruction	C&D waste standards, recovery guidelines	Coordinates municipalities, oversees Recovery Agency	Sorting/ recycling integration in recovery
State Environmental Inspectorate (SEI)	Enforcement, inspections, sanctions	Inspection plans, acts	Controls operators, landfills, hauliers	Focus on hazardous & demolition waste
National Energy & Utilities Regulatory Commission (NEURC)	Tariff-setting for WtE and biogas	Tariff resolutions, licensing	Approves WtE/biogas models, tariffs	Bankable conditions for energy-from-waste
Ministry of Health	Sanitary norms, medical waste management	Sanitary protocols, waste rules	Approves technologies, oversees operators	Mobile facilities, safe disposal solutions
Regional & Local Authorities	Regional/local plans, service organisation	Regional plans, contracts, bylaws	Approve facilities, procure operators	Recycling hubs, separate collection

Source: compiled by the author based on [17; 18; 19; 20]

Analyzing the presented structure, it can be noted that the waste management system in Ukraine at the central government level is multi-level and at the same time complex. The Verkhovna Rada forms the foundations of the legislative framework, but the actual implementation of the policy largely depends on the executive branch – the Cabinet of Ministers and relevant ministries. The Ministry of Environmental Protection plays the role of a key coordinator in the development of standards, methodologies and regulations, while the Ministries of Infrastructure and Health are responsible for the integration of environmental requirements into the field of reconstruction and medical waste. An important element is the work of the State Environmental Inspectorate, which should not only control, but also stimulate compliance with modern recycling standards. The regulatory component, represented by the National Commission for the Regulation of Energy and Utilities of Ukraine, ensures a balance of economic feasibility and environmental safety in the field of energy production from waste, which is especially relevant in the context of post-war reconstruction. However, it is at the level of local government that the practical implementation of the policy is laid – through the organization of infrastructure, the introduction of separate collection and the development of regional recycling capacities. Given the post-war challenges, not only a vertical chain of control from parliament to communities is necessary, but also horizontal interaction between institutions and regions. Otherwise, the system will remain fragmented, and the potential of secondary resources will not be fully utilized. It is precisely the strengthening of coordination between state bodies, private operators and territorial communities that can ensure the creation of an integrated and effective waste management system in the conditions of post-war reconstruction.

5. Strategic guidelines and priorities for the development of the waste management system in post-war reconstruction

Strategic guidelines and priorities for the development of the waste management system in post-war reconstruction are defined as a key element of economic modernization and ensuring sustainable development of Ukraine. In conditions of significant growth in waste volumes caused by the destruction of infrastructure, intensification of construction processes and transformation of production chains, the waste management system acquires

special importance not only as an environmental, but also as an economic and social category. The formation of strategic guidelines should be based on a combination of recovery needs with the long-term objectives of Ukraine's integration into the European space, which involves harmonization of legislation, introduction of innovative technologies, digitalization of waste flow monitoring and development of the secondary resources market. In this context, the priorities are modernization of infrastructure, creation of conditions for a circular economy, stimulation of business and involvement of the public in the processes of recycling and reuse (Figure 1).

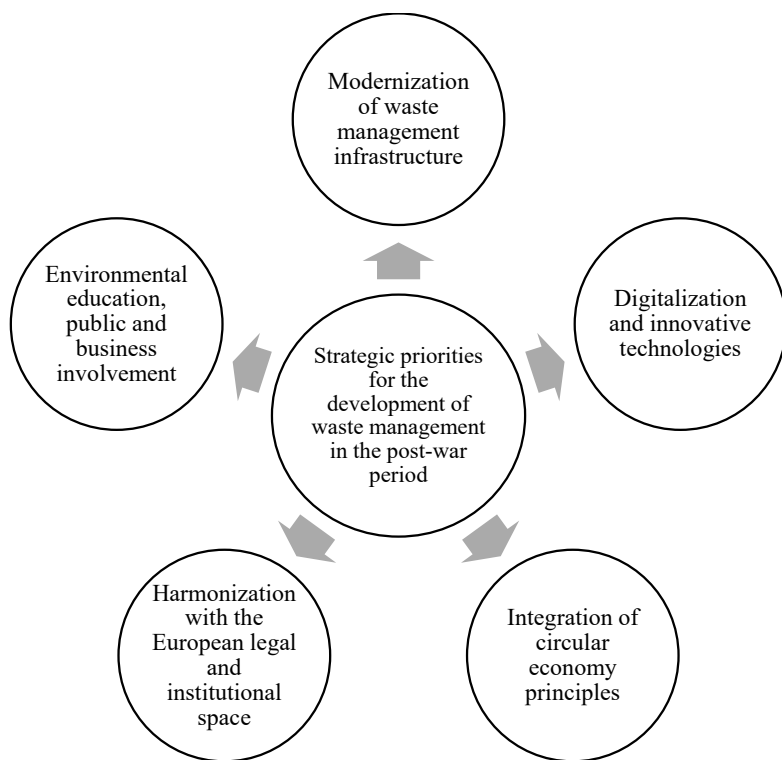


Figure 1. Strategic priorities for the development of waste management in the post-war period

Source: author's own development

1. Modernization of waste management infrastructure. The post-war stage of Ukraine's reconstruction poses new challenges to the waste management system and at the same time creates the prerequisites for large-scale modernization of the infrastructure. The destruction of a significant part of landfills, overloading of existing facilities, and the lack of a sufficient number of waste sorting and recycling complexes necessitate not only reconstruction, but also a qualitative transformation of the entire system. According to European practices, the emphasis should be placed on reducing landfill volumes, introducing modern sorting and recycling technologies, as well as on the formation of logistics hubs that will optimize transport costs and ensure interregional cooperation [21]. Modernization of waste management infrastructure involves, first, the gradual abandonment of outdated landfills that do not meet safety requirements and their replacement with facilities that take into account EU environmental standards. Secondly, a key area is the development of a network of waste sorting and recycling plants capable of handling mixed waste streams, including construction, industrial and household waste. Such infrastructure can create a basis for the emergence of a circular economy, where secondary raw materials are returned to production processes, reducing dependence on imported materials [22]. Thirdly, modernization is impossible without the development of logistics hubs that will ensure the rational movement of waste between regions, allowing less developed regions to use the capacities of large recycling centers.

In our opinion, it is a comprehensive approach to infrastructure modernization that can become the foundation of Ukraine's post-war environmental and economic strategy. Today, most landfills are operating at the limit of overload and do not meet environmental standards, so the reconstruction of existing facilities alone is insufficient. It is necessary to create a new waste management architecture that combines local facilities with regional sorting and processing centers. In this case, it is worth focusing not only on technical solutions, but also on the creation of a system of logistics hubs that will ensure the integration of regions and reduce transport costs. An additional impetus for modernization will be the attraction of private investment and international donors, who have already declared support in the field of "green" reconstruction. If these efforts are implemented, Ukraine will have a chance not just to restore the destroyed

infrastructure, but to build a modern, efficient and competitive waste management system integrated into the European space.

2. Digitalization and innovative technologies. In modern conditions, digitalization is one of the key drivers of the transformation of the waste management system. It ensures transparency of processes, efficiency of logistics and integration into the European digital space. The introduction of innovative technologies, from intelligent monitoring systems and IoT sensors to blockchain solutions for tracking waste flows, opens up opportunities for more rational use of resources and reduction of environmental risks [23]. The use of big data and artificial intelligence allows predicting waste generation in different sectors of the economy, optimizing collection routes and ensuring automated sorting. At the same time, it is necessary to take into account the institutional aspect of digitalization: the creation of a single national waste register integrated with regional databases is a necessary condition for the formation of a transparent control system. In the post-war period, digital innovations should also become a tool for rebuilding infrastructure, allowing the introduction of modern “smart” waste sorting complexes, mobile applications for engaging the population in separate collection, and integrated systems for monitoring emissions. In our opinion, digitalization will become the main tool for minimizing corruption risks and increasing the efficiency of resource use. If today the system often suffers from a lack of data and inconsistency between regions, then digital platforms can provide a single information space. Special attention should be paid to partnerships with business, because it is the private sector that has the technological capabilities to implement innovations, while the state has the regulatory mechanisms to scale up. The post-war reconstruction period provides a unique “window of opportunity” for creating a digital waste management system from scratch, avoiding outdated solutions.

3. Integration of circular economy principles. In the post-war period, the integration of circular economy principles becomes a fundamental prerequisite for the recovery of the Ukrainian economy, since it allows minimizing material losses, reducing the burden on the environment and creating new markets for secondary raw materials. The transition from a linear “take-produce-throw” model to a cyclical system, where waste is considered a resource, is not only an environmental but also an economic task that contributes to the formation of a competitive economy within the

framework of the European Green Deal [24]. The application of a circular economy in waste management means the formation of a system of closed material flows, where the key tools are: reuse of materials in construction and production, development of the market for recycled raw materials, introduction of ecodesign of products, extended producer responsibility (EPR) and digital accounting of resources [25, p. 225]. This requires synergy between the state, business and society, as well as the active implementation of the best European practices and standards.

For Ukraine, the principles of the circular economy are not only a theoretical concept, but also a practical tool for reconstruction. For example, millions of tons of construction waste can become the basis for creating new materials – cement mixtures, secondary crushed stone, insulation elements [26]. This will significantly reduce the cost of importing raw materials and will allow to reduce the cost of restoration projects. Another important element is to stimulate business to use secondary resources through a system of economic mechanisms: green tax breaks, grants for the implementation of eco-technologies, access to European recovery funds. In combination with digital solutions (tracking of material flows, electronic exchanges of secondary raw materials), this creates the prerequisites for a transparent market and the integration of Ukraine into a common European space of circular resources.

4. Harmonization with the European legal and institutional space. The post-war reconstruction of Ukraine is impossible without integration into a single European legal and institutional space for waste management. One of the key conditions is the adaptation of national legislation to the EU *acquis communautaire*, in particular to the provisions of Directive 2008/98/EC on waste, the Circular Economy Package (2018) and the new European Green Deal Strategy [27]. They define the waste management hierarchy (prevention – preparation for reuse – recycling – other recovery – disposal) and form legal obligations for the processing of municipal, construction and hazardous waste.

Harmonization involves not only changing the regulatory framework, but also forming an effective system of control and responsibility. This means strengthening the role of environmental inspection, expanding economic regulation tools (environmental taxes, a deposit-based packaging system, financial responsibility of producers), as well as creating

independent institutional structures that will ensure transparency in waste stream management. No less important is the development of interstate cooperation. Ukraine can become part of the European secondary resources market through the export of recycled raw materials, integration into a single waste monitoring system, and participation in joint cross-border projects with neighboring countries. This opens up new opportunities for regional specialization: some regions can focus on the processing of building materials, others on organic waste or the production of RDF fuel.

For Ukraine, the process of harmonization with European standards is not only a formal implementation of directives, but also a chance to build an effective waste management system based on the principles of transparency, responsibility, and sustainable development. In the context of post-war recovery, it is especially important to ensure the synchronicity of reforms: changes in legislation should be accompanied by the development of infrastructure and the introduction of innovative technologies. At the same time, harmonization will allow Ukraine to integrate into the European economic space, creating new markets for business and reducing environmental risks. In the future, this will contribute to the formation of regional clusters of the circular economy, where Ukrainian companies can become competitive players alongside European ones.

5. Environmental education, public and business involvement. One of the fundamental elements of the development of a modern waste management system is the formation of environmental awareness in society and the involvement of key stakeholders – the public and business, in active participation in the processes of waste reduction, sorting and reuse. In the conditions of post-war reconstruction of Ukraine, the relevance of this direction is only growing, because large-scale destruction and reconstruction create an unprecedented amount of waste, which requires a comprehensive and responsible approach. Environmental education plays a key role in changing the behavior patterns of the population. It should be based not only on traditional forms (school and university education), but also on informal tools – campaigns by public organizations, social advertising, local initiatives for garbage collection and sorting. An important component is the formation of understanding of the principles of the circular economy, which is aimed at minimizing waste through the reuse and recycling of resources.

Business acts as both a producer and a potential driver of change. The Extended Producer Responsibility (EPR) system, investments in modern recycling technologies, the introduction of environmental certification and corporate standards are mechanisms that can stimulate business to take greater responsibility in the field of waste management. Additionally, the role of small and medium-sized enterprises is important, which can become the basis for the creation of regional clusters for recycling and reuse of materials.

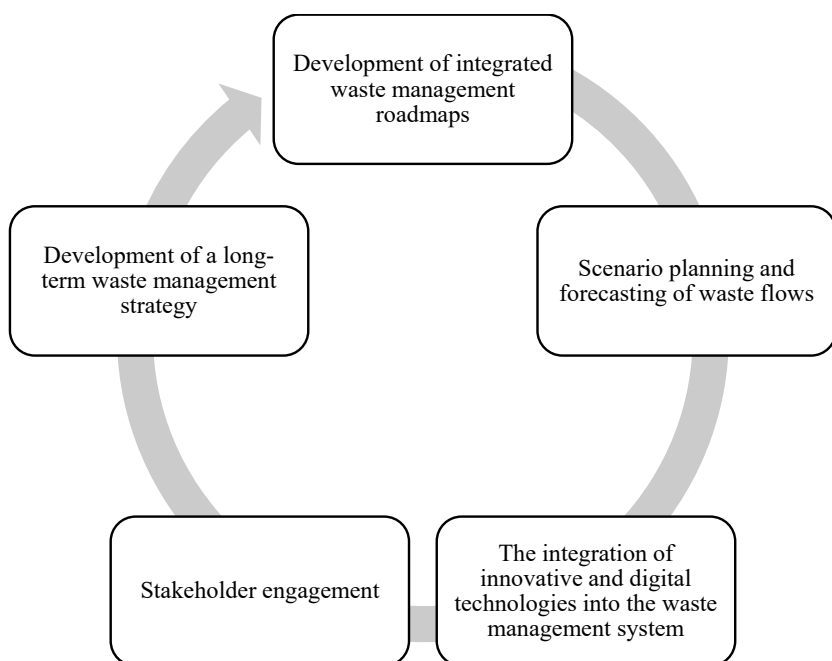
The public should also become a full participant in this process. The involvement of volunteer movements, zero waste initiatives, environmental startups and public organizations allows not only to expand sorting practices, but also to ensure transparency in waste management at the local level. This creates the basis for the formation of a culture of responsible consumption and participation in joint environmental projects.

In our opinion, it is environmental education and public participation that can become the “soft power” that will support institutional and infrastructural changes in the field of waste management. Without a change in the attitude of citizens and businesses, no legislative or engineering reform will be effective. At the same time, it is important that educational campaigns have a practical dimension: for example, they are accompanied by the creation of accessible recycling collection points, financial incentive programs for businesses or households, as well as transparent mechanisms for monitoring the results. Involving the public and business in waste management should also create a synergy effect: public initiatives stimulate demand for infrastructure, business provides innovation and financing, and the state sets rules and monitors their implementation. As a result, an integrated model of responsible waste management can be formed that will meet European standards and will become a guarantee of sustainable development of Ukraine in the post-war period.

6. Recommendations and prospects for the formation of an integrated waste management system

The formation of an effective integrated waste management system in Ukraine is a critically important task in the context of the post-war reconstruction of the economy and infrastructure. Integration involves combining legislative, institutional, technological and social components

into a single system capable of ensuring a sustainable circulation of materials and resources, minimizing negative environmental impacts and stimulating the development of a circular economy. In conditions of large-scale destruction, the issues of coordinating actions at the national and regional levels, forecasting waste volumes and their potential utilization, as well as the use of digital and innovative solutions for monitoring and optimizing waste flows are particularly relevant. The development of integrated strategies allows for the formation of roadmaps for the development of the waste management system, determining priority areas for infrastructure and technological investments, and stimulating the active participation of the public, business and international partners (Figure 2).



**Figure 2. Recommendations and prospects
for the formation of a holistic waste management system**

Source: author's own development

1. Development of integrated waste management roadmaps. The development of integrated waste management roadmaps is a key step in the formation of an effective and sustainable waste management system in Ukraine. These plans should take into account the specifics of each region, ensure interaction between different levels of government and institutions, and identify priority areas for infrastructure modernization. Given the post-war context, special attention should be paid to the restoration and development of infrastructure that meets European standards.

In January 2025, the Cabinet of Ministers of Ukraine approved the National Waste Management Plan until 2033, which defines the strategy for the development of the waste management system for the coming years. This document provides for the development of regional waste management plans that must be adapted to local conditions and needs. According to the plan, each region must develop its own plan within a year from the date of entry into force of the national plan. These plans should include the creation of waste processing infrastructure, as well as the closure of facilities that do not meet environmental safety requirements. The Waste Management for Ukraine (WM4U) programme, initiated by the Swedish Association for Waste Management and Recycling (Avfall Sverige) and the Swedish Association of Local Authorities and Regions (SALAR), aims to support waste management reforms in Ukraine [28]. The program aims to strengthen local capacities, encourage cooperation between municipalities and align with European environmental standards.

The development of integrated waste management roadmaps should be based on the principles of sustainable development, efficient use of resources and consideration of local conditions. The leading component is the involvement of the public and business in the process of planning and implementing measures. It is also necessary to ensure financing for the implementation of plans, in particular through attracting investments and international technical assistance.

2. Scenario planning and forecasting of waste flows are critical elements for effective waste management in the conditions of post-war reconstruction of Ukraine. Given the large-scale destruction of infrastructure and changes in consumer habits of the population, it is necessary to develop models that allow predicting the volumes and types of waste under different scenarios of the situation. This will allow optimizing resources, reducing environmental

risks and ensuring sustainable development of the waste management system.

According to a study conducted by the World Bank, about 500 million tons of waste are generated in Ukraine annually, of which 76% are primary industry waste. This indicates a high intensity of waste generation, which requires the development of effective strategies for their management. Forecasting waste flows under different scenarios allows us to determine the potential volumes of waste in the future and accordingly plan the necessary infrastructure for their treatment and disposal. In the context of post-war reconstruction, special attention should be paid to forecasting the volumes of construction waste. It is estimated that more than 209,000 residential buildings and 27,000 apartment buildings were destroyed as a result of hostilities. This creates a significant burden on the waste management system and requires the development of special strategies for the treatment and disposal of construction waste [29; 30].

3. The integration of innovative and digital technologies into the waste management system is a necessary condition for ensuring its efficiency, transparency and sustainable development. In the context of post-war reconstruction of Ukraine, it is especially important to implement modern solutions that allow optimizing the processes of waste collection, transportation, processing and recycling. Digital platforms, monitoring systems, analytics and “smart” logistics can significantly improve waste flow management and contribute to achieving the goals of the circular economy.

Projects aimed at implementing digital solutions in the field of waste management are already being implemented in Ukraine. For example, the E-Waste Platform, initiated by UNDP, provides for the creation of an electronic waste management information system that will ensure transparency and efficiency of waste management. Also in 2023, the “Zero Waste City” platform was launched in Ukraine, which is an interactive model of a city demonstrating a modern waste management system. In addition, scientific research confirms the effectiveness of implementing digital technologies in the waste management system. In particular, the use of the Internet of Things (IoT), RFID systems, and mobile applications allows you to optimize the processes of waste collection, transportation, and disposal, reducing costs and increasing system efficiency [30].

For the effective implementation of innovative and digital solutions in the waste management system in Ukraine, it is necessary to consider:

- infrastructure and technology: development of infrastructure for data collection and processing, implementation of modern technologies, such as IoT, artificial intelligence and big data;
- legislative and regulatory framework: development and implementation of legislative and regulatory acts regulating the use of digital technologies in the field of waste management;
- education and training: training of specialists in the field of digital technologies and waste management, conducting training programs for employees in the field;
- financing and investment: attracting financing for the implementation of projects aimed at the implementation of digital solutions, including through state programs, international grants and private investments;
- cooperation and partnership: creation of partnerships between state bodies, local communities, business and public organizations to implement joint projects in the field of waste management.

Taking these aspects into account will allow creating an effective and sustainable waste management system that meets modern requirements and contributes to the development of a circular economy in Ukraine.

4. An effective waste management system is impossible without the active participation of key stakeholders – government agencies, businesses, public organizations and international partners. In the post-war conditions of Ukraine, the creation of sustainable partnerships becomes especially relevant for the development of a circular economy and the maximum use of secondary resources. Interaction at all levels allows coordinating efforts, optimizing logistics processes and ensuring efficient use of resources, reducing environmental and economic risks. Scientific research demonstrates that a multi-stakeholder approach allows increasing the efficiency of the waste management system and promotes the implementation of innovative solutions. It is especially important to ensure the participation of local communities, which perform the role of control and monitoring, as well as businesses, which provide investment and technological support [31].

International partners can facilitate technology transfer, grant provision and expert support. The experience of the EU and other countries shows that effective integration of stakeholders ensures a comprehensive approach

to waste management and stimulates the development of the secondary resources market.

In the context of Ukraine, it is necessary to form mechanisms for regular interaction between government agencies and business, ensuring transparency, monitoring and data exchange. Creating partnerships between regions will allow pooling resources and optimizing waste logistics, and the participation of international organizations will contribute to the implementation of best practices of the circular economy.

5. A long-term waste management strategy is a leading element in ensuring sustainable development and effective functioning of the waste management system in Ukraine. The formation of national strategies and regional plans allows for the coordination of actions at different levels of government, ensuring the predictability of waste flows and the integration of the principles of the circular economy. Standardization of practices and the creation of a system of performance indicators allows for the evaluation of the results of waste management policy and the implementation of best international practices.

Scientific research shows that long-term planning in the field of waste management ensures:

- optimization of logistics flows and infrastructure solutions;
- effective use of the resource potential of secondary materials;
- increased transparency and responsibility of system participants;
- integration of Ukrainian practices with European and international standards.

Currently, Ukraine is experiencing fragmentation of strategic planning and the lack of unified waste management standards, which complicates interaction between regions and state bodies. The introduction of a system of key performance indicators will allow assessing the achievement of goals, adjusting policies and implementing innovative solutions. The experience of EU countries demonstrates that standardization of procedures and long-term strategies allow achieving a high level of recycling, reducing the burden on the environment and stimulating the development of the secondary resources market.

The implementation of a long-term waste management strategy is a necessary stage in the formation of an effective and integrated waste management system in Ukraine. In the context of post-war reconstruction,

the state needs clearly defined strategic goals, agreed at the national and regional levels, which allows planning logistics, infrastructure projects and waste recycling taking into account the resource potential of each region. Standardization of practices, introduction of a system of key performance indicators and adaptation to European norms create conditions for increasing the transparency of management processes, optimizing the use of secondary resources and stimulating the development of the recycling market. An effective combination of strategic planning and standards allows minimizing the risks associated with the fragmentation of legislation and uneven development of infrastructure, and also ensures the stability of the system in the long term.

5. Conclusions

The current state of the waste management system in Ukraine is characterized by significant challenges caused by the consequences of the war: destruction of infrastructure, increasing volumes of construction, organic and hazardous waste, fragmentation of regulatory and legal regulation and insufficient coordination between central and local authorities. It was found that the existing waste management system does not ensure the full use of resource potential and effective integration into European practices.

The resource and raw material potential of waste in the post-war period is significant and includes construction materials, scrap metal, wood, glass, plastic, as well as organic waste for the production of biogas and RDF fuel. The assessment of regional potential showed the different ability of the regions of Ukraine to provide secondary resources, which opens up opportunities for interregional cooperation and integration into the European market for secondary materials.

Institutional and organizational mechanisms for the development of the waste management system require strengthening the role of the state and central authorities in strategic planning, coordination of regions and creation of incentives for business. It is also important to actively involve private operators, technological partners, logistics hubs and the public to ensure effective exchange of resources and waste flows.

Strategic development guidelines include modernization of infrastructure (new landfills, sorting and processing complexes), implementation of digital and innovative technologies, integration of the principles of the circular

economy, harmonization with European standards and development of partnerships between state, private and public structures. Creation of a system of performance indicators and long-term strategies allows to increase the transparency of management processes and ensure the sustainability of results.

Recommendations for the formation of an integrated waste management system include the development of integrated roadmaps, scenario planning of waste flows, application of innovative and digital solutions, active involvement of stakeholders and creation of a single national strategic planning system. Such measures allow optimizing the use of secondary resources, reducing the burden on the environment, and contributing to the sustainable development of the country in the context of post-war reconstruction.

The scientific value of the work lies in the comprehensive approach to assessing the resource, institutional, and technological potential of the waste management system, and the practical significance lies in providing substantiated recommendations for state bodies, business, and the public on the effective implementation of waste management policy in Ukraine and integration into the European context.

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