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ASSESSMENT OF SOLID HOUSEHOLD WASTE MANAGEMENT EFFICIENCY BASED ON MATERIALS RECYCLING: THE INFLUENCE OF TERRITORIAL AND DEMOGRAPHIC FACTORS

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Summary. *The paper investigates materials recycling as one of the most important indicators of the quality and efficiency of modern solid household waste (SHW) management systems. The study is based on the analysis of the World Bank report «What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050» and examines the influence of objective geographical, demographic, and administrative factors on the choice and effectiveness of waste management strategies in different countries of the world, including Ukraine. Particular attention is paid to the relationship between the country's territorial area, population density, available land resources, and the implementation of recovery operations, including recycling, composting, and energy recovery. The research applies statistical, comparative, and analytical methods to evaluate existing SHW management schemes in countries with different territorial and demographic characteristics. The obtained results demonstrate that countries with large territories and relatively low population density, such as Ukraine, Canada, Russia, India, and Mexico, tend to use predominantly linear waste management schemes based on waste collection, transportation, and landfill disposal. In these countries, the proportion of waste disposed of in landfills usually exceeds 65%, while recovery operations remain at a relatively low level. The availability of extensive land areas often delays the implementation of more advanced and environmentally sustainable waste processing infrastructure. In contrast, countries characterized by smaller territories and higher population density, such as Germany, Sweden, Japan, France, Italy, and Great Britain, demonstrate significantly higher rates of SHW recovery, reaching 75–95% of total waste management operations. These countries actively apply circular waste management principles, where materials are repeatedly returned to economic circulation through recycling, reuse, composting, and other recovery processes. The study confirms that high population density combined with limited territorial resources creates strong economic and environmental incentives for the transition from linear to circular waste management models. Special attention is devoted to the current situation in Ukraine, where the dominant approach remains landfill-oriented waste management. The environmental and public health risks associated with this model are analyzed, including the accumulation of uncontrolled dumps and insufficient development of recycling infrastructure. The paper emphasizes the importance of implementing the principles of extended producer responsibility (EPR), improving state regulation, attracting investments, and creating new organizational and economic mechanisms for the development of the circular economy.*

Key words: *materials recycling, solid household waste, extended producer responsibility, SHW management scheme.*

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ОЦІНЮВАННЯ ЕФЕКТИВНОСТІ УПРАВЛІННЯ ТВЕРДИМИ ПОБУТОВИМИ ВІДХОДАМИ НА ОСНОВІ ПЕРЕРОБКИ МАТЕРІАЛІВ: ВПЛИВ ТЕРИТОРІАЛЬНИХ ТА ДЕМОГРАФІЧНИХ ФАКТОРІВ

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Резюме. Досліджено переробку матеріалів як один з найважливіших показників якості та ефективності сучасних систем управління твердими побутовими відходами (ТПВ). Дослідження базується на аналізі звіту Світового банку «Що за відходи 2.0: Глобальний знімок управління твердими відходами до 2050 року» та розглядає вплив об'єктивних географічних, демографічних та адміністративних факторів на вибір та ефективність стратегій управління відходами в різних країнах світу, включаючи Україну. Особливу увагу приділено взаємозв'язку між територіальною площею країни, щільністю населення, наявними земельними ресурсами та впровадженням операцій з утилізації, включаючи переробку, компостування та енергетичну рекуперацію. Застосовано статистичні, порівняльні та аналітичні методи для оцінювання існуючих схем управління ТПВ у країнах з різними територіальними та демографічними характеристиками. Отримані результати демонструють, що країни з великими територіями та відносно низькою щільністю населення, такі, як Україна, Канада, росія, Індія та Мексика, схильні використовувати переважно лінійні схеми управління відходами, засновані на збиранні, транспортуванні та захороненні відходів на полігонах. У цих країнах частка відходів, що захоронюються на полігонах, зазвичай перевищує 65%, тоді як операції з утилізації залишаються на відносно низькому рівні. Наявність великих земельних площ часто затримує впровадження більш просунутої та екологічно стійкої інфраструктури переробки відходів. На противагу цьому, країни, що характеризуються меншими територіями та вищою щільністю населення, такі як Німеччина, Швеція, Японія, Франція, Італія та Велика Британія, демонструють значно вищі показники утилізації ТПВ, досягаючи 75–95% від загального обсягу операцій з управління відходами. Ці країни активно застосовують принципи циклічного управління відходами, де матеріали неодноразово повертаються в економічний обіг шляхом переробки, повторного використання, компостування та інших процесів відновлення. Дослідження підтверджує, що висока щільність населення в поєднанні з обмеженими територіальними ресурсами створює сильні економічні та екологічні стимули для переходу від лінійних до циклічних моделей управління відходами. Особливу увагу приділено сучасній ситуації в Україні, де домінуючим підходом залишається управління відходами, орієнтоване на захоронення. Проаналізовано екологічні ризики та ризики для здоров'я населення, пов'язані з цією моделлю, включаючи накопичення неконтрольованих звалищ та недостатній розвиток інфраструктури переробки. У статті Наголошено на важливості впровадження принципів розширеної відповідальності виробника (РВВ), вдосконалення державного регулювання, залучення інвестицій та створення нових організаційно-економічних механізмів для розвитку циркулярної економіки.

Ключові слова: рециклінг матеріалів, тверді побутові відходи, розширена відповідальність виробника, схема управління ТПВ.

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Problem statement. In Ukraine, the problem of waste management, including solid household waste (SHW), remains unresolved. Unlike European countries, Ukraine has a very low level of SHW recycling and utilization and a high rate of waste disposal at landfills (On the Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the Period up to 2030, 2019). In 95 percent of cases, all of them are sent to landfills or dumpsites

(On the Recommendations of the Parliamentary Hearings on the Topic: «Priorities of the Environmental Policy of the Verkhovna Rada of Ukraine for the Next Five Years», 2020). A significant part of landfills is overloaded and does not meet environmental protection and sanitary standards.

The reasons for the growth of the above mentioned problems include, in particular, insufficient funding from state and local budgets for environmental protection measures, financing of such measures on a residual basis, the implementation of environmentally safe, resource- and energy-saving technologies, the development of renewable energy sources, and intangible natural resource use that occurs in unsystematic and excessively slow manner (On the Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the Period Until 2030, 2019).

In general, waste management is defined by the new framework law of Ukraine «On Waste Management» (hereinafter referred to as the Law). The latest key focus of this Law is the introduction, in accordance with European waste legislation, of the concept of extended producer responsibility (EPR), which is regulated by Article 10 of the Law.

In particular, it is determined that EPR is a set of economic, financial, administrative and organizational measures aimed at ensuring the responsibility of producers of certain types of products for managing the waste stage in the product life cycle. The components of the EPR system and the powers of the organization that carry out extended responsibility duties on behalf of the manufacturer or producers are indicated. The introduction of EPR is necessary because, according to World Bank forecasts, in 2025, urban residents will produce an average of 1.42 kg/person of SHW per day compared to the current 0.64 kg (Protsyk O., 2020).

Analysis of recent research and publications. The issue of solid household waste management was investigated by numerous scholars, including M. Malovany, M. Shchuryk, O. Nadraha, A. Serdiuk, H. Zhuk, Ye. Nikitin, A. Smikhula, K. Parpounas, V. Slabyi, T. Kolomychenko, O. Lototska, M. Dnistrianska and others.

The complexity of the SHW management situation in Ukraine compared to other developed countries is associated with large volumes of SHW generation and the lack of infrastructure for its management. This situation is influenced by several objective factors such as the availability of sufficient land for waste disposal, the time required to make the necessary decisions to implement a more energy-efficient and economically viable SHW management scheme, and relatively low population density. The consequences of the above mentioned objective reasons included the disposal of municipal solid waste (MSW) without consideration of potential hazardous impacts on the environment and human health, the inadequate level of waste utilization as secondary raw materials due to imperfect organizational and economic mechanisms for their integration and the lack of state funding for the creation of the network of infrastructure facilities for the processing and utilization of SHW as a separate sector of the national economy (On the Recommendations of Parliamentary Hearings on the Topic: «Priorities of the Environmental Policy of the Verkhovna Rada of Ukraine for the Next Five Years», 2020).

These objective factors also influence waste management in other countries of the world. The investigation of the data based on the World Bank report «What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050» (Parpounas K., Slabyi V., 2021) was carried out in order to assess the impact of these objective factors, particularly, the country's land area and population density, on the complexity of measures for SHW processing during its management in key developed countries of the world and in Ukraine. The impact of population density on SHW generation is highlighted in the papers by O. Lototska and others (Lototska O., Dnistrianska M., Krytska H., Flekei N., Smachylo O., 2023).

During the course of the investigation, statistical, information retrieval, analytical and comparative methods of the investigation of the actual data obtained from the report with the construction of corresponding supporting figures of dependency diagrams were used. Well-known data regarding the land areas of countries and their population was taken from available Internet sources.

Purpose of the study. The purpose of the study is to determine the influence of territorial and demographic factors on the efficiency of solid household waste management systems and to assess the role of materials recycling as an indicator of the transition from linear to circular waste management models.

Statement of the task. The tasks of the study are to analyze the relationship between the country's land area, population density, and the level of solid household waste recovery; compare linear and circular waste management schemes in different countries; identify the main limitations of the current waste management system in Ukraine; and propose a circular SHW management scheme based on the principles of sustainability development and extended producer responsibility.

Statements of the main material of the study. Among the countries mentioned in the report, the USA, Russia, Mexico, Ukraine, China, Canada, Sweden, Poland, Great Britain, France, Italy, India, Germany, Japan, we highlight a group of countries with large land areas (over 0.5 million km²) and low population density (up to 100 people/ km²), namely the USA, Russia, Mexico, Ukraine, China, Canada, India. Dependence of the percentage of landfill disposal operations for SHW on the land area of countries is shown in Figure 1.

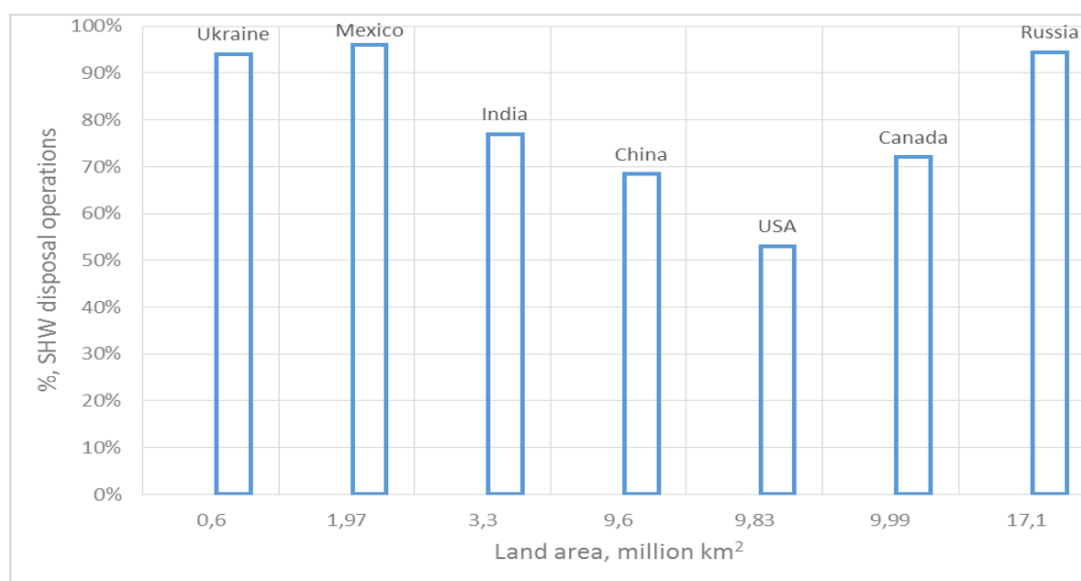


Figure 1. Dependence of the percentage of landfill disposal operations for SHW on the country's land area (over 0.5 million km²)

We observe that in most countries the percentage of SHW sent to landfills exceeds 65%. The only exception is the USA, where this figure is somewhat lower, at 53%. Thus, we can see that the presence of the large territory does not stimulate the above-mentioned countries to manage SHW through recovery or recycling initiatives.

The group of the rest countries from the list with smaller land areas, specifically less than 0.4–0.5 million km² (Great Britain, Italy, Poland, Germany, Japan, Sweden, France is shown in Figure 2.

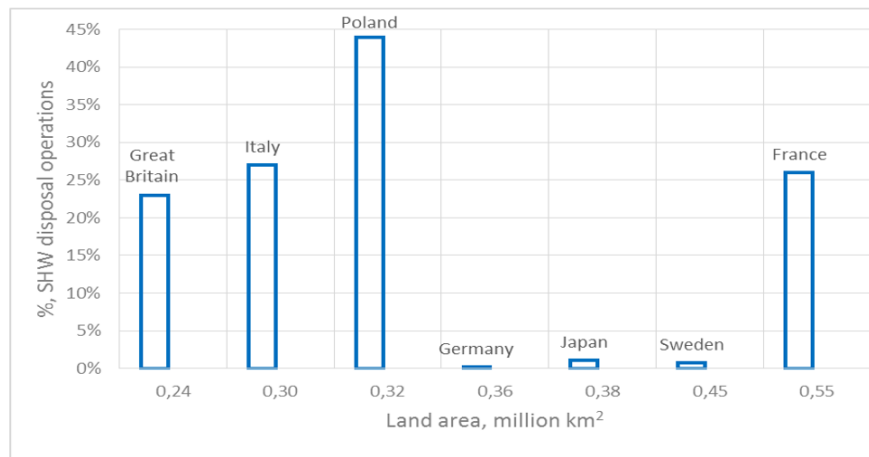


Figure 2. Dependence of the percentage of landfill disposal operations for SHW on the country's land area (less than 0.4–0.5 million km²)

Here we observe in a number of countries (Germany, Japan, Sweden) the percentage of waste sent to landfills is very low (0.2–1.1%) while in others (Great Britain, Italy, France) it is somewhat higher (22–26%). Only Poland stands out from the general trend, as it disposes of more than 44% of its SHW in landfills. Thus, the analysis of the presented data indicates that it is obvious that the sharp reduction in the country's land area, and therefore the possibilities (free and environmentally safe areas of the territory) for the SHW disposal, significantly reduces the percentage of their disposal. In this case, we observe a significantly lower percentage of SHW disposal operations. In our opinion, a powerful factor that encourages the national economies to implement recovery operations, including materials and waste recycling, in the course of waste management is the high population density with a relatively small area of the state's territory. In order to preserve and maintain the proper living environment for the population and safeguard public health, the implementation of comprehensive waste processing measures and the percentage of SHW recovery operations during their management sharply increases significantly.

SHW recovery operations include a range of measures such as materials and SHW recycling, incineration, composting (biological recovery of matter), and other related activities. In fact, the percentages of SHW recycling operations indicated below reflect the quality of materials and SHW management in a particular country. The dependence of the percentage of SHW recovery operations on population density for countries with more than 100-200 people/km² is presented in Figure 3.

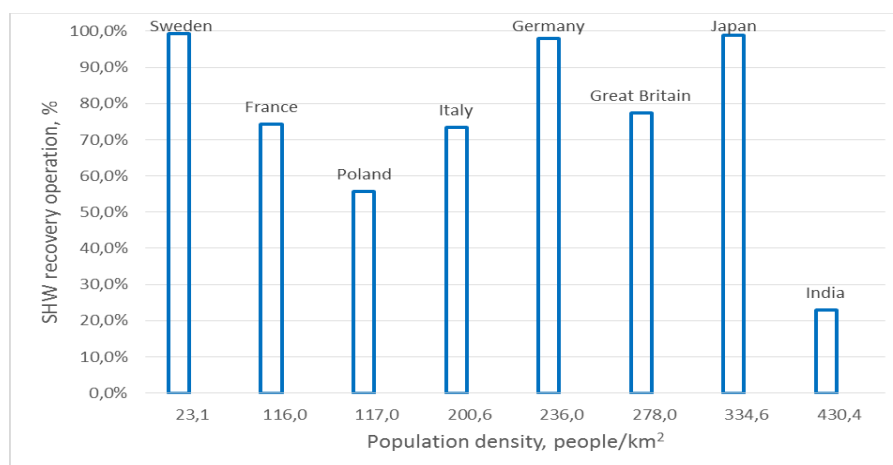


Figure 3. Dependence of the percentage of SHW recovery operations on population density for countries with more than 100-200 people/km²

Here we observe that more than 95% of SHW recovery operations are carried out in Sweden, Germany, and Japan, over 75% of MSW recovery – in France, Italy, and Great Britain, and slightly less in Poland – 56%. The notable features of recovery operations in these countries are that in Sweden, preference is given to incineration (51.2%), and in Japan, to composting (80.2%). In the rest of the countries, the volume of recycling and composting activities significantly exceeds those of SHW incineration. India is dissonant in the overall picture of SHW management. Here, despite the highest population density (430.4 people/ km²), 77% of SHW is sent to landfills and only 23% is directed to recovery operations, including recycling (5%) and composting (18%). It is evident that in this country the low percentage of SHW recovery operations is due to the advantage of the objective factor – aids large land area, which covers nearly 3.3 million km².

The dependence of the percentage of SHW recovery operations on the population density of the country (less than 100 people/ km²) is shown in Figure 4.

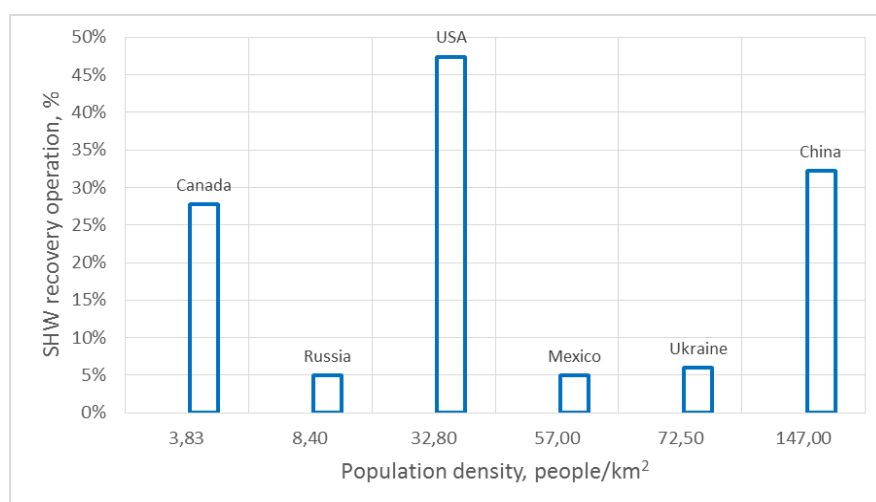


Figure 4. Dependence of the percentage of SHW recovery operations on the population density of the country (less than 100 people per km²)

In Figure 4, Russia, Mexico, and Ukraine have approximately 5% of SHW recovery operations, while Canada and China around 30%, only in the USA, as a highly industrialized country, the percentage is slightly higher – 47%. Thus, a large territorial area does not incentivize countries with extensive land areas to develop infrastructure facilities for SHW processing. Due to their low population density, there is no urgent need for this, that is, the ecological capacity of the territory makes it possible to postpone the solution to this problem. They still have time for this and, let's hope, the necessary opportunities in the future.

The investigation shows that in the above-mentioned countries as well as in Ukraine, the following linear SHW management scheme prevails: SHW collection – transportation – disposal.

Typical linear SHW management scheme is presented in Figure 5.



Figure 5. Typical linear SHW management scheme

It should be noted that in the above-mentioned simple scheme, the key role in Ukraine is played by transport companies (Kolomychenko T., 2021), which act as business entities in the field of waste management. The functioning of the linear SHW management scheme is facilitated

by the system of municipal tariff formation different from that in the European Union – where the tariff is linked to the cubic meter of waste, and by general sanitation and waste collection rules established by local self-government bodies (LSGs) (Kolomychenko T., 2021).

As a result, there is a large difference between the amount of SHW actually collected from the population and that delivered to the landfill. That is, a decision is made by business and consumers, which, with the tacit consent of LSG, is used by transportation companies to make profit. Transportation companies have high profits and wages, while the population faces further environmental pollution in their living areas, with a consequent increase in health risks. Still there are no dangerous levels of direct harmful impact on the population, because the areas under the jurisdiction of LSGs are large. Therefore, in our opinion, a kind of temporary balance of interests arises that suits all parties involved. And no one is responsible for this pollution.

The benefit for businesses in Ukraine of using a simplified linear SHW management scheme is also evidenced by the significant number of people wishing to be engaged in this activity. For example, in Lviv, 5 transport companies receive money from the city budget for SHW transporting, in Kyiv – 6, only in Kharkiv, which is considered to be the cleanest city in Ukraine, this process is more organized and 2 transport companies are engaged in activity (Kolomychenko T., 2021).

Regarding the awareness of the importance of solving the problem of SHW management and the willingness of the Ukrainian population to participate in waste management, in particular, in its separate sorting, a survey conducted among residents of the cities of Ternopil and Vinnytsia provides evidence (Lototska O., Dnistrianska M., Krytska G., Flekei N., Smachylo O., 2023). The survey showed that 99% of respondents are willing and ready to sort SHBW, but they want the conditions for this to be created in the cities where they live. That is, the necessary infrastructure for proper SHW management to be created.

In contrast, in countries with high population density (Sweden, Germany, Japan, France, Italy, Great Britain, Poland), such balance no longer exists. It is vitally important to maintain the living environment for the population in proper condition and the necessary level of public health. The urgency of the problem is indicated, in particular, by the fact that political parties with environmental focus, or those supporting state activities in the field of environmental protection, have significant influence on the political life of these countries.

In these countries, the circular SHW management scheme is used in accordance with the waste management hierarchy with the necessary infrastructure for SHW processing: SHW collection – transportation – product reuse – waste recycling – use of the obtained materials and substances – and collection again.

Let us present the proposed circular SHW management scheme in Figure 6.

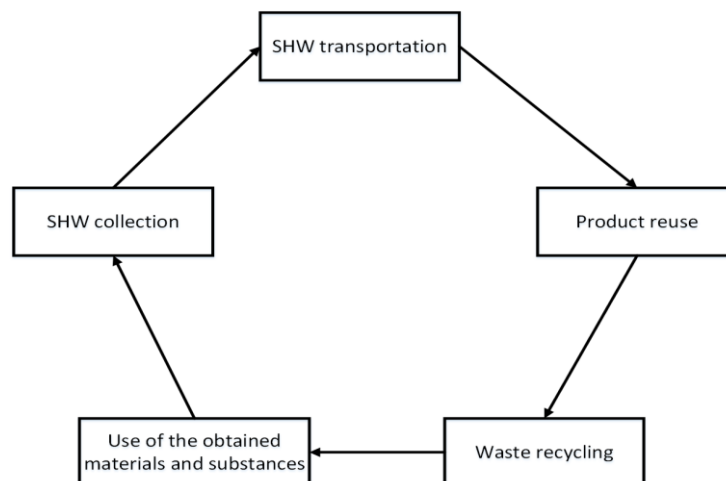


Figure 6. Circular SHW management scheme

The proposed scheme ensures increased operational efficiency in SHW management, and, consequently, significant depth of their processing, which confirms the statement that in the countries of the European Union their economies have a closed-loop nature (Polianska A., Stepaniuk H., 2020), are renewable, regenerative in nature, and the fact of waste generation indicates an incomplete cycle of technology from product production to waste recycling (Shchaslyva L., Pashkov A., Sprynska H., 2018).

Therefore, the dominant method of SHW management in Ukraine is its collection and disposal in landfills and dumps. At present, Ukraine ranks ninth in the world in terms of waste generation per capita. In 95 percent of cases, all of it ends up in landfills or dumps. In addition, due to insufficient control or the absence of an adequate MSW management system, over 27,000 unauthorized dumps are created each year (On the Approval of the National Waste Management Strategy in Ukraine until 2030, 2017). All this requires radical changes aimed at the implementation of a circular economy in Ukraine, which would significantly reduce the risks of harmful effects of waste on the environment and deterioration of public health. In the future, in our view, the latest trends in SHW management, depending on the types of management and the corresponding volumes of waste, are interesting and promising areas for research.

Conclusions. Based on the data of the carried out investigation, the following conclusions can be drawn. Countries (Mexico, India, China, Canada, the USA, Russia), including Ukraine, which have large territories with low population density, dispose more than 65% of SHW in landfills or dumps, they have a recovery rate of 5–30%, and use a simplified linear SHW management scheme. They currently do not face significant problems regarding living conditions or public health. Conversely, in countries (Sweden, Germany, Japan, France, Italy, Great Britain, Poland) with small territories, high population density, low percentage of SHW disposal to landfills or dumps (0.2–26%), and 75–95% of operations devoted to SHW recovery, a circular SHW management scheme is used.

In our opinion, for countries operating a linear SHW management scheme, the key to solving the problem of effective SHW management is the introduction of EPR, which would bring new business entities into the waste management sector, responsible for SHW management, whose purpose would be to implement a set of measures ensuring the responsibility of producers of certain types of products for managing the waste stage in the product life cycle, rather than merely making profit. All this should be done without waiting for the balance in the interests of the parties involved in SHW management to shift over time as a result of sharp deterioration in living conditions and public health in a given country.

In general, the new law should require that financing of waste management activities must be carried out at the expense of waste generators and owners. However, it is allowed to finance these activities, attracting funds from the state and local budgets. In our opinion, this will be the main source of financing in Ukraine over the next decade, as well as attracting funds from investors and grants from the European Union, the USA, Great Britain, Canada, Japan, Sweden, Norway and other leading countries in this field.

This conclusion is based on the fact that it is necessary to consider that, under martial law, with active combat operations taking place in several regions of Ukraine, there is a sharp increase in unemployment, widespread impoverishment of the population, decline in production volumes, and reduction of more than 40% in Ukraine's gross national product. Additionally, it takes into account that paragraph 1 of part three of Article 10 of the new law, regarding the complete implementation of the Extended Producer Responsibility system, will only come into effect seven years after the new law establishes the extended producer responsibility. It is possible that this period may be extended.

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