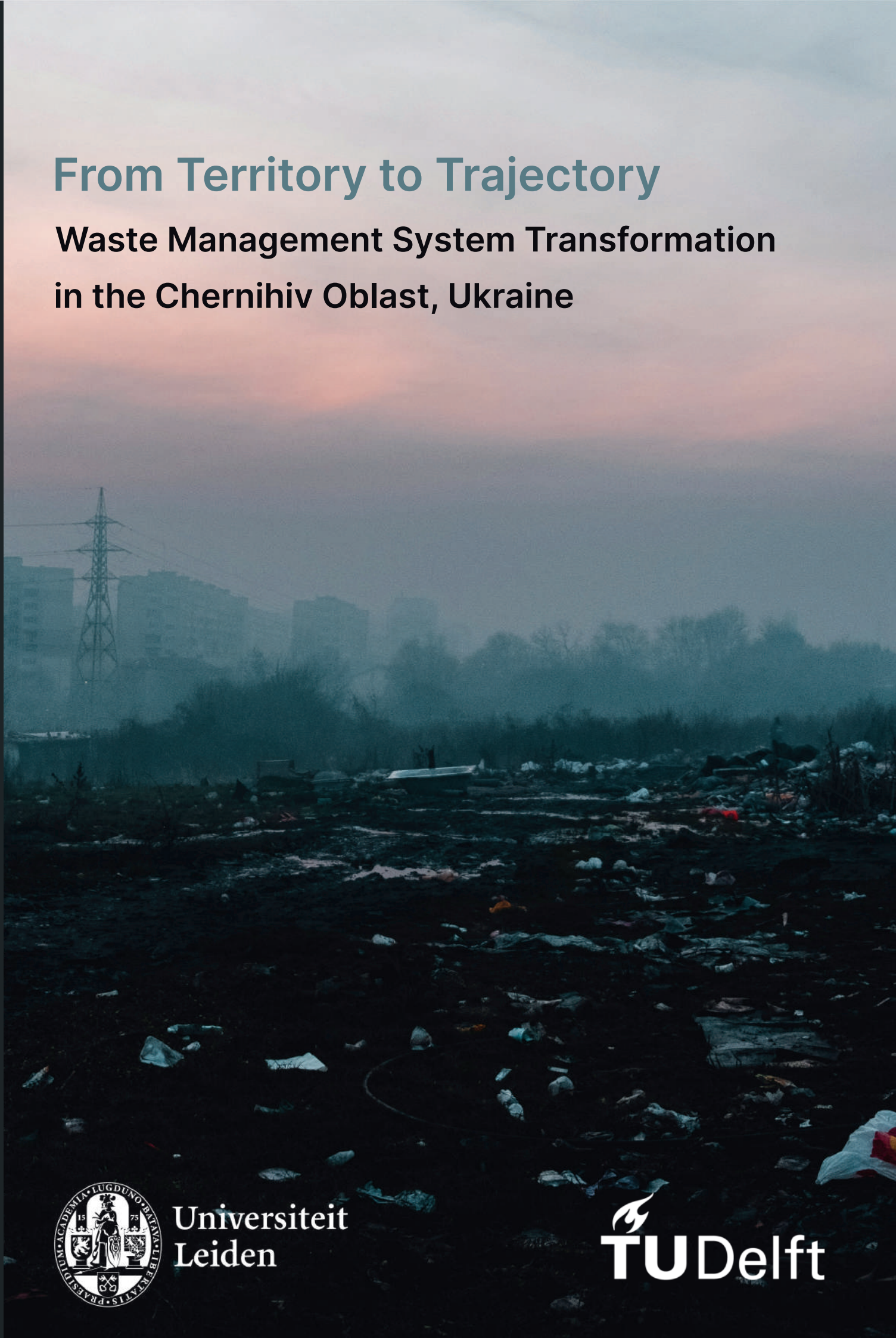
Kashtalian Oleksii Kashtalian Oleksii Kashtalian Oleksii Kashtalian Oleksii Kashtalian Oleksii

From Territory to Trajectory

Waste Management System Transformation in the Chernihiv Oblast, Ukraine



Universiteit Leiden

TU Delft

From Territory to Trajectory:
Waste Management System Transformation in the Chernihiv Oblast, Ukraine

Thesis

submitted in partial fulfilment of the requirements

for the degree of Master of Science

at Leiden University and Delft University of Technology

in Industrial Ecology

Author:	Oleksii Kashtalian
Student ID:	3961400 / 6119212
1st supervisor:	Dr. A. Ersoy
2nd supervisor:	Dr. H. Ward

July 29, 2024

Table of contents

List of figures

List of tables

List of abbreviations

WMS	Waste management system
EU	European Union
EPR	Extended producer responsibility
NGO	Non-governmental organization (civil society organization)

Executive summary

Unsustainable waste management systems, including waste dumping, burning, and littering, are significant challenges in the modern era. These unsustainable waste management practices impact regional development by posing a threat to environmental, social, and economic growth. The hazardous contaminants released from waste burning or unprotected disposal have a destructive impact on both human health and the environment, causing habitat damage, climate change, and disease transmission. Furthermore, unsustainable waste management systems contribute to resource depletion and emissions of greenhouse gases and, as a result, the acceleration of global warming. Regarding the financial aspect, unsustainable waste management systems place pressure on local governments and communities by diverting resources that could have been used in educational and health sectors, damaging the regional economy, increasing healthcare costs, and causing higher resource expenditures and productivity losses.

As a case study, this thesis project examines the waste management system in the Chernihiv Oblast, Ukraine. The key objective is to provide a transformational strategy for the regional waste management system by addressing the central research question: "How can the waste management system in the Chernihiv Oblast be transformed to address regional sustainability challenges?" As a result, the research employs an exploratory case study method that guides the analysis of the current state of the waste management system, examines effective systems within the European Union, and tailors these practices and initiatives to the local context.

The method helps identify the region's challenges and prospects for the transformation towards a sustainable waste management system. The primary issues include underdeveloped infrastructure, limited funding, and low public awareness and participation. The present waste management system entails unsorted waste collection and landfilling with little or no consideration for recycling or resource recovery, which, as a result, has adverse effects on the environment, public health, and resource efficiency.

The study of the European Union's systems and practices reveals that member states have holistic and long-term strategies for the waste management sector. In general, the European Union can be described as having a sound regulatory environment, technology advancement, and high citizen engagement. The key initiatives include extended producer responsibility,

advanced waste sorting and treatment technologies, and circular economy principles, which have demonstrated significant results in improving resource preservation.

As a result, the research provides relevant recommendations to national and regional governments that can contribute to the further transformation of the Chernihiv Oblast's waste management system. Moreover, such recommendations seek to contribute to the overall development of the waste management sector, where the transformation is viewed as both necessary and gainful. It is possible to build and implement a sustainable waste management system by learning from the European Union's challenges and implementing the most effective techniques. In a nutshell, this transformation requires the definition of clear environmental, social and economic values, the implementation of modern waste sorting and treatment technologies, market and government support, and, most importantly, a collaborative contribution from the stakeholders. Altogether, this will allow for long-term resource efficiency and sustainability, thereby improving the Chernihiv Oblast's environment, economy, and social well-being.

Keywords: waste management system, system transformation, regional development, circular economy, sustainable development

Chapter 1 – Introduction

With the large quantities and complexity of waste generated by current economies, serious threats are posed to ecosystems and human health. Each year, approximately 11.2 billion tonnes of solid waste is collected globally, and the decay of the organic waste fraction results in about 5 percent of global greenhouse gas emissions (United Nations Environment Programme, n.d.). Waste from electrical and electronic equipment along with newly developing and complex hazardous substances, creates a faster-expanding challenge for both developed countries and developing nations (United Nations Environment Programme, n.d.).

Furthermore, from the "I=PAT" formula that describes the impact of human activity on the environment, the generated amount of waste can be defined by the population size, affluence and technology (Chertow, 2008), which are continuously developing. Economic growth and improved level of life alongside consumerism increase the challenge of waste management systems (WMSs) in various regions worldwide, which is also harshened by expected population growth to 8 billion people by 2025 and 9.3 billion by 2050 (Abubakar et al., 2022). In developing countries, the amount of collected waste equals 50%-80%, with 80%-95% of budget expenditures on waste collection and transportation (Abubakar et al., 2022). Most low-income nations collect less than 10% of the generated waste (Abubakar et al., 2022). In summary, increased rates of generated waste and the lack of waste recovery processes contribute to the emergence of problems with public health, leading to environmental hazards and economic burdens (see Section 1.2), resulting in the acute necessity of improving existing WMSs.

1.1 Impacts of unsustainable waste management systems on regional development

Generally, WMS refers to all actions and plans directed to manage waste, from its generation to its final disposal (Stewart, 2010). A number of regions around the world lack sustainable practices within their WMSs, posing a significant challenge to regional development. Unsustainable WMSs are typically associated with the absence of waste sorting and treatment processes, together with disordered waste disposal, all of which have negative environmental, social, and economic consequences (Abubakar et al., 2022). These practices may include unprotected waste disposal, littering or open waste burning (see Figure 1), posing such issues as contamination of air, water, and land (Abubakar et al., 2022), thus, harming human health

and ecosystems. Furthermore, these practices contribute to such challenges as habitat damage, global warming, and disease transmission (Abubakar et al., 2022). On top of that, unsustainable WMSs can overload local infrastructure and resources, impede economic growth, and reduce overall regional sustainability (Abubakar et al., 2022).

Figure 1. Unsustainable waste management - unprotected waste disposal, littering and open waste burning (from You et al., 2020; Standard, 2019; Clean Water Action, 2018)

In fact, unsustainable WMSs lead to resource depletion and environmental pollution. A lack of resource recovery from waste streams through waste treatment and reuse results in material losses, which are then disposed of in landfills or incinerated (Abubakar et al., 2022). These practices worsen resource scarcity, increase energy consumption, and result in increased greenhouse gas emissions associated with raw material use due to increased extraction and refining of natural resources, harming the environment and contributing to climate change (De Haes et al., 2024). In addition, waste dumping can contribute to severe environmental damage across regions, since waste dumping occupies large areas of land, where soil and groundwater might be polluted with hazardous waste substances (Siddiqua et al., 2022). Such practice as open incineration puts danger to the surrounding environment and biodiversity, when harmful pollutants are released into the atmosphere, causing water, soil, and air pollution with CO_2 and toxic metals (Siddiqua et al., 2022).

A lack of sustainable WMSs also presents serious health risks to those living in the area. Unsustainable WMSs can produce a favourable environment for the reproduction of disease vectors such as flies, mosquitos and rats, increasing the risk of vector-borne diseases such as malaria or typhus (Omang et al., 2021). Furthermore, dumping and open waste burning emit harmful chemicals and particulate matter into the atmosphere, soil, and groundwater (Omang et al., 2021), where such residue might enter the food chain via crops or animal-based products. Furthermore, leakage from landfills can contaminate water supplies, causing waterborne diseases like cholera and infectious dysentery (Omang et al., 2021).

Moreover, unsustainable WMSs pose a significant financial burden on local governments and communities. The costs of waste collection, transportation, and disposal are relatively high, particularly in locations with poor infrastructure (Abubakar et al., 2022). Municipalities might be forced to redirect funds from other critical public services, such as education, healthcare, and infrastructure development, to waste management services (Matheson, 2019). Ultimately, unsustainable WMSs can strain local economies and increase economic costs connected with environmental degradation and public health consequences (Matheson, 2019). For instance, unsustainable practices might result in an increase in healthcare charges and loss of productivity (Matheson, 2019). Lastly, unsustainable WMSs can impact citizens' livelihoods and put regional food security at risk when polluted with wastewater bodies threaten the fish population (Bashir et al., 2020).

1.2 Sustainable waste management systems

On the contrary, sustainable WMS is often viewed as an integrated effort with a number of interconnected activities and practices aimed at reducing the harmful effects of waste on the social, environmental and economic aspects (Iacovidou et al., 2020). Sustainable WMSs typically include processes such as sorting, collection, treatment and disposal of waste materials, where waste, based on its composition, can be classified into paper, plastic, coloured and transparent glasses, metals, organic, hazardous and electronic wastes, etc (Stewart, 2010). Furthermore, such sustainable WMSs integrate practices aimed at waste reduction, reuse or rethinking and initiatives like extended producer responsibility (EPR) or circular product design to minimize the harm caused by generated waste and redistribute responsibility over it (Rubio et al., 2019).

In addition, sustainable WMSs are an integral component of a circular economy concept. This approach seeks to balance the consumption of limited resources and the challenges of the take-make-waste paradigm (Bandh et al., 2024). Sustainable WMSs address the challenges posed by a linear consumption society by offering direct solutions to various waste-related problems, which include reducing landfills through waste recovery programs and promoting the reuse of materials in manufacturing processes (Bandh et al., 2024). This might include implementing composting initiatives for organic waste that can significantly reduce waste sent to landfills or incentivising the implementation of reusable packaging (Bandh et al., 2024).

Sustainable WMSs can be aggregated into five processes comprising waste generation (together with sorting at the source), collection, post-sorting, resource recovery, and final disposal. An example of the waste management processes is presented in Figure 2 and elaborated in detail in Table A.

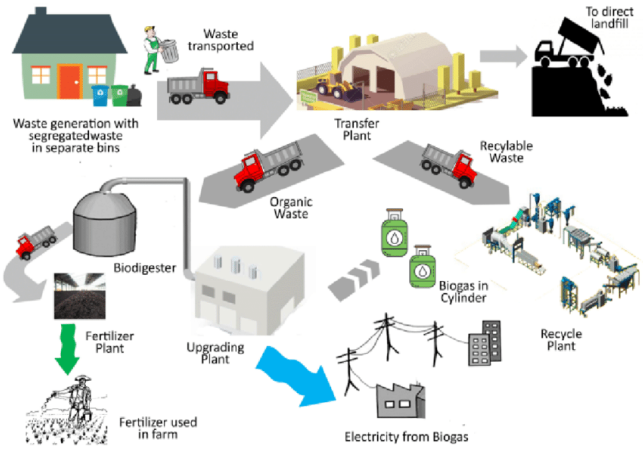


Figure 2. Waste management stages (from Maharjan and Lohani, 2020)

1.3 Waste management challenges with a focus on the Chernihiv Oblast

As a continuum from the introduction of the broader scope of waste management principles and challenges, this section contextualises them with the unique landscape of Ukraine, specifically the Chernihiv Oblast. While many regions are facing the problem of unsustainable WMSs, Ukraine has its own set of challenges (Kovalenko et al., 2022). Regarding Ukraine, sustainable waste management techniques are at a relatively low stage of development and are currently being hampered by a number of challenges that impede the progress towards their implementation (Kovalenko et al., 2022). The most urgent issues for the WMSs are the

lack of proper ecological education and a shortage of suitable infrastructure (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2019). Low recycling rates are caused by underdeveloped and inaccessible facilities and programmes, followed by financial factors (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2019). As a result, it limits demand for waste recovery strategies since the profitability is questionable (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2019). These issues originate from an ineffective system of financial incentives and insufficient support for promoting effective natural resource use (Kashtalian, 2020). Apart from this, the current goal of the ecology regulatory sector is to combat issues that have already arisen rather than avoid them, which prevents the decision to implement sustainable waste management practices (Kashtalian, 2020).

Along with the multiple difficulties mentioned above, the Chernihiv Oblast will become the centre of the WMSs research in Ukraine. The region, combined with the general challenges of Ukraine, has its specific set of problems related to its socio-environmental situation (Kashtalian, 2020). In 2020, the Chernihiv Oblast already faced a number of ecological challenges, including waste management, alongside limited funding for environmental initiatives; social issues that comprise population decrease and low household income; and also lagged behind in economic growth due to poor financial indicators (Kashtalian, 2022).

Concerning regional WMS, the 2021 report “Regional Waste Management Plan of the Chernihiv Oblast”, states that a critical issue for the region is the mismatch of waste generation and disposal rates (Derii et al., 2021). During the studied period, an average of solely 1/6 of the volume of generated waste was subject to proper disposal each year (Derii et al., 2021). This quantity is lower than the all-Ukrainian average and reveals a critical fall. Additionally, a considerable growth in waste amount was observed in 2010 – 2015, with an average annual growth of 18.8%, which was followed by a slowdown after 2015, with an average yearly decline of -5.36% since 2015 (Derii et al., 2021). Another critical regional issue is waste accumulation, where the amount of accumulated waste per person is growing rapidly. On average, the annual growth rate was 4.8% (Derii et al., 2021). In 2010, one resident of the region accounted for 8.0 tons of accumulated waste, and in 2019, 12.2 tons, which is 52.5% more than in the base year (Derii et al., 2021).

Moreover, landfilling is the leading waste management practice, with incineration only serving as a subsidiary (Derii et al., 2021). It is relevant to mention, that most landfill facilities already exceed 60% capacity implies systematic inefficiency in the WMS (Derii et al., 2021). However, even in areas with a low level of loading of landfills, there are general regional problems of waste management infrastructure: there are no special environmental protection facilities, no ecological monitoring systems, waste is collected unsystematically, compaction and dusting are not carried out in a timely manner or are not carried out at all (Derii et al., 2021). The insufficient number and technical condition of specialized equipment (see example in Figure 3) generally endanger the waste disposal process in most district centres. On top of that, the region does not have proper facilities solely designated for e-waste, used tyres, and medical waste disposal, contributing to these sectors' particular issues (Derii et al., 2021).

Figure 3. Chernihiv landfill (from Serhiy Prima, 2017)

Additionally, there are a number of complementary challenges the region is facing after the war actions between February 24 and April 3, 2022, which comprise increased air, water, and soil contamination, higher resource costs, lower capital investment ratings, and a decline in entrepreneurial activity (Leclerc, 2023). Over the years, the negative impact of war actions has deepened these existing challenges, especially in the waste management sector, with the appearance of war waste in the form of destroyed buildings and infrastructure (see Figure 4), explosive materials or other civil goods (UNDP, 2023).

Figure 4. War waste in Chernihiv from the war actions (from Vlasova at al., 2024; Zinets & Humphries, 2022; Buzovska, 2023; Reuters, 2023)

Altogether, this highlights the urgent need for intervention, upgrading waste management infrastructure, implementing waste treatment practices, and establishing dedicated facilities for specific waste categories, including newly emerged war waste. Within this investigation, it would be vital to explore the complexity of the WMS transformation in the Chernihiv Oblast, through which the region's peculiarities could be addressed and the ways for sustainable development could be uncovered.

1.4 Transformative nature of the development of waste management systems

Understanding the implications of sustainable WMS implementation will help chart transformation strategy and assess its contribution to regional growth. WMS transformation refers to a radical shift from traditional WMSs, which are based mostly on business-as-usual waste management approaches, and towards more sustainable and holistic practices that view waste as a source (Shukla & Khan, 2022). A conventional WMS paradigm primarily focuses on waste collection, transportation, and disposal, whereas environmental issues, resource recovery, and long-term sustainability have little attention (Parajuly et al., 2020). Such a linear model mainly manages the flow of waste through disposal, primarily landfilling and incineration (Shukla & Khan, 2022), which has a negative impact on the environment, the circulation of natural resources, and also on public health (see Section 1.2).

In contrast, a transition towards sustainable WMS goes beyond solely technology framework and involves transforming behaviours, legislation and approaches from a linear to a circular economy. To achieve the primary aim of this approach, waste management companies, governments, businesses, civil society organisations and the general public have to focus on waste reduction, reuse, recycling, and materials recovery to boost resource efficiency and protect the environment (Seadon, 2010). In addition, such transformation requires developing infrastructure improvements and establishing legislation (Seadon, 2010) to encourage the use of sustainable ways to managing waste along the whole waste value chain. Therefore, this study attempts to encourage systemic change and strengthen resilience to future sustainability challenges by allowing stakeholders to engage in the transformation process actively.

Furthermore, this study's transformative nature arises from its multidisciplinary and systems-thinking approach (OECD & International Institute for Applied Systems Analysis, 2020), which recognises the interdependence of indigenous and exogenous elements of WMS. This thesis project aims to develop a contextually suitable WMS transformation plan in the Chernihiv Oblast by combining local context, socioeconomic concerns, and environmental considerations. As a result, this research aims to be transformative by providing an inclusive and holistic solution that combines both indigenous (regional characteristics of the WMS) and exogenous factors (general agenda for transforming towards sustainability) to create a more sustainable WMS in the Chernihiv Oblast.

1.5 Research objectives and questions

The role of the local context becomes essential for the development of WMSs (Anuardo et al., 2022). Proper knowledge of the regional socio-economic state, WMS and general environment characteristics is critical for the provision of adequate waste management solutions that will consider the needs and challenges of the region (Perkumienė et al., 2023). For instance, waste collection systems and recycling facilities in highly populated urban zones typically have to treat large waste loads; however, a decentralized method of waste treatment in rural areas might be needed as in such areas access to infrastructure might be limited (Vinti & Vaccari, 2022). In addition, socioeconomic attributes, primarily incomes and cultural features have impacts on waste generation and resource recovery behaviour levels. For example, the regions with high incomes tend to have higher levels of waste generation, where cultural peculiarities

might negatively impact citizens' attitudes towards the adoption of sustainable waste management practices (OECD, 2019).

Second, in order to cover WMS issues in the Chernihiv Oblast, there is a need to analyse the most effective waste management practices to reveal a concrete transformation strategy for the regional WMS. Considering Ukraine's present attempts to become a part of the European Union (EU), the EU's waste management directives are crucial for the attainment of sustainable development goals and the creation of harmonious relations with the European partners (Prysiazhniuk & Chechulina, 2023; Environment People Law, 2022). Since Ukraine, primarily the Chernihiv Oblast, lacks in waste management sustainability and overall seeks to comply with EU standards, a thorough examination of the EU WMSs and techniques becomes inevitable. Therefore, this study will conduct a comprehensive investigation of waste management practices, policies, other initiatives, and significant components that have been adopted by the EU member states. To get a more comprehensive understanding of Ukraine's geographical position and the specific location of the Chernihiv Oblast in relation to the European Union, refer to Figure 5.

Figure 5. Geographical position of the Chernihiv Oblast, Ukraine and the European Union (adapted from Wikimedia Commons, 2020)

The assessment of the EU WMSs will serve as a foundational pillar for developing a transformation strategy for the WMS in the Chernihiv Oblast. This detailed assessment will allow for an identification of the sustainable solutions suitable to meet regional challenges,

setting the way for a targeted transformation strategy. By studying and embracing EU waste management practices, Ukraine can facilitate knowledge transfer, technology exchange, and partnerships, thereby enhancing collaboration in addressing shared environmental concerns and fostering mutual understanding with EU counterparts.

The research question arising from the previously noted objectives is: “How can the waste management system in the Chernihiv Oblast be transformed to address regional sustainability challenges?” As a result, this study will aim to reveal critical elements of the current state of the WMS in the Chernihiv Oblast, providing insights into the regional features; an assessment of the most effective practices and WMSs across European Union member states; and finally present a concrete strategy for the WMS transformation in the region with recommendations directed on the regional and national governments.

Since drawing a transformational strategy for the WMS in the Chernihiv Oblast will involve exploration into the diverse set of waste management elements and systems, this will require decomposing the main research question into three subgroups:

The first dimension seeks to give an overview of the local context of the WMS in the Chernihiv Oblast. Therefore, this will include such research sub-question as “What are the actual state and main barriers hindering the development of sustainable waste management system in the Chernihiv Oblast?”

In addition, this study will seek to identify and introduce the European Union’s best practices in the waste management sector. This dimension will be addressed by the following research sub-question: “What constitutes the most effective waste management systems across European Union member states?”

Having taken a European Union approach into account, this study will explore the application process of the EU waste management practices to the regional WMS. This objective will be investigated by posing the question: “How can the European Union practices be applied to transform the Chernihiv Oblast’s waste management system?” Ultimately, the outcomes of these research questions are expected to play a significant role in shaping policies, encouraging stakeholders’ involvement, and introducing modern approaches to waste management, thus supporting decisions that will collectively maintain sustainability and resilience for the region.

Chapter 2 – Literature review and conceptual frameworks

The literature review provides a more in-depth examination of the significant elements of sustainable WMSs and clarifies the research frameworks that will guide the study in assessing the current state of the WMS in the Chernihiv Oblast, emphasising the importance of learning from well-functioning models from the European Union, and focusing on the step-by-step transformation strategy for the regional WMS.

2.1 Essential elements for the waste management system transformation

When regions lack sustainable WMSs, supporting their transformation towards modernisation and improvement is crucial. First, the current state of WMSs should be assessed to identify weaknesses and potential areas for enhancements (Adeleke et al., 2021). This is typically focused on the evaluation of existing practices, comprising the efficiency of sorting, treatment and recycling plants and other infrastructure for managing waste. Another area of emphasis is the investigation of the regulatory framework and the governance concerning WMSs across different levels, such as regional and national, where the primary focus is their capability to support and promote sustainable attitudes (Bonnet et al., 2023). Also, it is crucial to realise the levels of consciousness on waste management issues among a diverse set of stakeholders and to which extent they are involved in such activities (Rosilawati et al., 2023).

The increasing amount of waste globally, a shortage of waste management facilities and environmental education, and intensified ecological concerns signal the pressing call to cooperatively tackle issues related to sustainable waste management (World Bank Group, 2018; United Nations Environment Programme, & International Solid Waste Association, 2024). Therefore, the transformation of WMSs calls for aligned actions at both regional and national governmental levels, together with local municipalities and their communities, waste management enterprises and NGOs involved in the waste management sector (Buruzs, 2024). In this regard, it is vital to create clear goals and identify social, economic, and ecological values of involved stakeholders to realize their motivation in performing actions towards the transformation of WMSs. As for the governments, regional and national bodies can play a central role in assisting the transformation of WMSs by adopting strategic policies and providing official guidelines (Buruzs, 2024). Through enacting and directing policies which contribute to waste reduction, resource conservation, and other waste-related procedures,

governments can create favourable settings which will support innovation and investment in waste management sectors.

Resource mobilization is integral to WMS transformation, as local knowledge and participation should be utilized to design solutions specific to the given regional challenges (Lag-Brotons et al., 2020; Sakai et al., 2017). As for governments, they can enable cooperation among actors related to WMSs and contribute to enabling collaborative action as well as knowledge exchange (Vasconcelos et al., 2021). Dialogues and community actions are essential tools for stakeholders' involvement as they support a greater focus on the environmental programmes of waste management and the general sustainability of communities. Through the devolution of environmental education to the school curriculum and the facilitation of classes and seminars, stakeholders can be acknowledged about the importance of waste-related issues and, thus, lead them to form environmentally sustainable lifestyles (Hoang et al., 2021). Last but not least, the use of "smart" channels and mobile apps can stream information within the stakeholders and, therefore, provide offline and online communication platforms (Samsukha, 2022). Through collective effort and collaboration with various stakeholders, it will be possible to improve the decision-making process in waste management sectors and incorporate the most beneficial strategies into the plans.

Technology and innovation are another critical factors involved in the transformation process towards sustainable WMSs (Czekała et al., 2023). Often technologies are mixed up with solely recycling, however they also comprise sorting and treatment facilities, the use of automated machines and modern AI algorithms to support the efficiency of WMSs (Mohammed et al., 2022). These innovative technologies tend to process waste more precisely that typically goes to landfills, leaving limited amounts for waste disposal. Furthermore, sustainable WMSs can be based on sensors, real-time data analysis, as well as routing algorithms that reflect the actual level of waste bins, which results in greater transportation efficiency and lower costs by saving fuel and truck trips (Hin et al., 2021). However, even rather traditional waste treatment technologies are able to contribute to resource efficiency and recover valuable resources from waste. For example, waste-to-energy technology can utilize the energy out of organic waste materials, which, in turn, results in the energy production and spare use of fossil fuels (Tabasová et al., 2012).

2.2 Conceptual framework "System-based waste management assessment"

Based on the literature review and academic findings in the waste management field, this study applies a system thinking approach which supports the identification of the most crucial WMS elements. These findings will guide the evaluation of the current state of the regional WMS and identify potential practices within the EU member states. Based on the research of Boardman & Sauser (2006), the study recognizes the multifaceted nature of the WMS elements. In this approach, the WMS is not considered as a set of separate inputs but as a system of linked components that interact to have a common objective — effective and sustainable waste management (Boardman & Sauser, 2006). Moreover, according to Iacovidou et al. (2020), a particular emphasis should be placed on understanding the concept of resource recovery systems. In the context of their findings, such an assessment will involve a detailed investigation of the core sub-systems and surroundings that considerably affect the operation of WMS. These sub-systems include processes, actors and values, whereas the surroundings in a wider system include activities ranging from technologies, infrastructure and innovation to policy framework, business activities, and wider environmental factors. As a result, the proposed conceptual framework "System-based waste management assessment" elaborating on the WMS system concept is presented in Figure 6.

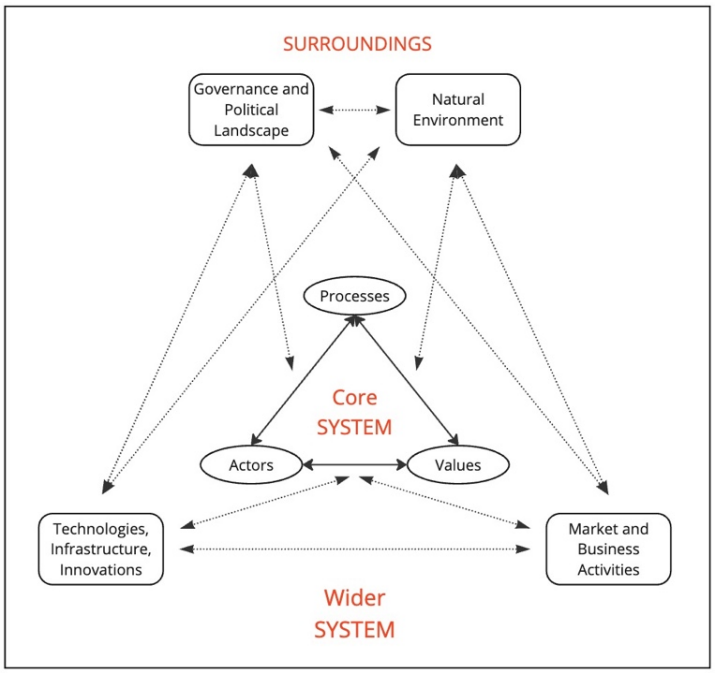


Figure 6. "System-based waste management assessment" conceptual framework (adapted from Iacovidou et al., 2020)

The core system comprises three main sub-systems: processes, actors, and values. Sub-systems are highly interrelated, form the inner elements of the WMS, and can alter the properties and behaviour of the core system (Iacovidou et al., 2020). The core processes of WMS are the stages of waste management, which include waste generation, collection, sorting, treatment, and disposal (see Table A). The actors represent various players involved in the WMS, including government agencies, waste management companies, NGOs, businesses and citizens who influence policies, undertake practices, and overall perform their activity within the WMS. Core values are represented by the environmental, economic, and social factors that direct waste management practices with sustainability, resource efficiency, and community well-being. Lastly, the system's boundary, presented by the arrow-triangle figure around the system, is defined by geographical boundaries. For more information, a detailed description of the core WMS's elements is presented in Table B.

In addition, the "System-based waste management assessment" conceptual framework considers that the performance of WMSs is determined not only by the (inner) core system's factors but also by its surroundings from the (external) wider system, in line with the holistic approach that has been proposed by Iacovidou et al. (2020). All these elements comprise indirect effects from and to the external environment, which comprises natural environment, governance and political landscape, market and business activities, technologies, infrastructure and innovations, see Table 1.

Table 1. A description of the surrounding elements of waste management systems (adapted from Iacovidou et al., 2020)

Natural Environment	The environmental setting consists of factors, such as resource availability, ecosystem health, and biodiversity, on which resource use and, as a result, WMS is built. Such understanding of the correlation between waste management approaches and the natural environment is a crucial factor for protecting against environmental-related impacts and maintaining ecosystem resistance.
Governance and Political Landscape	Waste management stakeholders operate in the context defined by the regulatory and policy framework for waste management practices. Analysing governance systems, regulatory arrangements, and political dynamics creates an institutional map and avenues for policy solutions to manage systemic problems and promote sustainable WMSs.

Market and Businesses Activities	Economic landscape and market dynamics significantly influence waste generation patterns, resource utilization, and investment in waste management infrastructure. Inquiring into the role of firms and market systems in the process of creating waste management solutions also makes it possible to recognize how business interests can be harmonized with regional sustainability goals.
Technologies, Infrastructure, and Innovations	Waste management's technological capabilities and infrastructural assets often dictate operational effectiveness and resource usage. Analysing the sector's degree of innovation, infrastructural and technological readiness will allow for identifying areas for enhancing waste management and resource recovery infrastructure.

As a result, the research aims to examine the above-mentioned surroundings to be able to come up with a deeper understanding of the complex relations between the core elements of WMSs and the surrounding environments.

2.3 Conceptual framework "Dynamic waste management system transformation"

Concerning WMS transformation, "Dynamic waste management system transformation" conceptual framework, presented in Figure 7, provides common development phases of the WMS that range from the lack of key constituents of the system to a circular economy (Soudachanh et al., 2024 & RETech Germany, n.d.). There is a five-step process towards a circular economy concept, where the development process starts with the complete absence of sustainability elements (Stage 1), which then progresses to the provision of reliable waste collection and enhanced landfills (Stage 2). The next stage is to collect and sort waste materials that are separated at the source (Stage 3), which will lead to the enhancement of the recycling industry (Stage 4). Finally, the WMS development process ends in a closed-loop system in which waste is perceived and managed as a valuable input (Stage 5).

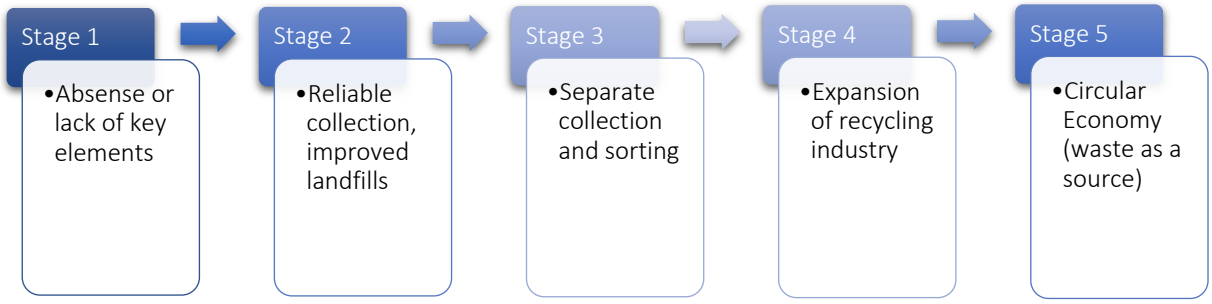


Figure 7. "Dynamic waste management system transformation" conceptual framework (adapted from Soudachanh et al., 2024)

The process starts at Stage 1, which involves the disposal of waste without sorting at the source (Soudachanh et al., 2024). This is mainly done through dumping and open burning. At this stage, the main emphasis is placed on the exclusion of waste from the territory of residential premises. At Stage 2, waste collection activities are ramped up, which still remain inconsistent, particularly in rural areas (Soudachanh et al., 2024). Sanitary landfills are close to the full coverage of waste disposal, and simple recycling plants have been incorporated due to the need to enhance human health and end uncontrolled dumping and burning. Stage 3 sees a more pronounced focus on the environment with improvements in waste segregation at source, higher collection rates and the implementation of the EPR to drive down landfills and emissions (Soudachanh et al., 2024). At Stage 4, the focus is shifted to the recognition of waste as a resource, further development of the recycling industry and promoting the principles of waste minimization (Soudachanh et al., 2024), thus achieving the goal of having only inert and pre-treated waste sent to landfills. Lastly, Stage 5 focuses on the circular economy business model, with high recycling rates and further utilization of recycles in the economy (Soudachanh et al., 2024). The key driver for reaching a circular economy is to conserve natural resources and the environment, which is supported by waste avoidance and enhancement of resource efficiency (Zhang et al., 2022). For more information, Table 2 presents a more detailed overview of the five stages of WMS development, indicating the main objectives, targets and drivers relevant to each stage.

Table 2. Five development stages of the waste management system, relevant drivers and targets (adapted from Soudachanh et al., 2024)

Stage	Overview	Target	Driver
Stage 1	- No sorting at source - Waste disposal primarily in uncontrolled dumps or through open burning - Informal sector plays a crucial role in waste management	Collection and removal of waste from housing areas	Removal of waste
Stage 2	- Expansion of waste collection, but not complete coverage (e.g., rural areas) - Waste disposal mainly in controlled landfills - Implementation of basic recycling plants	Stop uncontrolled dumping and open burning	Protection of human health
Stage 3	- Waste segregation at source, high collection rates, increased use of sorting facilities - Consideration of energy recovery and fermentation as waste treatment alternatives	Reduction of landfill volume and emissions	Environmental and climate protection

	- Introduction of extended producer responsibility		
Stage 4	- Expansion of the recycling sector - Only inert and pre-treated waste is landfilled - Decrease in municipal solid waste landfilling rates - Increasing importance of waste prevention	Increase the value of waste as a resource	Resource value of waste
Stage 5	- Circular economy as a key concept in resource management and implementation - Growth of innovative business models (e.g., leasing, sharing) - High recycling rates and improved recyclates in the economy	Avoid waste and enhance resource efficiency	Conserve natural resources

2.4 Integrated conceptual frameworks for the waste management system transformation in the Chernihiv Oblast

The two conceptual frameworks are synergistic and are used to explain how the WMS elements interact with each other and how they evolve between stages to reach complete resource circularity. The "System-based waste management assessment" conceptual framework (see Section 2.2) is built on the system thinking approach and mainly supports the assessment of the current WMS state in the Chernihiv Oblast, highlighting fundamental elements of system organization, including process, actors, and values. Moreover, it supports the decomposition of the EU WMSs in order to identify specific practices and features present among the EU member states. For the assessment of the current state of the WMS, the Chernihiv Oblast will serve as a system's boundary, whereas the European Union will serve as a system's boundary for the assessment of EU waste management practices.

On this basis, the "Dynamic waste management system transformation" conceptual framework (see Section 2.3) elaborates on the development path towards advancing the current WMS towards a circular economy. WMS transformation goes through five stages, beginning with orderless waste disposal and ending with the overall advanced and resource-efficient WMS. It is a step-by-step development process, with each stage addressing specific WMS shortcomings and introducing increasingly innovative and, consequently, sustainable technologies, procedures, and principles.

When analysing the transformation process of the WMS within the "Dynamic waste management system transformation" conceptual framework, every single subsystem from the "System-based waste management assessment" conceptual framework – the processes, the actors, and the values – changes dramatically. During Stage 1, both the processes subsystem and key actors, such as government agencies and waste management companies, are merely in the process of developing initial waste collection and systematic waste disposal systems. Furthermore, stakeholders fail to advance processes and systems due to the lack of problem understanding and realizing values. At later stages of WMS transformation, such processes will be more refined and will include waste sorting, treatment, recycling and protected disposal. At the same time, actors' functions change, and NGOs, civil society organisations, and the private sector engage in the promotion of sustainable initiatives in the waste management sector. The values subsystem also develops, and while the initial focus is given to the key basic needs of the individuals – remove waste from residential areas, at later stages the values start to encompass the principles of environmental, economic, and social sustainability. This transformation makes the WMS become more integrated to be effective in each development phase in a way that ultimately leads to the goal of a circular economy where there is little or no waste but a maximum level of resource conservation.

Based on the synergy of conceptual frameworks and recognizing a complex interplay between internal subsystems and external environment, these frameworks give a complete picture of the Chernihiv Oblast WMS elements, which, in the end, form a base for developing targeted interventions and strategic initiatives for its transformation. By a broad assessment of the regional WMS and the larger environment in which waste management operates, this baseline assessment will provide a detailed review of the current state of the WMS in the Chernihiv Oblast. In addition, the conceptual frameworks will support the analysis of EU member states WMSs, which will serve as a base to formulate proper recommendations to local and national governments to address present issues and take advantage of opportunities for the regional WMS transformation.

Chapter 3 – Methods

The research adopts an exploratory case study method to address the research objectives (described in Section 1.5) and support the investigations on the transformation strategy for the WMS in the Chernihiv Oblast.

3.1 Rationale for a case study method

A case study is a prevalently qualitative research approach that involves a thorough analysis and critical assessment of a specific phenomenon, event, organisation, or individual in its environment (Rebolj, 2013). This method provides an in-depth understanding of the nuanced aspects of the subject under study by observing it in its natural environment. A case study frequently employs several data sources, such as interviews, observations, documents, and other research outputs, to allow the researcher to obtain insights about the object under investigation.

A case study examines the underlying dynamics, linkages, and activities that shape the object of study (Takahashi & Araújo, 2019) by providing an extensive and detailed picture of its features. With rigorous data collection and proper analysis, research can identify patterns, themes, and linkages within the case, providing vital knowledge about broader theoretical ideas or practical implications in the research field. Furthermore, case studies enable researchers to analyse atypical and specific objects, study more complex phenomena, and generate ideas for future research (Takahashi & Araújo, 2019), making them adaptable and valuable tools in both academic and practical contexts.

In particular, this research will utilize an exploratory case study which is defined by its concentration on the investigation of new or understudied cases, usually with the purpose of producing new insights or hypotheses (Lucas et al., 2018). An exploratory case study, unlike a confirmatory case study, which aims to validate an existing theory or model, is characterized by its exploratory nature as an attempt to discover previously unknown features of a specific event or environment (Lucas et al., 2018). This strategy will allow this research to look deeply into complex and multidimensional waste management issues, revealing hidden patterns, linkages, and underlying dynamics that would be impossible to uncover using conventional research methods.

In addition, the adaptability of the case study method allows the research to extensively analyse each element of the WMS, use various data sources to ensure the accuracy of findings and build a deep knowledge of the regional WMS settings (Lucas et al., 2018). Lastly, such a method ensures that the transformation process is informed by practical, real-world examples and evidence, leading to more effective and sustainable waste management outcomes.

3.2 Data collection and analysis

Considering the chosen conceptual frameworks (presented in Sections 2.2 and 2.3), which support the investigation of the complex interrelations between WMS elements and their evolution through WMS development stages, a case study appears to be a suitable method for conducting an analysis of the Chernihiv Oblast's unique context. Under this method, the research will create a rigorous model of the regional WMS to analyse the core sub-systems and wider system elements affecting the WMS in the region. In addition, the case study method is particularly suitable for researching sustainable WMSs and practices across EU member states due to its ability to provide an in-depth and context-rich understanding of complex processes and policies within the WMSs. By examining specific examples of WMSs in the EU member states, the research can gain valuable insights into the effectiveness and adaptability of different strategies and technologies. This detailed analysis will serve as a robust foundation for transforming the WMS in Chernihiv Oblast, Ukraine, allowing for the adoption of best practices and innovative solutions tailored to the region's specific needs and challenges.

Regional and EU levels

The research is built on the "System-based waste management assessment" conceptual framework (see Section 2.2) to create a comprehensive model of the Chernihiv Oblast WMS and structure elements of the European Union WMSs and practices. This way complex WMSs both in the region and in the EU member states are decomposed into sub-systems and surroundings, simplifying the systems' structures.

Regarding the regional assessment, the research primarily utilizes the latest environmental report, "Regional Waste Management Plan of the Chernihiv Oblast" (Derii et al., 2021). This report provides the most comprehensive overview of the region's socio-economic state, offering detailed information on the WMS sub-systems and their surroundings. It includes

region-specific data on waste generation, collection, transportation, treatment, and disposal, as well as an analysis of environmental impacts and sustainability practices. When specific data concerning any of the WMS elements is not available in the Derii et al. (2021) report, a thorough review of existing academic works is conducted to fill these gaps, ensuring a holistic understanding of the WMS. Keywords for searching lacking data include "Chernihiv Oblast waste management," "regional waste management policies", "waste processing and recycling in Chernihiv" and other keywords related to specific waste management sub-systems and surroundings. Such keywords are searched both in Ukrainian and English, utilizing sources made by Ukrainian authors and international institutions. Additionally, a detailed review of the regional and national legislative frameworks is undertaken, which supports providing insights into the regulatory and policy environment governing the waste management sector in the Chernihiv Oblast. With this method, the study is guaranteed to be comprehensive, region-specific and informed by the most recent and relevant data available.

To source and analyse data on WMSs and practices across EU member states, a comprehensive literature review is conducted using academic databases such as Scopus and Google Scholar. This review focuses on identifying peer-reviewed articles, governmental reports, and policy documents relevant to the waste management sector within the EU. Additionally, the European Environment Agency website is utilized as a critical resource for extensive data and reports on waste management across the EU member states. Such keywords as "EU waste management practices," "EU waste management case studies," and "EU waste policy analysis" are employed to refine the search and ensure the relevance of the materials gathered. Moreover, publications and case studies from individual EU member states are examined to gain detailed insights into their specific systems and practices and to provide alternative practices and approaches to managing waste. Such a multifaceted approach ensures a robust and comprehensive understanding of the details of WMS elements and specifics of waste management practices and initiatives within the EU member states.

Charting strategy for the Chernihiv Oblast waste management system transformation

To address the waste management challenges in the Chernihiv Oblast, the regional WMS is benchmarked against EU WMSs with the aim to incorporate best practices, innovative technologies, and sustainable approaches that have been proven effective in the EU context.

By adapting the EU's advanced waste management strategies and policies, the final goal is to develop a detailed and step-by-step strategy based on the "Dynamic waste management system transformation" conceptual framework (see Section 2.3), directed at regional and national governments. This strategy will cover various aspects including WMS actors, processes and values together with the system surroundings comprising natural environment, market and business activities, technologies, infrastructure and innovations (see Table 1).

Chapter 4 – Assessment of the waste management system and regional characteristics of the Chernihiv Oblast

4.1 General overview of the Chernihiv Oblast

Administrative characteristics

The Chernihiv Oblast, which has an area of 31900 km^2 (5.3% of the area of Ukraine), is one of the country's largest regions in terms of territory. It is located in the north of Ukraine and borders the Gomel Oblast, Belarus to the northwest, Bryansk Oblast, russia to the north, Sumy Oblast, Ukraine to the east, Kyiv Oblast, Ukraine to the southwest, and Poltava Oblast, Ukraine to the south (Agriculture, forestry and fishing | Head Department of Statistics in the Chernihiv Oblast, n.d.).

The population of the Chernihiv Oblast as of January 1, 2020, was 991,300 people, or 2.37% of the total population of Ukraine (Population and migration | Head Department of Statistics in the Chernihiv Oblast, 2020; Demographic and social statistics / Population and migration | State Statistics Service of Ukraine, 2020). According to the characteristics of population localization, the Chernihiv Oblast is an outsider in Ukraine, and the population dynamics during the last decade has a clear tendency to decrease. On average, the annual reduction in the region's population is 11,613 thousand people (Derii et al., 2021).

Economic characteristics

The regional economic system of the Chernihiv Oblast is agrarian-industrial with a predominance of the agro-industrial component. By the volume of the gross regional product in 2018, it took the 16th position among the regions of Ukraine, providing 1.98% of the national total (Gross regional product | State Statistics Service of Ukraine, 2020). The recent trend is the growth of the agriculture share in the gross added value - from 18.3% in 2010 to 28% in 2018. The Chernihiv Oblast is integral to the state's economic system and produces 1.4% of its industrial output (Economic statistics | Head Department of Statistics in the Chernihiv Oblast, 2020; Gross regional product | State Statistics Service of Ukraine, 2020). During the last ten years, the volume of sales of the region's industry mainly decreased, eventually leading to a decrease in its share in the regional gross added value to 17%.

As for the structural aspect of the industry, the largest share (69.5% in 2019) of the regional sales volume is concentrated in enterprises of the processing industry, among which the production of food products, beverages and tobacco products prevails (41.3%), wood products, paper and printing activities (9.2%), mechanical engineering (6.8%) (Derii et al., 2020). The share of mining and quarrying enterprises in the total volume of industrial production equalled 9.7%, and the share of electricity, gas, steam and air conditioning supply was 19.7% (Derii et al., 2020).

The dominant position in the region's industry is in the food, beverage, and tobacco products industries, which includes almost 100 enterprises with an annual sales volume of over 14 billion hryvnias (Economic statistics | Head Department of Statistics in the Chernihiv Oblast, 2020). In addition to these, nearly 400 small enterprises process agricultural products. The situation in the regional industry is rather ambiguous, where, to a large extent, it is determined by the specifics of the industry structure, where each leading industry is based mainly on one or two enterprises (Derii et al., 2021). Over the past ten years, general dynamics of the regional industry production has had a relatively straightforward downward trend.

4.2 Core system level – processes

Waste generation

Over the period of 2010-2019, the trends in waste generation in the Chernihiv Oblast underwent significant shifts. Initially, there was a steady increase in waste generation, with an average annual growth of 18.8% until 2015 (Natural environment | Head Department of Statistics in the Chernihiv Oblast, 2020). However, since 2015, a noticeable slowdown has been observed, with an average annual decrease of -5.36% (Derii et al., 2021). This change in trend is mirrored in the region's share of the all-Ukrainian waste volume, which tripled from 0.09% to 0.28% between 2010 and 2015, but then decreased to 0.16% by 2019 (Derii et al., 2021).

Considering the region's natural and economic factors, the main components of the waste generated are solid household and industrial waste of the IV hazard class (low-hazard solid waste, construction waste, cleaning materials, plastic waste), which is mainly disposed of in landfills or waste accumulators (Derii et al., 2021). The total volume of accumulated waste is characterized by an established tendency to increase: on average, the annual increase was

3.4%. In 2019, the indicator exceeded the value of 2010 by 35.6% (Natural environment | Head Department of Statistics in the Chernihiv Oblast, 2020).

Regarding the sources of waste generation, the situation remained almost unchanged: annually, from 2012 to 2019, the bulk of waste in the region was generated due to the economic activity of enterprises and organizations (70%), and household waste accounted for 30% on average (Natural environment | Head Department of Statistics in the Chernihiv Oblast, 2020). Instead, the structure of waste generation sources in Ukraine as a whole is rather different: 98% of waste is generated from economic activity and only about 2% - from the activity of households (Economic statistics / Natural environment | State Statistics Service of Ukraine, 2020). In particular, on average, almost 520,000 tons of waste is generated annually from economic activity (as of 2019), when in 2011 its volume was 488,27 thousand tons (Derii et al., 2021). The volume of household waste shows a more pronounced dynamic: by 2014, it was growing (6.6 times more compared to 2011), then decreased in 2019, still exciding the 2011 values in four times (Derii et al., 2021).

In the waste structure by activity type, more than half of all waste generated in the region (55.3%) results from processing industry enterprises, 23.2% - from agricultural activities, and 12.8% - from enterprises supplying electricity, steam and air conditioning (Natural environment | Head Department of Statistics in the Chernihiv Oblast, 2020). In 2019, a study of the I-IV hazards classes waste generation structure by material categories showed that more than 40% of waste is of plant origin: animal by-products not intended for human consumption (17.5%), incineration waste (12.8%), household and similar waste (6.3%), wood waste (6%), and sorting residues take a share of 4.8% (Derii et al., 2021).

The regional waste structure by categories of materials radically differs from the general Ukrainian state, where mineral waste dominates. If all categories of materials represent the structure of waste generated from economic activity, households generate mainly sludge, typical household and similar waste (Derii et al., 2021). Also, the structure of household waste includes relatively tiny amounts of ferrous and non-ferrous metal waste, paper, cardboard, and plastic waste.

From a geographical perspective, the distribution of waste generation in the Chernihiv Oblast is highly uneven (Natural environment | Head Department of Statistics in the Chernihiv Oblast, 2020). In 2019, the majority of waste (59.8%) was generated in the Chernihiv city, Prylutsky, and Horodnyansky districts. The regional centre, Chernihiv, topped the list in terms of waste generation volume, producing 160.7 thousand tons of waste of I-IV hazard classes in 2019 (Derii et al., 2021). The largest volumes of waste were transported to designated areas in Chernihiv city, with lower but still significant amounts in the cities of Nizhyn and Pryluky (Derii et al., 2021). This geographical disparity in waste generation creates significant variations in the waste accumulation indicators across cities and districts in the region.

A comparative analysis of indicators of the average per capita level of household waste generation shows that most intensively waste was generated by households of the Horodnyanskyi and Semenivskyi districts (Natural environment | Head Department of Statistics in the Chernihiv Oblast, 2020). They exceeded the regional average by 12.8 and 5.3 times, respectively (Derii et al., 2021). The indicators in the Pryluky, Nizhyn, and Borzna districts were also higher than the regional average.

Waste collection and transportation

The lack of provision by local governmental bodies and district state administrations of a properly organized solid waste collection system leads to the emergence of disordered landfills, where the placement of waste is systemic, and the landfills are not liquidated for a long time (Derii et al., 2021). Today, in the absence of waste collection infrastructure and targeted funding, local government bodies do not provide solutions to problems in the field of waste management.

In the district centres of the Chernihiv Oblast, certain measures are being taken to organize the collection of resource-valuable waste. Such measures mainly include points of reception of secondary raw materials and defining areas for placing containers for the collection of household waste from the population (Derii et al., 2021). Thus, in particular, in the city of Chernihiv, the largest settlement in the region, a unitary solid waste collection system operates, in which waste is mixed in one container, where the coverage of the population by solid waste collection services is 90% (Derii et al., 2021).

Waste sorting

The introduction in 2018-2019 of the system of separate collection of household waste in the settlements of Mena, Koryukiv, Korop, and Varvy districts did not further develop in the absence of economic incentives and the imbalance of the secondary raw materials market (Derii et al., 2021). As a result, the collected secondary raw materials are not further sold and accumulate on the local landfills.

Waste treatment

It should be noted that waste is generated in the Chernihiv Oblast on a significantly larger scale than it is being treated or properly disposed of (Natural environment | Head Department of Statistics in the Chernihiv Oblast, 2020). During the studied period, an average of 1/6 of the volume of generated waste was subject to disposal each year. This indicator is lower than the average for Ukraine and is decreasing. Thus, in 2019, 9.9% of waste was disposed of by waste-producing enterprises in the region, while the state indicator equalled 24.5%, in 2018 – 15.3% and 29.4%, respectively, in 2017 – 17.8% and 30.2%, in 2016 – 14.5% and 28.6%, in 2015 – 15.4% and 29.6%, in 2010 – 22.7% and 34.2%, respectively (Derii et al., 2021).

Among the leading waste treatment operations in the Chernihiv Oblast, only seven operations are carried out by the generating enterprises: recycling/utilisation of organic substances that are not used as solvents (R3), recycling/utilisation of metals and their compounds (R4), recycling/utilisation of other inorganic materials (R5), re-distillation of used petroleum products or their other reuse (R9), soil treatment that has a positive effect on agriculture or improves the ecological situation (R10), use of waste obtained from operations under codes R1-R10 (R11), exchange of waste for operations under codes R1-R11 (R12) (Derii et al., 2021). During the analysed period, the WMS in the Chernihiv Oblast was mainly represented by the R10 operation and constituted the highest waste disposal volume, ranging from 85% to 90%, followed by the R5 operation with a share of 5.6% to 9.6% (Derii et al., 2021). The remaining treatment operations, comprising recycling/utilization of organic substances, plastic and metals, re-distillation or reuse of used petroleum products, and other waste treatment processes, are presented in small shares that all together do not exceed 10% (Derii et al., 2021).

It should be noted that enterprises that produce waste and carry out waste management operations also carry out waste treatment operations, however, the volume of disposal by such enterprises is constantly decreasing and halved over the past five years (Derii et al., 2021).

During 2010-2019, the dynamics of incinerated waste volumes did not acquire an evident trend (Natural environment | Head Department of Statistics in the Chernihiv Oblast, 2020). The smallest volumes were recorded in 2013 (8.2 thousand tons) and 2014 (8.6 thousand tons), the largest in 2016 (15.6 thousand tons), on average, 11.7 tons, or 1.7% of the total mass of all waste generated in the region (Derii et al., 2021). The region's share in the national volume of incinerated waste remains insignificant, in 2019, it was 1.3%, where the bulk of the waste was burned to obtain energy (Derii et al., 2021).

In 2019, compared to 2010, the amount of waste sent to organised storage facilities (burial) decreased by 3.5 times (Natural environment | Head Department of Statistics in the Chernihiv Oblast, 2020). A sharp reduction occurred in 2011, and the annual volume of removed waste was at approximately the same level in subsequent years (Derii et al., 2021).

As for industrial waste, there is a negative tendency towards a rapid decrease in the level of treatment (with the exception of 2013) - over the last 10 years it has decreased by almost 3.3 times (Derii et al., 2021), which, if such dynamics are maintained, can cause an extremely negative impact on the general indicators of waste management and the ecological condition of the region as a whole. In other words, given the tendency to decrease the quality of waste management, the region lacks an effective strategy regarding waste treatment.

Waste storage and disposal

When analysing the average per capita waste accumulation at landfills, it becomes clear that, despite the reduction in the Chernihiv Oblast residents' number, the volume of accumulated waste per person is growing rapidly. On average, the annual growth rate equalled 4.8% (Derii et al., 2021). When in 2010, one region resident accounted for 8.0 tons of accumulated waste, then in 2019 – 12.2 tons, which is 52.5% more than in the base year (Natural environment | Head Department of Statistics in the Chernihiv Oblast, 2020). Compared to a similar indicator for Ukraine, the scale of waste concentration per capita in the Chernihiv Oblast is significantly lower. Despite the narrowing of the difference over the studied period, the differences

between national and regional indicators remain significant: in 2019, the average per capita volume of waste accumulation in Ukraine equalled 367.3 t/capita, which was 30 times higher than the indicator of the Chernihiv Oblast (Derii et al., 2021).

A similar situation was observed at the level of localisation - the amount of accumulated waste relative to the territory area. The average annual increase of the indicator equalled 2.6% (Derii et al., 2021). In fact, in 2019, there were 377.7 tons of accumulated waste per 1 km^2 of the Chernihiv Oblast territory, which is 35.6% greater than in 2010 (Natural environment | Head Department of Statistics in the Chernihiv Oblast, 2020). Together with the positive dynamics of the average per capita indicator, such trends indicate the presence of threats to the ecological balance of the regional development. Compared to the average indicator for Ukraine, it remains significantly lower in the region: in 2019, the average level of waste accumulation per unit of territory in Ukraine equalled 25,500.2 t/km2, which was 67.5 times higher than the indicator of the Chernihiv Oblast (Derii et al., 2021).

Chernihiv city naturally remains the central location of accumulated waste. As of the end of 2019, 79.8% (9,615 thousand tons) of all waste in the region was concentrated there; the rest of the cities and districts have significantly lower share (Natural environment | Head Department of Statistics in the Chernihiv Oblast, 2020). In particular, Pryluky is the largest waste generator in the region (except Chernihiv city), which, in the end of 2019, had 173.9 thousand tons of waste on its territory, contributing to solely 1.4% of the regional waste generation amount (Derii et al., 2021). It is vital to note, that such cities as Chernihiv (Vol./ter. = 2060.13 t/km2), Nizhyn (Vol./ter. = 883.54 t/km2) and Pryluky (Vol./ter. = 739.51 t/km2) acquire the status of crisis areas (Derii et al., 2021), having extremely high rate of waste accumulation compared to other regional municipalities.

4.3 Core system level – actors

Citizens and companies generating waste

Over the years, the weight of the urban population in the region prevailed over the rural population, and the gap, as revealed by trend models, is increasing. As of January 1, 2020, 649.1 thousand people or 65.5% of the total population of the region, lived in urban settlements, and 342.2 thousand people, or 34.5%, lived in rural settlements (Demographic

and social statistics / Population and migration | State Statistics Service of Ukraine, 2020; Law of Ukraine on the basic principles (strategy) of the state environmental policy of Ukraine for the period until 2030, 2019).

According to statistical accounting data, which is formed in accordance with the list determined by the Ministry of Environmental Protection and Natural Resources of Ukraine, 355 enterprises that generate waste are registered in the region. Most of them are concentrated in Chernihiv city (112 units), Nizhyn and Pryluky cities (29 units each), Ichnyanskyi (21 units), Semenivskyi (17 units), and Koryukivskyi (16 units) districts (Economic statistics | State Statistics Service of Ukraine, 2020).

Waste management companies

Waste collection is provided by 92 enterprises, where waste utulization is carried out by only one enterprise located in the Varvy district; 82 enterprises deal with waste disposal, of which 33 are located in Chernihiv district and 14 in Borznyan district (Economic statistics | State Statistics Service of Ukraine, 2020). In 2019, 89 regional enterprises had specially designated places and facilities for waste disposal, with a total number of 146 units, of which 115 were for household waste (Derii et al., 2021). In the Chernihiv Oblast, 14 enterprises are equipped with 37 plants for the incineration of waste for the purpose of obtaining energy with a total capacity of 19548 t/year; solely 3 enterprises have plants for waste incineration for the purpose of thermal processing - their combined capacity is 5178 t/year (Derii et al., 2021). 5 enterprises have plants for disposal and processing of waste with a total capacity of 118,000 tons per year, where three of them are located in Chernihiv city, one each in the city of Nizhyn and the Varva district (Derii et al., 2021).

Governmental agencies

Government agencies consist of the following bodies: local state administrations, Chernihiv Regional State Administration (including the Department of Ecology and Natural Resources), State Environmental Inspection of the Chernihiv Oblast, Head Office of the State Production and Consumer Services in the Chernihiv Oblast, local government bodies, united territorial communities, State statistics service, and in particular the Head Department of Statistics in the Chernihiv Oblast.

The main responsibilities of the local state administrations, particularly the Chernihiv Regional State Administration, encompass executing governmental laws and acts, participating in national waste management programs, and developing regional and local waste management strategies (Law of Ukraine "On Local State Administrations", 2001). The Department of Ecology and Natural Resources focuses on environmental protection activities, including waste management, while the State Environmental Inspection of the Chernihiv Oblast ensures compliance with environmental laws related to waste handling (Regulatory framework | State Environmental Inspection of the Chernihiv Oblast, n.d.). The Head Office of the State Production and Consumer Services in the Chernihiv Oblast is responsible for approving waste disposal site passports and managing waste facilities (Legal principles of activity | Head Office of the State Production and Consumer Service in the Chernihiv Oblast, n.d.). Local government bodies and united territorial communities ensure compliance with waste legislation, organize waste collection and disposal, and stimulate business involvement in waste management (Derii et al., 2021). The State Statistics Service, particularly the Head Department of Statistics in the Chernihiv Oblast, supports waste management by collecting, processing, and providing relevant data and statistics (Documents / Legislative and regulatory acts | The Head Department of Statistics in the Chernihiv Oblast, n.d.). These institutions collectively work towards effective and environmentally safe waste management within the Chernihiv Oblast. Additional information on these governmental bodies can be found in Appendix D.

NGOs and other institutions

An important role in shaping the public's awareness of waste management belongs to information and educational campaigns, where the Department of Education and Science of the Chernihiv Regional State is entrusted with the tasks of (Regulatory framework | the Department of Education and Science of the Chernihiv Regional State, n.d.):

– Ensuring the implementation of state policy in the field of education, scientific, technical, innovative activities, technology transfer, and intellectual property;
– Ensuring the development of the education system with the aim of forming a harmoniously developed, socially active, creative personality;
– Ensuring the development of educational, creative, and scientific potential, considering the region's national, cultural, socio-economic, ecological, and demographic characteristics.

On top of that, the department conducts information and education campaigns on sustainable development and waste management.

Moreover, the regional WMS has a set of NGOs which mainly conduct educational activities, including the waste management sector. In 2020, in the city of Chernihiv, the project "Superosrters" was implemented - an educational environmental project to reduce the negative impact on the environment from the disposal of solid household waste (Sknews, 2020). The project was implemented by the NGO “Chernihiv - Eco City” in partnership with the Chernihiv Regional Youth Centre with the financial support of the Ministry of Foreign Affairs of the Czech Republic as part of the “Transition Promotion Program” (Derii et al., 2021). As a result, the first educational sorting station in Chernihiv was equipped with containers for a separate collection of more than 20 types of secondary raw materials (Sknews, 2020). Additionally, volunteers have conducted 20 excursions and 100 lessons on waste sorting for schoolchildren since the beginning of the project (Sknews, 2020). Furthermore, with the financial support of the Government of Germany, a practical seminar “Let’s deal with garbage: European experience from the northern regions of Ukraine”, was held in in 2020 in the Chernihiv city for representatives of executive authorities and local government bodies, public organizations of environmental orientation, organized by the Public School of Effective Practices of the EU and the Polish Foundation for International and Regional Studies (PFIRS, 2020).

4.4 Core system level – values

Environmental values

Regarding environmental values, the main focus is directed to solving existing ecological issues which include air, soil and water contaminations, waste concerns and the damage caused by chemical plant protection products.

Among a number of environmental problems that exist in the region, the problem of waste management is particularly acute (Order on making changes to the Natural Environment Protection Program surrounding in the Chernihiv Oblast for 2021 – 2027, 2024). Waste management is one of the biggest pollutants in the environment and negatively affects all its components. The situation is complicated by the fact that there is a significant gap between

the volume of accumulated waste and the volume of its disposal and processing (Derii et al., 2021). In order to increase the efficiency of work on waste management, the regional program for 2021-2027 includes measures for the collection, storage, transportation, disposal and treatment of waste, including the reconstruction of landfills, arrangement on landfills, acquisition and implementation of installations, equipment and machines for collection, transportation, treatment, disposal and storage of waste, containers for the introduction of separate collection of solid household waste (Derii et al., 2021). An important task today is the preservation of valuable natural complexes and landscapes, biological diversity, as well as the rational use of natural resources for future generations. In order to preserve the objects of the nature reserve fund, the regional program for 2021-2027 provides for the development of land management documentation for the territories and objects of the nature reserve regional fund (Derii et al., 2021).

Additionally, in recent years, the main problem with regard to the protection and rational use of water resources in the region is the pollution of surface water bodies, where the main polluters are housing and communal enterprises. This issues mainly appeared due to the discharge of insufficiently treated wastewater as a result of the inefficient operation of sewage treatment facilities, the failure to restore coastal protective strips and water protection zones to nature, as well as non-maintenance, primarily in populated areas, clogging of water bodies with household waste (Order on making changes to the Natural Environment Protection Program surrounding in the Chernihiv Oblast for 2021 – 2027, 2024).

On top of that, a significant threat to underground aquifers and soils is posed by unusable chemical plant protection products (hereinafter referred to as chemical plant protection products) available on the territory of the Chernihiv Oblast, of which 222.9 tons remain in the region, namely: in Koryukivsk (15.0 tons), Nizhynsk (56.8 tons), Prylutsky (142.0 tons), Novgorod-Siversky (4.0 tons), Chernihiv (5.1 tons) districts (Order on making changes to the Natural Environment Protection Program surrounding in the Chernihiv Oblast for 2021 – 2027, 2024). The condition of the available storage places for ownerless 39 warehouses is unsatisfactory (Derii et al., 2021). Considering that a significant part of the components is located in the basins of the Dnipro and Desna rivers, which are sources of drinking water supply, in order to reduce the man-made load on the environment and prevent environmental

pollution, it is extremely necessary to ensure the removal of the residues of the specified dangerous substances.

Social values

The socio-economic development of the Chernihiv Oblast is closely and inextricably linked with the state of the region's natural environment and directly depends on the implementation of strategic tasks in the field of environmental protection and preservation of citizen's health. The main principles of regional ecological policy formation include protecting and improving the state of the natural environment, guaranteeing safe ecological conditions for the population's life and health, and implementing an ecologically balanced system of nature use and preservation of natural ecosystems (Order on making changes to the Natural Environment Protection Program surrounding in the Chernihiv Oblast for 2021 – 2027, 2024).

The main goal of the regional program for 2021-2027 is the implementation of the state policy of Ukraine in the field of environmental protection, ensuring ecological safety, protecting the life and health of the population from the negative impact caused by pollution of the natural environment; mitigating the negative consequences of climate change; preservation of biological and landscape diversity and formation of an ecological network; ensuring ecologically balanced nature use; raising the level of public awareness of the environmental component and achieving harmony in the interaction of society and nature (Order on making changes to the Natural Environment Protection Program surrounding in the Chernihiv Oblast for 2021 – 2027, 2024).

There is a problem in the region, which today does not contain a pronounced character, but after a particular time, its consequences will pose a real threat to both environmental objects and the health of the region's citizens. Its essence is that due to the population's activities, waste is generated that contains dangerous components, particularly used fluorescent and energy-saving lamps, used chemical current sources, damaged electronic equipment and electrical equipment, motor vehicle waste, etc (Derii et al., 2021). Considering the achievements of scientific and technical progress, the volume of household waste generated by the population and containing dangerous components will constantly increase. The indicated waste groups are generally not removed but are taken to landfills and waste

accumulators according to a unitary disposal scheme (Derii et al., 2021). At the same time, it is impossible to estimate their volumes and consequences for the environment at this stage.

In the absence of targeted funding and appropriate infrastructure for collecting and processing waste, local government bodies cannot provide sufficient solutions to the specified problems. The main reasons for this situation are the lack of funds for the local government bodies responsible for ensuring this area of work and the improper performance of duties by certain utility companies (Derii et al., 2021). Lastly, in the modern conditions of scientific and technical progress and sustainable socio-economic development, it is extremely necessary to form an ecological culture and awareness among the population and to educate modern people to have a careful, constructive, and respectful attitude towards nature.

Economic values

It is important to carefully develop financing strategies, considering the specific needs and opportunities of the region, as well as to ensure transparent and efficient use of the received funds to achieve environmental goals. Given the complexity of financing environmental protection measures in the field of waste management, it is important to consider more detailed aspects and possible ways to solve this problem (Resolution on approval of the list of activities related to environmental protection measures, 1996):

1. State budget: Allocating funds from the state budget to finance environmental protection measures in the field of waste management is one of the keyways to ensure the necessary resources. This may include the creation of a special fund or the allocation of funds through subventions to local budgets.

2. Investments: Attracting investments can become an additional source of financing for the implementation of waste management projects, in particular for the development and implementation of new waste disposal and treatment technologies.

3. Funds of private entities: Enterprises and organizations that generate a large amount of waste can contribute to the financing of environmental protection measures in their sphere of activity through participation in joint programs or investment projects.

4. Loan funds: In some cases, it is possible to raise loan funds to finance waste management projects. It is important to ensure that such loans are cost-effective and aimed at achieving specific environmental goals.

5. Revenue from services provided: Some waste management measures can become a source of income through the provision of various services, such as waste treatment, environmentally friendly production or sale of secondary raw materials.

4.5 Wider system level – surroundings

Natural environment

The Chernihiv Oblast is located in two physical and geographical zones - mixed forests and forest steppe, which determines the diversity of its landscapes. Most of the region lies within the Dnieper lowland, the southern part lies within the Poltava plain and has, mainly, a slightly undulating surface with absolute heights of 100-220m (Regional ecological network scheme of the Chernihiv Oblast, 2017). According to landscape features, the Chernihiv Oblast is divided into 4 physical and geographical regions: Chernihiv and Novgorod-Siversky Polyssia, The North Dnieper terrace lowland and the North Poltava upland (Regional ecological network scheme of the Chernihiv Oblast, 2017).

As of 2019, the region's land fund amounted to 3,190.3 thousand hectares. In the structure of the land fund, the largest share falls on agricultural lands - 64.6% (2060.4 thousand hectares); the second most important component is forests and other wooded areas (700.0 thousand hectares) - 21.9% (Derii et al., 2021). Built-up (127.7 thousand ha) and open wetlands (126.3 thousand ha) account for 4.0% each (Derii et al., 2021). Over the past decade, there have been no significant changes in the structure of the land fund. However, it is worth noting that the structure of the land according to the target purpose is arbitrary and does not have sufficient economic and ecological validity (Law of Ukraine on the basic principles (strategy) of the state environmental policy of Ukraine for the period until 2030, 2019). Additional information on the natural environment of the Chernihiv Oblast can be found in Appendix E.

Governance and political landscape

The main framework law that regulates relations related to the production, collection, sorting, transportation, treatment, utilization and disposal of generated waste in Ukraine is the Law

“On Waste” (Law of Ukraine "On Waste", 2022). Since 2015, livestock waste management issues have been formulated in a separate law on by-products of animal origin, not intended for human consumption (Law of Ukraine "On by-products of animal origin, not intended for human consumption", 2015), which defines categories of products (based on the magnitude of risks to human and animal health), management methods for each of these categories, rights and obligations of market operators, requirements for waste management facilities, as well as responsibility for violating these requirements (Order on the approval of the National Waste Management Strategy in Ukraine until 2030, 2017).

In accordance with the Association Agreement with the EU, Ukraine implements the EU Directives in the field of waste management into national legislation, which will contribute to the improvement of the WMSs and the transition to a circular economy, the implementation of an effective waste management hierarchy, as well as the creation of an effective waste management planning system in particular at the regional level (Derii et al., 2021).

In addition, according to Art. 17 of the Law of Ukraine “On Waste”, subjects of economic activity in the field of waste management, whose activities lead exclusively to the generation of waste, for which the indicator of total generation of waste is from 50 to 1000, are required to submit a declaration of waste according to the form and procedure established by the Cabinet of Ministers of Ukraine (Law of Ukraine “On Waste”, 2022). A more detailed description of the governance in the Chernihiv Oblast’s WMS can be found in Appendix F.

Technologies, infrastructure, and innovations

Unsatisfactory trends in waste accumulation indicators are the result of shortcomings in the waste management infrastructure. As of January 1, 2020, 9 landfills and 491 solid waste landfills were entered into the Chernihiv Regional Register of Waste Disposal Sites (Environmental protection program of the Chernihiv Oblast | The Department of Ecology and Natural Resources of the Chernihiv Regional State Administration, n.d.). The specified objects cover an area of 586.3046 hectares. Most of the active waste disposal sites in the region (531 out of 546) belong to category B – hazardous facilities (Derii et al., 2021). The most hazardous waste disposal sites are located in Horodian (65 facilities) and Chernihiv (62 facilities) districts. The number of unregistered waste disposal sites in the region was 161, of which 29 are located

in the Kozeletsk district, 22 in the Minsk district, 19 in the Nizhyn district, and 18 in the Novgorod-Siversky district (Derii et al., 2021).

The waste disposal and processing infrastructure of the Chernihiv Oblast is represented by 8 waste collection points for electronic and electrical equipment in the city of Chernihiv (Derii et al., 2021). In the region there are no points for collection of used tires, vehicles for disposal, and medical waste. Regional problems in the field of solid household waste management have reached their highest level of aggravation (Derii et al., 2021).

The state of solid waste disposal sites poses a real danger to the environment and the population living in the surrounding areas. Thus, at the end of 2019, the average occupancy level of specially designated places and waste disposal facilities exceeded 60% (Derii et al., 2021). The Chernihiv landfill is 75.1% full, Nizhyn - 14.3%, Novgorod-Siverskyi - 19.6%, Pryluky landfill (by area of use) - 62.2%. In the district dimension, more than half of the project capacity of waste disposal sites and facilities has been exhausted in Varvinskyi (69.4%), Snovskyi (64%), Ichnyanskyi (58.9%), Borznyanskyi (57%), Menskyi (56.5%) districts (Derii et al., 2021).

However, even in areas with a low level of occupancy of waste disposal sites, regional-wide problems of waste management infrastructure are observed: there are no special environmental protection facilities and ecological monitoring systems, technological maps are not defined, waste accumulation is carried out unsystematically, compaction and sprinkling of soil is not carried out in a timely manner or is not carried out at all, waste records are not kept, leading to littering of the surrounding areas (Derii et al., 2021). The insufficient number and technical condition of specialized equipment generally endangers the waste disposal process in most district centres.

Currently, the implementation of the project “Construction of a plant for the complex utilization of solid household waste with a capacity of 100,000 tons per year for the production of electricity and motor fuels” is being developed in the Chernihiv Oblast (Derii et al., 2021). The initiator of the project is “Ecological products of Ukraine” LLC with the cost of the project of 150 million dollars, expecting more than 500 new jobs to be created (Derii et al., 2021). During the 1st quarter of 2020, several meetings of representatives of Chernihiv Regional State Administration were held with representatives of the company in order to study the

possibilities of implementing the above-mentioned project in the territory of the region (Derii et al., 2021). However, the project has seen no development since then.

In addition, negotiations are underway with representatives of the Czech company IVP CZ (Industry Vision Progress) regarding the signing of a Memorandum of Cooperation (Derii et al., 2021). The Czech company IVP CZ specializes in municipal waste sorting and processing technologies and is interested in the prospects of building a waste treatment plant in the Chernihiv Oblast and is ready to fully finance this project (Derii et al., 2021), however, as of now, no land plot has been allocated for the above-mentioned project.

Market and businesses activities

As of January 1, 2020, centralized collection and disposal of waste covered 75.2% of the region's population, accordingly, the rest of solid waste is removed disorderly, and unauthorized landfills are growing (Derii et al., 2021). The decrease of this indicator from 93.2% in 2016 is due to the fact that there was an increase in tariffs for solid waste management and the population did not conclude service contracts, which indicates the unsatisfactory work of local government bodies in this area. In recent years, there has been a steady trend towards the introduction of separate collection of solid waste by main components: paper, glass, plastic and PET, however, in the total volume of solid waste collected and transported by enterprises, as of 2019 the share of waste sent to collection points is 0.19% (Derii et al., 2021).

As of January 1, 2020 (according to 1-TPV reporting), there are 31 enterprises in the region that provide services in the field of solid waste management (Derii et al., 2021). Of them, 27 enterprises are communally owned (87%), 3 are privately owned, and 1 enterprise is partially communally owned (Derii et al., 2021). It should be noted that the region has insufficient number and unsatisfactory condition of specialized equipment (as of January 1, 2020, there are 115 garbage trucks in the region, the level of wear and tear of which is 59.1%), the low level of financial security of the territories regarding the possibility of reproducing objects and elements of the waste management infrastructure (Derii et al., 2021). The main reasons for this state of the WMS are lack of regulation at the legislative level and insufficient funding.

There is no system of separate collection of household hazardous waste in the region. Batteries, power elements that are unusable, thermometers, mercury-containing lamps can be

handed in by the public directly to ZHEK and ZHED (household alliances) (Derii et al., 2021). A number of enterprises, shops, and supermarkets have also installed containers for collecting used batteries, which are then transferred to housing and communal service enterprises for further transportation and disposal outside the region (Derii et al., 2021). Moreover, the Chernihiv Oblast is not homogeneous in the field of waste management, with some settlements that have implemented waste sorting and its separate collection (Derii et al., 2021), but it is more the exception than the rule for communities.

There are no specialized enterprises in the region that collect organic waste, electrical and electronic equipment waste (Derii et al., 2021). Bulky and repair waste as part of household waste is transported separately from other types of household waste according to separate agreements. Treatment of such waste types is not carried out in the region, and it is buried in landfills and other disposal sites.

The solid waste treatment infrastructure in the Chernihiv Oblast includes 4 enterprises that process secondary raw materials. In 2019, 3,500.3 m^3 or 440.3 tons of secondary raw materials were collected by procurement points in the Chernihiv Oblast, part of which was used by local enterprises (Derii et al., 2021). “Ametist” LLC is the only enterprise on the regional market for the production of toilet paper and paper towels, which uses secondary raw materials - waste paper supplied by the "Ukrvtorma" enterprise (Derii et al., 2021). Polymer waste is used by the enterprises "Slov'yani" LLC, "Plast A Pak" LLC, and "Chernigiv Package Company" LLC (Derii et al., 2021). The main volume of collected secondary raw materials of this group is exported to processing enterprises outside the region to the cities of Odesa, Kharkiv, Kyiv, and Dnipro. However, in general the region has a problem with waste treatment, especially with the secondary use of construction waste, both from households and from the business sector (Derii et al., 2021). Treatment of this type of waste is not established, being buried without returning into the economic cycle.

The volume of hazardous waste transfers in 2019 decreased by 11.4% and was carried out by both waste producers (362.06 t or 96.3%) and waste processors (13.98 t or 3.7%) (Natural environment | Head Department of Statistics in the Chernihiv Oblast, 2020). In terms of materials, three categories of waste dominate among those transferred to the side: used oil

(192.0 t), chemical waste (112.1 t) and accumulators and battery waste (39.4 t), which constitutes 51.1%, 29.8% and 10.5% respectively (Derii et al., 2021).

Import and export of waste can take place both within the region, country, and beyond (cross-border transportation of hazardous waste). Cross-border transportation of hazardous waste is carried out in accordance with the Regulation on the control of cross-border transportation of hazardous waste and its utilization/removal and the "Yellow" and "Green" lists of waste, approved by the Resolution of the Cabinet of Ministers of Ukraine dated July 13, 2000 No. 1120 (Derii et al., 2021). In 2018-19, the export and import of hazardous waste of classes I-III was not carried out within the Chernihiv Oblast (Derii et al., 2021).

4.6 Conclusions

Considering the existing practices in the waste management sector in the Chernihiv Oblast, including a high share of waste disposal and primary attempts to introduce waste sorting and recycling schemes, it can be concluded that the region is still at Stage 2 of the “Dynamic waste management system transformation” conceptual framework (see Section 2.3). This stage concentrates on the provision of protected waste disposal systems as well as the enhancement of the efficiency of the landfills. The transition to this stage suggests that initial attempts are being made to establish reliable methods for waste collection in addition to improving the standards of landfills to reduce negative impacts on the environment and the citizens’ health. Although some cities in the region have tried to implement basic recycling stations, and there are local initiatives for sorting and recycling waste, this is still far from covering the entire volume of waste of the Chernihiv Oblast. On top of that, the region does not qualify for Stage 3 due to experiencing such challenges as incomplete services in waste collection and sorting, and, similarly, unsustainable ways of landfill management. Lastly, energy recovery, fermentation, and EPR were not introduced enough in the region and still take a low share.

Chapter 5 – Assessment of the waste management systems and practices in the European Union

Since the Chernihiv Oblast, Ukraine has completed Stage 2 of the "Dynamic waste management system transformation" conceptual framework (see Section 2.3 and Chapter 4), it is crucial to undertake a comprehensive review of the European Union's practices from Stage 3 onwards. This includes examining approaches for the separate collection and sorting of waste, strategies for expanding the recycling industry, and practices directed on achieving a circular economy where waste is utilized as a resource. The objective of this review is to gain a thorough understanding of the advanced waste management practices employed in the European Union member states and identify feasible strategies and interventions for transforming the WMS in the Chernihiv Oblast.

5.1 Core system level – processes

Regarding processes for the following stages (from Stage 3 to Stage 5), a great focus is placed on reaching high waste sorting levels, implementation of various waste treatment practices, waste prevention and minimization schemes (Soudachanh et al., 2024). The key goal for the processes subsystem is to achieve low waste generation and landfilling diversion rates, together with high efficiency of waste sorting, treatment and, as a result, resource reuse. Specifically in the EU, member states undertook a number of significant actions starting in the 1990s, intensifying in the 2000s and reaching top positions nowadays in achieving high circularity rates (EEA, 2015).

Waste generation

Waste generation is a vital concern in waste management sectors, where waste prevention is broadly considered to have greater environmental potential than the dominant waste management practices of waste treatment and landfilling (Gentil et al., 2011). According to the EU Waste Framework Directive, waste prevention is defined as "measures taken before a substance, material or product has become waste, that reduce: a) the quantity of waste, including through the reuse of products or the extension of the life span of products; b) the adverse impacts of the generated waste on the environment and human health; or c) the content of hazardous substances in materials and products" (EUR-Lex, n.d.).

Moreover, based on circular economy strategies, smarter product use and manufacture is one of the of major approaches that can be applied for WMS to impact waste generation process (Morseletto, 2020). This group encompasses Refuse, Rethink, and Reduce strategies which occur when products are conceived, designed, and developed. “These strategies are precursory, enabling, and transformative. Precursory because they occur before other CE strategies. Enabling because they favour all other methods. Transformative because if applied extensively, they can make the economic system truly circular” (Morseletto, 2020). By adopting a broad set of practices within the Refuse, Rethink and Reduce strategies, waste loads are decreased, which results in lower rates of waste processed by the whole WMS.

As for the waste prevention measures in the European Union, more than 85% of them in the plans refer to the communicative measures of information campaigns (22%), cooperation (9%), investigation (32%), and promotion (23%) (Johansson & Corvellec, 2018). Examples of waste prevention measures in the plans include “cooperate,” “advise,” “assess,” “develop guidelines,” “try to enable,” “promote,” “communicate,” “identify,” and “coordinate.” These measures are considered soft, not backed by law, and not mandatory. This trend is evident at all levels of the administration and is characterized by low levels of governmental interference and coercion. The least frequently used measures in the plans are the regulative (5%) and the economic (2%) (Johansson & Corvellec, 2018). Thus, a limited number of economic measures adopted at the national level are not to be sought at the national level but at the European and municipal levels. For instance, in the municipalities that intend to charge their clients based on the weight of the waste they are disposing of. Regulatory measures are uncommon at all levels and are primarily associated with procurement (Johansson & Corvellec, 2018).

The most frequent characteristic of measures for waste prevention is that 22% of all measures aim at increasing the capacity and 21% at increasing the knowledge among the public (Johansson & Corvellec, 2018). Examples of such measures are mainly located at the community and country levels. Other general objectives of the measures are to encourage reuse (19%), which is also supported at the local and national levels, and to improve production efficiency (11%), mainly supported by the plans at the national and European levels (Johansson & Corvellec, 2018). Production efficiency may include better storage facilities and reducing waste in the production process. This shows that measures targeted at reducing consumption are relatively minimal, constituting less than one percent of all the available measures. At

national and municipal levels, the only proposed measure to reduce consumption is urging households to examine if any textiles are not being used before investing in new ones.

When analysing waste prevention measures on a more detailed level, it can be observed that various types of waste can be prevented in various ways. For instance, 36% of the measures for food waste prevention are focused on the production of food, such as “improve animal health,” “reduce the diversion of damaged fruits”, “bycatches,” and “improve logistics” and “storage”. On the other hand, there are no measures for managing electronic waste and only a few for textile waste industry (2%) (Johansson & Corvellec, 2018).

The waste prevention measures for textile, electronic, construction and demolition waste focus instead on the later part of the product’s lifecycle: to encourage reuse (18–29%) and, to some extent, recycling (2–15%) through “campaigns”, “improving the current system”, “voluntary producer responsibility” and “product declarations with information for disassembly” (Johansson & Corvellec, 2018). Strategies to control hazardous waste focus mainly on enhancing capacity and awareness and improving waste management through “more collection centres for hazardous waste”. Lastly, strategies regarding sustainable consumption, for instance, "manufacturing products with a longer lifetime", are primarily available for electronic waste (15%) and much less for food waste prevention (3%), construction and demolition waste (0%), and textile waste (2%) (Johansson & Corvellec, 2018).

Waste sorting and collection schemes

When waste is unavoidable or has already been generated, proper sorting procedures should be utilised before treatment (Zhao & Zhang, 2023). Countries in the European Union recognise the necessity of waste separation for proper waste recycling and other waste treatment approaches. As a result, the EU has established guidelines and standards for its member states to implement effective waste sorting and recycling systems (European Commission, n.d.). Waste sorting begins at the source when families and companies are obliged to separate their waste into several waste fractions (see example in Figure 8). These categories may include organic waste such as food and garden waste, paper and cardboard, plastics, metals, glass, and other types of waste (European Environment Agency, 2022). Separate sorting facilities also collect other types of waste materials, including textiles, furniture, healthcare products and

hazardous materials such as batteries, electronics, and chemicals. After all, sorted waste is sent to recycling facilities, where it is further processed, cleaned, and treated.

Figure 8. Bins for waste sorting in Germany (from Tomorrows World Today, 2022)

Such sorting procedures differ significantly across the European Union countries, where Austria, Belgium, Czechia, Denmark, Germany, Luxembourg, the Netherlands, and Slovenia are considered the leaders (European Environment Agency, 2023). For instance, Austria has classified household waste into seven categories: clear and coloured glass, packaging waste, paper with cardboard, organic waste, metals, and residual waste (Österreichs Digitales Amt, n. d.). Also, used clothes, batteries, energy-saving lamps, medicines, peptides, glue, bulky waste, household appliances, and chemicals can be sorted and collected separately at waste collection centres, which prevents the leakages of hazardous substances and increases the rate of recycling (Stadt Wien, n. d.). As for the Netherlands, the waste sorting system is well structured and effective in its approach towards sorting waste at the source and involving communities (European Environment Agency, 2022). Various coloured bins are available for households to dispose of organic waste, paper and cardboard, plastics, metals and packaging, glass sorted by colour, residual waste, and textiles. Larger items and specific waste types are directed to municipal recycling centres equipped to handle hazardous materials and bulk waste (Ministery of Infrastructure and Water Management, n.d.).

In addition, the goal is also to develop efficient waste-sorting labels. Scholars from the European Commission claim that the evidence-based design and empirical testing of such labels can promote waste collection and involve more waste generators (Beaumais et al., 2024). Waste-sorting labels on product packaging and waste receptacles inform consumers on how to dispose of materials properly. These measures include increasing accessibility,

accuracy, intuitiveness, clarity, compatibility, conciseness, consistent placement, etc (for more details see Figure 9). In a nutshell, effective waste-sorting labels should focus on three critical factors: presentation (clarity of information), quality and content (substantive and perceived value), and accessibility (user-friendliness) (Beaumais et al., 2024). Clear, concise, and easily understood labels help consumers quickly determine the correct disposal methods.

Figure 9. Measures to increase the quality of wastebin labels (from Beaumais et al., 2024)

Recycling

The waste recycling system in the European Union is well-regulated by laws that aim to encourage recycling and decrease the amount of waste that is dumped. The process starts with collecting recyclables, which can be through the bins provided by the municipalities, recycling centres or drop-off points (Chioatto & Sospiro, 2022). These materials are then disposed of at material recovery facilities and processed into secondary materials (Bourtsalas & Themelis, 2022). Last but not least, recycled materials are sold to manufacturers to make new products, completing the recycling process.

The recycling processes remain a work in progress within the EU member countries due to the heterogeneity in policies, facilities, and people's cooperation (European Union, 2023). Recycling in the European Union is a very systematic process with several stages, and each of them is aimed at conversion of waste into secondary materials. After the waste is sorted, it is

taken to material recovery facilities (Grant et al., 2020). This type of waste then passes through several post-sorting processes, which are done to sort out different types of waste and to improve household sorting.

Sorting might also include cleaning processes that are done on the materials before or after sorting to ensure that any impurities that may still be there are removed (Lahtela & Kärki, 2018). For instance, paper and cardboard are washed to remove ink, adhesive, and other kinds of dirt (Rekart, 2023). Plastics are cut into small pieces, washed, and then melted into pellets (small round shapes of plastic), which are then used in making new plastic products (see an example in Figure 10). Metals are melted down and reformed into new metal products, and glass is crushed, melted, and reformed into new glass items (Wang et al., 2023).

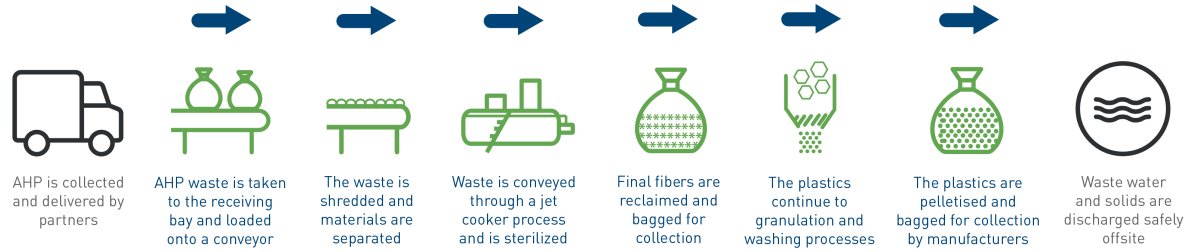


Figure 10. Plastic recycling process (from Knowaste, n.d)

In the recycling process, it is seen that each member state of the EU has formulated its own pathway according to its necessities and potentialities. For instance, Germany's Green Dot system entails that the manufacturers have to bear the cost of recycling the packaging materials, which encourages them to produce easily recycled products (Der Grüne Punkt, n.d.). This system has resulted in the development of a complex network of waste sorting and recycling capacities, generating high recycling rates (Da Cruz et al., 2014). On the other hand, Italy's recycling system exhibits regional disparities. The recycling plants and rates are more developed in northern Italy than in the southern regions, where the facilities and public involvement are not as evolved (Agovino et al., 2016).

Treatment

Besides recycling, the European Union employs multiple other waste management approaches to guarantee the preservation of resources while the remaining waste is disposed of properly. Composting is one of the most extensively utilised techniques (see an example in Figure 11), in which organic material such as food waste, yard waste, and other materials are

degraded to produce nutrient-rich compost (Tokarchuk & Tomliak, 2023). This compost may be used to improve soil fertility, support agriculture sector, and reduce the need for artificial fertilisers. Biogas and composting plants treat organic waste through aerobic and anaerobic decomposition. Anaerobic digestion creates not only digestate but also biogas, which may be utilised for heating, electricity, and fuelling vehicles (Tokarchuk & Tomliak, 2023). These strategies are fundamental to the EU's waste management policy, which support minimising landfill use and greenhouse gas emissions while recovering valuable materials.

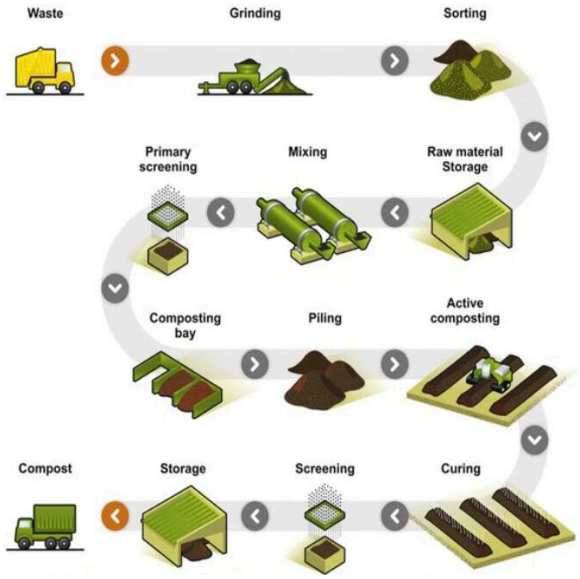


Figure 11. Composting process (from Zhang, 2023)

Another prominent waste treatment technology is mechanical-biological treatment, which combines mechanical sorting and biological processes. In a mechanical-biological treatment facility (see an example in Figure 12), waste is mechanically processed to separate recyclables and biological contaminants. The residual organic fraction is later biologically processed, either by composting or anaerobic digestion (Suchowska-Kisielewicz et al., 2017). This technique dramatically decreases waste volume while also stabilising the organic material, making it acceptable for disposal or use as a soil conditioner. Mechanical-biological treatment is especially useful for managing mixed municipal waste and diverting organic waste away from landfills, which reduces methane emissions and leachate from landfill sites (Suchowska-Kisielewicz et al., 2017).

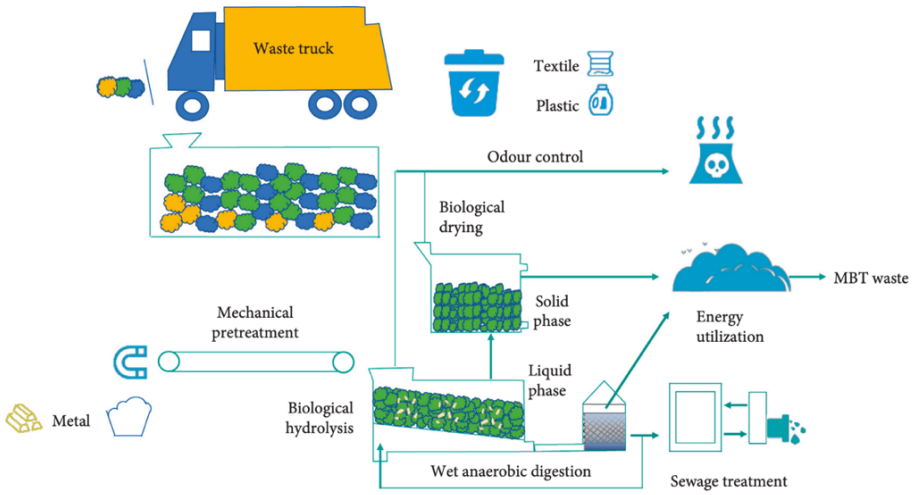


Figure 12. Mechanical biological treatment process (from Wang et al., 2022)

Thermal treatment, such as incineration, is also employed in the EU member states, although its application is limited from the circular economy perspective due to its adverse environmental impact when avoiding resource recovery. Incineration is the process of burning waste materials at high temperatures to reduce their volume and produce energy (Tabasová et al., 2012). Modern waste-to-energy facilities (see an example in Figure 13) use modern emissions control systems to reduce pollution and maximize energy production out of waste. For example, plants in Czech Republic use state-of-the-art technologies to guarantee emissions are under EU guidelines, decreasing environmental effects (Tabasová et al., 2012). Incineration offers the advantages of reducing waste and producing energy, but it also has the downside of eliminating elements that may be recycled and reused in the resource cycle (Block et al., 2015).

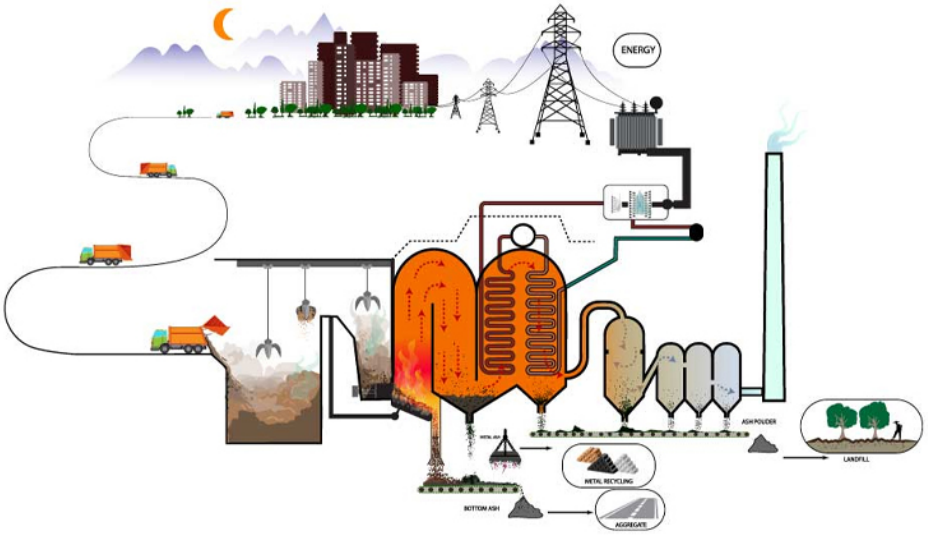


Figure 13. Waste to energy process (from Carmeuse Systems, n.d.)

Disposal

The EU's waste management plan focuses heavily on landfill minimization and complete landfill bans. When landfills are not properly sealed, landfilling is the least desirable option due to its long-term negative consequences on the environment, including greenhouse gas emissions (particularly methane), water and soil contamination, and the destruction of wildlife habitat (Skryhan et al., 2017). These issues are addressed by the EU Landfill Directive (1999/31/CE), which requires reducing the quantity of biodegradable waste disposed of in landfills and establishing specified standards for the operation and construction of landfills. To decrease the reliance on landfilling, the EU member states have established economic tools such as landfill fees, pay-as-you-throw systems, and deposit-refund schemes (Skryhan et al., 2017). Furthermore, virtually all EU member states have banned disposal of separate waste categories in landfill sites, such as hazardous waste and biodegradable waste that has not been pretreated. Such bans assist in promoting the use of waste treatment methods, thereby encouraging innovation and adequate investment in sustainable WMSs (Wang et al., 2019).

5.2 Core system level – actors

Waste management in the European Union is a combined initiative of citizens, recycling companies, governments, NGOs, and other institutions. Each stakeholder plays a crucial role in ensuring the effectiveness of the waste management process and in promoting circular economy principles.

Citizens are one of the key stakeholders in the EU WMSs as they are directly involved in waste generation and sorting at the source (Lynch et al., 2018), thus, they play a vital role in waste management at early stages. A crucial aim for the general public is to gain awareness about the importance of sustainable waste management and the benefits of waste recovery, which is often implemented through various educational campaigns (Lynch et al., 2018). Moreover, there is a number of incentive programs, like deposit-return schemes for beverage containers (Lynch et al., 2018), which also help promote responsible behaviour among the general public.

Waste management companies are involved in the collection, post-sorting, treatment, and disposal of waste and the conversion of waste into secondary materials. These companies operate collection and sorting infrastructure, together with material recovery facilities and

other waste processing plants, utilizing mechanical forces and advanced technologies to maximize the efficiency and quality of waste recovery (Weghmann & EPSU, 2023). They also play a key role in developing and implementing innovative recycling solutions and technologies, contributing to the overall improvement of the EU WMSs.

As stated in the "System-based waste management assessment" conceptual framework (see Section 2.2), WMS is a complex system that involves coordinating and implementing activities within local, regional, and national governments to set standards and/or guidelines. The EU Waste Framework Directive, for instance, provides specific national targets for recycling and waste management for the member countries (European Union, 2008). Governments, in turn, invest in waste management facilities, promote innovations in waste sorting and treatment infrastructure, and regulate companies' environmental performance to achieve those targets (Di Maria et al., 2020).

Non-governmental organizations (NGOs) and other non-profit institutions play their part by campaigning for sustainable waste management, educating the public, and putting pressure on businesses and governments (Harangozó & Zilahy, 2015). Regarding the problem of waste and recycling, NGOs can conduct educational activities, studies, and community work. They are also involved in monitoring compliance with environmental standards and waste management practices to ensure sustainability of WMSs.

To achieve circularity and improve the overall WMS, there are two key strategies aiming at citizens and business involvement:

Campaigns are important in raising awareness of the need to manage waste, the right way to sort it and the need to recycle. Such campaigns may consist of school programs, mass media, community workshops, and other measures to address people's behaviour and make their activity more sustainable (Harangozó & Zilahy, 2015). These campaigns serve a significant purpose of raising the public's awareness about environmental issues and, specifically for waste management, increase the involvment in waste collection and sorting processes.

Extended producer responsibility (EPR) is another vital approach that can contribute to waste reduction and prevention (Rubio et al., 2019). EPR programmes are often adopted to guarantee that manufacturers are responsible for the treatment of waste coming from their

products (Watkins et al., 2020). The EU's Packaging and Packaging Waste Directive (94/62/EC) required member states to implement EPR programmes for packaging waste. Several EPR systems for electronics, batteries, and automotive sectors have been adopted by the EU member states. These initiatives encouraged companies to create more sustainable products and reduce waste output. For example, France initiated its EPR programme for electronics in the early 2000s, which resulted in a significant increase in e-waste recycling (European Environment Agency, 2022).

5.3 Core system level – values

Several social, ecological, and economic variables influence the European Union's waste management status and its transition to a circular economy. All of these factors are interconnected and, when combined, serve as important drivers of environmental and climatic protection by recognising waste as a resource and preserving natural resources.

The social factors driving the development of waste management in the EU include a growing awareness of environmental problems, which fosters a sense of shared responsibility for decreasing pollution and conserving resources (Triguero et al., 2016). Moreover, considerations for the health and safety of people highlight the importance of properly treating waste in order to prevent the spread of infections, among other concerns. Sustainable waste management approaches have less of an impact on public health and encourage cleaner practices, resulting in a positive feedback loop (Triguero et al., 2016). Social justice and inequality are other parameters that ensure that all communities have an equal opportunity to receive waste management services (Pires et al., 2011).

Environmental drivers include well-developed WMSs that reduce greenhouse gas emissions, particularly methane from landfills, as well as other contaminants. This is the result of sustainable waste management operations such as recycling and composting, which reduce the carbon impact on the environment and thus contribute to avoiding climate change (Mihai & Apostol, 2012). In a word, mitigating the negative impact of waste on the ecosystem is a critical ecological need where sustainable WMSs are able to decrease the demand for raw materials (due to waste treatment), allowing ecosystems to remain uninterrupted and conserving natural habitats from overuse (Mihai & Apostol, 2012).

Regarding economic value, one critical goal is to view waste as a resource that serves as the foundation for circularity. Recyclable waste materials can be returned to the production cycle, reducing costs associated with raw material extraction and processing (Gardiner & Hajek, 2020). This economic incentive pushes enterprises to implement technologies and methods for sorting and reusing secondary materials. Furthermore, sustainable waste management companies provide an additional occupation potential, ranging from collection and sorting to recycling and manufacturing (Gardiner & Hajek, 2020). Finally, waste management industries contribute to economic growth by encouraging the emergence of new markets for secondary materials (Gardiner & Hajek, 2020).

5.4 Wider system elements – natural environment

Resource scarcity is a major issue that affects the European Union and, therefore, raises the question of resource use efficiency. The EU is a resource-scarce alliance, especially on energy sources and critical raw materials, which leads to a dependency on the import of resources (Tanning & Tanning, 2015). This makes the EU face challenges such as supply chain risks, price fluctuations, and political disruptions. The demand for energy resources in the global market is still on the rise (Eurostat, 2024), which puts a significant pressure on proper resource management through, for example, waste-to-energy technology, which can produce energy sources out of waste.

In addition, advanced WMSs support the management of scarce resources by turning waste into secondary materials (Domenech & Bahn-Walkowiak, 2019). The EU can thus efficiently collect, sort, and treat waste materials and thus obtain valuable sources that can be fed back into production. This process minimizes the use of the resources that have to be extracted locally or imported from other countries and, therefore, increase the efficiency of resources use. When applying circular economy principles, resources can cycle in closed-loop systems, where waste is reused or recycled and hence does not require more raw material inputs (Soudachanh et al., 2024).

5.5 Wider system elements – governance and political landscape

The European Union has established a strong legal framework to encourage circular waste management initiatives and promote sustainability among its member states. One of the

fundamental pieces of legislation is the Waste Framework Directive (2008/98/EC) (European Union, 2008). This directive establishes fundamental principles and definitions linked to waste management, such as the waste hierarchy, which prioritises waste prevention, reuse, recycling, and recovery over disposal. It also established the concept of "polluter pays", which assures that the costs of waste management are met by the initial waste producer. Another critical piece of legislation is the Landfill Directive (1999/31/EC), which seeks to minimise or mitigate the negative impacts of waste landfilling (Di Maria et al., 2020). This directive establishes significant technical criteria for waste landfilling, including a reduction in biodegradable waste sent to landfills to reduce greenhouse gas emissions. As a result, it required member states to reduce the amount of biodegradable waste sent to landfills to 35% of the 1995 levels by 2020.

The Packaging and Packaging Waste Directive (94/62/EC) aims to reduce the amount of packaging materials and their environmental impacts (Niero, 2023). It encourages recycling and recovery of packaging waste and requires member states to implement actions to reduce packaging waste production, stimulate reuse, recycling, and other forms of recovery, restricting direct packaging waste landfilling. The regulation establishes particular recycling targets for certain materials, guaranteeing that by 2025, 65% of all packaging waste is recycled (Niero, 2023).

The Waste Electrical and Electronic Equipment (WEEE) Directive (2012/19/EU) is another critical piece of legislation addressing the growing issue of electronic waste. This directive seeks to reduce the amount of WEEE generated while also improving the environmental performance of all bodies involved in the life cycle of electrical and electronic equipment (Mihai et al., 2019), notably those responsible for waste collection, treatment, recycling, and recovery. The WEEE Directive establishes collection, recycling, and recovery targets for all types of electronic items, with the goal of reducing e-waste and its negative impacts on the environment and human health. Additionally, the RoHS Directive (2011/65/EU) supplements the WEEE Directive by limiting the use of certain hazardous compounds present in electrical and electronic products. This directive restricts the use of six hazardous (e.g. the heavy metals lead, mercury, cadmium and hexavalent chromium) in homogeneous materials when producing electronic and electrical equipment (Puype et al., 2015). Such an initiative supports preventing hazardous chemicals from entering waste streams and mitigating their effects on the environment and human health.

The Circular Economy Package, adopted in 2018, is another key legislative framework aimed at increasing waste recovery and reducing waste (Stankevičius et al., 2020). This package includes a set of legislative ideas aimed at reducing waste and encouraging sustainable resource management. New targets for recycling municipal and packaging waste, as well as an obligatory target to reduce landfill waste to no more than 10% by 2035, are key components (Stankevičius et al., 2020). It also requires member states to make efforts to reduce waste generation and support product reuse and recycling, further integrating the waste hierarchy into national legislations.

5.6 Wider system elements – technologies, infrastructure, and innovations

Currently, waste management infrastructure and technological development vary substantially among EU member states. Generally, southern EU nations seek to create additional steps to undertake more integrated WMSs and meet EU targets, whilst central EU countries seek to rationalise their technical choices and management plans (Pires et al., 2011). Although the EU is investing in novel and modernised recycling infrastructure, certain EU countries are working to improve the development of waste management facilities. For example, the Czech Republic has adopted a strategic multi-stage waste processing infrastructure design in order to satisfy particular landfilling and recycling targets (Kůdela et al., 2019). The primary goal of such development is to achieve circularity in waste management sector, which will be based on sorting facilities, recycling plants, waste-to-energy facilities, and so on. These investments are aimed at improving the capacity and effectiveness of waste treatment and recovery procedures while reducing reliance on disposal and other non-sustainable practices (Kůdela et al., 2019).

Collection systems

Waste collection infrastructure consists of a network of colour-coded bins, containers, and pickup vehicles. Specialised trucks with compactors are prevalent in cities, although more standard collection methods may be used in rural regions. A part of European Union member states has installed underground waste collection systems to keep waste out of sight and reduce its smells (Hidalgo et al., 2018). These systems use underground containers that can be accessed via above-ground channels, improving aesthetics and hygiene in public settings. For example, Barcelona, Spain, employs a pneumatic waste collection system in which waste is

carried to central collection stations via underground tubes, decreasing the need for regular garbage trucks (Hidalgo et al., 2018).

Sorting facilities

Sorting facilities use innovative techniques to separate various types of waste materials. Mechanical sorting is using conveyors, screens, and shredders to sort through large amounts of waste and bash up garbage bags (Lahtela & Kärki, 2018). New technologies such as optical sorters are devices that use light beams to sort different plastics and other materials by their characteristics. Magnetic separators remove the ferrous metals, on the other hand, eddy current separators remove non-ferrous metals (Cimpan et al., 2015). In the end, manual sorting is applied at various stages to ensure purity and remove contaminants. Austrian sorting facilities, for example, use optical sorting devices that can identify and separate various types of plastics based on their polymer composition and colour (Friedrich et al., 2021).

Recycling plants

These plants are specialised facilities that convert recyclable waste into secondary materials. For example, glass recycling plants crush and melt collected glass to make new glass items, whereas plastic recycling plants clean, shred, and melt plastic to make plastic pellets (Cimpan et al., 2015). Metal recycling factories employ procedures such as smelting to extract valuable metals from waste. In the Netherlands, plastic recycling plants use a process known as “plastics-to-oil”, which converts plastics into synthetic crude oil that may subsequently be processed into fuels and chemicals (WPSP, 2018).

Bio-waste treatment is an essential element of the European Union’s waste management strategy, which aims to reduce environmental impact while also boosting resource recovery (Araya, 2018). Bio-waste, which includes organic materials like food scraps, garden debris, and agricultural leftovers, is handled in a range of ways to produce such valuable products as compost, biogas, and biofertilizers. An important technology is anaerobic digestion, which breaks down biowaste in the absence of oxygen to produce biogas and digestate (Akhiar et al., 2020). The biogas can be used as a renewable energy source, and the digestate can be used as a fertiliser. Germany is a bright example of utilizing advanced bio-waste treatment infrastructures, with more than 10,000 plants, using state-of-the-art anaerobic digestion facilities to maximize biogas production and energy recovery (Akhiar et al., 2020). These

processes not only divert significant amounts of organic waste from landfills but also contribute to the EU's renewable energy targets and the circular economy by returning valuable nutrients to the soil and reducing greenhouse gas emissions.

Waste-to-energy plants

These facilities convert non-recyclable waste into energy using procedures such as incineration, gasification, and anaerobic digestion (Alao et al., 2022). Waste-to-energy plants use incinerators, turbines, and generators to convert waste into electricity and heat. Moreover, they also utilize profound emission control systems to reduce environmental effect. For example, Stockholm, Sweden, the Högdalen CHP facility employs modern flue gas cleaning technology to keep emissions well below the EU's standards (Noor et al., 2020). As a result, this facility provides power and district heating to the city of Stockholm.

Landfills

Modern landfills in the EU include numerous environmental protection measures. First of all, liners or sealing techniques are used to keep leachate out of groundwater and gas collection systems (see an example in Figure 14) to capture methane for energy use (Madon et al., 2020). Moreover, landfills typically serve as the last alternative for waste disposal, and European Union regulations seek to decrease landfill use by encouraging recycling, other waste treatment or waste-to-energy approaches. In Helsinki, Finland, the Ämmässuo landfill has a biogas plant that transforms methane from waste into energy, greatly reducing greenhouse gas emissions potentially emitted when processing crude oil (Manfredi et al., 2009).

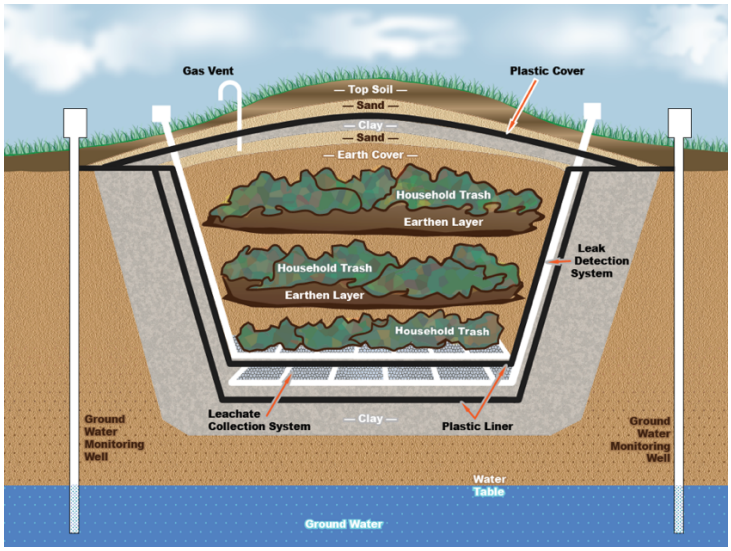


Figure 14. Landfill protection (from Indiana Department of Environmental Management, n.d.)

Innovations and circularity

Concerning circular design and innovation, the EU supports circular design principles while also encouraging product design innovation to make goods more durable, repairable, and recyclable (Bocken, 2022). Design for disassembly and remanufacturing is increasingly being promoted as a solution to extend product lifecycle while reducing waste generation. The EU, in particular, encourages waste management innovation, development and implementation of intelligent waste-management solutions in order to progress towards the circular economy. The EU also provides policy and financial support for research, innovation, and implementation of new waste management and recycling technology (European Commission, 2018). For instance, Horizon Europe and the European Regional Development Fund are two initiatives that provide support for innovation projects aimed at achieving sustainability goals and transition towards circular economy.

5.7 Wider system elements – market and business activity

The improvement of circularity in the EU led to stricter regulation on all levels of the legal framework, which, in turn, has affected business environment and general market (Kirchherr et al., 2018). Due to the enhancement of circularity standards, many organizations started paying more attention to sustainability in their operations, product development, and supply chain establishment. This includes elements such as green design, waste reduction, recycling, and material utilization in production.

Stringent legislation towards circularity has also increased the research and development investment to develop new technologies, processes, and products for circular economy systems (Kirchherr et al., 2018). It is also important to note that firms are now investing in projects concerning recycling technologies, waste-to-energy solutions, biodegradable packaging and so on. In addition, numerous organizations are hiring waste management companies and other parties to improve the options for waste collection, sorting, recycling, and disposal (Ritter et al., 2024). This cooperation implies that the two companies are linked by partnership, joint venture, and supply chain management and, therefore, tend to create less waste.

Stricter circularity laws have compelled companies to implement measures on the disposal and control of their products with the aim of reducing waste and improving the use of resources, thus, reducing the effects on the environment (Hartley et al., 2020). This comprises using environmentally friendly materials in production, reducing packaging materials, and providing for the take-back of the products and recycling them. In addition, the circular economy concept is increasingly gaining adoption, and many organizations are applying such strategies in their business operations as product and material reuse, re-manufacturing and recycling (Hartley et al., 2024). This also includes approaches such as product as a service, leasing, and take-back programs that enable firms to acquire products and manage their life cycle.

Last but not least, the circularity and reporting standards are also catching the attention of businesses. It is the process of tracking, analysing, and documenting waste, recycling, and environmental footprint indicators for businesses to meet the regulatory and other stakeholders' standards (Di Vaio et al., 2022). Also, firms are investing in their consumer education and engagement in the circular economy to enhance the awareness and advocacy of the circular economy among the community. This includes various marketing campaigns like the use of logos, commercials, and sustainability reporting to explain circular economy value propositions and change the consumer's behaviour (Di Vaio et al., 2022).

5.8 Challenges in the European Union in achieving complete circularity

Although the EU has done a fair job transitioning to complete circularity, such goal still remains a complex task. This includes social, economic and time-related challenges, that are further aggravated by occasional inefficiencies in implemented measures.

Social challenges

A key issue in circularity promotion is the level of public participation and awareness. The implementation of circular economy strategies cannot be done without the involvement of citizens, organizations and general public (Kirchherr et al., 2018). However, the challenge of involving all EU citizens is due to the unequal levels of knowledge and concern among the population of different member states. The concept of circular economy is still not explicitly understood by the general population despite numerous campaigns and programs. Thus, education plays a vital role in developing awareness and knowledge in this case. In order to

close this knowledge gap, there must be elaborate educational interventions that can be disseminated to society, from school-going children to adults (Smol et al., 2018). To promote the circular economy and the advantages of its practices, the proper communication measures must be employed. The difficulty lies in creating messages that speak to the intended audience and employing different media outlets to propagate the message. For a positive outcome, there should be a synergy of approaches, which will comprise traditional media, social media and community-based interventions.

Economic challenges

The transition towards a circular economy also offers a certain number of economic issues since it is a costly process (Rizos et al., 2016). Organizations have to redesign their goods and services to optimize for recycling and reducing waste. Such changes often demand a drastic amount of capital investments, especially at the beginning, which might be rather unattractive, especially for small and medium enterprises. Such investments are used for economic trials, such as pilot projects and market tests, which are crucial in generating and implementing circular economy solutions. However, even successful trials cannot guarantee that new circular products or business models will be taken by the market. In addition, consumer resistance may be evident, especially when new goods are seen as being of lower quality or when consumption patterns need to be altered.

Further, governments or waste management companies have to invest in waste management infrastructure and offer remunerations for circular activities, which can become a burden on the governmental or private budgets (Kirchherr et al., 2018). Transition to sustainable waste management requires modern sorting facilities and waste treatment plants, which are capital intensive. These are upfront costs, which are rather high, particularly for the less prosperous EU member states, thus resulting in the unequal pace of circular economy development. Lastly, high start-up costs may discourage private sector participation, particularly in areas with poor economic returns or developing markets.

One of the observed challenges is the provision of stable markets for recycled material. Some materials, such as metals, are profitable secondary materials, which have lower costs compared to raw ones since they can be produced with less energy or without extraction of raw materials (EEA, 2023). However, materials such as paper or residual waste are not always

self-sufficient to generate profit and need governmental or market backup. Therefore, creating stable demand and proper pricing for secondary resources and materials is a permanent process and requires proper management. These markets are essential in absorbing the products from recycling activities and creating business opportunities for circular activities.

Political and temporal challenges

One of the main temporal issues is the time lag between the implementation of circular economy actions and the appearance of the corresponding outcomes (Friant et al., 2021). Measures and strategies aimed at supporting circularity may not result in visible changes for years, which can lead to waning enthusiasm and support from all involved actors. This delay can be a big turn-off for policymakers, businessmen, and general public. In addition, it hampers the process of identifying the efficiency of these measures and the possibility of their modification (Meyer et al., 2022). Between the time of enforcing the policy and the time of its achievement, there is a loss of resources. This could entail the financial capital used in making long-term investments with no return in the near future and the natural capital that is further depleted by continued inefficiencies during the transition period. These resource losses underscore a great importance of proper planning and management of transition phases.

Despite the EU's efforts, some circular economy programs have failed due to inefficient measures. According to a study of Johansson & Corvellec (2018), certain initiatives have not achieved their intended outcomes because of poorly designed policies and inadequate implementation strategies. These failures often result from a lack of coordination among stakeholders, insufficient funding, and gaps in regulatory frameworks. Inefficiencies in waste collection and recycling systems, as well as challenges in enforcing compliance with circular economy regulations, further hinder progress. Lastly, in the last few years, the success of separate collection of several waste fractions has started to decrease, which could be an inhibiting factor in the future achievement of the EU waste targets (European Environment Agency, 2022).

5.9 Conclusions

It is relevant to mention that the EU waste management systems are based on supportive legislative principles, effective waste management infrastructure, and an emphasis

on sustainability and transition to a circular economy. These factors are supported by substantial investments, technical innovation, and widespread public participation. The European Union has implemented viable waste management policies, demonstrating the need for circularity and resource efficiency. Advanced waste treatment technologies and public awareness campaigns further enhance the efficiency and effectiveness of waste management, ensuring that the community embraces policies. The EU's commitment to research and innovation continually fosters the development of sustainable materials and processes. Collectively, these efforts underscore the EU's comprehensive approach to promoting circularity and resource efficiency, aiming for long-term environmental protection and sustainable development.

Although the EU has implemented numerous initiatives in order to apply circular economy principles, the process of achieving total circularity is challenging and influenced by social, economic, political, and technological factors. There is a noticeable difference in public engagement between EU member states due to varying levels of awareness. Economically, transition necessitates significant investments in waste management facilities and product development, which are costly to companies, particularly small and medium-sized businesses, and burden government budgets. Another problem is maintaining stable markets for secondary materials, which vary and cause instability for both resource providers and consumers. Politically, the outcomes of initiatives can be delayed, causing stakeholders to lose interest and hindering the assessment of policies' success. In addition, some EU member states find it challenging to integrate their national legal systems with EU directives. Technologically, integrating modern waste treatment technologies and establishing market acceptance for circular products necessitates ongoing adaption and financial commitments.

Chapter 6 – Recommendations for transforming the waste management system in the Chernihiv Oblast

By effectively addressing challenges in the European Union and learning from past success, the Chernihiv Oblast can make a significant step forward (from Stage 2 of the "Dynamic waste management system transformation" conceptual framework) to transition towards a sustainable and circular development of the regional WMS (Stage 5 of the "Dynamic waste management system transformation" conceptual framework). By understanding and adapting the EU waste management strategies to local conditions, including addressing economic, social, and environmental contexts, the region can avoid common mistakes and ensure a more effective and sustainable WMS. This will require charting a strategy for the Chernihiv Oblast WMS transformation based on the assessment of the regional WMS conducted in Chapter 4, EU practices analysed in Chapter 5 and the "Dynamic waste management system transformation" conceptual framework (see Section 2.3). This chapter provides recommendations directed on national (see Section 6.1) and regional authorities (see Section 6.2).

6.1 Recommendations for the national government

The national government of Ukraine plays a pivotal role in waste management by establishing the overarching framework for the waste management sector and implementing a comprehensive national legislative base. Therefore, the recommendations towards the national government are as such:

Overall transformation of the waste management sector

– develop and implement policies that would technically and financially support the growth of waste sorting and treatment industries;
– provide a stable and supportive policy environment for waste management companies with clear guidelines and timelines for compliance;
– provide financial support to waste initiatives aimed at strategies like Refuse, Rethink, and Reduce;
– strengthen regulations on waste disposal to reduce landfill usage, and mandating waste sorting and treatment;

– strengthen regulations on treating hazardous wastes, including used car components, medical, electronic and bulky wastes;
– provide incentives for compliance, such as tax breaks or grants, and penalties for non-compliance to ensure adherence to waste management regulations;
– encourage businesses to adopt sustainable waste practices, such as bio-degradable packaging or product eco-design, by granting green businesses and initiatives.

Communication and partnership in the waste management sector

– support international collaboration with European Union member states on circular economy initiatives, sharing best practices and innovations to accelerate the transition to a circular economy;
– promote extended producer responsibility and take-back schemes within the private sector to ensure producers financial and logistical involvement in the end-of-life management of their products.

Common goal towards circular economy concept

– promote community awareness about the environmental benefits of efficient resource use, proper waste sorting and treatment, through educational programs and public initiatives;
– facilitate the creation of markets for secondary raw materials through policy support and financial measures, ensuring stable demand for recycled products;
– cultivate a market preference for recycled goods by promoting their environmental and economic benefits and supporting circular business models like the sharing economy and product-as-a-service models.

6.2 Recommendations for the regional governmental bodies

Regional governmental bodies in Ukraine are responsible for implementing national waste management policies, overseeing waste collection and disposal, and ensuring compliance with regulations. Additionally, they are involved on developing and maintaining waste management infrastructure, conducting public education campaigns, and collaborating with private sector entities to enhance sector efficiency. Therefore, the recommendations towards the regional government are as such:

Region clusterization

The region can be clustered into sub-regions, strengthening of the role of economic factors and the weakening of administrative ones, which makes cluster management a universal tool in conditions of decentralization. The proposed division (based on National Strategy for Waste Management in Ukraine until 2030) of the Chernihiv Oblast is as such: West, East, South and Central clusters, also presented in Figure 15. This division divides the region into four clusters with the aim of minimization of waste transportation and disposal costs, and minimization of waste disposal volumes. To add to it, the division into clusters is based on the distribution of the impact on the general WMS between the largest cities, where Chernihiv (the capital of the region, the largest city) is the head city in the West cluster, Nizhyn (the 2nd largest city in the region) is in the Central cluster, Pryluky (3rd biggest city in the region) is in the South cluster and Mena in the head of the East cluster (the union of other large cities of the region). For additional details on the regional clusterization, refer to Table C.

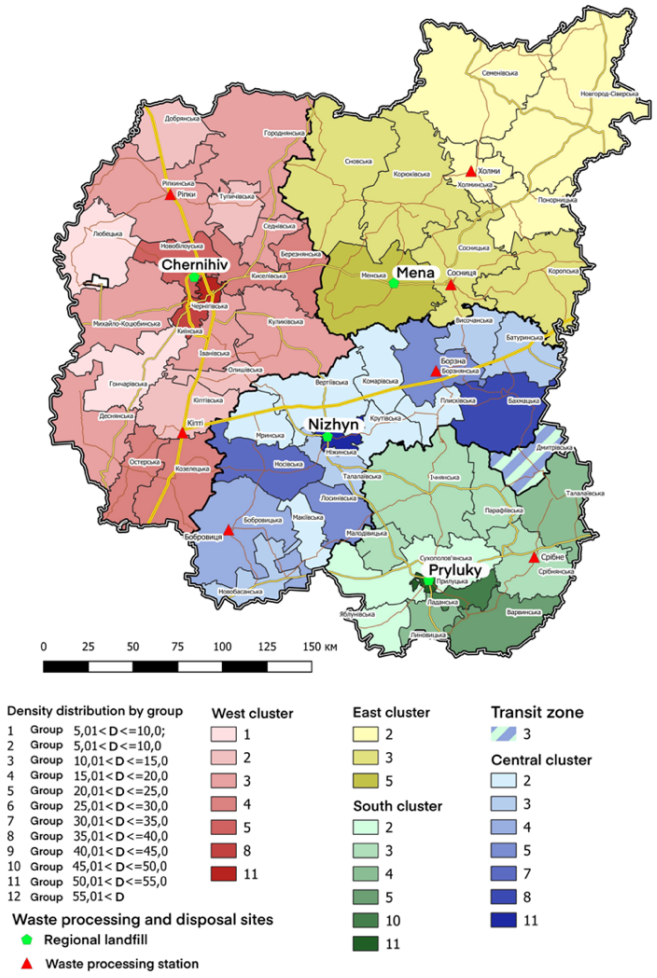


Figure 15. Clusterization of the Chernihiv Oblast (adapted from Derii et al., 2021)

Development and implementation of waste management plans

– conduct a detailed analysis of the existing WMSs in regional clusters (see Table C and Figure 15);
– define specific goals, tasks and indicators of success for WMSs transformation plans in each cluster and community;
– involve related bodies (stakeholders), including representatives of communities, businesses and NGOs, in the development of the waste management programmes and strategies;
– support private and state initiatives in building and increasing capacities in waste sorting and treatment, particularly in energy recovery (waste-to-energy technology) and fermentation, by providing financial incentives, technical and informational assistance.

Implementation of a separate waste collection and sorting systems

– stimulate investments in the construction of waste sorting infrastructure*;
– initiate information and educational campaigns for the local population regarding the importance and rules of separate waste collection at the source;
– support the unification and develop standardized protocols for waste sorting facilities across the region, ensuring compatibility with national, international or EU standards for separate waste collection (containers, collection sites, garbage cans, trucks, etc);
– guide the development of waste sorting infrastructure with technical and regulatory support to ensure corresponding to the capacity of generated waste, utilizing such technologies as conveyors, mechanical separators, magnets, optical sorters, advanced robotic systems, etc;
– control and assess the efficiency of waste sorting infrastructure to further maximize the output of those practices.

Creation and development of infrastructure for waste treatment

– stimulate investments in the construction of waste treatment infrastructure*;
– consider energy recovery and composting as waste treatment alternatives (first step);
– support the unification and develop standardized protocols for waste treatment facilities across the region, ensuring compatibility with national, international or EU standards;
– consider anaerobic digestion, recycling and gasification as waste treatment alternatives (second step);

– guide the development of waste treatment infrastructure with technical and regulatory support to ensure corresponding to the capacity of sorted waste, utilizing such technologies as anaerobic digestion for organic waste and chemical treatment for hazardous waste, recycling, incineration, anaerobic digestion and gasification plants;
– control and assess the efficiency of waste treatment infrastructure to further maximize the output of those practices.

(*) Stimulation of investments, financial support and incentives in the field of waste management

1) public-private partnership (PPP):
– to encourage cooperation between the public and private sectors for the implementation of waste management projects;
– offer financial guarantees for private investors who invest in infrastructure for waste sorting and treatment.

2) financial mechanisms:
– organize contests for obtaining grants for the implementation of waste management projects;
– provide support for local initiatives by providing subsidies for the integration of waste sorting and treatment facilities;
– introduce tax benefits for enterprises engaged in waste sorting and treatment;
– develop a system of fines for companies and citizens who violate waste management regulation;
– provide financial benefits for enterprises that actively implement ecological-friendly technologies (e.g. sustainable packaging) and reduce the amount of produced waste.

3) forums and exhibitions:
– organize local and regional investment forums to attract investors in the regional waste management sector;
– organize exhibitions of technologies and solutions for waste management sector, which will allow companies to find partners and investors.

Improvement of the legislative framework, transparency and reporting

– introduce transparent reporting mechanisms for the waste management sector;
– keep public registers on the volumes of generated, collected, treated and disposed waste;
– assess environmental impacts of the regional WMS and ensure its compliance with ecological standards, conducting regular audits and environmental impact assessments.

Integration of war waste management in the waste management system

1) Creation of specialized programs:
– develop and implement programs for the collection and disposal of war waste, such as construction waste, destroyed infrastructure, etc;
– invite international organizations to provide technical and financial support in eliminating the consequences of the war.

2) Temporary landfills and processing stations:
– organize temporary landfills for the storage of war waste before its disposal;
– create mobile processing stations for processing large volumes of construction waste.

3) Training of personnel:
– conduct trainings and educational programs for workers engaged in the collection and disposal of war waste;
– provide the necessary equipment and means of protection for the safe handling of hazardous waste.

4) Creation and development of infrastructure for the processing of war waste:
– support the inclusion of construction waste, explosive and hazardous materials in sorting and treatment processes;
– stimulate investments in the establishment of enterprises for the processing of war waste (develop a system of additional financial incentives);
– support research and development projects in the field of treatment and reuse of construction materials from war waste.

Chapter 7 – Discussion

7.1 Reasons for unsustainability of the waste management system in the Chernihiv Oblast

The WMS in the Chernihiv Oblast is characterized by problems typical for the post-Soviet area. These problems include poor waste management legislation, excessive dependence on landfilling and the lack of supportive measures for its banning, a weak system of forecasting and planning, outdated tariff policy and statistic accounting, undeveloped infrastructure for recycling and treatment and the lack of effective economic instruments for stimulating the recycling and reducing waste generation (Skryhan et al., 2018). Thus, the systemic problems lead to low-efficiency indicators compared to the EU, which calls for significant enhancement.

Furthermore, the lock-in effects strongly impact the WMS of the Chernihiv Oblast, like many other regions of Ukraine. This situation arises where the current systems and structures of managing wastes hinder the implementation of more sustainable waste management practices (Aminoff & Sundqvist-Andberg, 2021). Current systems, which were based on outdated technologies, are widely spread because of the investments made in the past (Papagiannis et al., 2021). Moreover, such inertia can be explained by solid citizens' habits who historically managed waste through landfilling and did not receive proper education on the benefits of sustainable WMSs. Over the years, waste disposal has largely been done through landfills, especially in the Chernihiv Oblast (Derii et al., 2021). This practice has become the norm because this method is cheaper and easier than the more complex recycling and other waste treatment methods. Due to its widespread use, this results in a reinforcing loophole where the current physical and institutional structures and policies support the continued use of landfills, preventing new and sustainable alternatives.

Financial barriers are crucial for transforming WMSs, which is capital intensive, and often, local municipalities do not have sufficient funds to invest in such technologies (Shishpanova, 2023). This can be attributed to the fact that there is typically a lack of governmental budget and support from international donors which all together prevents the development of modern infrastructure. Technical barriers also make a major contribution in this regard. A lack of adequate facilities for sorting and processing waste materials hampers the development of

efficient WMSs (Debrah et al., 2022). This issue is compounded by a shortage of skilled professionals who can initiate and further implement the new technologies and methods of sustainable waste management. Organizational and cultural factors are equally important. Citizens and companies are resistant to change, and waste management firms are not exempted from this, mainly due to a lack of awareness regarding the benefits of advanced WMSs (Foellmer et al., 2022).

Nevertheless, local practices in the Ukrainian waste management sector, in particular in the Chernihiv Oblast, revealed several effective practices for waste sorting and treatment, together with the involvement of local communities (Derii et al., 2021). Such schemes, which are mostly driven by local authorities, NGOs and other community-based organizations, have demonstrated that it is possible to address certain waste management problems in a given locality. However, the share of waste processed within such regional initiatives remain extremely low (Derii et al., 2021) which necessitates to spread the local approaches to achieve a greater impact and guarantee positive changes in the whole WMS (Bandari et al., 2024). This process is defined as the expansion of effective local approaches and tactics to the regional and national levels of WMSs, which requires the attraction of larger budgets for waste management projects, and the search for synergies between different stakeholders, including government agencies, private companies and international organizations (Bandari et al., 2024). Furthermore, successful examples of waste-related initiatives can be used across other regions, which will result in greater uniformity in the improvement of the waste management sector, increased focus on environmental sustainability, and compliance with the national and EU strategies.

Lastly, the Chernihiv Oblast will require a deep transformation of its WMSs which goes far beyond solely recycling, and it encompasses a comprehensive array of strategies aimed at minimizing waste and maximizing resource efficiency (Möslinger et al., 2023). These approaches commonly refer to as the 9Rs including such waste strategies as Refuse, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover (Muñoz et al., 2024). These strategies collectively address the entire lifecycle of products, from design and consumption to disposal and recovery. Refusing unnecessary items and reducing consumption are the first steps in preventing waste generation. Reusing, repairing, and refurbishing extend the lifespan of products while remanufacturing and repurposing give new life to used

materials. Recycling transforms waste into new products and recovering energy or materials from waste further minimizes environmental impact. By integrating the 9R strategies, Ukraine, and specifically the Chernihiv Oblast can develop more sustainable and efficient WMSs that ideally, will prevent waste from even reaching the recycling stage.

7.2 Factors urging and supporting the transformation of the waste management system in the Chernihiv Oblast

It is relevant to mention, that the ongoing conflict in Ukraine has led to much destruction, with many structures, facilities and property destroyed (UNDP, 2023). In the context of the acute humanitarian crisis and the urgent requirements of national defence, attention to waste management has diminished, which resulted in the lack of traditional waste analysis and, as a result, statistics on it. However, in the future, when Ukraine is planning for the reconstruction process, the aspect of waste management can be seen as a great prospect. The debris and remnants of the destroyed infrastructure and buildings can, therefore, be reused especially in the construction of new buildings, thus promoting circularity (United Nations, 2024). Ukraine can turn the problem of war waste into a promising direction for the effective use of resources and contribute to the achievement of the ultimate objectives of economic recovery and environmental protection.

It is worth noting that because of the destruction of energy infrastructure, the demand for energy overcomes the supply (BDO Ukraine, 2024). Thus, the application of modern methods of waste treatment may become one of the possible solutions to the energy shortage in Ukraine. Ukraine can opt for processes like anaerobic digestion and waste-to-energy incineration to turn its organic waste and non-recyclable material into useful energy sources like biogas and electricity (UA Energy, 2023). Besides the management of waste, these technologies also have the possibility of contributing to energy security, decreasing the use of fossil fuels, and the minimisation of the negative waste impacts.

Moreover, the current strategic cooperation with the European Union and the possibility of Ukraine's accession to the EU can give a strong boost to the process of the country's WMS innovation. This partnership means that Ukraine might get essential support through consulting services, funding, examples of efficient strategies, and an extensive technical

assistance in the waste management sector (Delegation of the European Union to Ukraine, 2024). The EU waste management regulations and directives are rather stringent and present a good reference for Ukraine to develop its legal and practical frameworks (European Parliament, 2023). Furthermore, the European Union has a long history of development and introduction of sustainable concepts, such as the circular economy business models or extended producer responsibility (European Commission, 2023), which can be used in the Ukrainian context. Therefore, by utilizing this partnership, Ukraine could enhance its transition to the development of advanced, efficient, and environmentally sound WMS that will conform to the EU norms and boost the nation in the integration into the European Union.

In addition, Ukraine is receiving a significant amount of international funding for its reconstruction during and after the war and, as such, has a chance to revamp and improve its WMS (European Commission, 2024). The EU funding programs and financial instruments, including grants and loans, can be a source of funding to develop necessary infrastructure and adopt innovative waste management technologies (Delegation of the European Union to Ukraine, 2024). Ukraine can use the funds allocated for the reconstruction (European Commission, 2024b) and improve the general waste management sector by resolving the existing problems of landfilling, the lack of waste sorting facilities, and the absence of integrated waste treatment processes. Such injection of funds can help Ukraine change its WMS and meet the European Union standards, improving the environmental conditions and the health of the population.

7.3 Potential impacts from the transformation of the waste management system in the Chernihiv Oblast

The transformation of the regional WMS has a potential to give benefits that go far beyond solely waste sorting and recycling, providing gains to ecological, social and economic sectors. Encouraging the adoption of sustainable WMS conserves finite natural resources while lowering waste output, energy consumption, and greenhouse gas emissions (Kaza et al., 2018). Furthermore, it encourages environmental preservation by raising public awareness about waste recovery and other sustainable practices, preventing land use from waste landfills, and lowering emissions. In public health, sustainable WMS is critical for reducing and preventing potential health risks connected with hazardous waste exposure and the transmission of

infectious illnesses (Ashtari et al., 2020). On top of that, the construction of modern waste management infrastructure has the ability to increase job opportunities and support local economies (Ekins et al., 2019) by creating new markets for secondary materials and environmentally friendly products (Aleisa & Al-Jarallah, 2017).

From an ecological standpoint, sustainable WMS reduces pollution and protects natural resources, which helps limit environmental damage. Waste that is properly processed, recycled, and disposed of reduces air, water, and soil contamination, protecting ecosystems and biodiversity (Moustakas & Loizidou, 2018). Furthermore, by lowering greenhouse gas emissions into the atmosphere from landfills and waste incineration, sustainable WMS positively contributes to the fight against climate change by minimising its negative impacts on ecosystems and communities (US EPA, 2024a).

From a societal standpoint, sustainable WMS is a crucial effort that preserves the region residents' health and well-being. Sustainable methods of waste separation, treatment, and disposal may ensure that hazardous materials, chemicals, and biological waste are managed for the preservation of public health and the environment (Gupta et al., 2023), by reducing exposure to hazardous waste materials and minimising the spread of infectious illnesses (World Health Organization, 2018). It is relevant to mention, that sustainable WMS also aids in facilitating the elimination of pollutants and litter from the surrounding area (Honda, 2023), hence assisting in the development of attractive and healthful living spaces for local inhabitants. Furthermore, sustainable WMS reduces the risk of environmental hazards including land fires and hazardous leaks, which pose serious risks to public health.

Sustainable WMS has a potential to boost the economy by generating employment and business opportunities, which eventually strengthens the region's economy as a whole (Allen, 2023). Reusing and reselling secondary materials reduces manufacturing impacts and energy consumption, which in turn lowers the need for raw materials and, as a result, reduces production prices (US EPA, 2024b). Sustainable WMS might lower environmental charges and fees, increase the profitability of businesses and communities and minimise operating expenses associated with waste collection, transportation, and disposal (Das & Bhattacharyya, 2015). In addition, private companies benefit from business activities when selling recycled materials, such as paper, plastics, metals, or glass. The exploitation of power potential by

waste-to-energy technologies brings the ability to produce electricity or thermal energy that is later utilized on-site or sold to utilities (Rezania et al., 2023). In addition, implementing the concepts of the circular economy and resource efficiency attracts investments and encourages innovation (Binsuwadan et al., 2023), all of which boost economic competitiveness and general regional development.

Although establishing a sustainable waste management system is critical for reducing environmental impacts and improving resource efficiency, it also presents several potential negative effects that must be considered. One of the primary concerns is the economic and financial burden associated with the initial setup of a sustainable WMS. Developing the necessary infrastructure and technology requires substantial financial investments, which can decrease local budgets (Ansari et al., 2024). This issue is particularly acute in developing countries like Ukraine, where the high costs can be prohibitive, leading to challenges in both implementation and maintenance. Technical and operational challenges are also significant. Implementing advanced waste management technologies requires technical expertise and operational training (Czekała et al., 2023), which may be lacking in a region, leading to inefficiencies or WMS transformation failures.

Social and health impacts also pose significant challenges. Certain waste management practices, such as treatment of hazardous materials, can pose health risks to workers (Gutberlet & Uddin, 2017) and nearby communities. Composting and anaerobic digestion, while environmentally friendly, can still produce by-products that may be harmful if not managed properly (Lamolinara et al., 2022). Moreover, the transformation towards sustainable WMS can have disproportionate development, leading to limited access to effective waste management services for less prosperous communities (Abubakar et al., 2022) Lastly, introduction of sustainable practices and construction of waste management facilities can lead to community opposition, known as the "Not In My Backyard" syndrome, which can delay or pause projects (De Souza et al., 2023).

In conclusion, while establishing a sustainable WMS has a set of beneficial impacts that are essential for environmental and resource management, it also involves economic, social, and technical challenges, which must be addressed comprehensively to ensure sustainable outcomes.

Chapter 8 – Conclusions, limitations and future research

This research aimed to address the primary question: "How can the waste management system in the Chernihiv Oblast be transformed to address regional sustainability challenges?" The study was structured around three key objectives: assessing the current state of the WMS in the Chernihiv Oblast; examining European Union waste management practices and systems; and charting a strategy for the waste management system transformation in the Chernihiv Oblast.

8.1 Central research question

- "How can the waste management system in the Chernihiv Oblast be transformed to address regional sustainability challenges?"

The transformation of the WMS in the Chernihiv Oblast can be achieved through a phased approach that begins with improving basic infrastructure and gradually introducing more profound waste management elements, comprising waste sorting and treatment processes, protected waste disposal, etc. Furthermore, such a transition will require the introduction of policies and frameworks for waste prevention, minimization, raising awareness and responsibility over waste generation. By leveraging insights from the European Union WMSs and tailoring them to local conditions, the region can move towards a more sustainable, efficient, and circular WMS. To launch the transformation process, environmental, social and economic values together with circularity-related metrics should be established, which will support the establishment of new waste management processes and track the success and efficiency of their implementation. This transformation requires coordinated efforts and collaboration between involved stakeholders, comprising government agencies, businesses, NGOs, and the general public. Regarding surrounding elements of the regional WMS, the legislative basis should serve as a supportive platform for the introduction of advanced technologies and business activity; the private sector and the general market should direct the business focus on the resource value and raising responsibility over their economic activity; research and development activity should support innovation, reconstruction of infrastructure and provide viable technologies for enhancing waste conversion into secondary materials; lastly, environmental development should become a focal point of everyday life activity, where processes are built circularly in order to preserve already extracted resources.

8.2 Research sub-questions

- "What are the actual state and main barriers hindering the development of sustainable waste management system in the Chernihiv Oblast?"

The investigation into the current state of the WMS in the Chernihiv Oblast highlighted several critical barriers. These include inadequate infrastructure, insufficient funding, and a lack of public awareness and engagement. The region's waste management practices are mainly traditional and linear, focusing primarily on waste collection and landfilling with minimal emphasis on recycling or resource recovery. The presence of local initiatives, mainly led by NGOs, in waste sorting or establishing contracts with foreign companies specialized in treating waste, does not provide the expected results since they treat a minor share of generated waste. Generally, a lack of sustainability of the regional WMS leads to environmental degradation, health risks, and economic inefficiencies, undermining regional development.

- "What constitutes the most effective waste management systems across European Union member states?"

The study of the European Union waste management practices and systems revealed a comprehensive approach to sustainability and circularity. The EU's waste management framework is characterized by sound legislation, significant technological advancements, and strong public participation. Key initiatives such as EPR, advanced waste treatment technologies, and general agenda towards resource value have proven effective in reducing waste generation and enhancing resource recovery. On top of that, the EU is one of the pioneers in developing waste-prevention strategies, including take-back systems, upcycling initiatives, etc, which makes it a role model for a number of regions, including the Chernihiv Oblast. Such a comprehensive set of approaches within the EU member states has transformed the traditional ideology of product consumption - "cradle-to-grave" into "cradle-to-cradle", setting circular economy goals as one of the key principles of national strategies.

- "How can the European Union practices be applied to transform the Chernihiv Oblast's waste management system?"

In order to provide a transformation strategy for the Chernihiv Oblast's WMS, it is essential to consider challenges and failures faced by European Union member states, which can help avoid

resource losses and redundant investments in research, infrastructure development and processes' establishment, generally easing the process of such implementation. Secondly, the EU experience presents an invaluable source of experience related to effective waste management development, highlighting the most prominent approaches and technologies currently in use. To adapt EU practices to the Chernihiv Oblast, it is essential to consider local socio-economic conditions, cultural attitudes, and existing infrastructure. A phased approach is recommended to improve basic infrastructure and introduce more profound waste management elements, including the introduction of sustainable waste management processes, relevant infrastructure, stakeholder collaboration, etc. This step-by-step approach will support the implementation of advanced features of the EU WMSs and avoid common pitfalls that burden social, ecological, and economic resources.

8.3 Reflection on the choice of methods

The exploratory case study method, build on the synergy of conceptual frameworks (see Sections 2.2 and 2.3), proved to be effective in providing details on the transformations features for the Chernihiv Oblast's WMS. First, a complete picture of the regional WMS was presented, covering all the core and surrounding elements of the system based on the "System-based waste management assessment" conceptual framework. The method enabled a thorough understanding of the regional context, the socio-economic and cultural context going beyond the core WMS. As a result, the analysis also covered regional market and business activities, legislative frameworks, technology and innovation sectors together with providing details on the general environment. This made the research focus on a specific region, having captured features of the waste management practices, important obstacles towards sustainability and areas for improvement (Awasthi et al., 2023), which might not be seen when the research is done on a national scale.

Second, the method supported the evaluation of the EU waste management practices and systems by providing vital details on WMSs sustainability across different EU member states. These findings comprised the features of the waste management infrastructure, stakeholders involved, relevant processes and other system elements. In the end, the findings of both analyses formed a strong basis for the transformation of the regional WMS, build upon "Dynamic waste management system transformation" conceptual framework. In sum, the

method allowed for the development of solutions and recommendations based on experience of the EU member states and the needs of the Chernihiv Oblast and prominent, thus, increasing the likelihood of the effectiveness of the regional WMS growth.

However, the qualitative nature of the method may have limited the scope of the findings. Qualitative research, while valuable for understanding complex human behaviours and social contexts, often lacks the statistical rigor required for generalization (Carminati, 2018). This limitation can result in findings that are rich in detail but potentially lacking in breadth and replicability. The research could have improved its robustness by incorporating quantitative methods, such as surveys and statistical analyses, since the use of quantitative data can lead to the identification of patterns and relationships that may not be evident through qualitative analysis alone (Pilcher & Cortazzi, 2023). Additionally, quantitative methods can facilitate the generalization of findings to broader populations, increasing the external validity of the study. For example, using statistical tools to analyse the efficiency and cost-effectiveness of various waste management solutions can provide clear, objective evidence to support decision-making (Teixeira et al., 2014). Thus, a mixed-methods approach, combining the depth of qualitative insights with the breadth of quantitative data, would result in a more comprehensive and actionable understanding of the potential waste management solutions and their outcomes.

8.4 Research limitations

A critical disadvantage of the research is its reliance on secondary data. Secondary data, while useful for providing broad context and background, can have several limitations. Researchers have no control over the quality, accuracy, and completeness of the data, which may not be collected with the specific research questions in mind, leading to potential gaps or biases (Tripathy, 2013). Additionally, secondary data may be outdated or not reflective of current conditions, affecting the relevance and applicability of the findings (Olabode et al., 2018). The data might lack the depth needed to fully explore nuanced aspects of the research question and may have been collected using varied methodologies, making it difficult to integrate and compare. Last but not least, such reliance on secondary data was, most probably, the only available solution for assessment of the Chernihiv Oblast's WMS, since after the beginning of the war, on the 24th of February 2022, municipalities and regional government paused issuing

report on waste management and have not introduced the assessment of war waste within the region.

Furthermore, an important research limitation is the absence of comprehensive cooperation with local waste management stakeholders in the Chernihiv Oblast. As a result, a lack of collaboration with local government agencies, companies, community organisations, and citizens may have hindered the understanding (Boaz et al., 2018) of the current waste management state and behavioural patterns. A more thorough overview of the region's waste management challenges would have been possible with improved engagement with these stakeholders (Martinez et al., 2019), who may have offered additional insights and useful information when gathering information through surveys or interviews to complement the findings of the research. This restriction highlights the necessity of increased stakeholder participation in the development of strategies the transformation of the Chernihiv Oblast's WMS to also increase the practical relevance of the findings.

Another limitation is a scarce assessment of the technological and economic viability of implementing advanced WMSs established by the European Union. Waste management technology innovations have the potential to significantly enhance efficiency and environmental effects, however, the region's readiness to apply such technologies is determined by a variety of factors, including infrastructure, financial resources, and technical competence (Gurevich, 2023 & Scottish Environment Protection Agency, 2023). The study did not specifically address these elements, which are important in establishing the feasibility of implementing advanced technologies. An in-depth examination of the region's current capabilities and possible barriers would provide a more accurate picture of the steps required to achieve technology integration and successful implementation.

Additionally, a more detailed assessment of the WMSs employed by the EU member states could have provided deeper insights into the various waste management initiatives and practices. This limitation leads to a limited understanding of diverse approaches and policies each member state implements, which significantly affect the efficiency and sustainability of WMSs (Weghmann, V. & EPSU, 2023). By conducting a comprehensive analysis across all member states, the research could have uncovered a broader range of best practices and common challenges, leading to more robust and applicable recommendations. It is vital that

future studies consider an extensive evaluation of individual member states to enhance the understanding of waste management strategies within the EU.

Finally, while the study focused on the Chernihiv Oblast, the findings may not be fully applicable to other Ukrainian regions or similar contexts without additional validation. Each region has distinct socioeconomic, cultural, and environmental characteristics (Deineko, 2021) that influence WMSs, regional approaches, behaviours and issues. As a result, the Chernihiv Oblast-specific observations and recommendations may not be explicitly applicable throughout the country. Further research is required to validate these findings in other regions and tailor the recommendations to specific local settings. This stage would be critical to ensure that the practices are effective and applicable, avoiding a one-size-fits-all approach.

8.5 Directions for the future research

First of all, the research on the Chernihiv Oblast waste management sector would benefit from performing a comprehensive assessment of the economic expenditures and potential gains from implementing sustainable waste management system. The future research could analyse the financial implications of adopting advanced technologies and infrastructure, highlighting potential cost savings, revenue generation, and economic impacts for the community.

In addition, it is vital to conduct research on assessing the long-term impacts of waste management interventions and tracking progress towards sustainability goals. This includes evaluating the environmental, economic, and social outcomes of implemented strategies over years to determine their effectiveness in the regional growth, including socioeconomic and environmental development.

Furthermore, it is crucial to reveal suitable approaches for raising awareness among waste management stakeholders in the Chernihiv Oblast. Further research could focus on identifying behaviour specifics, level of awareness and values among regional stakeholders to provide the most effective methods for educating the public on the features and potential benefits of applying sustainable waste management practices.

Enhancing stakeholder collaboration is another relevant field for the waste management system transformation within the region. The future research could focus on the approaches which can encourage greater community participation and identify strategies for improving

collaboration between local authorities, businesses, community organizations, and residents to create more cohesive transformation strategy.

Additionally, research on war waste management in the Chernihiv Oblast is crucial due drastic amounts of waste generated and relative stability, currently being outside of the war actions area. Gaining such experience can allow for developing and implementing comprehensive strategies for war waste not only within the region but also in other war-torn localities around Ukraine.

Lastly, the transformation of the regional waste management systems would benefit from exploring the potential of emerging technologies, such as sensor-based and AI-based sorting, using robots in waste management processes or real-time data analysis. Evaluating these technologies' feasibility, cost-effectiveness, and environmental impact could provide actionable insights for their implementation within the region.

By conducting further research, the Chernihiv Oblast, Ukraine could have obtained additional insights and a more thorough examination of existing gaps in the waste management system. By investigating these areas, such as technology advances and regulatory frameworks, stakeholder involvement, and economic analysis, these studies may provide more comprehensive solutions and practical insights, ultimately leading to more effective and sustainable waste management system transformation in the region.

References

Abubakar, I. R., Maniruzzaman, K. M., Dano, U. L., Al-Shihri, F. S., Alshammari, M. S., Ahmed, S. M., Al-Gehlani, W. a. G., & Alrawaf, T. I. (2022). Environmental sustainability Impacts of solid waste management practices in the global South. International Journal of Environmental Research and Public Health/International Journal of Environmental Research and Public Health, 19(19), 12717. https://doi.org/10.3390/ijerph191912717

Access to public information / Legislation | Department of Health Protection of the Chernihiv Regional State Administration. (n.d.). https://uoz.cn.ua/dpizakon.php

Adeleke, O., Akinlabi, S. A., Jen, T., & Dunmade, I. (2021). Environmental impact assessment of the current, emerging, and alternative waste management systems using life cycle assessment tools: a case study of Johannesburg, South Africa. Environmental Science and Pollution Research International, 29(5), 7366–7381. https://doi.org/10.1007/s11356-021-16198-y

Agovino, M., Garofalo, A., & Mariani, A. (2016). Effects of environmental regulation on separate waste collection dynamics: empirical evidence from Italy. Journal of Cleaner Production, 124, 30–40. https://doi.org/10.1016/j.jclepro.2016.02.082

Agriculture, forestry and fishing | Head Department of Statistics in the Chernihiv Oblast. (n.d.). https://www.chernigivstat.gov.ua/books/silgosp.php

Akhiar, A., Zamri, M. F. M. A., Torrijos, M., Shamsuddin, A. H., Battimelli, A., Roslan, E., Marzuki, M. H. M., & Carrere, H. (2020). Anaerobic digestion industries progress throughout the world. IOP Conference Series. Earth and Environmental Science, 476(1), 012074. https://doi.org/10.1088/1755-1315/476/1/012074

Alao, M. A., Popoola, O. M., & Ayodele, T. R. (2022). Waste-to-energy nexus: An overview of technologies and implementation for sustainable development. Cleaner Energy Systems, 3, 100034. https://doi.org/10.1016/j.cles.2022.100034

Aleisa, E., Al-Jarallah, R. A triple bottom line evaluation of solid waste management strategies: a case study for an arid Gulf State, Kuwait. Int J Life Cycle Assess 23, 1460–1475 (2018). https://doi.org/10.1007/s11367-017-1410-z

Allen, C. (2023). The Economic and Environmental Benefits of Efficient Waste Management. Adv Recycling Waste Manag, 8, 297. Retrieved March 4, 2024, from https://www.hilarispublisher.com/open-access/the-economic-and-environmental-benefits-of-efficient-waste-management.pdf

Aminoff, A., & Sundqvist-Andberg, H. (2021). Constraints leading to system-level lock-ins—the case of electronic waste management in the circular economy. Journal of Cleaner Production, 322, 129029. https://doi.org/10.1016/j.jclepro.2021.129029

Ansari, A., Dutt, D., & Kumar, V. (2024). Catalyzing paradigm shifts in global waste Management: A case study of Saharanpur Smart city. Waste Management Bulletin, 2(1), 29–38. https://doi.org/10.1016/j.wmb.2023.12.003

Anuardo, R. G., Espuny, M., Costa, A. C. F., & Oliveira, O. J. (2022). Toward a cleaner and more sustainable world: A framework to develop and improve waste management through organizations, governments and academia. Heliyon, 8(4), e09225. https://doi.org/10.1016/j.heliyon.2022.e09225

Araya, M. N. (2018). A Review of Effective Waste Management from an EU, National, and Local Perspective and Its Influence: The Management of Biowaste and Anaerobic Digestion of Municipal Solid Waste. Journal of Environmental Protection, 09(06), 652–670. https://doi.org/10.4236/jep.2018.96041

Ashtari, A., Sadegh Tabrizi, J., Rezapour, R., Rashidian Maleki, M., & Azami-Aghdash, S. (2020, September 1). Health Care Waste Management Improvement Interventions Specifications and Results: A Systematic Review and MetaAnalysis. Iranian Journal of Public Health. https://doi.org/10.18502/ijph.v49i9.4074

Awasthi, P., Chataut, G., & Khatri, R. (2023). Solid waste composition and its management: A case study of Kirtipur Municipality-10. Heliyon, 9(11), e21360. https://doi.org/10.1016/j.heliyon.2023.e21360

Bandari, R., Moallemi, E. A., Kharrazi, A., Trogrlić, R. Š., & Bryan, B. A. (2024). Transdisciplinary approaches to local sustainability: aligning local governance and navigating spillovers with global action towards the Sustainable Development Goals. Sustainability Science. https://doi.org/10.1007/s11625-024-01494-6

Bandh, S. A., Malla, F. A., Wani, S. A., & Hoang, A. T. (2024). Waste management and circular economy. In Springer eBooks (pp. 1–17). https://doi.org/10.1007/978-3-031-42426-7_1

Bashir, I., Lone, F. A., Bhat, R. A., Mir, S., Dar, Z. A., & Dar, S. A. (2020). Concerns and threats of contamination on aquatic ecosystems. In Springer eBooks (pp. 1–26). https://doi.org/10.1007/978-3-030-35691-0_1

BDO Ukraine. (2024). The energy sector in Ukraine and the world. Forecasts and current challenges. https://www.bdo.ua/uk-ua/insights-2/information-materials/2024/energy-sector-in-ukraine-and-the-world-forecasts-and-challenges

Beaumais, O., Kirakozian, A., Lazaric, N., Bruns, H., Dupoux, M. (2024). Behavioural insights for waste-sorting labels in the European Union. JRC Publications Repository. https://doi.org/10.2760/641099

Binsuwadan, J., Yousif, G., Abdulrahim, H., & Alofaysan, H. (2023, November 14). The Role of the Circular Economy in Fostering Sustainable Economic Growth in the GCC. Sustainability, 15(22), 15926. https://doi.org/10.3390/su152215926

Block, C., Caneghem, J., Brecht, A., Wauters, G., & Vandecasteele, C. (2015). Incineration of Hazardous Waste: A Sustainable Process? Waste and Biomass Valorization, 6, 137-145. https://doi.org/10.1007/S12649-014-9334-3.

Boardman, J. & Sauser, Brian. (2006). The Meaning of System of Systems. System of Systems Engineering. 6 pp.-. 10.1109/SYSOSE.2006.1652284.

Boaz, A., Hanney, S., Borst, R., O'Shea, A., & Kok, M. (2018). How to engage stakeholders in research: design principles to support improvement. Health Research Policy and Systems, 16(1). https://doi.org/10.1186/s12961-018-0337-6

Bocken, N., Baldassarre, B., Keskin, D., & Diehl, J. C. (2022). Design thinking tools to catalyse sustainable circular innovation. Retrieved from https://www.researchgate.net/publication/371491988_Design_thinking_tools_to_catalyse_sustainable_circular_innovation

Bonnet, F., Lahboubi, N., Habchi, S., & Bari, H. E. (2023). Waste management institutional and legislation aspects in developing countries. In Springer eBooks (pp. 91–109). https://doi.org/10.1007/978-3-031-28001-6_6

Bourtsalas, A., & Themelis, N. J. (2022). Materials and energy recovery at six European MBT plants. Waste Management, 141, 79–91. https://doi.org/10.1016/j.wasman.2022.01.024

Buruzs, A. (2024). Systemic Relationships Between Regional Sustainability and Waste Management. In: Fuzzy Cognitive Maps. Studies in Fuzziness and Soft Computing, vol 427. Springer, Cham. https://doi.org/10.1007/978-3-031-37959-8_2

Buzovska, M. (2023, August 2). UNESCO updated the list of architectural monuments damaged by the Russians in Ukraine - PRAGMATIKA.MEDIA - Ukraine, Kyiv. PRAGMATIKA.MEDIA. https://pragmatika.media/en/news/iunesko-onovyla-spysok-poshkodzhenykh-rosiianamy-pam-iatok-arkhitektury-v-ukraini/

Campitelli, A., Kannengießer, J., & Schebek, L. (2022). Approach to assess the performance of waste management systems towards a circular economy: waste management system development stage concept (WMS-DSC). MethodsX, 9, 101634. https://doi.org/10.1016/j.mex.2022.101634

Carmeuse Systems. (n.d.). WHAT IS WASTE-TO-ENERGY? CARMEUSE SYSTEMS. https://systems.carmeuse.com/en/industries/waste-to-energy-process/

Carminati, L. (2018). Generalizability in Qualitative Research: A tale of two traditions. Qualitative Health Research, 28(13), 2094–2101. https://doi.org/10.1177/1049732318788379

Chertow, M. (2008). The IPAT equation and its variants. Journal of Industrial Ecology, 4(4), 13–29. https://doi.org/10.1162/10881980052541927

Chioatto, E., & Sospiro, P. (2022). Transition from waste management to circular economy: the European Union roadmap. Environment, Development and Sustainability, 25(1), 249–276. https://doi.org/10.1007/s10668-021-02050-3

Cimpan, C., Maul, A., Jansen, M., Pretz, T., & Wenzel, H. (2015). Central sorting and recovery of MSW recyclable materials: A review of technological state-of-the-art, cases, practice and implications for materials recycling. Journal of Environmental Management, 156, 181–199. https://doi.org/10.1016/j.jenvman.2015.03.025

Clean Water Action. (2018, July 30). Why littering is not the true problem. Clean Water Action. https://cleanwater.org/2018/07/30/why-littering-not-true-problem

Czekała, W., Drozdowski, J., & Łabiak, P. (2023, July 31). Modern Technologies for Waste Management: A Review. Applied Sciences, 13(15), 8847. https://doi.org/10.3390/app13158847

Da Cruz, N. F., Ferreira, S., Cabral, M., Simões, P., & Marques, R. C. (2014). Packaging waste recycling in Europe: Is the industry paying for it? Waste Management, 34(2), 298–308. https://doi.org/10.1016/j.wasman.2013.10.035

Das, S., & Bhattacharyya, B. K. (2015, September). Optimization of municipal solid waste collection and transportation routes. Waste Management, 43, 9–18. https://doi.org/10.1016/j.wasman.2015.06.033

De Haes, S., Lucas, P., & PBL Netherlands Environmental Assessment Agency. (2024). Environmental impacts of extraction and processing of raw materials for the energy transition (CML Leiden, German Environment Agency (UBA), & PBL, Eds.). PBL Netherlands Environmental Assessment Agency. https://www.pbl.nl/system/files/document/2024-02/PBL-2024-Environmental-impacts-of-extraction-and-processing-of-raw-materials-for-the-energy-transition-5364.pdf

De Souza, M. A., Gonçalves, J. T., & Valle, W. a. D. (2023). In my Backyard? Discussing the NIMBY effect, social acceptability, and residents' involvement in Community-Based Solid Waste Management. Sustainability, 15(9), 7106. https://doi.org/10.3390/su15097106

Debrah, J. K., Teye, G. K., & Dinis, M. a. P. (2022). Barriers and challenges to waste management Hindering the circular economy in Sub-Saharan Africa. Urban Science, 6(3), 57. https://doi.org/10.3390/urbansci6030057

Deineko, O. (2021). Decentralization, regional diversity, and conflict. The case of Ukraine. East European Politics, 38(1), 165–166. https://doi.org/10.1080/21599165.2021.2006640

Delegation of the European Union to Ukraine. (2024). With the EU support, Ukraine improves its air quality and waste management legislation. https://www-eeas-europa-eu.translate.goog/delegations/ukraine/eu-support-ukraine-improves-its-air-quality-and-waste-management-legislation_en?s=232&_x_tr_sl=en&_x_tr_tl=ru&_x_tr_hl=ru&_x_tr_pto=sc

Demographic and social statistics / Population and migration | State Statistics Service of Ukraine. (2020). https://www.ukrstat.gov.ua/

Der Grüne Punkt. (n.d.). German Packaging Act. https://www.gruener-punkt.de/en/packaging-licensing/packaging-act

Derii, Zh. V., Shadura-Nykiporets', N. T., Minina, O. V., Baranovs'kyi, M. O., Tsybulia, S. D., Kupchyk, O. Yu., Zosymenko, T. I., Korniienko, I. V., & Derii, O. Yu. (2021). Regionalnyi plan upravlinnia vidkhodamy Chernihivs'koi oblasti. Departament ekolohii ta pryrodnykh resursiv Chernihivs'koi oblasnoi derzhavnoi administratsii. https://eco.cg.gov.ua/web_docs/2145/2020/01/docs/%20%D0%A0%D0%9F%D0%A3%D0%92%20(wecompress.com)_2023_02_07_09_36_47.doc

Di Maria, F., Sisani, F., Contini, S., Ghosh, S. K., & Mersky, R. L. (2020). Is the policy of the European Union in waste management sustainable? An assessment of the Italian context. Waste Management, 103, 437–448. https://doi.org/10.1016/j.wasman.2020.01.005

Di Vaio, A., Hasan, S., Palladino, R., & Hassan, R. (2022). The transition towards circular economy and waste within accounting and accountability models: a systematic literature review and conceptual framework. Environment, Development and Sustainability, 25(1), 734–810. https://doi.org/10.1007/s10668-021-02078-5

Documents / Legislative and regulatory acts | The Head Department of Statistics in the Chernihiv Oblast. (n.d.). https://www.chernigivstat.gov.ua/zakon/

Domenech, T., & Bahn-Walkowiak, B. (2019). Transition towards a resource efficient circular economy in Europe: policy lessons from the EU and the member States. Ecological Economics, 155, 7–19. https://doi.org/10.1016/j.ecolecon.2017.11.001

EEA. (2015, February). Briefing on waste. European Environmental Agency. Retrieved May 26, 2024, from https://www.eea.europa.eu/soer/2015/europe/waste

EEA. (2023). Markets for many commonly recycled materials struggle in the EU. https://www.eea.europa.eu/en/newsroom/news/markets-commonly-recycled-materials-struggle

Economic statistics / Natural environment | State Statistics Service of Ukraine. (2020). https://www.ukrstat.gov.ua/

Economic statistics | Head Department of Statistics in the Chernihiv Oblast. (2020). https://www.chernigivstat.gov.ua/statdani/

Economic statistics | State Statistics Service of Ukraine. (2020). https://www.ukrstat.gov.ua/

Ekins, P., Domenech, T., Drummond, P., Bleischwitz, R., Hughes, N., & Lotti, L. (2019). The Circular Economy: What, Why, How and Where. Background paper for an OECD/EC Workshop on 5 July 2019 within the workshop series “Managing environmental and energy transitions for regions and cities”, Paris. Retrieved February 27, 2024, from https://www.oecd.org/cfe/regionaldevelopment/Ekins-2019-Circular-Economy-What-Why-How-Where.pdf

Environment People Law. (2022, January 15). Compliance of the public policy of Ukraine in the area of waste management with the priorities and goals of the European Green Deal.

Retrieved April 29, 2024, from https://epl.org.ua/en/eco-analytics/vidpovidnist-derzhavnoyi-polityky-ukrayiny-u-sferi-povodzhennya-z-vidhodamy-priorytetam-ta-tsilyam-yevropejskogo-zelenogo-kursu/#

Environmental protection program of the Chernihiv Oblast | The Department of Ecology and Natural Resources of the Chernihiv Regional State Administration. (n.d.). https://eco.cg.gov.ua/index.php?id=28158&tp=1&pg=

EUR-Lex. (n.d.). Waste hierarchy. https://eur-lex.europa.eu/EN/legal-content/glossary/waste-hierarchy.html

European Commission. (n.d.). Waste Framework Directive. https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en

European Commission. (2018). A sustainable bioeconomy for Europe: strengthening the connection between economy, society and the environment. https://boku.ac.at/fileadmin/data/H99000/H99500/Biooekonomie/Dateien/European_Bioeconomy_Strategy_2018.pdf

European Commission. (2023). Circular economy action plan. https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en

European Commission. (2024). The Ukraine Facility. Supporting Ukraine's recovery, reconstruction, and path towards EU accession. https://eu-solidarity-ukraine.ec.europa.eu/eu-assistance-ukraine/ukraine-facility_en

European Commission. (2024b). The Ukraine Facility. Supporting Ukraine's recovery, reconstruction, and path towards EU accession https://eu-solidarity-ukraine.ec.europa.eu/eu-assistance-ukraine/ukraine-facility_en

European Environment Agency. (2022). Early warning assessment related to the 2025 targets for municipal waste and packaging waste. Country profile: Netherlands. https://www.eea.europa.eu/publications/many-eu-member-states/netherlands

European Environment Agency. (2023, June 8). Many EU Member States risk missing waste recycling targets. https://www.eea.europa.eu/en/newsroom/news/many-eu-member-states

European Parliament. (2023). EU-Ukraine 2035 : strategic foresight analysis on the future of the EU and Ukraine. Publications Office of the EU. https://data.europa.eu/doi/10.2861/956276

European Union. (2008). Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588599143722&uri=CELEX:02008L0098-20180705

European Union. (2023). Open data to track progress in the EU's recycling targets. https://data.europa.eu/en/publications/datastories/open-data-track-progress-eus-recycling-targets

Eurostat. (2024). Energy statistics - an overview. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_statistics_-_an_overview#:~:text=In%202022%20the%20EU's%20energy,of%20it%20covered%20by%20imports.

Foellmer, J., Liboiron, M., Rechenburg, A., & Kistemann, T. (2022). 2. RESULTS. How Do the Cultural Contexts of Waste Practices Affect Health and Well-being? - NCBI Bookshelf. https://www.ncbi.nlm.nih.gov/books/NBK582041/

Friant, M. C., Vermeulen, W. J., & Salomone, R. (2021). Analysing European Union circular economy policies: words versus actions. Sustainable Production and Consumption, 27, 337–353. https://doi.org/10.1016/j.spc.2020.11.001

Friedrich, K., Fritz, T., Koinig, G., Pomberger, R., & Vollprecht, D. (2021). Assessment of technological developments in data analytics for Sensor-Based and robot sorting plants based on maturity levels to improve Austrian waste sorting plants. Sustainability, 13(16), 9472. https://doi.org/10.3390/su13169472

Gardiner, R., & Hajek, P. (2020). Municipal waste generation, R&D intensity, and economic growth nexus – A case of EU regions. Waste Management, 114, 124–135. https://doi.org/10.1016/j.wasman.2020.06.038

Gentil, E. C., Gallo, D., & Christensen, T. H. (2011). Environmental evaluation of municipal waste prevention. Waste Management, 31(12), 2371–2379. https://doi.org/10.1016/j.wasman.2011.07.030

Grant A., Cordle M., Bridgwater E. Eunomia Research & Consulting. (2020). Quality of recycling: Towards an operational definition. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC122293/final_quality_of_recycling_report.pdf

Gross regional product | State Statistics Service of Ukraine. (2020). https://www.ukrstat.gov.ua/

Gupta, P. P., Bankar, N. J., Mishra, V. H., Sanghavi, S., & Badge, A. K. (2023, October 19). The Efficient Disposal of Biomedical Waste Is Critical to Public Health: Insights from the Central Pollution Control Board Guidelines in India. Cureus. https://doi.org/10.7759/cureus.47303

Gurevich, M. (2023, October 13). Examining the impact of financial resources on solid waste management practices: A Cross-Country Analysis - NHSJS. NHSJS. https://nhsjs.com/2023/examining-the-impact-of-financial-resources-on-solid-waste-management-practices-a-cross-country-analysis/

Gutberlet, J., & Uddin, S. M. N. (2017). Household waste and health risks affecting waste pickers and the environment in low- and middle-income countries. International Journal of Occupational and Environmental Health, 23(4), 299–310. https://doi.org/10.1080/10773525.2018.1484996

Harangozó, G., & Zilahy, G. (2015). Cooperation between business and non-governmental organizations to promote sustainable development. Journal of Cleaner Production, 89, 18–31. https://doi.org/10.1016/j.jclepro.2014.10.092

Hartley, K., Baldassarre, B., & Kirchherr, J. (2024). Circular economy as crisis response. Journal of Cleaner Production, 434, 140140. https://doi.org/10.1016/j.jclepro.2023.140140

Hartley, K., Van Santen, R., & Kirchherr, J. (2020). Policies for transitioning towards a circular economy: Expectations from the European Union (EU). Resources, Conservation and Recycling, 155, 104634. https://doi.org/10.1016/j.resconrec.2019.104634

Hidalgo, D., Martín-Marroquín, J. M., Corona, F., & Juaristi, J. L. (2018). Sustainable vacuum waste collection systems in areas of difficult access. Tunnelling and Underground Space Technology, 81, 221–227. https://doi.org/10.1016/j.tust.2018.07.026

Hin, L. C., Hameed, V. A., Vasudavan, H., & Rana, M. E. (2021, October 24). An Intelligent Smart Bin for Waste Management. 2021 IEEE Mysore Sub Section International Conference (MysuruCon). https://doi.org/10.1109/mysurucon52639.2021.9641618

Hoang, A. T., Al-Tawaha, A. R., Lan Anh Vu, Van Viet Pham, Qaisi, A. M., & Křeček, J. (2021). Integrating Environmental Protection Education in the Curriculum: A Measure to Form Awareness of Environmental Protection for the Community. Environmental Sustainability Education for a Changing World, 191–207. https://doi.org/10.1007/978-3-030-66384-1_12

Honda S. (2023, September 5). Waste Management's Crucial Role In Beating Air Pollution. UNEP - UN Environment Programme. https://www.unep.org/ietc/news/story/waste-managements-crucial-role-beating-air-pollution

Hormiz O. (2016). Water management problems in the Chernihiv Oblast. Scientific Notes, 228–229. http://geography.tnpu.edu.ua/wp-content/uploads/2016/12/35.pdf

Iacovidou, E., Hahladakis, J. N., & Purnell, P. (2020, December 7). A systems thinking approach to understanding the challenges of achieving the circular economy. Environmental Science and Pollution Research, 28(19), 24785–24806. https://doi.org/10.1007/s11356-020-11725-9

Johansson, N., & Corvellec, H. (2018). Waste policies gone soft: An analysis of European and Swedish waste prevention plans. Waste Management, 77, 322–332. https://doi.org/10.1016/j.wasman.2018.04.015

Kashtalian, O. (2020). Ecological component of the modern socio-economic system (Samko, Ed.). Retrieved October 17, 2023, from https://stu.cn.ua/wp-content/uploads/2021/11/yunist-2020.pdf

Kashtalian, O. (2022). Features of the implementation of the sustainable development concept in Ukraine based on the experience of the countries of the European Union. Institutional Repository of Chernihiv Polytechnic National University. Retrieved October 14, 2023, from http://ir.stu.cn.ua/handle/123456789/26645

Kaza, S., Yao, L. C., Bhada-Tata, P., & Van Woerden, F. (2018). What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Urban Development. Washington, DC: World Bank. http://hdl.handle.net/10986/30317 (CC BY 3.0 IGO).

Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., & Hekkert, M. (2018). Barriers to the circular Economy: evidence from the European Union (EU). Ecological Economics, 150, 264–272. https://doi.org/10.1016/j.ecolecon.2018.04.028

Knowaste. (n.d.). The Knowaste Recycling Process. Knowaste Technologies. http://www.knowaste.com/the-knowaste-recycling-process.html

Kovalenko, V. V., Radchenko, O. O., Kireikou, A. A., Yu Stanishevskiy, V., Lahoiko, A. M., & Sinitsky, J. (2022, June 1). Problem of municipal solid waste of Ukraine and ways to solve it. IOP Conference Series: Earth and Environmental Science, 1049(1), 012019. https://doi.org/10.1088/1755-1315/1049/1/012019

Kůdela, J., Šomplák, R., Nevrlý, V., Lipovský, T., Smejkalová, V., & Dobrovský, L. (2019). Multi-objective strategic waste transfer station planning. Journal of Cleaner Production, 230, 1294–1304. https://doi.org/10.1016/j.jclepro.2019.05.167

Lag-Brotons, A. J., Velenturf, A. P. M., Crane, R., Head, I. M., Purnell, P., & Semple, K. T. (2020, April 3). Editorial: Resource Recovery From Waste. Frontiers in Environmental Science, 8. https://doi.org/10.3389/fenvs.2020.00035

Lahtela, V., & Kärki, T. (2018). Mechanical sorting Processing of waste material before composite manufacturing – a review. Journal of Engineering Science and Technology Review, 11(6), 35–46. https://doi.org/10.25103/jestr.116.06

Lamolinara, B., Pérez-Martínez, A., Guardado-Yordi, E., Fiallos, C. G., Diéguez-Santana, K., & Ruiz-Mercado, G. J. (2022). Anaerobic digestate management, environmental impacts, and techno-economic challenges. Waste Management, 140, 14–30. https://doi.org/10.1016/j.wasman.2021.12.035

Law of Ukraine "On Local State Administrations", No. 586-XIV (2001). https://shorturl.at/hilG8

Law of Ukraine "On Waste", No. 2320-IX (2022). https://zakon.rada.gov.ua/laws/show/187/98-%D0%B2%D1%80#Text

Law of Ukraine "On by-products of animal origin, not intended for human consumption", No. 287-VIII (2015). https://zakon.rada.gov.ua/laws/show/287-19#n263

Law of Ukraine on Local government bodies, No. 3441-IX (2024). https://zakon.rada.gov.ua/laws/show/280/97-%D0%B2%D1%80#Text

Law of Ukraine on the basic principles (strategy) of the state environmental policy of Ukraine for the period until 2030, № 2697-VIII (2019). https://zakon.rada.gov.ua/laws/show/2697-19#Text

Leclerc, G. (2023). Russia's war on Ukraine: High environmental toll. European Parliament. Retrieved December 14, 2023, from https://www.europarl.europa.eu/RegData/etudes/ATAG/2023/751427/EPRS_ATA(2023)751427_EN.pdf

Legal principles of activity | Head Office of the State Production and Consumer Service in the Chernihiv Oblast. (n.d.). https://dpsscn.gov.ua/pro-sluzhbu/pravovi-zasady.html

Lucas, P., Fleming, J., & Bhosale, J. (2018). The utility of case study as a methodology for work-integrated learning research. ResearchGate. https://www.researchgate.net/publication/329356543_The_utility_of_case_study_as_a_methodology_for_work-integrated_learning_research

Lynch, D., Kupper, F., & Broerse, J. (2018). Toward a socially desirable EU research and innovation agenda on urban waste: A transnational EU citizen consultation. Sustainability, 10, 1-19. https://doi.org/10.3390/SU10051641.

Madon, I., Drev, D., & Likar, J. (2020). Long-term groundwater protection efficiency of different types of sanitary landfills: Model description. MethodsX, 7, 100810. https://doi.org/10.1016/j.mex.2020.100810

Maharjan, M. K., & Lohani, S. P. (2020). Municipal solid waste management in Nepal: Opportunities and challenges. Journal of the Institute of Engineering, 15(3), 222–226. https://doi.org/10.3126/jie.v15i3.32185

Manfredi, S., Niskanen, A., & Christensen, T. H. (2009). Environmental assessment of gas management options at the Old Ämmässuo landfill (Finland) by means of LCA-modeling (EASEWASTE). Waste Management, 29(5), 1588–1594. https://doi.org/10.1016/j.wasman.2008.10.005

Martinez, J., Wong, C., Piersol, C. V., Bieber, D. C., Perry, B. L., & Leland, N. E. (2019). Stakeholder engagement in research: a scoping review of current evaluation methods. Journal of Comparative Effectiveness Research, 8(15), 1327–1341. https://doi.org/10.2217/cer-2019-0047

Matheson, T. (2019). Disposal is Not Free: Fiscal Instruments to Internalize the Environmental Costs of Solid Waste. IMF Working Papers, 2019(283), A001. Retrieved Apr 29, 2024, from https://doi.org/10.5089/9781513521589.001.A001

Meyer, M., Tylenda, E., Chen, G., Singer, B., Bingham, D. R., Corbett, B., Jones, E., Kim, K., & Aggarwal, R. (2022). Assessing the Financial Links to Natural Capital. Goldman Sachs. https://www.goldmansachs.com/intelligence/pages/gs-research/assessing-the-financial-links-to-natural-capital/report.pdf

Mihai, F., & Apostol, L. (2012). Disparities in municipal waste management across EU-27: a geographical approach. Zenodo (CERN European Organization for Nuclear Research). https://doi.org/10.5281/zenodo.19123

Mihai, F., Gnoni, M., Meidiana, C., Ezeah, C., & Elia, V. (2019). Waste Electrical and Electronic Equipment (WEEE): Flows, Quantities, and Management—A Global Scenario. In Elsevier eBooks (pp. 1–34). https://doi.org/10.1016/b978-0-12-816190-6.00001-7

Ministerie van Landbouw, Natuur en Voedselkwaliteit. (2019). Study on Waste Management in Ukraine. Retrieved February 27, 2024, from https://www.agroberichtenbuitenland.nl/documenten/publicaties/2019/02/24/ua-waste-management-study

Ministery of Infrastructure and Water Management. (n.d.). From Waste to Resources. https://rwsenvironment.eu/subjects/

Mohammed, M. A., Abdulhasan, M. J., Kumar, N. M., Abdulkareem, K. H., Mostafa, S. A., Maashi, M. S., Khalid, L. S., Abdulaali, H. S., & Chopra, S. S. (2022, July 28). Automated waste-sorting and recycling classification using artificial neural network and features fusion: a digital-enabled circular economy vision for smart cities. Multimedia Tools and Applications, 82(25), 39617–39632. https://doi.org/10.1007/s11042-021-11537-0

Morseletto, P. (2020). Targets for a circular economy. Resources, Conservation and Recycling, 153, 104553. https://doi.org/10.1016/j.resconrec.2019.104553

Moustakas, K., Loizidou, M. Sustainable waste management. Environ Sci Pollut Res 25, 35761–35763 (2018). https://doi.org/10.1007/s11356-018-3548-z

Möslinger, M., Ulpiani, G., & Vetters, N. (2023). Circular economy and waste management to empower a climate-neutral urban future. Journal of Cleaner Production, 421, 138454. https://doi.org/10.1016/j.jclepro.2023.138454

Muñoz, S., Hosseini, M. R., & Crawford, R. H. (2024). Towards a holistic assessment of circular economy strategies: The 9R circularity index. Sustainable Production and Consumption, 47, 400–412. https://doi.org/10.1016/j.spc.2024.04.015

Natural environment | Head Department of Statistics in the Chernihiv Oblast. (2020). https://www.chernigivstat.gov.ua/statdani/Navk/index.php

Niero, M. (2023). Implementation of the European Union´s packaging and packaging waste regulation: A decision support framework combining quantitative environmental sustainability assessment methods and socio-technical approaches. Cleaner Waste Systems, 6, 100112. https://doi.org/10.1016/j.clwas.2023.100112

Noor, I., Martin, A., & Dahl, O. (2020). Water recovery from flue gas condensate in municipal solid waste fired cogeneration plants using membrane distillation. Chemical Engineering Journal, 399, 125707. https://doi.org/10.1016/j.cej.2020.125707

OECD. (2019). Waste management and the circular economy in selected OECD countries. In OECD Environmental Performance Reviews. https://doi.org/10.1787/9789264309395-en

OECD & International Institute for Applied Systems Analysis. (2020). Systemic Thinking for Policy Making. The Potential of Systems Analysis for Addressing Global Policy Challenges in the 21st Century. https://doi.org/10.1787/879c4f7a-en

Olabode, S. O., Bakare, A. A., & Olateju, O. I. (2018). AN ASSESSMENT OF THE RELIABILITY OF SECONDARY DATA IN MANAGEMENT SCIENCE RESEARCH. LASU Journal of Employment Relations & Human Resource Management, 1(1), 182–194. https://doi.org/10.36108/ljerhrm/8102.01.0102

Omang, D. I. K., John, G. E., Inah, S. A., & Bisong, J. O. (2021). Public health implication of solid waste generated by households in Bekwarra Local Government area. African Health Sciences, 21(3), 1467–1473. https://doi.org/10.4314/ahs.v21i3.58

Order on the approval of the National Waste Management Strategy in Ukraine until 2030, No. 820-p (2017). https://zakon.rada.gov.ua/laws/show/820-2017-%D1%80#Text

Order on the approval of the perspective plan for the formation of territories of communities of the Chernihiv Oblast, No. 564-r (2020). https://www.kmu.gov.ua/npas/pro-zatverdzhennya-perspektivnogo-

a564r?fbclid=IwAR0RHNlOMTopEO1OryLhVOQYTY8KilmdGfc_l-yIJSzTZmjsx3QyXyRvxG0

Orders on making changes to the Natural Environment Protection Program surrounding in the Chernihiv Oblast for 2021 – 2027, No. 258 (2024). https://eco.cg.gov.ua/web_docs/2145/2021/03/docs/%D0%A0%D0%BE%D0%B7%D0%BF%D0%BE%D1%80%D1%8F%D0%B4%D0%B6%D0%B5%D0%BD%D0%BD%D1%8F_258_15.04.2024.pdf

Papagiannis, F., Gazzola, P., Burak, O., & Pokutsa, I. (2021). A European household waste management approach: Intelligently clean Ukraine. Journal of Environmental Management, 294, 113015. https://doi.org/10.1016/j.jenvman.2021.113015

Parajuly, K., Fitzpatrick, C., Muldoon, O. T., & Kuehr, R. (2020). Behavioral change for the circular economy: A review with focus on electronic waste management in the EU. Resources, Conservation & Recycling. X, 6, 100035. https://doi.org/10.1016/j.rcrx.2020.100035

Perkumienė, D., Atalay, A., Safaa, L., & Grigienė, J. (2023, June 28). Sustainable Waste Management for Clean and Safe Environments in the Recreation and Tourism Sector: A Case Study of Lithuania, Turkey and Morocco. Recycling, 8(4), 56. https://doi.org/10.3390/recycling8040056

PFIRS. (2020, January 18). Public panel discussion “Let's deal with garbage: European experience from the northern regions of Ukraine.” https://pfirs.org/novini-fondu/item/469-1354.html

Pilcher, N., & Cortazzi, M. (2023). “Qualitative” and “quantitative” methods and approaches across subject fields: implications for research values, assumptions, and practices. Quality and Quantity. https://doi.org/10.1007/s11135-023-01734-4

Pires, A., Martinho, G., & Chang, N. (2011). Solid waste management in European countries: a review of systems analysis techniques. Journal of environmental management, 92 4, 1033-50. https://doi.org/10.1016/j.jenvman.2010.11.024.

Population and migration | Head Department of Statistics in the Chernihiv Oblast. (2020). https://www.chernigivstat.gov.ua/statdani/Demog/index.php

Prysiazhniuk O., Chechulina K., (2023). Ukraine initiates waste management reform. CMS Law-Now. https://cms-lawnow.com/en/ealerts/2023/05/ukraine-initiates-waste-management-reform

Puype, F., Samsonek, J., Knoop, J., Egelkraut-Holtus, M., & Ortlieb, M. (2015). Evidence of waste electrical and electronic equipment (WEEE) relevant substances in polymeric food-contact articles sold on the European market. Food Additives & Contaminants. Part a. Chemistry, Analysis, Control, Exposure & Risk Assessment, 150119061656008. https://doi.org/10.1080/19440049.2015.1009499

Rebolj, A. B. (2013). The case study as a type of qualitative research. ResearchGate. https://www.researchgate.net/publication/265682891_The_case_study_as_a_type_of_qualitative_research

Rekart. (2023, May 16). How paper, metal, wood, glass and plastics are recycled. Medium. https://medium.com/@rekart/how-paper-metal-wood-glass-and-plastics-are-recycled-27912dfef8b5

Regional State Administration of the Chernihiv Oblast (2019). Plan of measures for the implementation in 2021-2023 of the strategy of sustainable development of the Chernihiv Oblast for the period until 2027. https://cg.gov.ua/web_docs/1/2019/04/docs/%D0%9F%D0%9B%D0%90%D0%9D_2021-2023_%D0%9E%D0%9A_.pdf

Regional ecological network scheme of the Chernihiv Oblast, No. 18-8/VII (2017). https://chor.gov.ua/images/Razdely/Norm_docum/Rishennia/7_sklykannia/8_sessiya/Regionalna_shema_oblasti.pdf

Regulations on the Department | The Department of Ecology and Natural Resources of the Chernihiv Regional State Administration. (n.d.). https://eco.cg.gov.ua/index.php?id=16801&tp=1&pg=

Regulatory framework | State Environmental Inspection of the Chernihiv Oblast. (n.d.). https://www.chernigiv.dei.gov.ua/post/645

Regulatory framework | The Department of Education and Science of the Chernihiv Regional State. (n.d.). https://uon.cg.gov.ua/#

Resolution on approval of the list of activities related to environmental protection measures, No. 1147 (1996). https://zakon.rada.gov.ua/laws/show/1147-96-%D0%BF#Text

RETech Germany. (n.d.). The five phases of waste management. German RETech Partnership. https://www.retech-germany.net/en/themes/steps-to-modern-waste-management/the-five-phases-of-waste-management

Reuters, T. (2023, August 19). Russian missile attack leaves 7 dead, over 100 injured in Chernihiv, Ukrainian officials say. CBC. https://www.cbc.ca/news/world/russia-ukraine-chernihiv-missile-1.6941499

Rezania, S., Oryani, B., Nasrollahi, V. R., Darajeh, N., Lotfi Ghahroud, M., & Mehranzamir, K. (2023, August 27). Review on Waste-to-Energy Approaches toward a Circular Economy in Developed and Developing Countries. Processes, 11(9), 2566. https://doi.org/10.3390/pr11092566

Ritter, M., Schilling, H., Brüggemann, H., Fröhlich, T., Goldmann, D., Henze, R., Kuhlmann, M., Mennenga, M., Mrotzek-Blöß, A., Niemeyer, J. F., Schmidt, K., Spengler, T., Sturm, A., Vietor, T., Woisetschläger, D. M., & Kauffeld, S. (2024). Towards achieving the sustainable development goals: a collaborative action plan leveraging the circular economy potentials. Gruppe. Interaktion. Organisation. Zeitschrift Für Angewandte Organisationspsychologie. https://doi.org/10.1007/s11612-024-00733-9

Rizos, V., Behrens, A., Van Der Gaast, W., Hofman, E., Ioannou, A., Kafyeke, T., Flamos, A., Rinaldi, R., Papadelis, S., Hirschnitz-Garbers, M., & Topi, C. (2016). Implementation of Circular Economy Business Models by Small and Medium-Sized Enterprises (SMES): Barriers and enablers. Sustainability, 8(11), 1212. https://doi.org/10.3390/su8111212

Rosilawati, Y., Rahmawati, F., & Hidayat, T. (2023). Engaging Stakeholders through Proper Waste Management System to Achieve a Sustainable Campus: A Case Study at UMY, Indonesia. E3S Web of Conferences, 440, 02007. https://doi.org/10.1051/e3sconf/202344002007

Rubio, S., Ramos, T. R. P., Leitão, M. M. R., & Barbosa-Povoa, A. P. (2019). Effectiveness of extended producer responsibility policies implementation: The case of Portuguese and Spanish packaging waste systems. Journal of Cleaner Production, 210, 217–230. https://doi.org/10.1016/j.jclepro.2018.10.299

Sakai, S., Yano, J., Hirai, Y., Asari, M., Yanagawa, R., Matsuda, T., Yoshida, H., Yamada, T., Kajiwara, N., Suzuki, G., Kunisue, T., Takahashi, S., Tomoda, K., Wuttke, J., Mählitz, P., Rotter, V. S., Grosso, M., Astrup, T. F., Cleary, J., . . . Moore, S. (2017). Waste prevention for sustainable resource and waste management. Journal of Material Cycles and Waste Management, 19(4), 1295–1313. https://doi.org/10.1007/s10163-017-0586-4

Samsukha, A. (2022, September 9). Role Of Technologies And Mobile Apps In Waste Management. Forbes. https://www.forbes.com/sites/forbestechcouncil/2022/09/09/role-of-technologies-and-mobile-apps-in-waste-management/

Scottish Environment Protection Agency. (2023). GUIDANCE REGARDING PROVISION AND ASSESSMENT OF TECHNICALLY COMPETENT MANAGEMENT AT WASTE MANAGEMENT FACILITIES. In WST-G-002. https://www.sepa.org.uk/media/5tqhkxzl/technically_competent_management_licenced_waste_management_facilities.pdf

Seadon, J. K. (2010). Sustainable waste management systems. Journal of Cleaner Production, 18(16–17), 1639–1651. https://doi.org/10.1016/j.jclepro.2010.07.009

Serhiy Prima. (2017). Chernihiv landfill. Sergey Prima YouTube Channel. https://www.youtube.com/watch?v=B19b4wdDn8o&ab_channel=%D0%A1%D0%B5%D1%80%D0%B3%D1%96%D0%B9%D0%9F%D1%80%D0 %B8%D0%BC%D0%B0

Shishpanova, N. (2023). Modern waste management in communities according to the principles of circular economy. Ekonomìka Ta Suspìl'stvo, 49. https://doi.org/10.32782/2524-0072/2023-49-35

Shukla, S., & Khan, R. (2022). Sustainable waste management approach: A paradigm shift towards zero waste into landfills. In Elsevier eBooks (pp. 381–395). https://doi.org/10.1016/b978-0-323-85792-5.00006-x

Siddiqua, A., Hahladakis, J. N., & Al-Attiya, W. a. K. A. (2022). An overview of the environmental pollution and health effects associated with waste landfilling and open dumping. Environmental Science and Pollution Research International, 29(39), 58514–58536. https://doi.org/10.1007/s11356-022-21578-z

Sknews. (2020, October 16). Chernihiv residents summarized the results of the environmental project "Superosrters". https://www.sknews.net/chernihivtsi-pidsumuvaly-rezultaty-ekolohichnoho-proektu/

Skryhan, H., Melnikova, I., Shilova, I., Karpenko, Y., Arlouski, P., Shashanka, S., … Scharenberg, L. (2017). Comparison of waste management systems in Western and transition economies. Retrieved from https://watra.boku.ac.at/wordpress/wp-content/uploads/2018/04/D.1_Comparison-of-WM-systems-in-western-and-transition-economies.pdf

Skryhan, H., Shilova, I., Khandogina, O., Abashyna, K., & Chernikova, O. (2018). WASTE MANAGEMENT IN POST-SOVIET COUNTRIES: HOW FAR FROM THE EU? Detritus, In Press(1), 1. https://doi.org/10.31025/2611-4135/2018.13657

Smol, M., Avdiushchenko, A., Kulczycka, J., & Nowaczek, A. (2018). Public awareness of circular economy in southern Poland: Case of the Malopolska region. Journal of Cleaner Production, 197, 1035–1045. https://doi.org/10.1016/j.jclepro.2018.06.100

Soudachanh, S., Campitelli, A., & Salhofer, S. (2024). Identifying priorities for the development of waste management systems in ASEAN cities. Waste, 2(1), 102–121. https://doi.org/10.3390/waste2010006

Stadt Wien. (n.d.). Small action, big impact. Retrieved from https://www.wien.gv.at/umwelt/ma48/service/publikationen/pdf/flugblatt-getrennte-sammlung-en.pdf

Standard. (2019, September 1). The environmental impacts of burning waste. Newsday. https://www.newsday.co.zw/thestandard/2019/09/01/environmental-impacts-burning-waste

Stankevičius, A., Novikovas, A., Bakaveckas, A., & Petryshyn, O. (2020). EU waste regulation in the context of the circular economy: peculiarities of interaction. jssidoi.org. https://doi.org/10.9770/jesi.2020.8.2(32)

State Forestry Agency of Ukraine (2020). General characteristics of the forests of Ukraine. https://forest.gov.ua/napryamki-diyalnosti/lisi-ukrayini/zagalna-harakteristika-lisiv-ukrayini

Statistical information | Head Department of Statistics in the Chernihiv Oblast. (2020). https://www.chernigivstat.gov.ua/statdani/

Stewart, R. (2010). Waste management. In Elsevier eBooks (pp. 39–61). https://doi.org/10.1533/9781845697662.1.39

Suchowska-Kisielewicz, M., Sądecka, Z., Myszograj, S., & Płuciennik, E. (2017). Mechanical-biological treatment of municipal solid waste in poland - case studies. Environmental Engineering and Management Journal, 16, 481-491. https://doi.org/10.30638/EEMJ.2017.048.

Tabasová, A., Kropáč, J., Kermes, V., Nemet, A., & Stehlík, P. (2012, August). Waste-to-energy technologies: Impact on environment. Energy, 44(1), 146–155. https://doi.org/10.1016/j.energy.2012.01.014

Takahashi, A. R. W., & Araújo, L. (2019). Case study research: opening up research opportunities. RAUSP Management Journal, 55(1), 100–111. https://doi.org/10.1108/rausp-05-2019-0109

Tanning, L., & Tanning, T. (2015). Analysis of the Resource Productivity of New Members of the European Union. Journal of Behavioural Economics, Finance, Entrepreneurship, Accounting and Transport, 3(1), 21-31.

Teixeira, C. A., Avelino, C., Ferreira, F., & Bentes, I. (2014). Statistical analysis in MSW collection performance assessment. Waste Management, 34(9), 1584–1594. https://doi.org/10.1016/j.wasman.2014.04.007

Tokarchuk, D., & Tomliak, T. (2023). A REVIEW OF WASTE MANAGEMENT IN THE EU COUNTRIES AND THE EXPERIENCE OF ITS ENERGY USE. "ECONOMY. FINANCES. MANAGEMENT: Topical issues of science and practical activity". https://doi.org/10.37128/2411-4413-2023-2-3

Tomorrows World Today. (2022). Top Recycling Countries Around the World. Tomorrows World Today. https://www.tomorrowsworldtoday.com/sustainability/top-recycling-countries-around-the-world/

Triguero, A., Álvarez-Aledo, C., & Cuerva, M. (2016). Factors influencing willingness to accept different waste management policies: empirical evidence from the European Union. Journal of Cleaner Production, 138, 38–46. https://doi.org/10.1016/j.jclepro.2016.05.119

Tripathy, J. P. (2013, December 1). Secondary data analysis: Ethical issues and challenges. PubMed Central (PMC). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4441947/

UA Energy. (2023). Energy from waste is a step towards a circular economy. Ukrainian Energy. https://ua-energy.org/uk/posts/enerhiia-z-vidkhodiv-krok-do-tsyrkuliarnoi-ekonomiky

UNDP. (2023, August 15). An environmentally friendly method to rebuild Ukraine. https://www.undp.org/ukraine/news/environmentally-friendly-method-rebuild-ukraine

United Nations. (2024). UNDP supports innovative solution to ‘war waste’ in Ukraine. https://news.un.org/en/story/2024/06/1150906

United Nations Environment Programme. (n.d.). Solid waste management. https://www.unep.org/explore-topics/resource-efficiency/what-we-do/cities/solid-waste-management

United Nations Environment Programme, & International Solid Waste Association (2024). Global Waste Management Outlook 2024 - Beyond an age of waste: Turning Rubbish into a Resource. https://wedocs.unep.org/20.500.11822/44939.

United territorial communities of the region | Chernihiv Regional Council. (2020). New official web portal. https://chor.gov.ua/ob-ednani-teritorialni-gromadi-oblasti

US EPA. (2024a). Resources, Waste and Climate Change. US EPA. https://www.epa.gov/smm/resources-waste-and-climate-change

US EPA. (2024b). Reducing and reusing basics. US EPA. https://www.epa.gov/recycle/reducing-and-reusing-basics

Vasconcelos, L. T., Silva, F. Z., Ferreira, F. G., Martinho, G., Pires, A., & Ferreira, J. C. (2021, October 1). Collaborative process design for waste management: co-constructing strategies with stakeholders. Environment, Development and Sustainability, 24(7), 9243–9259. https://doi.org/10.1007/s10668-021-01822-1

Vinti, G., & Vaccari, M. (2022, November 2). Solid Waste Management in Rural Communities of Developing Countries: An Overview of Challenges and Opportunities. Clean Technologies, 4(4), 1138–1151. https://doi.org/10.3390/cleantechnol4040069

Vlasova, S., Shukla, S., & Edwards, C. (2024, April 18). Russian strike kills at least 18 as Ukraine's air defenses struggle again to protect cities. CNN. https://edition.cnn.com/2024/04/17/europe/russia-strike-chernihiv-ukraine-air-defense-intl/index.html

Wang, D., Tang, Y., Long, G., Higgitt, D., He, J., & Robinson, D. (2019). Future improvements on performance of an EU landfill directive driven municipal solid waste management for a city in England. Waste management, 102, 452-463. https://doi.org/10.1016/j.wasman.2019.11.009.

Wang, Q., Zhang, Z., Wang, M., & Wang, B. (2022). Smart Management Platform for Landfilling of Waste after Mechanical Biological Treatment. Advances in Civil Engineering, 2022, 1–11. https://doi.org/10.1155/2022/5376066

Wang, Z., Hu, Y., Wang, S., Wu, G., & Zhan, X. (2023). A critical review on dry anaerobic digestion of organic waste: Characteristics, operational conditions, and improvement strategies. Renewable & Sustainable Energy Reviews, 176, 113208. https://doi.org/10.1016/j.rser.2023.113208

Watkins, E., Gionfra, S., & Institute for European Environmental Policy (IEEP). (2020). How to implement extended producer responsibility (EPR): A briefing for governments and businesses. WWF. https://wwfint.awsassets.panda.org/downloads/how_to_implement_epr___briefing_for_government_and_business.pdf

Weghmann, V. & EPSU. (2023). Waste management in Europe [Report]. https://www.epsu.org/sites/default/files/article/files/Waste%20Management%20in%20Europe_EN_1.pdf

Wikimedia Commons. (2020, February 1). EU-Eastern Partnership. https://commons.wikimedia.org/wiki/File:EU-Eastern_Partnership.svg

World Bank Group. (n.d.). Transitioning to a Circular Economy. Chapter 1 | Background and Context. https://ieg.worldbankgroup.org/evaluations/transitioning-circular-economy/chapter-1-background-and-context

World Bank Group. (2018, September 24). Global Waste to Grow by 70 Percent by 2050 Unless Urgent Action is Taken: World Bank Report. World Bank. https://www.worldbank.org/en/news/press-release/2018/09/20/global-waste-to-grow-by-70-percent-by-2050-unless-urgent-action-is-taken-world-bank-report

World Health Organization. (2018). Preventing disease through healthy environments: A global assessment of the burden of disease from environmental risks. Retrieved March 4, 2024, from https://www.who.int/publications/i/item/9789241565196?ua=1

WPSP. (2018). Port of Amsterdam – Integrated Green Energy Solutions (IGES). The World Ports Sustainability Program. https://sustainableworldports.org/project/port-of-amsterdam-integrated-green-energy-solutions-iges/#:~:text=IGES%20Amsterdam%20uses%20plastic%20feedstock,million%20litres%20of%20fuel%20annually.

You, S., Sonne, C., & Ok, Y. S. (2020). COVID-19's unsustainable waste management. Science, 368(6498), 1438. https://doi.org/10.1126/science.abc7778

Zhang, C., Hu, M., Di Maio, F., Sprecher, B., Yang, X., & Tukker, A. (2022). An overview of the waste hierarchy framework for analyzing the circularity in construction and demolition waste management in Europe. Science of the Total Environment, 803, 149892. https://doi.org/10.1016/j.scitotenv.2021.149892

Zhang N. (2023). Industrial composting. LinkedIn. https://www.linkedin.com/posts/noah-tedpack_composting-biodegradable-commercialcomposting-activity-7070398691609640960-dja6/

Zhao, Y., & Zhang, J. (2023). Literature mapping of waste sorting and recycling behavior research: a visual analysis using CiteSpace. Environmental Science and Pollution Research International, 30(26), 67953–67973. https://doi.org/10.1007/s11356-023-27295-5

Zinets, N., & Humphries, C. (2022, April 6). Russia bombards and U.S. imposes sanctions as Ukraine urges decisive help. Reuters. https://www.reuters.com/world/europe/us-allies-ready-new-russia-sanctions-after-bucha-killings-2022-04-06/

Österreichs Digitales Amt. (n.d.). Waste disposal/refuse collection.Ooesterreich.gv.at https://www.oesterreich.gv.at/en/themen/bauen_und_wohnen/umzug/5/Seite.180301.html

Appendices

A) Detailed description of the waste management stages

Table A. Waste management stages (adapted from Campitelli et al., 2022)

Waste Management Stages	Description
Stage 0: Waste Generation	Waste generation refers to the production of unwanted or unusable materials by households, businesses, and industries, often as a byproduct of consumption and production processes. It encompasses all types of waste, including municipal, industrial, hazardous, and agricultural, that must be managed to prevent environmental pollution and health hazards.
Stage 1: Waste Collection	The primary component of waste management is waste collection, which involves gathering waste materials from various sources, including households, businesses, industries, etc. This process often entails using specialized collection vehicles to transport waste to designated collection points, where it can be further processed. Depending on the distance and volume of waste to be transported, specialized vehicles such as garbage trucks, transfer stations, or rail and barge transport might be utilized.
Stage 2: Waste Sorting	Waste is then sorted at specialized facilities and categorized into recyclables, compostables, and non-recyclables. Trained personnel or automated systems sort incoming waste to extract materials for recycling, recovery or disposal. Recyclable materials are sorted and processed for their further reuse in manufacturing processes; compostable organic waste is separated for composting, whereas non-recyclable waste is prepared for treatment or disposal.
Stage 3: Resource Recovery	After all, sorted waste goes through the resource recovery stage, which involves extracting essential resources from waste materials through recycling or recovery processes. For materials like metals, plastics, glass, paper, or other matter, such processes typically aim to recover materials for their reuse in manufacturing. Other treatment methods may include incineration with energy recovery, anaerobic digestion, or biological and chemical treatment processes. Such types of waste recovery reduce its volume, mitigate environmental impacts, and recover remaining resources.
Stage 4: Waste Disposal	Disposal becomes necessary for waste materials that cannot be effectively treated or recycled. This typically involves landfilling, where waste is buried in designated landfills, or incineration without energy recovery, where waste is burned at high temperatures to reduce its volume and sterilize hazardous components.

B) Detailed description of the core waste management system's elements

Table B. Detailed description of the core waste management system's elements (adapted from Iacovidou et al., 2020)

Element of the subsystem	Area of investigation	Expected findings
Process subsystem		
Waste Generation	The phase will include a detailed analysis of the waste generation process in the Chernihiv Oblast to understand its composition, quantity for different sectors (residential or commercial), and distribution by the area of origin.	Recognizing these patterns and waste flows will support a precise definition of the waste generation features in the region.
Collection and Transportation	This analysis will include the assessment of waste collection and transportation elements, namely, the process of waste collection in bins (or other options for waste collection) and logistics of waste to further treatment facilities.	This will be studied to identify any possible logistics bottlenecks and areas of optimization.
Sorting and Separation	This phase will comprise assessment of sorting and separation facilities effectiveness to separate waste into recyclable, compostable, and residual streams.	Findings are expected to illuminate these facilities' operational status, efficiency, and impact on waste management practices, providing valuable insights for optimizing related processes or infrastructure.
Treatment and Disposal	All the treatment approaches, as well as disposal of the waste streams, are critically examined. Composting, recycling, incineration with energy recovery, and landfilling are evaluated in terms of their sustainability, as well as in terms of their regulatory settling.	Findings will provide insights into these treatment methods' presence, effectiveness and related impacts, informing decision-making processes for treatment strategies in the Chernihiv Oblast.
Actors' subsystem		
Government Agencies	An analysis will be carried out on the contribution of government agencies to the development of waste management policies, regulations and funding systems in the Chernihiv Oblast.	Governmental agencies will be examined as regulators and facilitators in creating a favourable, or vice versa, impedimental environment for the transformation processes.

Waste Management Companies	Waste management companies will be assessed for collection, transportation, treatment and disposal services and their efficiency.	This assessment aims to assess the efficiency of the waste management companies to fulfil the regional waste-handling needs.
NGOs and Civil Society Organizations	The discussion will focus on the critical actions NGOs take to sensitize the community and ensure sustained waste management practices.	This research is aimed to explore NGOs' efficacy in raising public awareness, support waste and recycling initiatives, and monitor stakeholders' activity.
Citizens and Companies (generating waste)	The study will investigate citizens' and firms' involvement in the regional WMS, their level of awareness and engagement in waste management activities, focusing on waste generation, separation, and disposal.	By exploring citizens' and firms' attitudes and behaviour towards waste management, the research seeks to identify barriers to effective waste reduction and raising a culture of sustainability in waste management.
Values' subsystem		
Environmental Values	A study will examine the current and potential ecological impacts of the present waste management activities on the environment.	The objective of the examination is to shed light on the ecological footprint of waste disposal techniques and the long-term consequences that arise from undertaking the activities.
Economic Values	The cost-effectiveness of the waste disposal system will be examined, including the incomes that may be provided by the current projects.	The benefits and the negative sides of the present WMSs are examined, which will reveal potential bottle-necks in the current financial state.
Social Values	The research will be taken into consideration social implications of the WMS, spanning aspects of public health, employment generation or other elements leading to general public well-being.	Through assessment, the research obtains the overview of the social elements that impact public health, quality of life, or other aspects which effect communities.

C) Characteristics of the four clusters of the Chernihiv Oblast

Table C. Characteristics of the clusters in the Chernihiv Oblast (adapted from Derii et al., 2021)

Main Parameters	Clusters	West	East	South	Central
Area, km²		10245	9202,3	7221,8	5210,3
Population, thousand people		456,2	154,9	224,8	155,4
Potential volumes of solid waste generation, thousand tons/year		170,4	46,5	67,4	46,6
Existing solid waste landfills:	units	3	3	3	0
	hectares	47,2	12,96	27,25	0
Other landfills:					
	units	155	146	99	92
	hectares	154,65	132,56	116,51	97,25

D) Detailed description of the governmental bodies of the Chernihiv Oblast

The power of local state administrations in the field of waste management includes (Law of Ukraine "On Local State Administrations", 2001):

a) Execution of various governmental levels' laws and acts;
b) Participation in the development of national programs for the use of waste and the introduction of energy-saving technologies;
c) Organization of development and implementation of regional and local waste management programs;
d) Coordination and support of business activities in the field of waste management;
e) Control over the use of waste, taking into account their resource value and safety;
f) Control over the activities of waste management facilities;
g) Interaction with local government bodies;
h) Development and approval of schemes for sanitary cleaning of settlements;
i) Organization and support of the creation of specialized enterprises for waste processing and disposal;
j) Attracting funds to finance related projects;
k) Keeping registers of waste and its infrastructure;
l) Organization of accounting and certification of specific waste types;
m) Organization of waste collection and disposal;
n) Issuance of permits for operations with waste;
o) Liquidation of illegal waste dumps;
p) Clarifying the legislation among the population and encouraging them to participate in waste-related programs;
q) Control and consideration of violations in the field of waste management.

During the preparation of local budget drafts, regional state administrations make proposals to attract funds necessary for the implementation of measures in the field of waste management.

The Department of Ecology and Natural Resources of the Chernihiv Regional State Administration carries out its environmental protection activities, including waste management (except radioactive waste management) in the territory of the Chernihiv Oblast

(Regulations on the Department | The Department of Ecology and Natural Resources of the Chernihiv Regional State Administration, n.d.). In accordance with the order of the head of the Chernihiv Regional State Administration No. 443 dated 26.07.2019, the structure of the Department was approved, which provides for the Department of Regulation of Natural Resources and Waste as part of the Department of Budget Financing and Natural resources.

The main task of the Department of Regulation of Natural Resources and Waste, in accordance with its regulations, is to ensure, within the limits of its powers, the implementation of state policy aimed at regulating water resources, atmospheric air, and other natural resources (except biological resources) and waste (except radioactive waste management) in the territory of the Chernihiv Oblast (Derii et al., 2021).

Responsibilities of the Department of Regulation of Natural Resources and Waste include (Regulations on the Department | The Department of Ecology and Natural Resources of the Chernihiv Regional State Administration, n.d.):

– Timely review and registration of waste declarations in the electronic system;
– Management of electronic services of the Ministry of Environmental Protection and Natural Resources of Ukraine in the field of waste;
– Preparation of passports for waste disposal sites and registration of maps for waste generation, processing, and disposal facilities;
– Registration of waste disposal sites and waste generation, processing and disposal facilities;
– Responding to requests to identify unauthorized landfills through the "Interactive map of the Ministry of Ecology and Natural Resources of Ukraine" service;
– Conducting an annual inventory of places of accumulation of chemical plant protection products in cooperation with district inventory commissions in order to prevent a negative impact on the health of the population.

The work of the Department of Ecology and Natural Resources in the field of waste management is carried out in cooperation with other structural divisions of the Chernihiv Regional State Administration, in particular with the Department of Energy Efficiency, Transport, Communications and Housing and Communal Services, which is entrusted with the

following functions (Regulations on the Department | The Department of Ecology and Natural Resources of the Chernihiv Regional State Administration, n.d.):

– Analysis of urban development areas state (greening, lighting, road maintenance, household waste management);
– Providing proposals for collecting and removing household waste, creating landfills for their disposal, as well as carrying out a separate collection of valuable materials;
– Providing proposals for the development and approval of schemes for sanitary cleaning of settlements.

There are several other important institutions and departments which play a crucial role in the regional WMS:

1. State Environmental Inspection of the Chernihiv Oblast: responsible for monitoring compliance with the requirements of environmental legislation in the field of handling waste and hazardous chemicals (Regulatory framework | State Environmental Inspection of the Chernihiv Oblast, n.d.).

2. Department of Health Protection of the Chernihiv Regional State Administration: ensures the implementation of legislation and standards in the field of health care aimed at preserving the environment (Access to public information / Legislation | Department of Health Protection of the Chernihiv Regional State Administration, n.d.).

3. Head Office of the State Production and Consumer Service in the Chernihiv Oblast: responsible for approving passports of waste disposal sites and registration cards of waste generation, processing and disposal facilities (Legal principles of activity | Head Office of the State Production and Consumer Service in the Chernihiv Oblast, n.d.).

All these institutions jointly control and supervise compliance with the requirements of sanitary legislation on waste management, taking the necessary measures to ensure safe and environmentally friendly waste management.

Local government bodies in the field of waste management ensure (Law of Ukraine on Local government bodies, 2024):

a) Compliance with the requirements of the legislation on waste;

b) Development and approval of schemes for sanitary cleaning of settlements;

c) Organization of household waste collection and disposal, including their separate collection and creation of landfills;

d) Approval of local and regional waste management programs and control over their implementation;

e) Taking measures to stimulate business entities in the field of waste management;

f) Resolving issues regarding the location of waste management facilities on the territory;

g) Coordinate the activities of business entities located on their territory;

h) Implementation of control over rational use and safe handling of waste on its territory;

i) Liquidation of unauthorized and uncontrolled waste dumps;

j) Facilitating the clarification of waste legislation among the population and stimulating their participation in collecting and harvesting waste as secondary raw materials;

k) Exercising other powers in accordance with the laws of Ukraine.

Local governments play a key role in the field of waste management, ensuring compliance with legislation and organizing activities at the local level (Derii et al., 2021). They make decisions regarding the allocation of land plots for the placement of waste and the construction of waste management facilities. Local government bodies, together with local state administrations, ensure the collection and removal of household waste, the creation of landfills for their disposal, and the separate collection of valuable materials of this waste.

The cooperation of united territorial communities is an important tool in municipal waste management (Derii et al., 2021). However, currently, in the Chernihiv Oblast, there are not enough agreements on territorial community cooperation in waste management, which complicates the effective work of waste management clusters.

The State Statistics Service, particularly the Head Department of Statistics in the Chernihiv Oblast, provides information support for waste management, particularly regarding waste generation and management (Documents / Legislative and regulatory acts | The Head Department of Statistics in the Chernihiv Oblast, n.d.). They collect, process, and transmit the necessary information, form databases, and provide access to information about the state of the environment and the impact on it caused by waste.

E) Detailed description of the natural environment of the Chernihiv Oblast

Hydrogeologically, the entire territory of the Chernihiv Oblast is within the Dnieper artesian basin (Hormiz, 2016). The region is provided with underground water resources to a sufficient extent. According to the State Service of Geology and Subsoil of Ukraine, estimated underground water resources in the Chernihiv Oblast amount to 3.038 billion m3. Operational reserves of underground water amount to 188.0 million m3. Only underground water is used for the drinking and sanitary needs of the region's population.

The subsoil of the Chernihiv Oblast is rich in minerals. On the territory of the region, the State balance of reserves includes 323 deposits (282 deposits and 41 accounting objects) of six types of minerals, in particular fuel (gaseous, liquid, solid) and non-metallic (mining and chemical, non-ore for metallurgy, construction) (Statistical information | Head Department of Statistics in the Chernihiv Oblast, 2020). 106 deposits are being developed (72 deposits and 34 accounting objects), while 176 deposits remain undeveloped. In the structure of mineral resources of the Chernihiv Oblast, fuel and energy minerals (oil, gas, condensate, peat) prevail, the share of which is 58% (Derii et al., 2021). Construction raw materials (chalk, sand, quartz sand, clay, loam) comprise almost a third (31.1%) of the total mineral resources. Another 8.3% is accounted for by fresh and mineral underground waters, 0.7% by non-metallic minerals for metallurgy and bischofite. Reserves of high-quality quartz (glass) sands (Ripkinsky district) and oil are of national importance. Oil condensate fields are concentrated in the Talalaiv, Ichnyan, Prylutsky, Varvyn, and Sribnyan districts and are part of the Dnipro-Donetsk oil and gas-bearing province.

Peat, an alternative (ecological) fuel, has balance reserves of 66.146 million tons, and peatlands cover more than 200,000 hectares (Derii et al., 2021). Chalk deposits in the Novgorod-Siversky district, brick raw materials throughout the region, and clay reserves suitable for the manufacture of roof tiles, ceramic tiles, pottery, and art ceramics are of great industrial importance.

On the region’s territory, there are 10 promising oil and gas facilities prepared for deep drilling. Promising resources are estimated at 12.471 billion m3 for gas and 3.695 million tons for oil (Derii et al., 2021). Peat reserves are estimated at 99 deposits and amount to 66.146 million

tons, of which 9 with reserves are being developed at 10.4 million tons (peat reserves—55.746 million tons).

The Chernihiv Oblast is a forest region. The level of forest cover in the region is 20.9%, which is higher than the average indicator for Ukraine (15.9%) (Statistical information | Head Department of Statistics in the Chernihiv Oblast, 2020; State Forestry Agency of Ukraine, 2020). The area of the forest fund of the region is 739.5 thousand hectares, including the area of forest plots is 708.06 thousand ha. The species composition of the forests of the Chernihiv Oblast has the following structure: pine – 57.8%, oak – 15.3%, birch – 11.6%, and other tree species and shrubs – 15.3%. Reforestation is one of the main activities of enterprises. Over the past five years, the annual average volume of forest reproduction is 2,750.3 hectares. The main method of reforestation is the creation of forest crops, which is 85% on average.

The recreational potential of the region includes territories and objects of the nature reserve fund. The largest of them is the Ichnyanskyi (area of 9.66 thousand hectares) and Mezynskyi (area of 31.03 thousand hectares) national natural parks, part of the national natural park "Zalissya" (area of 1.28 thousand hectares), the regional landscape park " Mizhrychynsky" (78.75 thousand ha), "Nizhynskyi" regional landscape park (6.12 thousand ha), "Yalivshchyna" regional landscape park (168.7 ha) (Statistical information | Head Department of Statistics in the Chernihiv Oblast, 2020). They play an important role in preserving the entire complex of ecosystems, habitats of species and their genetic diversity, as well as landscapes, routes of animal migrations, distribution and preservation of plants in the region and are attractive for regulated recreation and ecotourism.

F) Detailed description of the governance in the Chernihiv Oblast

The materials of the inspections are sent to law enforcement agencies, the involved business entities are presented with claims for voluntary compensation for damages (Derii et al., 2021). Requests for liquidation of unauthorized waste dumps are sent to local government bodies and district state administrations. The inspectorate conducts inspections of compliance with legislation in the field of environmental protection at waste disposal facilities. Based on the results of such inspections, compliance / non-compliance with current requirements is established.

The planning and implementation of measures in the Chernihiv Oblast regarding activities in the field of waste management is provided according to the program document of the regional level "Strategy of sustainable development of the Chernihiv Oblast for the period until 2027" and "Plan of measures for its implementation" (Regional State Administration of the Chernihiv Oblast, 2019), which is the main strategic planning document in region. One of the objectives of the Strategy is to transform the Chernihiv Oblast into an ecologically clean region. Strategic and operational goals envisage, in particular, the development of the field of solid household waste management. Achieving the outlined goals aims to reduce the amount of disposal of unprocessed household waste; implementation of the system of separate collection of solid household waste; growth in the share of procurement, utilization and use of waste as secondary raw materials. Similar development strategies are developed by village, settlement, and city councils of united territorial communities.

To date, the Chernihiv Region Environmental Protection Program for 2014-2020 operates in the region (Environmental protection program of the Chernihiv Oblast | The Department of Ecology and Natural Resources of the Chernihiv Regional State Administration, n.d.). According to the Program, the Department of Ecology and Natural Resources of the Chernihiv Regional State Administration ensures the implementation of environmental protection measures, the implementation of which contributes to solving environmental problems and improving the state of the region's environment. When solving environmental problems within the framework of the Program, the efforts of local authorities and local government bodies, environmental protection organizations, enterprises, scientific institutions, mass media, population, public organizations are combined and coordinated.

The program defines the following areas of funding (Environmental protection program of the Chernihiv Oblast | The Department of Ecology and Natural Resources of the Chernihiv Regional State Administration, n.d.):

- protection and rational use of water resources;
- protection and rational use of land;
– protection and rational use of natural plant resources, preservation of the nature reserve fund;
- rational use, storage and disposal of production waste and household waste;
– organization of the system of ecological monitoring of the environment;
– science, information and education;
- atmospheric air protection.

In connection with the expiration in 2020 of the Environmental Protection Program of the Chernihiv Region for 2014-2020, the Department has developed the Environmental Protection Program of the Chernihiv Region for 2021-2027 (order of the head of the Chernihiv Regional State Administration dated February 14, 2020 p. No. 92).

Analysis of regional documents of strategic planning of activities related to waste management shows that the main emphasis of planning is on the management and handling of unsuitable hazardous waste and solid waste, namely: solid household waste management; introduction of new technologies and forms of management of solid household waste; construction of facilities for the reception, processing and disposal of solid waste, expansion of the spheres of their use as secondary raw materials; construction of new solid waste landfills that meet established standards; carrying out an educational and informational campaign among the population regarding the ecological necessity of constant and correct handling of household waste and the importance of implementing separate collection of solid household waste (Derii et al., 2021).