Recommendations for improvement of Ukrainian Solid Waste Management System

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I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the *Universidade de Lisboa*.

To all my beloved people, who I ignored or disappointed while developing this dissertation.

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Abstract

Municipal solid waste generation is growing constantly all over the world. Soil, air, and water are being contaminated as a result of irresponsible waste treatment. Therefore, the development of a decent waste management system is an important part of natural resources usage and transformation to a sustainable economy. Nowadays, Ukraine lacks basic features of a proper waste management system on every level – legislative, technical, economical. In the current master dissertation, the waste management system Strategic Plan was developed for Ukraine. Such Plan has its aim to provide practical guidance on how Ukraine might reach waste management goals adopted by EU until 2030. In order to start the development of such a plan, both legislative and practical levels of Ukrainian waste management were examined. Waste generation, existing waste treatment practices and facilities were assessed as well. Calculation rules for desired goals and mass balances for future waste treatment facilities were established in order to perform the calculation of future waste streams in Ukraine. Based on performed calculations, it was confirmed that Ukraine has theoretical chances to reach the main of established goals – landfill less than 45% of waste in 2030. It is possible only through the introduction of major changes in the waste management system. For that reason, Strategic Plan provides technical guidance on waste collection, treatment and landfill systems, alongside economic and legislative improvement recommendations. Required installed capacities for waste treatment and their possible locations were addressed. Suggested legislative changes and economic instruments are described as well. Developed Strategic Plan was compared to existing Ukrainian waste management plan.

Keywords

Ukraine, European Union, Waste management, Waste hierarchy, Waste framework directive, Waste legislation, Waste management plan

Resumo

A geração de energia usando resíduos sólidos urbanos tem vindo a aumentar globalmente. Como resultado de um tratamento irresponsável dos resíduos, tanto a terra, como o ar e até como a água têm vindo a ser contaminados. Por essa razão, o desenvolvimento de um sistema de gestão de resíduos decente é uma parte importante na utilização e transformação de fontes naturais numa economia sustentável. Hoje em dia na Ucrânia há uma grande falha nos sistemas de gestão de resíduos a vários níveis, legislativo, técnico, económico. Nesta dissertação foi desenvolvido um Plano Estratégico para a gestão do sistema de resíduos, na Ucrânia. Neste plano são dadas guias em como a Ucrânia pode atingir os objectivos adoptados pela União Europeia (UE) para 2030. Para se começar o desenvolvimento de tal plano, foram examinadas tanto a componente legislativa como a componente prática dos processos de tratamento de resíduos ucraniana. Foram também exploradas tanto as práticas de gestão de resíduos assim como as próprias instalações. Por forma a calcular possíveis futuros de vapor residual na Ucrânia foram desenvolvidos cálculos para se atingis os objectivos estabelecidos e balanços mássicos para possíveis futuras instalações de tratamento de resíduos. Com base nos cálculos feitos, foi possível confirmar-se que a Ucrânia tem condições, teóricas, para atingir o principal objectivo estabelecidos – reduzir para 45% a quantidade de desperdício que é enviada para os aterros existentes, até 2030. Tal objectivo é apenas conseguido pela introdução de grandes alterações ao sistema de gestão de resíduos. Por essa razão, o Plano Estratégico oferece um guia técnico para a recolha e tratamento de desperdício assim como para sistemas de aterros, juntamente com algumas recomendações de melhoramento nas secções económica e legislativa. A capacidade das instalações de tratamento de resíduos e sua localização foram critérios considerados importantes e endereçadas neste trabalho. Finalmente, o Plano Estratégico desenvolvido foi comparado com o actual plano de gestão de resíduos ucraniano.

Palavras-chave

União Europeia; Ucrânia; Resíduos Sólidos Urbanos; Hierarquia de resíduos; Legislação de resíduos; Plano de gestão de resíduos

Table of Contents

List of Figures

List of Tables

List of Acronyms

AA	Association Agreement
AD	Anaerobic Digestion
AP	Action Plan
BMW	Biodegradable Municipal Waste
BREF	Best Available Techniques Reference Document
CAPEX	Capital Expenses
CEP	Circular Economy Package
CWGN	Cumulative Waste Generation Number
EAP	Environmental Action Plan
EC	European Commission
EPR	Extended Producer Responsibility
EU	European Union
EUR	Euro
FL	Framework Law “About Waste Management”
GDP	Gross Domestic Product
ISWA	International Solid Waste Association
LD	Landfill Directive
MBT	Mechanical-Biological Treatment
MSW	Municipal Solid Waste
NSWM	National Strategy On Waste Management Of Ukraine Until 2030
NWMP	National Waste Management Plan Of Ukraine
OPEX	Operational Expenses
OV	Organic Valorisation
PAYT	Pay-As-You-Throw
RDF	Refuse Derived Fuel
RREE	Roadmap To A Resource Efficient Europe
SRF	Solid Recovered Fuel
TS	Thematic Strategy
WEEE	Waste Electrical And Electronic Equipment
WFD	Waste Framework Directive
WMP	Waste Management Planning
WTE	Waste-To-Energy

List of Symbols

ε	Aerial waste collection coverage % in 200_i year, %
η	Collection coverage in 200_{i-1} year, %
C_{200i}	Collected amount of MSW, ton
G_{200i}	The generated amount of MSW, ton
R_{separ}	Waste separate collection rate annual growth, %
C_{separ}	Waste separate collection rate, %
$R_{landfill}$	Waste landfilling rate annual growth, %
$C_{landfil2030*}$	Waste landfilling rate, %
Re_{TOTAL}	Recycling rate, %
x_{sort}^{i}	Usage coefficient of sorting waste treatment technology
x_{OV}^{i}	Usage coefficient of organic valorisation waste treatment technology
x_{MBT}^{i}	Usage coefficient of mechanical-biological waste treatment technology
x_{IND}^{i}	Usage coefficient of individual composting waste treatment technology
b_{sort}	Rest fraction from sorting plant
a_{recov}^{MBT}	Percentage of compost from MBT treatment plant.
$W_{WTE}^{/}$	Amount of rest fraction to undergo secondary incineration
$x_{WTE}^{/}$	Usage coefficient for rest fraction incineration

$L_i^{/}$	Amount of waste to landfill after secondary incineration
S_i	Amount of waste in a waste stream
kg	Kilogram
^{o}C	Celsius Degree
MJ	Mega Joule
m^3	Cubic meter

1 Introduction

Over the years, municipal solid waste (MSW) generation was growing constantly in both developed and developing countries. Nowadays the world generates 2 billion tonnes of MSW annually, and such number expected to reach 3,4 billion tonnes to 2050[1]. Soil, air, and water are being contaminated as a result of irresponsible waste treatment. Even though, municipal solid waste represents only around 10% share among all waste generated in Europe[2], the benefits of its wise treatment are, indeed, diverse and valuable. Instead of choosing simple landfilling method, which was invented thousands years ago, nowadays it is possible to process waste in a relatively environmentally-friendly way in order to store it, collect valuable raw materials from it, extract energy from waste, use waste in production of completely new goods or even decrease waste generation to reduce its harmful impact. Mentioned options create so-called “waste hierarchy” – widely accepted approach in waste management, which values landfilling method the least, and considers prevention of waste generation as the best option[3]. Nevertheless, the main challenge is to apply such conception in practice.

1.1 Overview of Municipal solid waste management problem in Ukraine

There are 461 cities, 883 small-scale cities, and 28,376 villages in Ukraine[4]. Ukraine has landfill-oriented MSW management, practically implemented through waste disposal facilities, which are mostly do not meet modern environmental standards or even created illegally. Development of a decent waste management system is considered as an integral part of natural resources usage and transformation to a sustainable economy. Obviously, such dependence on landfilling in waste management can no longer remain Ukrainian feature. Nowadays it is vital to rethink Ukrainian waste management system with the only purpose – to change it as quickly as possible in the direction of reusing and recycling and clean treatment of MSW. Important is to use economic and resource potential of waste. As for solid waste – it is a resource, and with appropriate treatment, it can bring a lot of economic and environmental dividends to Ukraine.

Nowadays Ukraine lacks a lot of features of a proper waste management system on every level – legislative, technical, financial, social. Legislatively, Ukrainian waste management was governed by outdated laws and management plans for decades. Fortunately, the last couple of years Ukraine showed some progress – the first legislative document, which is claimed to be in line with European provisions was issued in 2017[5]. There is a number of drafts of legislative documents which Ukraine is planning to sign in the present year. Financially, it is obvious that one of the biggest countries with one of the weakest

economies in Europe[6] cannot invest a lot of funds into any of its particular activities. Therefore, in case of insufficient funding a backup plan should be emerged – Ukraine has to at least put a decent landfilling system in place. Particularly to close existing dump sites and establish a new system of disposal sites. That will at least provide environmental and health benefits to population, in case there is not sufficient financing for waste hierarchy development. It should be noted that in such case Ukraine have to be sure there is enough storage place for MSW and closure of dump sites will not bring new obstacles. Socially, the Ukrainian population is not fully ready to implement proper waste management practices on a personal level. But there is a wide and heated public discussion on waste management topic has emerged in recent years, which makes further positive changes possible.

Lastly, the technical side of Ukrainian MSW management is in stagnation. In 2018 Ukraine has landfilled close to 94% of its MSW[7]. One of the biggest factors for that is lack of waste treatment opportunities to be used. Ukraine possesses only one big waste-to-energy incineration plant in Kyiv. As of 2018, the cumulative capacity of such waste treatment technologies as Organic Valorisation, Mechanical/Mechanical-Biological treatment is not reaching 0,5 million tonnes of MSW. Sorting plants for separately collected waste have a cumulative capacity of 0,5 million tonnes too. But nowadays Ukraine imports waste for recycling to keep mentioned plants at full load, as there is not enough sorted waste in Ukraine to perform that. Ukrainian waste generation is a little more than 9 million[7]. Naturally, Ukraine does not have a theoretical chance to landfill less than 90% of its MSW under named conditions. Therefore, the technical side of MSW management requires closer attention and bigger changes. Again, there is a slow but positive trend to technical aspect either. Ukraine has already contracted or started construction of many waste treatment plants with cumulative capacities over one million tonnes for next years.

1.2 The motivation for Master dissertation

Briefly described Ukrainian waste management problems are not new, the current situation was shaping for the last two decades. But only in 2014, Ukraine has signed the “Association Agreement” with the European Union, the European Atomic Energy Community, and their Member States[8]. In terms of waste management, such agreement dictates, that Ukraine shall take immediate and decisive measures towards implementation of European standards and practices in the area. Therefore, the current topic is very actual in Ukraine. It took Ukraine a couple of years after the “Association Agreement” ratification in order to start practical actions in terms of waste management.

Waste management problem initiates intense legislative work in appropriate Ministries and a wide public discussion in Ukrainian society. That creates a unique environment for current dissertation, where new updates on the mentioned problem – new statistical data, new legislative documents, and decisions are

being issued monthly. In fact, there was a number of new legislation documents issued already after the current master dissertation was started, which makes it even more important, as current dissertation and Ukrainian efforts in waste management planning are simultaneously developing, which means that there is a possibility to perform the comparison.

It has been observed that even though Ukraine has recently started to address the MSW management problem in a proper way, most of the achievements lie on a legislative side of things. Quality of such achievements will be discussed further, but it is undeniable that Ukraine needs to start taking practical measures for waste management as quickly as possible. It has been 5 years since Ukraine signed "Association Agreement" and there were only very minor practical improvements in terms of MSW technical or planning parts of waste management which is discussed in the appropriate chapter.

Therefore, the main goal of the current dissertation is to create a Strategic Plan for MSW management in Ukraine. Such a plan will take into account the current legislative and practical state of the waste management system in Ukraine and will provide guidance on how to possibly achieve major EU goals in terms of waste management. Naturally, according to "Association agreement" mentioned plan have to be in line with EU practices in that regard. Such a plan will emphasize the practical side of MSW management, namely needed waste treatment facilities, waste collection schemes, economical tools to reach EU waste management goals. Legally, Ukraine is leaving such assessment out of the scope of MSW management on a National Level, stating that it should be included on a lower administrative level. This decision considered inappropriate, as Ukraine has a very centralized administrative system in terms of resources and competency distribution.

Named Strategic Plan is an important feature, as it will provide a rough waste management action plan for Ukraine on a National level and will be a foundation for further waste management plans on municipal levels. Currently, such a Strategic Plan is a kind of document that does not exist in Ukraine, but the author considers its usefulness.

1.3 Contents of Master dissertation

Structurally, the current dissertation is divided into six Chapters. The main chapter is the fifth – an actual strategic plan for Ukrainian MSW system. In order to be able to create such a plan, it is important to address both legislative and practical sides of MSW management.

Therefore, Chapter 2 "European legislation and planning in terms of waste management" provides an assessment of EU waste management legislation and its development. It will address active Framework directives, Environmental Action Plans and Circular Economy principles as those, who are shaping current

waste management conception. In addition, named chapter provides insights on waste management planning across the EU, its main features and trends.

Chapter 3 “Ukrainian municipal waste management legislation and planning” contains an assessment of current documents which regulate MSW management, particularly in Ukraine. Some of them are active, some are only in development state. Assessment will be performed minding provisions from Chapter 2 in order to check if developed MSW legislation is in line with EU standards. There is waste management planning in place in Ukraine, its quality and usefulness will be inspected. Named chapter will provide actual legislative and strategic background in order to further develop the Strategic Plan in the current dissertation.

Chapter 4 “Assessment of current Ukrainian waste management system and statistics” provides data on the amount and structure of municipal solid waste in Ukraine. Particularly, performance assessment will be provided in terms of overall municipal waste generation and its trends, established waste collection schemes and their performance. Another important side of the problem is Ukrainian technical options in terms of waste treatment, such as waste-to-energy, organic valorisation, mechanical-biological treatment, waste sorting and recycling, waste landfilling. Having both EU provisions and Ukrainian waste management theory and practice examined, it will be possible to evaluate certain goals that need to be achieved in Ukraine in terms of waste management. All the mentioned topics will be assessed in order to realize the starting point for the development of the Strategic Plan of the current dissertation.

Chapter 5 “Strategic Plan for Ukrainian municipal solid waste management” contains assumptions, calculations and evaluated recommendations for improvement of Ukrainian MSW management system. Chapter 5 contains “assumptions” part, where Ukrainian geography and territorial division and will be examined in order to establish an appropriate aerial division. After that, future morphology and collected amount of municipal solid waste will be predicted for the observed timeframe. Next step will be an evaluation of desirable goals to alongside with main calculation rules. The last piece of “assumptions” part will be a description of waste treatment technologies which is possible to apply in Ukraine alongside with their mass balances for calculation purposes. Based on provided goals and waste management background, it was possible to calculate waste streams for the observed timeframe and, therefore, to assess how much waste treatment equipment is needed for that and where to locate it. Evaluated waste streams made it possible to develop improvement recommendations for Ukraine. Such recommendations addressing collection system, various waste treatment technologies which will be applied in Ukraine. Separately will be discussed the landfill system and its improvements.

Lastly, Chapter 6 contains conclusions on developed Strategic Plan, quality assessment of it in terms of EU requirements and comparison with existing Ukrainian MSW planning.

2 European waste management legislation and planning

European waste policy is already developing for over than 40 years[9] through a series of environmental action plans and introducing an appropriate framework of legislation. The ultimate goal is to reduce a negative impact on the environment and public health[10]. The other task is to create an economy with effective use of resources and energy. Starting with EU's Sixth Environment Action Program (2002-2012) waste prevention and management was identified as one of four top priorities[11]. This led to the development of many long-term strategies for waste. In the current paragraph, European policies and strategies will be assessed, in relation to their timeline. It should be noted, that since in the following chapter providing legislation provisions, it is assumed appropriate to use direct law citation in some cases. Such citations are quoted.

2.1 Thematic Strategy on the prevention and recycling of waste

In December 2005 the European Commission has adopted the Thematic Strategy on the prevention and recycling of waste (Waste TS). It was published with the proposition of reviewing the Waste Framework Directive (2006/12/EC) (WFD). It transferred to establishing a new Waste Framework Directive 2008/98/EC, which includes many Waste TS from goals. Waste TS describes a set of crucial points adopted nowadays – waste prevention, promotion of reusing and recycling, establishing a recycling society. Mentioned objectives should have contributed to an overall decrease of harmful impacts of resource usage and improve overall environmental protection level. A vital requirement of Waste TS was a promotion of waste hierarchy, that was translated to a Waste Framework Directive 2008/98/EC which is described further. Other provision is that existing EU law should have been assessed through a life cycle analysis prism and simplified as well[12].

Basically, Waste TS could be summed up as follows: decreasing the amount of waste sent to landfills, better and bigger-scale recycling system. The main focus was put on environmental impacts in legislation – to make it more efficient[12]. Waste TS promoted an increase in composting and energy recovery levels, creation of better waste management policies on a national level. Waste TS gave momentum to cause changes in the waste framework directive and the establishment of a new one.

2.2 Waste framework directive 2008/98/EC

In order to closely assess a municipal solid waste management strategy adopted by the EU, it is necessary to inspect existing legislation. The main source of legislative guidance is the active Framework Directive 2008/98/EC on waste (WFD), established in 2008, which replaced previous Directive 2006/12/EC[3]. The purpose of the document was to establish basic concepts and definitions in terms of waste management. Such cornerstone principles of appropriate waste management as the waste hierarchy, the 'polluter-pays principle' and 'extended producer responsibility' were established by WFD. The crucial provisions from Directive 2008/98/EC are provided below.

Generally, "Directive lays down measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use*"* [3]. The very term "waste" is defined in Directive as "any substance or object which the holder discards or intends or is required to discard"[3]. Another important provision from the directive is the legal establishment of the waste hierarchy, to set priorities in waste prevention and management policies.

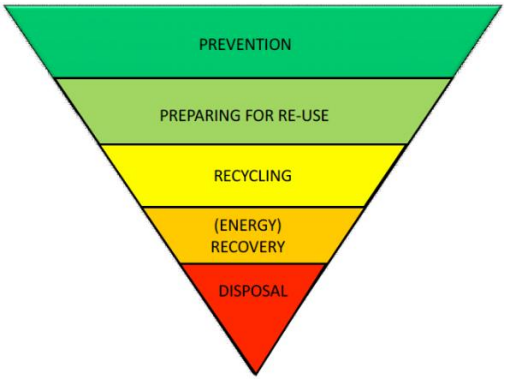


Figure 2.1 – Waste hierarchy according to Waste framework directive

However, while adjusting the waste management system to such hierarchy, each particular country has to overlook its waste streams from the life cycle assessment point of view in order to achieve the best overall environmental outcome. Certain waste streams may be excluded from the standard waste hierarchy in order to reduce its environmental impact. For example, in some cases, incineration of waste near its origin creates less harmful effect than transporting process to the recycling facility and further treatment[3].

Extended producer responsibility is advised to be implemented via legislative or non-legislative measures by the directive. That means that product producer should be economically responsible for the management of its own product when it became waste. As for separate collection – the minimum required in accordance with WFD waste separation into at least four streams: paper, metal, plastic, and glass.

2.3 Directives on packaging waste and landfilling

In order to detail address certain waste streams and treatment options, the European Parliament issued a number of separate directives over the years. Current subchapter will briefly assess the most important ones.

In 1999 the EU established a Council Directive 1999/31/EC “on the landfill of waste” (LD). At that time WFD was not existing, therefore this document was established to meet the requirements of Directive 75/442/EEC from the year 1975[13]. The main objective was to unify and straighten technical and operational requirements on landfills and waste, reduce harmful effects on the environment from landfilling during the whole life-cycle of it. Since WFD was not existing, LD established basic definitions for such terms as “waste”, "municipal waste", "hazardous waste", "landfill", “treatment” etc.[13]

Classification of landfills divided all disposal sites into landfill for hazardous waste, a landfill for non-hazardous waste, a landfill for inert waste. Waste acceptance and permitting procedures were included alongside with general requirements for landfills, waste acceptance criteria, and control and monitoring procedures. According to the directive, landfills should not accept liquid waste, flammable substances, tires or medical waste. Municipal waste should go to non-hazardous waste landfills as stated by LD.

One of the most important features of such a directive was the introduction of quantitative goals for biodegradable waste disposal. In five, eight, fifteen years’ biodegradable municipal waste going to landfills must be reduced to 75 %,50%,35% of the total amount (by weight) of biodegradable municipal waste produced in 1995[13]. Named directive underwent a number of amendments. Decision 2003/33/EC was made in order to establish the criteria and procedures for the acceptance of waste at landfills[14]. The most recent amendment is of May 2018, where EU member states got an obligation of 10% or less of Landfilled MSW in the year 2035[15].

In 1994 EC issued a directive 94/62/EC “on packaging and packaging waste”, which “lays down measures aimed, as a first priority, at preventing the production of packaging waste and, as additional fundamental principles, at reusing packaging, at recycling and other forms of recovering packaging waste and, hence, at reducing the final disposal of such waste”[16]. This directive promoted the prevention of packaging waste generation, set goals for plastic bags reduction. Common goals for recovery and recycling of packaging were introduced there. Another important feature was the establishment of requirements to return, collection and recovery systems alongside with marking and identification system for packaging waste. Directive declared the maximum allowed concentration of heavy metals in plastic packaging[16].

Named directive was amended with the directive (EU) 2018/852 in 2018[17]. Such an amendment should contribute to the prevention of packaging waste production, promotion of recycling and “other recovery”, contribute to a circular economy. Minimum percentages of reusable packaging placed on the market are established, alongside producer responsibility schemes. Among other, such amendment introduced new

targets for packaging waste recycling for years 2025 and 2030[17], which are closely discussed in Chapters 4,5.

2.4 Roadmap to a Resource Efficient Europe and 7th Environment Action Plan

In 2011 the European Commission has adopted the Roadmap to a Resource Efficient Europe (RREE) which outlines how society should transform Europe's economy into a sustainable one by 2050. It contains proposals on the ways of increasing resource productivity and on uncoupling of economic growth from resource use[18].

In relation to waste management, the RREE contains a paragraph about turning a waste into a resource. If waste is able to enter the economy as raw material, the main priority should be given to re-use and recycle according to the RREE. A combination of policies should create a full recycling economy: integration of life-cycle approach into product design improved coordination between all factors on the market, better waste collection process, appropriate legislative framework, initiatives for waste recycling and prevention[18].

According to Roadmaps to a Resource Efficient Europe, some milestones were introduced for waste management[18].

- Waste should become a manageable resource by the year 2020;
- Waste generation per capita over EU should decrease constantly;
- Re-use and recycling of waste should become economically attractive through the establishment of the respective market and improvement in the separate collection;
- Existing waste legislation should be implemented properly and fully;
- Landfilling of waste should be as limited as possible.

Further development of EU waste policies and legislation were driven by the establishment of the 7th Environmental Action Plan (EAP) in 2013. EAP is intended to guide EU environmental policies until the year 2020. But it also extends EU vision on the environmental problems further – to set fundament for the year 2050. After revising a previous 6th Acton Plan, EC stated that it “delivered benefits for the environment and provided an overarching strategic direction for environmental policy. Despite those achievements, unsustainable trends still persist in the four priority areas identified in the 6th EAP: climate change; nature and biodiversity; environment and health and quality of life; and natural resources and wastes”[19].

A new EAP was designed to cover 7 years (2014-2020), unlike the previous plan, which was working for

a decade. The relevant EU institutions and the Member States are responsible for taking appropriate action, with a view to delivering the priority objectives set out in the EAPs, including the seventh one[20].

2.5 Circular economy package 2015 and legislative Framework revision

On December 2, 2015, the EC adopted a Circular Economy Package (CEP), which created a driving force for the EU to move in direction of the circular economy. The concept of circular economy transfers to the establishment of a regenerative economy system, where inputs of resources, emissions and waste are minimized by closing energy and material loops[21]. Figure 2.2 provides a general conceptual scheme of such loops. The adopted document is ambitious and in the current dissertation, we will look only on waste management-related provisions from it. CEP includes the Action Plan(AP) to support the circular economy and legislative proposals on waste, with long-term targets to reduce landfilling and increase of waste recycle and reuse[22].

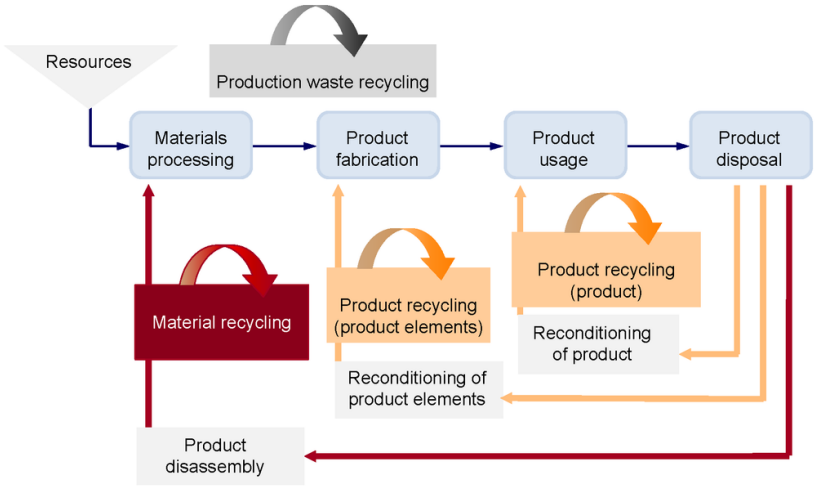


Figure 2.2 – Product scheme of circular economy

Circular economy package document confirms that more packaging waste, mainly from households and industrial/commercial sources has been recycled in the EU after the introduction of EU-wide targets for paper, glass, plastics, metal, and wood packaging. As for improving collection and sorting systems effectiveness, EC proposed to establish minimum requirements for transparency and cost efficiency. Another important part of revised waste legislation was calculation methods of recycling rates, which is important to ensure a qualitative comparison of statistics across the EU[22].

Under the CEP, the EU has revised its waste Framework legislation. On May 2018, the EU issued a revising document for the number of directives, including Waste Framework Directive of 2008. That introduced changed targets for preparing for re-use and recycling of waste; add a number of new definitions; set out exemptions for separate waste collection; establish bio-waste separation; establish a household hazardous waste collection. A new requirement was added for bio-waste separation. By 31st December 2023, bio-waste must be separated and recycled at source or must be collected separately and not mixed with other types of waste[23].

As it was described above, legislative changes also were implemented through revised Directive 1999/31/EC “on the landfill of waste”, Directive 94/62/EC “on packaging and packaging waste” after CEP adoption. Directives 2000/53/EC “on end-of-life vehicles”, 2006/66/EC “on batteries and accumulators and waste batteries and accumulators”, and 2012/19/EU “on waste electrical and electronic equipment” was also renewed[24]. Summarizing provisions from the Circular economy package and its action plan it is to be said that key elements of the revised waste proposal include: [21]

- A common EU target for recycling 65% of municipal waste by 2035;
- A common EU target for recycling 75% of packaging waste by 2030;
- A landfill target to reduce landfill to a maximum of 10% of municipal waste by 2035;
- A ban on landfilling of separately collected waste;
- Promotion of economic instruments to discourage landfilling;
- Simplified and improved definitions and harmonized calculation methods for recycling rates throughout the EU;
- Concrete measures to promote re-use and stimulate industrial symbiosis –turning one industry's by-product into another industry's raw material;
- Economic incentives for producers to put greener products on the market and support recovery and recycling schemes (for packaging, batteries, electric and electronic equipment, vehicles).

2.6 Waste management planning across EU

As legislation creates frames for legal waste management actions, practical directions, and guidance provided in Waste Management Plans (WMP). It is one of the main tools through which EU legislation is being implemented within the country or region. According to the WFD, all countries should establish at least one waste management plan, which will be covering all geographical territory of a given state, or the combination of such plans[3]. Other requirements given in the 28th article of the Directive include requirements on information about:

– Type, source and amount of waste generated within the examined territory;
– Established waste collection schemes, existing waste treatment plants;
– Waste management policies, technologies, and methods used in particular member state.

Mentioned requirements are stated in the 3rd paragraph of the 28th article WFD [3] and represent the mandatory date to be included in waste management planning.

Such waste management plans must be re-evaluated at least every six years within the respective countries. WPMs should be reported to the European Commission in order to be assessed on existing gaps in them and to get recommendations for improvement. Member states are free to develop such planning on a national, regional, local levels, or the combination of those[3]. In order to improve the overall quality of crated WMPs and to unify them to a certain level, the European Commission has issued guidance on how to prepare a good WMP[25].

Mentioned requirements should be applied to a newly created or revised WMP. Structurally is advised to create a WMP which consist of the “status part” and” planning part”. Additional aspects like management policies, packaging waste management or any other important legislative provisions should be added. As for the managerial levels, it is preferable for national planning to be of more strategic nature with a desirable objectives description. Regional or local planning is usually created in a more applicable manner – with a detailed assessment of existing separation or collection schemes, available disposal or treatment facilities, etc.[25] It is important to divide planning by levels as it is possible to implement completely different tools, penalties or stimulation measures within the whole country or particular city/area.

A possible version of a WMP might include background part at first, with the assessment of overall waste problematic in a territory, EU legislation, national legislation, description of the national waste policy and prevailing principles to address overall waste problematic in line with the waste hierarchy, description of objectives set in specific areas. Next part is a mentioned Status part with waste amounts, waste streams, waste sources, waste management options. There might be included also waste collection and treatment, waste shipment, organization, and financing. As a result – an Action Plan should be created containing measures for achieving objectives for: collection systems, waste management facilities, responsibilities, economy, and financing[25].

In order to understand common trends, achievements and flaws in waste management plans among EU member states, European Commission issuing reports carried out by consulting companies on the current topic[26]. Brief description of such assessment with the main criteria and results provided in Annex I.

3 Ukrainian waste management legislation and planning

In order to understand the driving force of Ukrainian waste management process, it is important to understand its foundation which represented by legislative background, and its future directions represented by waste management plans. Nowadays Ukraine appears to be at a major turning point in terms of the whole conception of Ukrainian waste management. Therefore, such a topic should be addressed carefully, with a necessary point of emphasis. Therefore, both existing and drafted waste legislation should be assessed in order to have a clear provision on Ukrainian legislative background. Current chapter provides an assessment of Ukrainian waste management legislation in historical perspective and its future development. Recent strategic documents on waste management are discussed and assessed in terms of their quality. It provides a legislative background for future waste management planning proposed by current dissertation.

3.1 Ukrainian waste management legislation in historical perspective

The general scheme of Ukrainian waste management legislation provided in Figure 3.1. It is noticeable, that currently most legislative documents on waste management in Ukraine are relatively new, or even not properly approved yet. That creates an interesting legislative environment in Ukraine. New approaches and standards were established in “National Strategy on waste management” (NSWM) in 2017[5], but the rest of active waste legislation still is not in line with it. It created a three-year gap, were newly established waste management goals and practices should be implemented through existing outdated legislation, which does not contain necessary tools to perform that task. Fortunately, such a vital document as new Framework Law “About waste management” is already developed and should be signed in the current year[27]. Framework Law will conceptually substitute existing Law “About waste” to provide a legislative base for existing National Strategy and already developed “National Waste Management Plan” (NWMP)[28]. All mentioned legislative documents should be signed until the end of 2019.

Figure 3.1 – Projected Ukrainian waste management legislation structure for the year 2019

It is to be said, that the first legislative instrument for waste management established in independent Ukraine was “Law about the protection of natural environment N 1264-XII” signed 1991[29]. It was a foundation for future natural protection actions, but the main principles of that document during its development were taken from the 1960s USSR law. Since then there were few major improvements in waste legislation in Ukraine, the latest one was driven by signed association agreement between EU and Ukraine.

Ukrainian “Law about Waste” serves as the next major milestone in waste legislation[30]. That document defined basic principles such as the term “waste”, the object of “waste treatment”. Alongside that, fundamental concepts of “prioritization of environment and human health protection”, “wise usage of natural mineral and energy resources”, “scientifically-approved ecological economic and social drivers in a sphere of waste management” were defined. Since 1998, during two decades of its existence, such Law underwent 16 changes with the latest in 06.09.2018 but not all of them are waste management related. Such document is a cornerstone piece for of waste management in a country and it was visibly renovated gradually in order to respond to modern trends and current Ukrainian realities in waste management.

The third active law that controls environmental aspects, including a waste management topic in Ukraine, is the law “About main principles(strategy) of government ecological actions in Ukraine to 2020”[31]. Such a major document was developed back in 2011 and had to address numerous topics related to environmental protection such as water or air protection, protection of flora and fauna, raising awareness about pollutions and hazardous materials. Planning, tools and measures, responsibilities, performance indicators and measuring methodologies, goals, and deadlines were described in that document as well.

But in terms of exclusively MSW management, there were not much said in law “About main principles(strategy) of government ecological actions in Ukraine to 2020”. Certain points as the minimization of waste generation, increase of waste sorting, recycle and safe utilization or disposal are described in the document very generally. However, there are some goals and performance indicators were established there for 2020:

– “Ensuring by 2015 the storage of 70 percents of municipal waste from cities with a population of at least 250 thousand people at specialized and environmentally safe landfills, – by 2020 – 100% storage of such waste.”[31]– such a goal was not achieved, as it will be discussed in Chapter 4.
– *“*Achieve a 15% reduction by 2020 of biodegradable MSW landfilled*”*[31]– to this point, there is no clear separate data on biodegradable waste landfilled in Ukraine. Minding that, Ukraine has landfilled 93,21%[7] of its MSW in 2018, mentioned goal seems doubtful.
– *“*An increase to 15% the volume of collection, utilization, and use of recycled waste by 2020*”*[31]– for recycled waste usage, the most recent data shows that only 4,48% of collected MSW was recycled or reused[7]. It illustrates that a 15% goal is hardly achievable to 2020 if the situation will not change drastically.

Summarizing, it is obvious that all the mentioned goals were not achieved. Possible reasons are mainly political changes and low interest in the subject from the government and public. Lack of financing and outdated fundamental legislation played its part as well. In addition, the very structure of the mentioned document was not in line with EU standards, even though it was issued 3 years after the EU issued its WFD 2008. Overall, it is to be concluded, that Ukraine lacked proper and up-to-date waste management legislation for all its independent history, and, fortunately, there are changes currently happening.

3.2 Project for Ukrainian Framework Law “About waste management”

3.2.1 Main provisions from Framework Law “About waste management”

In November 2018, Ukrainian Ministry of Ecology issued for public discussion the project of a future Framework Law “About Waste Management” (FL)[32]. The legislative basis for such important move was a ratification of the Association Agreement between Ukraine and the European Union, the European Atomic Energy Community, and their Member States in 2014[8]. Legally, Ukraine has undertaken the responsibility

to implement provisions of the Waste Framework Directive 2008/98 / EC in a timespan of three to five years from the date of the Agreement validity acquisition.

The practical necessity of such legislation is very high as it was discussed above. For example, most of the articles from Ukrainian Code on Administrative Violations in the field of waste management have not changed since 1999 and are no longer in line with the requirements of the modern economic, technical and social environment.

Conceptually, this new law should substitute the active law “About waste” – fundamental law which was described above. The draft version of the FL introduces for the first time in national legislation the fundamental principles and provisions of European waste management legislation: the establishment of the waste hierarchy, extended producer responsibility, a system of long-term waste management planning at the national, regional and local levels[33]. Despite the fact that such law is only on a development level, it is already possible to examine the text of it in order to get the real perspective on changes made and assess its claimed compatibility with EU Waste Framework Directive.

A number of main articles are almost directly transferred from EU legislation to Ukrainian. List of the waste, waste hierarchy, prevention of waste, re-use and recycling, extended producer responsibility – such principles are to be adopted in Ukraine almost word-to-word. Waste Management Strategies and Plans are required to be developed by a new law and will be discussed further. Record keeping is also to be improved and unified with EU standards. Important provisions such as “ban on the mixing of hazardous waste” is also reflected pretty close – “legal waste producer should prevent the mixing of hazardous waste with other types of hazardous waste, non-hazardous waste, as well as hazardous waste that can be recovered, with non-recoverable waste” [33], – which is in line with WFD 2008.

Alongside with that, the new law draft proposes new fees and penalties, mainly in order to increase their effectiveness. Most of the penalties in the field of waste management in Ukraine were established in the 2000s and are no longer representing any economical encouragement or restriction due to inflation.

Another part of the changes suggested by the new law are corrections made to other existing laws. For example, in the current law “About alternative energy sources” the definition of bio-waste was introduced, in accordance with the EU framework. Before that, there was only more general “organic waste” concept. Same goes for introduced “municipal waste concept” which was previously partially covered with the term “domestic waste”. Also, it is proposed to change a licensing procedure for permissions on treatment and landfilling of municipal waste. It will no longer be included in Law of Ukraine "On Licensing Types of Economic Activities", even though it was introduced there only in 2016[33].

3.2.2 Comments regarding the quality of “Framework Law on Waste Management” draft

As the mentioned document is a Law, it should be precisely assessed from a legal standpoint in order to check its loopholes and breaches, which is not possible in the scope of the current dissertation. But it should be mentioned that the current draft of the Framework Law is certainly copied from EU waste framework directive. Most of the definitions and passages are an almost direct translation of it. It could be seen as an advantage, meaning that it is a good way to fully implement European principles without any derogations. However, it is also alerting situation, as Ukrainian waste realities and overall differences between Ukraine and EU member states should be taken into consideration, and such document should be appropriately tailored.

Over 300 corrections and improvement propositions for FL were submitted to the responsible Ministry by a number of stakeholders. Here we will provide some of the most important propositions issued particularly by the International Solid Waste Association (ISWA), as an authority in the field of waste management[34]. ISWA states, that the draft FL does not contain clear waste management quantitative goals. Generally, the establishment of quantitative targets in Law text is not typical of Ukrainian legislation. But the introduction of waste management goals into National legislation is one of the most important requirement according to Directive 2008/98/EC[3] [34]. An incomplete transposition of the WFD into Ukrainian legislation will be considered as non-compliance with the requirements of the mentioned Association Agreement.

Next mentioned issue was the absence of requirement regarding waste management plans. Current FL draft states the creation of the National Waste Management Plan, but its shape and content are not specified[34]. As it was mentioned in Chapter 2, WFD contains article 28, whose 4th paragraph established such requirements. Therefore, such imperfection has two unfortunate consequences: FL is simply not in line with WFD and future National Waste Management Plan will not be developed in a proper manner. Indeed, further in the current chapter, it will be illustrated, that developed NWMP is not the real waste management plan in terms of WFD requirement.

A similar situation could be observed regarding regional waste management planning established by FL. Their possible content is also not regulated. But a more important issue is that FL does not state a derogation possibility for regional planning[34]. Regional plans should be able to establish its own goals in terms of waste management, as such goals strongly depending on economic and technical options in every particular municipality. Goals stated in NSWM and NWMP should be flexible for municipalities, or they will become decorative aims, – practically unachievable numbers.

Another issue is a “ban on hazardous waste disposal” – such measure is not in line with Landfill Directive

1999/31/EC[13]. EU legislation suggests three types of with appropriate requirements on its technical characteristics and monitoring, including hazardous waste disposal sites. But the current FL draft does not transfer such provision, which should be fixed. Extended producer responsibility is also not fully transferred to FL draft from WFD, as it lacks certain provisions stated in Article 8a WFD – "General minimum requirements for extended producer responsibility schemes"[3].

In conclusion, it is to be said that current draft of Framework Law "about Waste Management" still needs to be reviewed, as it is not in line with WFD and, therefore, not in line with Association Agreement between Ukraine and EU. However, such a document is a big step towards better waste management regardless.

3.3 National Strategy On Waste Management in Ukraine

3.3.1 Scope and structure of the National Strategy On Waste Management

Mentioned legal acts providing a legislative basis for waste management in Ukraine. As for the strategic planning, there were not many documents on a national level in Ukraine over the last 20 years, all planning was required to develop on lower administrative levels. But in October 2017 Ukraine has adopted a "National Strategy on Waste Management to 2030"[5]. It claimed to be developed with regards to EU legislation as WFD and landfill, packaging, batteries, and WEEE directives. The NSWM contains a general set of actions related to waste management as a whole and special measures related to the management of specific types of waste. General measures of the NSWM should be implemented in three stages shown in Figure 3.4.

Figure 3.2 – Implementation stages of National Strategy on Waste Management in Ukraine

Important actions from the Short-term stage that should be completed until 2019 are (curved text indicates already achieved results as of spring 2019): [5]

- *Creation of a coordination group for implementation of the Strategy with the Prime Minister as a responsible government body;*
- *Creation of a working group on the basis of Ministry of Nature Resources in order to create the National Waste Management Plan;*

- *Creation of project for Ukrainian Framework Law "about Waste Management"*;
- Creation of separate legislation on waste disposal, waste incineration, municipal waste, packaging waste, waste petroleum products, waste batteries, waste electronic and electrical equipment, etc;
- *Development of a unified Glossary of Terms in the field of waste management;*
- Development of legal acts on the separate collection of all types of waste and recycling;
- Development of measures for holding a nationwide campaign to promote waste management issues (recycling of natural resources, recycling waste).

Stated actions are of legislative nature, which is important as a foundation for a waste management system. On the other hand, it may be seen as a "virtual problem solving", where instead of taking decisive measures government set a 2-3-year timespan exclusively for meetings and hearings. Nevertheless, as of spring 2019, Ukraine has not been able to sign a new Waste Management Framework law, which is stuck in procedural levels. Ministry of Justice took 8 months to read and comment draft FL, and there is still a lot of legal procedures left. Which means Ukraine past its own deadlines.

The second, mid-term (2019-2025), stage of implementation provides us with the following actions which include:[5]

- Development of an alternative classification of waste based on its properties, qualitative and quantitative indicators;
- Implementation of national waste management standards, which will be developed on the basis of international standards;
- Implementation of measures from the national campaign on the promotion of waste management

As for the long-term actions (2025-2030), they include mainly modernization of material base for waste recycling, creating a united web-resource on recycling problems and its launch. And ensuring of the functioning of:[5]

- Electronic information logistic scheme for handling natural resources from the moment of their extraction, obtaining from them useful products, the formation of waste, their recycling;
- The National Register of Sources of Waste Generation, Waste Management Capacity, the Best Available Technologies of Waste in electronic form;
- Information system of reporting by economic entities on activities in the field of waste management;
- State inventory of waste and secondary resources that are created and accumulated in Ukraine.

There are also a number of more specific measures provided in NSWM. Such measures are divided by the type of waste they're dealing with, but in this chapter, we will take a look only on part related to MSW.

3.3.2 Municipal Solid Waste management in the framework of National Strategy

Ukrainian national strategy on waste provides ten main groups of measures in the sphere of exclusively MSW management. Figure 3.3 provides a brief summation of those groups.

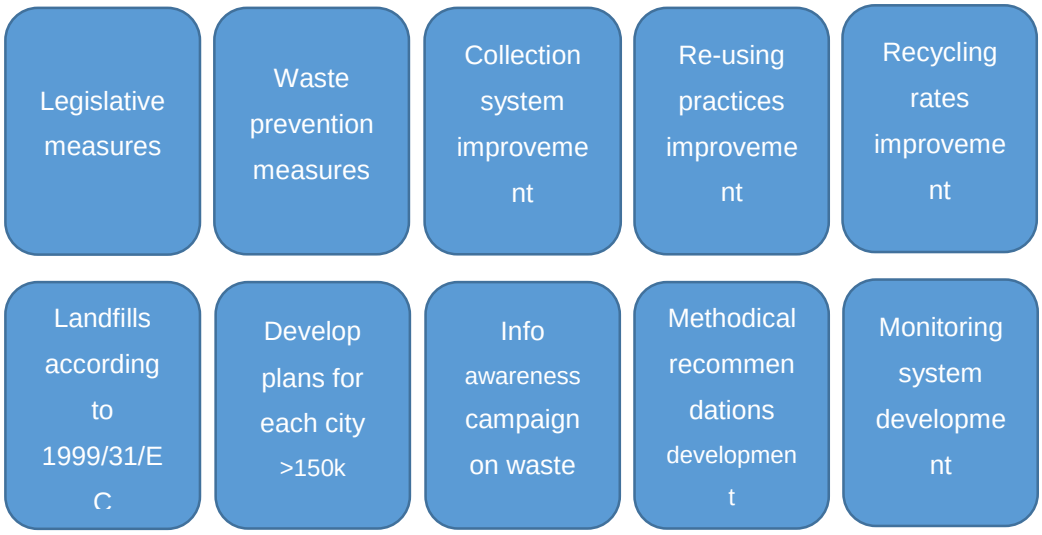


Figure 3.3 – Measures from National Strategy on Waste Management in Ukraine regarding MSW

The first measure is a legislative one and it requires to develop and approve the number of legislative acts in order to establish:[5]

- Handling of the ownership of household waste;
- Implementation of economic instruments, in particular: raising the ecological tax rate for landfilling of non-recycled household waste; tools for stimulating the recycling of household waste; the "pay as you throw" scheme; introduction of mechanisms for implementation of the "polluter pays" principle and "extended producer responsibility";
- Improvement of the procedure on the formation of tariffs for municipal waste management services;
- Setting requirements for the composition and properties of fuels derived from waste (RDF and SRF).

Mentioned mechanisms or procedures are not described, but rather stated that they should be established in some way. The next step, according to the strategy, is the measures for prevention of waste generation and minimizing of the amount of municipal waste generated, where it is achievable. And the respectable measures including the development of a National Program on Household Waste generation prevention and publishing of BREFs on waste management and resource efficiency in selected industries

Another problem that was addressed in the NSWM is a collection of MSW. The stated aim is the creation of an efficient waste collection and transportation system with maximum population coverage. And main established measures for that are:[5]

– Increasing population coverage in terms of collecting and transporting of household waste with the further expansion of services in villages;
– Implementation of separate collection and handling of certain hazardous components of household waste as links in the scheme of extended producer responsibility;
– Implementation of measures for extended producer responsibility system for individual types of household waste.

As for recycling rates, Ukrainian waste NSWM states certain goals, particularly a precise percentage of recycled MSW out of all collected MSW which country needs to achieve. Such goals are provided in Figure 3.4. Ukraine has a lot of changes to do in terms of recycling actions. As for now, the real MSW recycling rate is around 3%[7] according to statistics, which means that the growth rate should be increased rapidly. Current Ukrainian situation with recycling and comparison of Ukrainian and EU recycling targets is provided in Chapter 4.

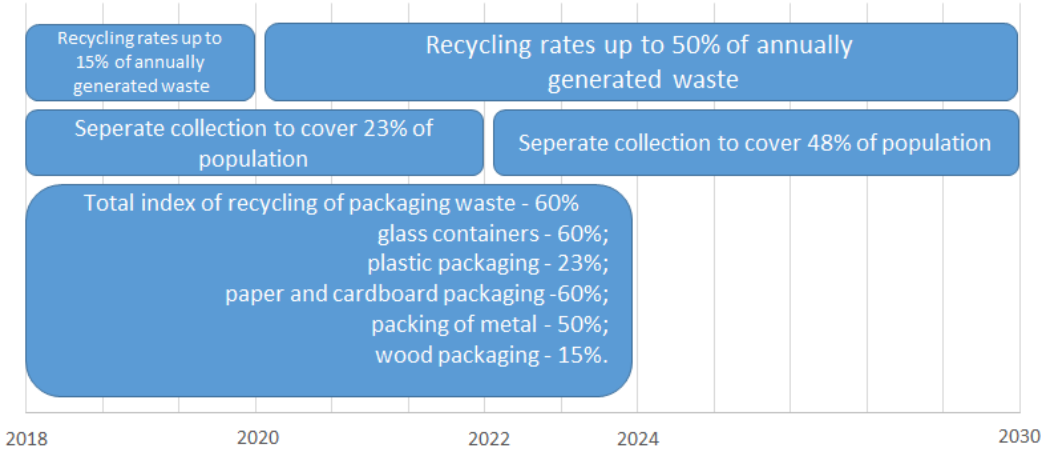


Figure 3.4 – Goals on recycling rates of MSW stated in NSWM [5]

Figure 3.5 shows another recycling target provided by NSWM which is expressed in a number of recycling and composting facilities to build in Ukraine. It is not clear which capacity, type or location such facilities should have It can be observed that by the end of 2018 Ukraine had to build 35 new recycling (sorting) plants and 50 new facilities for bio-waste composting according to NSWM. According to existing information Ukraine has not reached the stated goal[35].

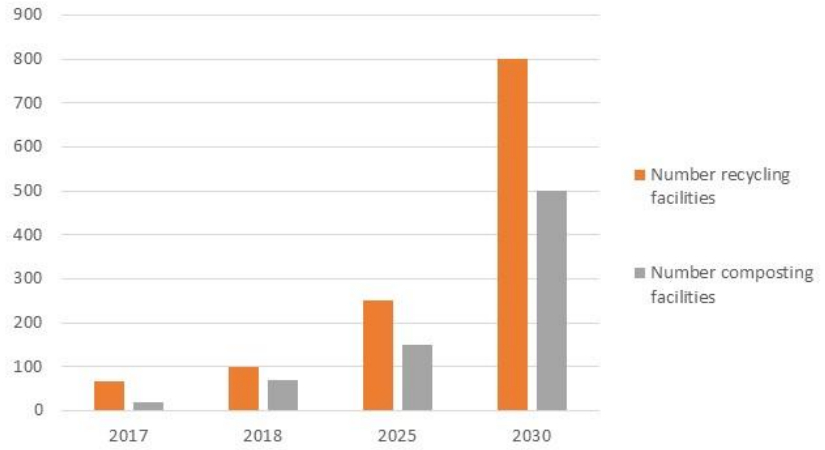


Figure 3.5 – Ukrainian strategic goals in terms of waste treatment capacities [5]

Landfills are a particularly weak spot in Ukrainian waste management, as it was mentioned above. In order to be in line with EU Landfill Directive 1999 and to improve the system in general, NSWM proposes such measures:

- Ensuring operation of a network of regional landfills that will comply with the requirements of EU Directive 1999/31 / EC of 26 April 1999 on waste disposal, transposed in national legislation;
- Preparation of the plans to bring landfills in line with environmental requirements made by municipalities and local authorities;
- Adopt national legislation on the operation of landfills in accordance with the requirements of EU legislation;
- In areas where new regional landfills will be organized and operate, ensure the cessation of exploitation, the closure, and reclamation of landfills that do not meet the requirements of environmental safety;
- Develop measures to reduce the volume of biodegradable waste disposal, taking into account the provisions EU Landfill Directive 1999.

As for the precise goals, there are clear aims set in the field of landfill management. Until the end of 2018, the number of existing MSW landfill facilities should be reduced from 6000 to 5000, to 1000 facilities in 2025 and to 300 facilities by 2030. According to data on MSW management in 2018[36], Ukraine still has 6107 landfills in operation, so Ukrainian own goal for 2018 is not met. By the end of 2018, Ukraine should cut the percentage of landfilled municipal waste to 80%[5], but statistical information provided in Chapter 4 proves such a goal also failed.

Some changes in the field of statistical accounting of municipal waste were introduced. For example, the transition from units of volume to units of weight for monitoring system was stated. It is a vital move, as all future assessment on how the strategy will work is based on gathered statistical data and there is a problem

nowadays with correct accounting and calculations due to different units and formulas.

According to the current Ukrainian waste management system, – development of regional and local waste management plans for areas with population coverage of more than 150,000 people should be performed. Such plans should be based on the National Waste Management Plan and should be able to create coherent, long-term and stable conditions for the provision of necessary facilities and infrastructure for rational management of MSW[5].

3.4 National Waste Management Plan draft

Recently, in November 2018, the Ukrainian ministry of Ecology issued a project of the “Waste Management Plan to 2030” for public discussion. It was required by NSWM, that such a plan should have been developed until the year 2019. Such a Plan should be able to provide Ukraine with more precise and practical guidance on waste management, in contrast to NSWM. Further, the main features of a plan will be described, with an emphasis on MSW management, but it should be clear that the text of the document is not final yet. The main general directions of the plan are quite similar to the ones provided in NSWM:[28]

- Development of a normative legal acts system in order to bring national legislation closer to the requirements of European legislation;
- Improvement of the licensing system in the waste management area;
- Development of technical regulations and standards in the field of waste management;
- Development and modernization of waste management infrastructure;
- Development of regional waste management plans;
- Education and awareness raising for stakeholders and the public on waste management;

In accordance with identified priorities, the” National Waste Management Plan until 2030” establishes the implementation of goals and measures related to the improvement of legislative regulation, institutional structure, information provision of waste management. Again, such general words don’t provide the real practical measures which plan should establish, but such actions are indeed necessary if implemented wisely.

Taking a look at municipal solid waste management, a draft of the discussed plan puts in place major tasks to be done alongside its deadlines, success criteria, and responsible officials. One of those five tasks addressing a wastewater topic, so it falls out of the scope of the current dissertation. Four remained tasks are described further. The first task contains purely legislative measures and strongly bounded with the establishment of framework law “About waste management” which was described. Six months after such framework law comes into power, the ministry of Ecology should finish the development and submission of

a new draft law “about *Municipal* Waste Management” [28]. The contents of future law are unclear, but the idea is to cover exclusively municipal waste management topic on the basis of newly introduced framework law. The second task is related to the collection and transportation of MSW. There is a clear timeline in place for all stated measures, which is shown in Figure 3.8.

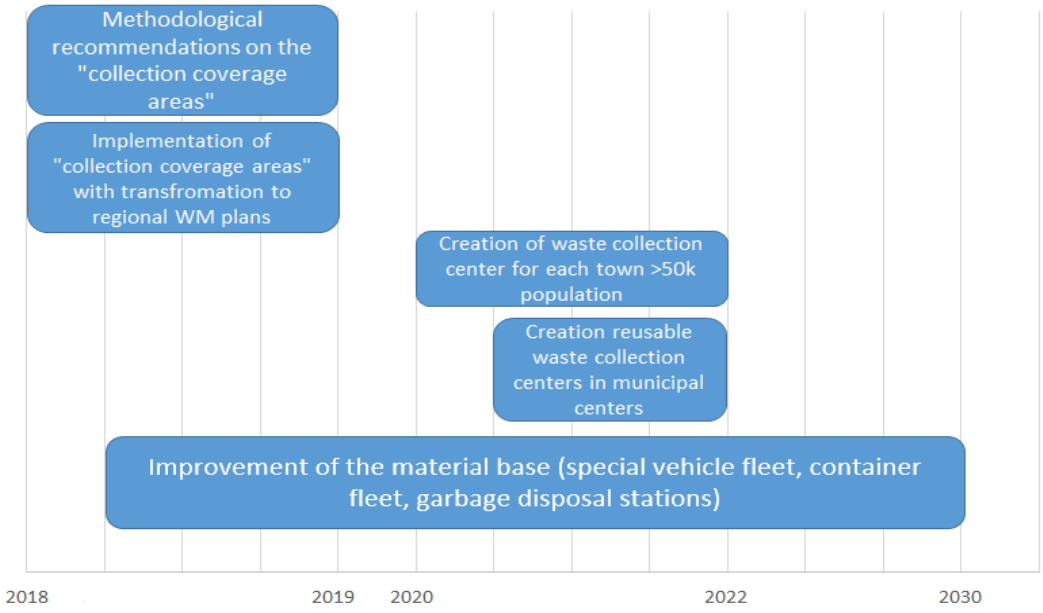


Figure 3.6 – Measures in terms of collection and transportation of MSW from the NWMP [28]

In Figure 3.6 there is a term “collection coverage areas” in place, which simply identifies the implementation of new territorial division in waste collection sphere. Such division will be performed minding the proximity principle from WFD. The means of achievement of these goals are to be developed on a lower administrative level, but it is visible that until 2020 there are no planned practical implementation measures, only legislative and organizational. It is clear, that provided recommendations are rather general to be able to provide a guidance in terms practical implementation, however, some of the shown provisions will be used to develop our strategic planning on waste management in Chapter 5.

The third task from the document describes measures in the field of infrastructure for the recycling of MSW. Figure 3.7 provides a timeline of stated measures. And again, no implementation actions are being planned until 2023. It is visible from the provided Figure that, again, plan postpones a lot of its major decisions to be addressed on lower administrative levels of waste management planning. It states “building of regional recycling facilities”, but do not specify its number, proposed capacity or location, leaving that to regional waste management plans.

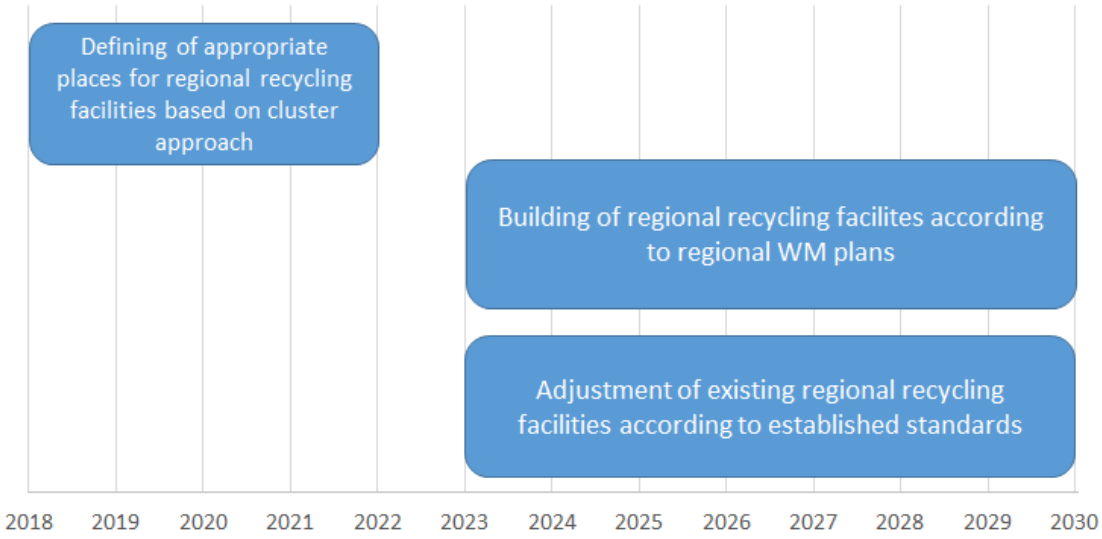


Figure 3.7 – Measures on recycling infrastructure improvement from the NWMP [28]

And the last task addresses a huge problem in present Ukrainian waste management system – landfill infrastructure. Even though according to best approaches landfilling of MSW are the least preferable option, it is obvious that Ukraine cannot adjust waste management system immediately, and therefore the total ban on landfill operations or rapid closure of existing landfilling facilities are not appropriate. On the other hand, the existing landfill material base, transportation practices, licensing practices, or even statistical monitoring should be the subjects of rapid fundamental changes. It is important to mention that this part of waste management planning excludes landfills for hazardous MSW out of its scope.

First stated measures (Figure 3.8) are to be “examination and risk assessment of all available landfill infrastructure” [28]. After that, inspected landfills should be renovated or closed, the process should start in 2022. This part of the waste management plan is considered appropriate and will be used in future waste management planning (Chapter 5) with some corrections and additions.

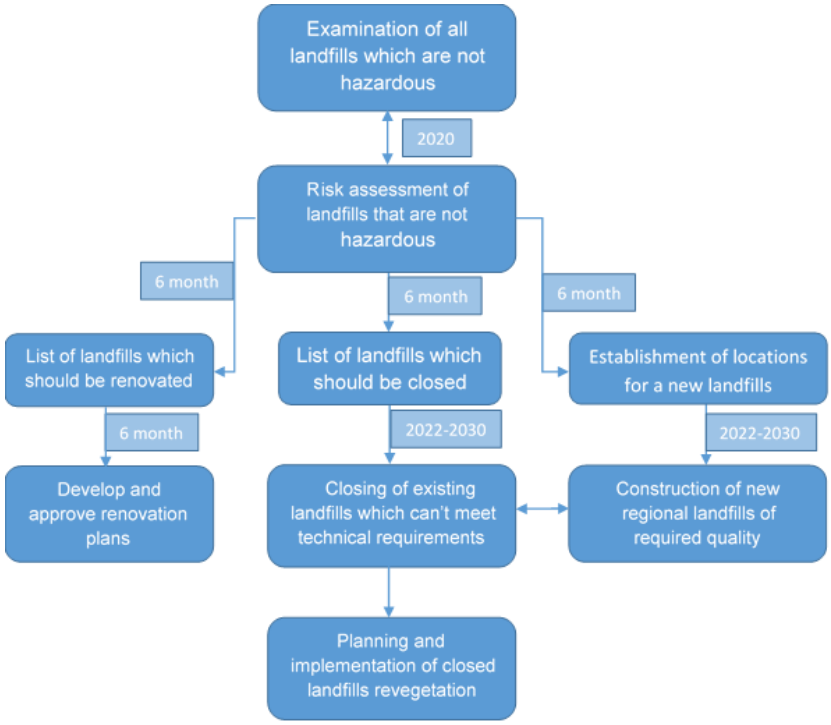


Figure 3.8 – Measures on landfill infrastructure improvement from the NWMP [28]

3.5 Conclusion on the quality of current state Ukrainian waste management planning

To sum up, provided legislative provisions, it is to be said that Ukrainian waste management currently is covered by two discussed documents – “National Strategy on Waste management” and “National Plan on Waste management”. The first document (Strategy) consists mostly of legislative measures and contains some waste management goals without precise means of its achievement. After it was issued, it was assumed that the next document will provide less legislative measures and evaluates more on the current Ukrainian situation on waste management and practical actions in its improvement.

Unfortunately, issued “National Plan on Waste Management” have broadened its ancestor mainly in terms of more detailed legislative regulation. It contains some practical recommendations on landfill system or waste recycling, but such guidance considered insufficient in terms of immediate practical actions, and Ukraine needs them. Therefore “National Plan on Waste management” seems to be a more detailed annex to “National Strategy on Waste management”, rather than a document with practical plan on waste management system improvement. Such an approach is acceptable, as EU guidance on waste management planning [25] states that a number of complementary documents (from different administrative

levels) could be used for WMP establishment. Which is alerting, is that Ukraine does not have an independent well-established administrative system on the municipal level, therefore it seems not wise to leave the most important practical decisions for such administrative level. It seems like a regular shift of responsibilities from one administrative level to another. Additionally, it seems more viable to combine two described documents into one, as they are of similar nature and both insufficient for waste management planning.

To be more detailed, there is a number of things lack in both documents. The current draft of NWMP lacks data on the morphology, amount and origin of waste generated within Ukrainian territory as well as evaluation on the future generation. There is no information on current waste collection schemes or future collection needs. Information on existing recycling, landfill, waste-to-energy facilities is not included. Additionally, such document lacks data on capacity or localization criteria for future waste treatment facilities, which are planned to be built. It is stated that in a year after the FL will be approved, the Government should develop a new law “on Landfilling of waste”, which is a long term considering that this branch of waste management requires immediate actions in order to meet stated aims.

National plan contradicts with National strategy on deadlines for regional planning development. Quite contradictory is the proposal to create a "Central Executive Body on waste management, whose activities will be directed by the Cabinet of Ministers of Ukraine through the Minister of Ecology and Natural Resources of Ukraine"[28]. Such an unfortunate experience has already been in the modern history of Ukraine. Probably better if the state will create effective economic conditions for the functioning of the industry and ensure control over the implementation. This approach is more natural than a low-performing and over-corrupted public administration.

As Ukrainian Waste management plan is developed and the Waste management strategy is approved, it is useful to take a closer look at them through the prism of EU recommendations regarding this topic. Mentioned document [25] provides a set of checklists for the contents of the good WMP. As it is stated that the Ukrainian National Plan on Waste management is in line with respective EU directives, then mentioned checklist could be applied to assess planning quality. The checklist will be provided in Chapter 6 after waste management planning proposed by the current master dissertation will be established. That will allow comparing current Ukrainian waste management planning with the proposed one.

Lastly, it is important to say, that provided criticism of Ukrainian waste management planning legislation is informal because according to EU provisions all mentioned issues might be covered in additional legislative documents on other administrative levels. Therefore, technically, the Ukrainian government did not make any mistakes in waste management planning. But minding previous experience with Ukrainian legislative system, high corruption, tough bureaucracy, and unstable political climate – such an approach seems very suspicious and certainly not the most effective. It looks like Ukraine trying to convince investors and EU officials that there is a working process ongoing while doing very small steps towards waste management goals.

4 Assessment of current Ukrainian waste management system

The chapter below contains an assessment of available Ukrainian MSW statistics and state of waste treatment infrastructure alongside with goals in terms of waste management. It is to be said, that available statistics in Ukraine is often not in line with EU standards, and therefore it is challenging to apply it correctly. As for the aims and goals, Ukraine has adopted a National strategy on waste at the end of 2017, and such strategy contains certain goals to be achieved. According to that, in this chapter, both Ukrainian and EC (from respectful directives) goals will be compared.

4.1 Amount and structure of municipal solid waste in Ukraine

At the present time, there are 461 cities, 883 small-scale cities and 28,376 villages in Ukraine[4]. According to active legislation, all of them are responsible for their own organization of municipal solid waste management[30]. In this subchapter, available MSW statistics will be inspected in order to underline the overall trends and the scale of the problem that should be addressed.

The first challenge regarding the assessment of MSW data is its quality, which is not reaching appropriate levels. There is no systematic research on morphological composition MSW in Ukraine. The available data is often scattered around different statistical documents, which sometimes are not correlating with each other. Without accurate and relevant statistics, it is difficult to plan, and therefore, it is difficult to effectively manage the waste system. Most of the provided information is collected by the Ministry of Regional Development of Ukraine.

Since 2014 Ukraine started to collect statistic on MSW in a renovated form, called “TPV-1”, and it is assumed inappropriately to combine data collected before and after 2014 in one research. That is dictated by the fact that the presented data was not obtained through direct measurement. Presented data are calculated values, which was obtained by a combination and recalculation of information provided by different municipalities. Such municipalities might have different measurement approaches (volumetric, weight) and different formulas to calculate their performance. Therefore, Figure 4.1 provides data on collected MSW in the years 2014-2018.

It is visible from the figure, that there is no stable increase or decrease in terms of collected MSW in

Ukraine, but generally collected amount revolves around 9,5-10,5 million tonnes. It is visible that collected MSW per capita in Ukraine is 210-260 kilograms[7][37], which is a rather small number, compared to EU states. In 2017 an average MSW generation per capita in EU was 487 kg, and the smallest result was registered in Romania with 272 kg[37]. Therefore, in terms of waste collected per capita, Ukraine is behind all EU members, but at the same time, Ukraine also has the weakest economy and comparably big population, which might explain that.

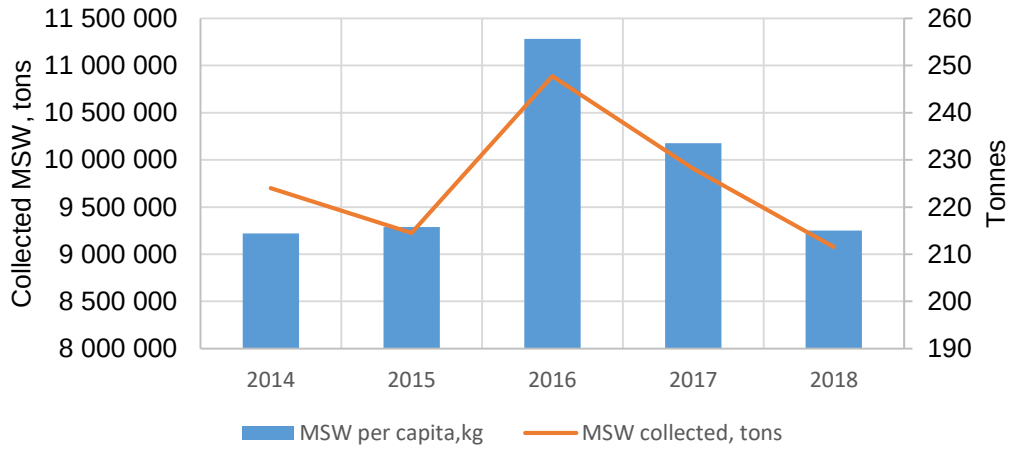


Figure 4.1 – Amount of collected MSW in Ukraine 2014-2018 [7]

It is possible to take a closer look at regional statistic in terms of MSW generation. Figure 4.2 provides information about collected MSW per capita at all Ukrainian municipalities and their contribution to overall MSW generation expressed in %.

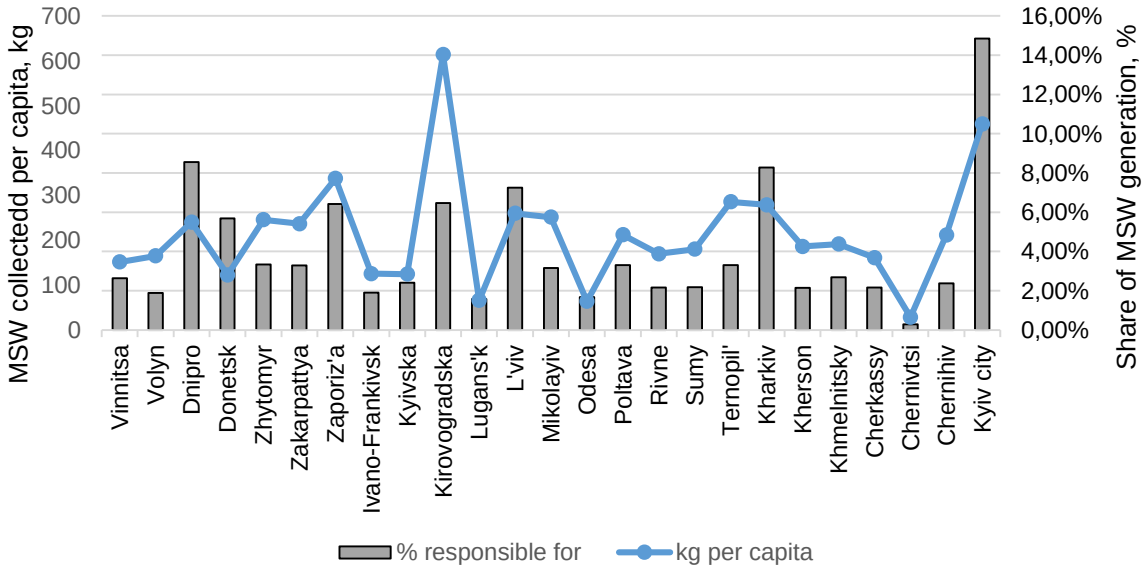


Figure 4.2 – Regional statistics on collected MSW in Ukraine, 2018[7] [37]

Figure 4.2 illustrates that even though MSW collected per capita is low on average in Ukraine, the most developed municipalities demonstrate an average EU number in that regard. Kyiv city has approximately 450 kg of MSW per capita, other big cities like Kharkiv, Dnipro or L'viv also have close-to-average EU numbers. Kirovogradska municipality most probably messed its numbers in reporting, as it is highly unlikely that MSW per capita there is 600 kg. That proves our assumption about economic factor which has an influence on MSW per capita numbers in Ukraine, as even inside Ukraine such number is not similar but depends on the level of area urbanisation. Additionally, it demonstrates mentioned imperfection of Ukrainian MSW accounting system.

In order to put provided data on MSW amounts in perspective, it is useful to compare it with other factors such as total population and gross domestic product per capita. The Gross Domestic Product (GDP) per capita serves here as an indicator of economic growth. Figure 4.3 represents such data, and to make it comparable, the year 2014 was appointed as a baseline and all data for the future years provided in terms of percentage in relation to 2014. It is important to mention that due to the annexation of Crimean Peninsula by Russian Federation and armed conflict which started in 2014 and currently ongoing in two Ukrainian municipalities, data for years 2014-2018 is represented only for territories which are fully controlled by the Ukrainian Government.

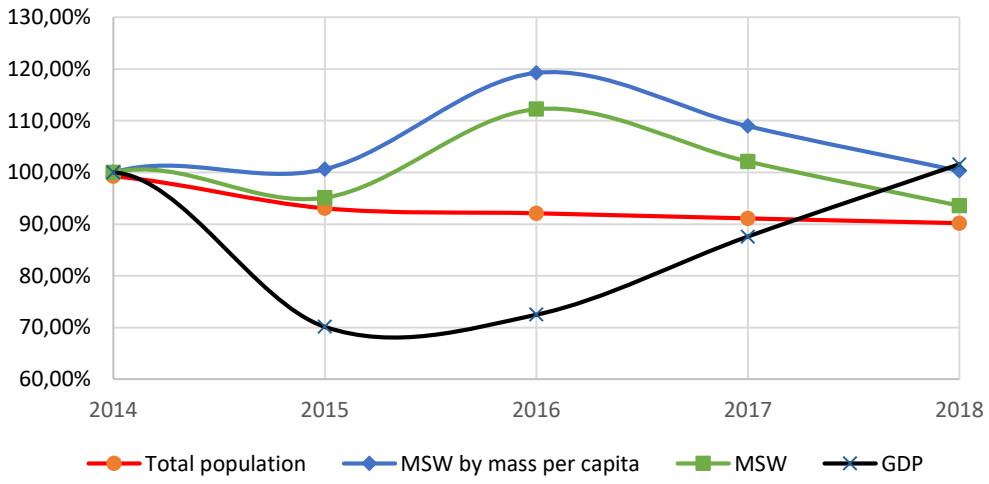


Figure 4.3 – Comparison of tendencies of selected factors in Ukraine, 2014-2018[7] [37][6]

Inspecting information from the provided figure, it is notable, that in the year 2015 Ukraine sustained a 30% economical drop in terms of GDP per capita. Additionally, in the same exact time period, Ukraine has lost 6% of the population which is understandable in a situation of national crisis. As for collected MSW, overall weight decreased by 5%. Collected MSW per capita remained the same – 216 kg in 2015 against 214 kg in 2014, which is natural, as two decisive factors (MSW weight, population) decreased simultaneously[7] [37][6]. After 2015 more interesting trends occur. In 2016 the population decreased one

more percent, GDP increased 3%, but the amount of collected MSW, as a whole, and per capita, increased 20%. In a timespan of 2016-2018 years, Ukrainian GDP per capita increased drastically and returned to the level of 2014. Population number still decreased reaching a 10% drop compared to 2014. The total amount of MSW and MSW per capita also fell down by 20% and returned to the level of 2014- 2015 years. It is to be concluded that Ukrainian MSW generation is rather stable over the last years. The prediction of future MSW generation will be performed in Chapter 5.

4.2 Coverage, collection, and transportation of MSW in Ukraine

A proper waste collection system is a vital element in waste management, as it provides the opportunity for technologically more advanced waste treatment. Re-use of generated waste, as well as recycling, require a separate collection to be performed. Naturally, to ensure the best performance, waste collection system should cover all area of waste generation in Ukraine where it is practically achievable.

The overall MSW collection coverage among Ukrainian territory is around 78%[36], but such number naturally differs between municipalities, which is shown in Figure 4.4. It can be observed that 8 municipalities are not reaching even a 70% level of coverage. The municipality of Dnipro has the second-highest waste generation rate but has one of the weakest coverage rates at the same time. As for the type of collection – urban areas are covered with door-to-door collection with only one bin for mixed MSW available. Rural areas are partially covered with the door-to-door collection, and in other cases with “bring points” for inhabitants to drop-off their mixed MSW[38].

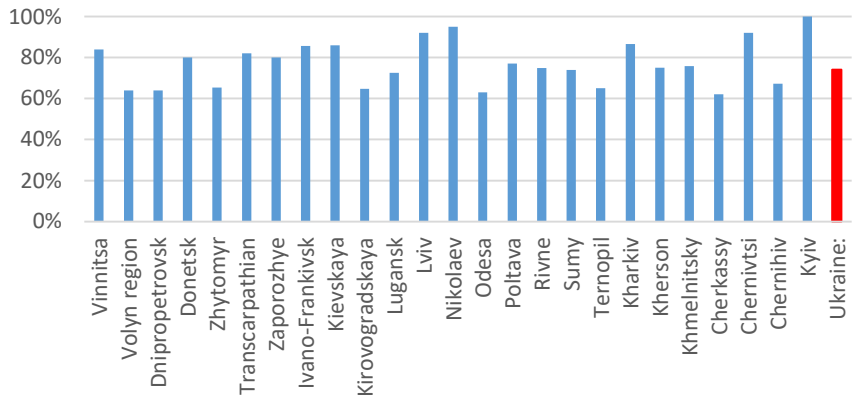


Figure 4.4 – Waste collection system coverage in Ukraine, 2017[36]

As for the separate collection territorial coverage, Ukraine has an overall score of around 3% in 2017 in

that regard[39]. Figure 4.5 shows the data from the last two assessed years, and it is observable that numbers are slightly improved from 2016 to 2017. But overall, Ukraine demonstrates very low coverage rates. Figure 4.6 provides a dynamic of the introduction of the separate collection system in Ukrainian settlements.

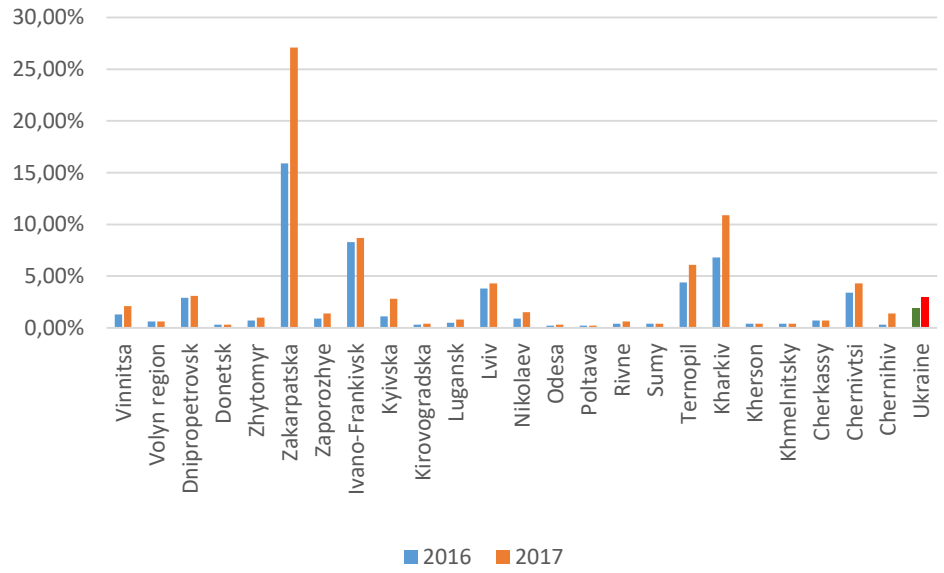


Figure 4.5 – Separate waste collection coverage in Ukraine, 2016-2017[39]

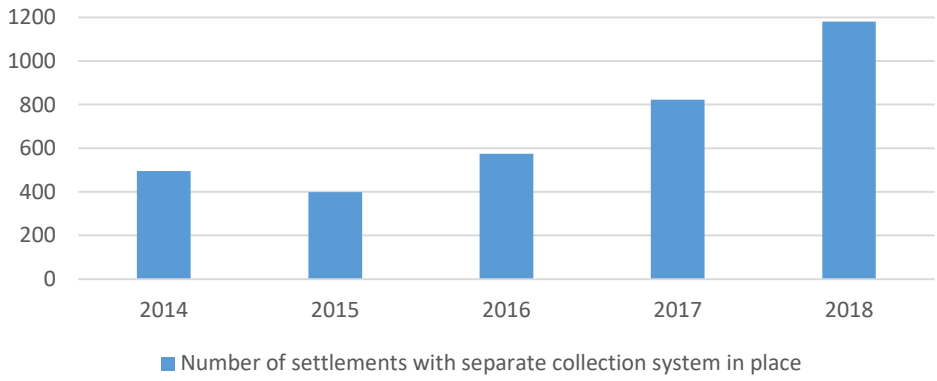


Figure 4.6 – Separate waste collection by settlements, 2014-2018[7]

It is visible that there is a positive trend of connecting more and more settlements to a separate collection system. Since 2014 Ukraine have increased the number of settlements with separate collection in place 3 times. It is important to notice, that it is not specified which particular type of separate collection was introduced. Meaning that it is uncertain how many different waste fractions it is possible to collect separately in named cities. However, Ukraine has more than 30,000 territorial units, so showed progress is not significant and should go much faster.

4.3 Assessment of MSW treatment technologies in Ukraine

4.3.1 Current waste management hierarchy in Ukraine

The latest statistical document on MSW management in Ukraine was issued in March 2018. Such document confirms that there was little to no progress in terms of implementation of the waste management hierarchy in comparison to a previous year. However, such progress was required by the goals introduced in NSWM[5]. Indeed, Ukraine landfilled 93,21% of MSW in 2018, in contrast to 93,4% of MSW in 2017.[7] That means that recycling and other treatment options for waste were not developed as it was required in NSWM. However, it is possible to notice a slow positive trend in that regard over the last 5 years. Figure 4.7 represents MSW treatment hierarchy in Ukraine since 2014.[7]. It is noticeable that waste-to-energy treatment remains more or less stable, but the recycled waste share is growing slowly. The following subchapter provides a short summary of waste treatment technologies which are used in Ukraine nowadays, in order to set the scene for future strategic planning for waste management system improvement.

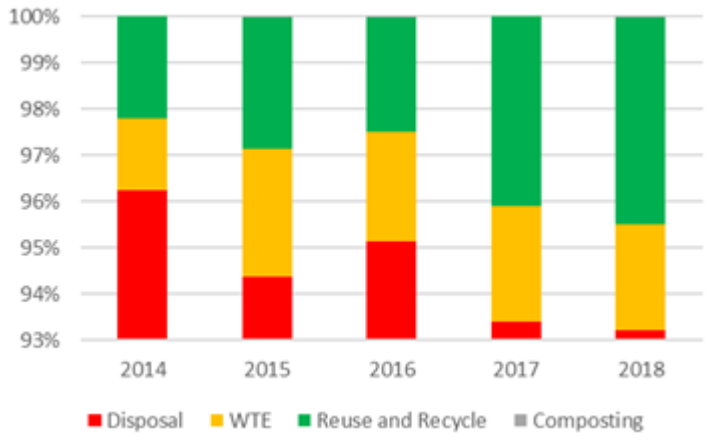


Figure 4.7 – Waste treatment in Ukraine 2014-2018[7]

4.3.2 Assessment of MSW Recycling technologies in Ukraine

The first obstacle in the assessment of the recycling process in Ukraine is a lack of monitoring system on this type of operations. Moreover, the available data is not often in line with respectable EU standards, which creates problems with appropriate representation of it. It is caused by the fact that not long ago, Ukraine had no separate waste hierarchy step for recycling (required by WFD)[30]. Recycling and other biological treatment fell into “Treatment and utilization procedures” – together with incineration, other Waste-to-Energy technologies (WTE), and fuel production. It changed at the end of 2017, after the adoption of a number of legislative documents including NSWM[5].

According to the newest available data, there have been some minor improvements in waste recycling rates in Ukraine. Figure 4.8 represents data on recycling operations in terms of percentage out of all collected MSW for years 2014-2018. It is visible that the recycling rate grows 0.5% annually over the last years, reaching 4,18% mark in 2018[7].

There are only two cites in Ukraine could be noticed in terms of recycling – Mykolaiv and Ternopil', who registered a decent rate while recycling 20% and 54% of collected MSW respectively. In Ternopil district, 54% of MSW has been sorted with the help of a newly introduced treatment facility. Most other regions have close to zero recycling rate.

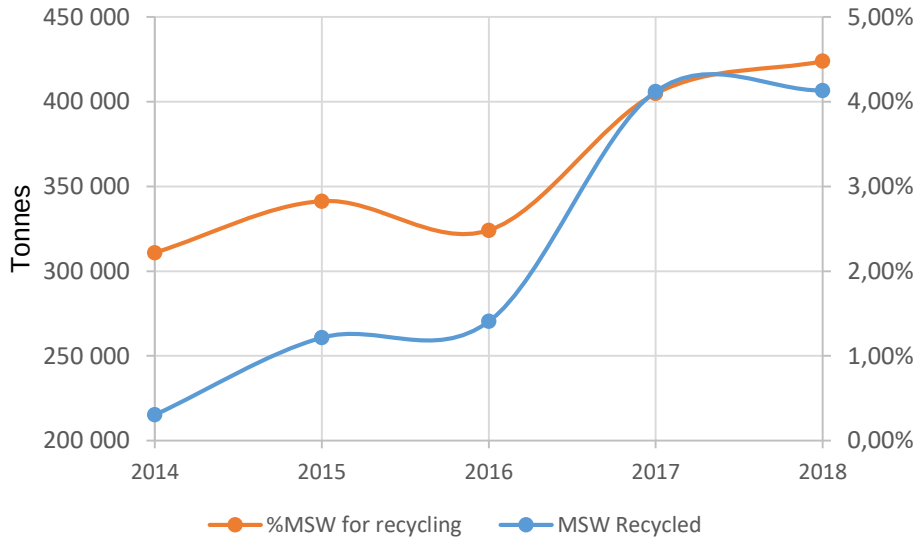


Figure 4.8 – Recycling rates and actual recycled amount of MSW in Ukraine [7]

To achieve provided results Ukraine currently has 26 sorting lines in place with an overall capacity of 262,000 tonnes annually[35]. In 2014 there were 22 sorting facilities in place[40], so there were no major improvements in that regard over 4 years. Ukrainian plants mainly using "clean sorting" technology for in its operation, meaning that they sort separately collected recyclables, not residual MSW.

4.3.3 Assessment of "Other recovery of waste" technologies in Ukraine

According to the Circular economy conception, WTE processes have different environmental impacts, and, therefore, may be considered to be a different part of the waste hierarchy – disposal, recovery and even recycling[22][3]. Anaerobic digestion for biogas and digestate production is considered as recycling process by Article 2 (6) of Commission Decision 2011/753/EU. But incineration with limited energy recovery considered as disposal operation[41]. Ukraine nowadays does not incinerate waste without energy extraction[7], so such treatment may fall into "other recovery" hierarchy step.

WTE treatment by incineration in Ukraine is represented by only one incineration facility which processed 2,29% of MSW in 2018[35]. That explains a stable share of WTE in overall waste treatment, as there were no new capacities installed over the last 20 years. The only change is the actual load of the facility, which is usually not reaching 100% of available (87% in 2018) [7]. Named facility is located in Kyiv and has installed capacity of 283,000 tonnes annually. But over the last years, it was receiving waste from all over the country. Moreover, like it was mentioned above, an only certain type of efficient incineration might be counted as "other recovery" by EU standards, unfortunately, Kyiv incineration plant has to undergo renovation to by compliable with them. Nevertheless, named plant provides electricity and heating to one of Kyiv districts, so it is assumed that such plant represents "other recovery" of waste.

The other waste treatment technologies are usually represented by biological treatment facilities with biogas extraction or mechanical-biological treatment plants (MBT) with the creation of Refuse-derived fuel (RDF)/ Solid recovered fuel (SRF). Unfortunately, currently, there are no such facilities in Ukraine in operation[35]. But there are some capacities that already in the construction process. L'viv and Odessa both will get Mechanical-Biological treatment facilities with Anaerobic Digestion (AD). Plants will be able to process a 240,000 and 350,000 tonnes of MSW annually respectively[42]. Another 120,000 tonnes annually facility is constructed in Zakarpatya, but not yet put into operation for legal reasons.

There is no established system based on RDF/SRF production technology in Ukraine. It was observed that useful product of such plants is not easy to sell on a market, even to cement companies, who are the main buyers of RDF. That is caused by the high standards for such fuel, which are often not met on RDF facilities worldwide. A good example is Poland, who is the leader of EU RDF production but have complications in putting produced RDF on its market. Mentioned MBT-AD plant in L'viv was initially planned to be an RDF technological facility, but investors and consultants from the European Environmental Bureau in a document[43] advised to not build it. The decision was made in favour of MBT with Anaerobic digestion not MBT with RDF production[42].

4.3.4 Assessment of landfilling technologies in Ukraine

Generally speaking, the landfill is the destination point for 93,21% of collected MSW over Ukraine in 2018. Apparently, landfills are on the top of the waste hierarchy in Ukraine. According to, there are 6,107 landfill facilities in place at 2018[36]. It is known that at least 1347 of them are not in line with environmental standards and 309 are overfilled, but the real numbers might be higher[36][44]. Figure 4.9 provides regional statistics in that regard. It is visible that the most problematic regions in terms of landfill quality are L'viv, Luhansk, Kirovograd and Kyiv region, 70%-90% of landfills there fail environmental standards and unacceptably harmful. That is an important issue and it should be addressed.

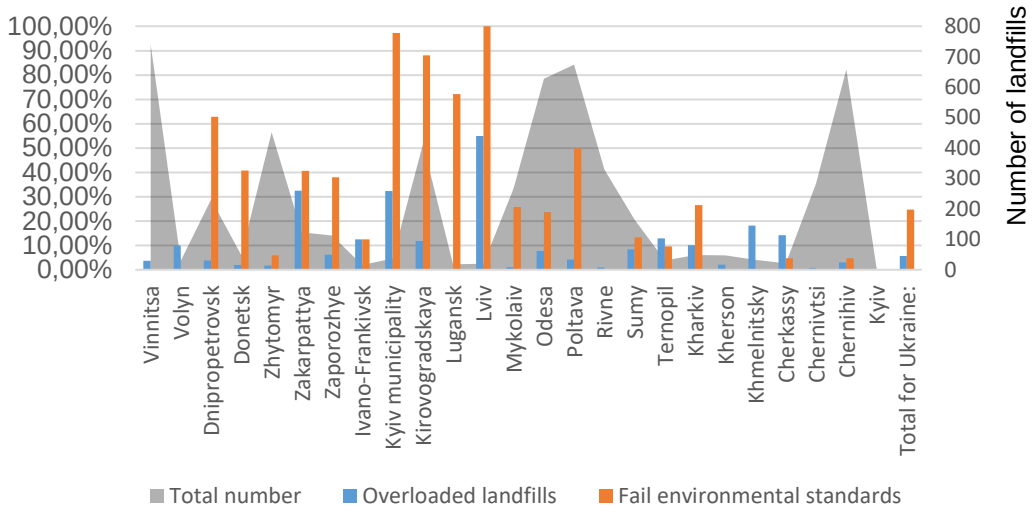


Figure 4.9 – Landfill quality assessment in Ukraine, 2018 [36][44]

In order to solve this problem, as one of the measures, Ukrainian legislation proposes the full assessment of existing landfills on their quality, and after that to start a gradual closing of the most harmful ones. At the same time, it is planned to start opening of new “clean” facilities. According to the data of[36], Figure 4.10 illustrates the overall demand in new landfill capacities by region.

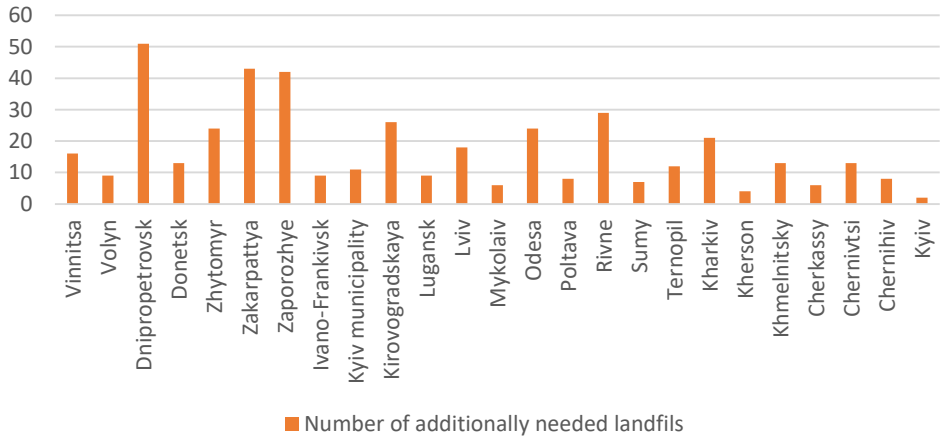


Figure 4.10 – Number of landfill facilities needed in Ukraine, 2017[36]

Overall, 424 new landfills needed over Ukraine, but that is only in terms of required capacity, but not quality. It is important to notice, that provided numbers reflect required disposal capacities only in the current paradigm of landfill management in Ukraine. In the next chapter, it will be discussed, that Ukraine may not construct that high number of smaller landfills, and create bigger facilities instead.

Another part of landfilling problem in Ukraine is the illegal dump sites. Each year over fifteen thousand of such objects are being identified and closed, but an almost equal amount of dump sites is being created next year instead[36].

4.4 Comparison of main waste management goals established by Ukraine and the EU

The following part contains a comparison of the main goals in terms of waste management provided by EU directives and the Ukrainian National strategy on waste. Such aims will be taken into account for future strategic planning on Ukrainian waste management. Goals provided by EU is considered more important.

Table 4.1 – Summary of established waste management goals [5], [15], [17], [23]

	Ukraine		EU	
Goal type	Criteria	Goal	Criteria	Goal
Diversion from landfill	MSW landfilled by weight	2018 – 80% 2023 – 50% 2030 – 30%	MSW landfilled by weight	2030 – 10%
Reuse and recycling	MSW recycled by weight	2018 – 5% 2023 – 15% 2030 – 50%	MSW recycled by weight	2025 – 50% 2030 – 55% 2035 – 65%
Packaging waste	Packaging fraction recycled by weight	2025 – 60% 40 % of plastic; 45 % of wood; 50 % of ferrous metals; 50 % of aluminum; 50 % of glass; 50 % of paper and cardboard; 2030 – 65% 60 % of plastic; 65 % of wood; 75% of ferrous metals; 75 % of aluminum; 75 % of glass; 75 % of paper and cardboard;	Packaging fraction recycled by weight	2025 – 65% 50 % of plastic; 25 % of wood; 70 % of ferrous metals; 50 % of aluminum; 70 % of glass; 75 % of paper and cardboard 2030 – 70% 55 % of plastic; 80 % of ferrous metals; 60 % of aluminum; 75 % of glass; 85 % of paper and cardboard.
WEEE recycling			Separate collection of WEEE generated on the territory of that Member State, %	Since 2021 – 85%

Waste management targets provided in the table above are not the full reflection of established goals, but ones considered sufficient for the scope of future strategic planning. It is noticeable that some EU goals are missing in NSWM. Moreover, comparing previously provided Ukrainian statistics on waste management, with Ukrainian goals for 2018 from the provided table, – it can be noticed that such goals as a diversion from landfill, recycling, or incineration were not achieved. Therefore, it is doubtful that the following goals (2023,2030) are achievable either.

5 Strategic Plan for Ukrainian municipal solid waste management

As Ukrainian MSW management situation and the main goals to achieve were defined in the previous chapters, it is possible to start strategic planning. The current chapter is a Strategic Plan of the actions which Ukraine should take in order to secure stated goals. That transfers to obtain a certain form of waste streams and waste hierarchy pyramid in a certain year. In terms of waste stream calculations, Ukrainian territory will be assessed as a whole, with distinguishing on “Urban” and “Rural” areas. As for particular actions which needed to be done and waste management facilities to be built, Ukraine will be divided into five areas, which is described further. The observed time frame of current planning is 2018-2030 years, as 2030 is a milestone year in terms of current NSWM, and current planning is considered as an alternative strategy in the same environment. Therefore, it would be appropriate to establish “milestone years” – time points at which appropriate calculations and evaluations will be made to ensure gradual progress, instead of having a 12-year “black box” with a certain goal in the end. In other words, it is proposed to divide planned timeframe into three parts: 2018-2023, 2023-2026, 2026-2030. Appropriate waste streams form, waste hierarchy, required actions, and construction plans will be evaluated for all milestone years.

5.1 Proposed geographical division for Strategic Plan

European directives in general, and provisions for waste management plans, in particular, provide proximity and self-sufficiency principles as ones, that should be followed during the development of waste management strategy. In other words, waste should be processed and disposed near its origin, and such process should be self-sufficient in the boundaries of the chosen area. Therefore, for the sake of current waste management planning, Ukrainian territory is divided into five areas. Naturally, since municipalities are responsible for their own waste management, it is not viable to have any of them divided between mentioned areas.

Original district division of Ukraine includes 24 municipalities and the city of Kyiv[4]. Isolated clusters which might be accountable for significant population or waste generation share in Ukraine do not exist, the distribution of named parameters across Ukrainian territory is mostly homogeneous (see Figure 4.1). The only exception is the city of Kyiv, which is responsible for up to 14,8% of collected waste and for 8% of the total Ukrainian population, but it is not sufficient values to validate Kyiv exemption into its own area. Therefore, existing Ukrainian municipalities are grouped into five areas on the basis of their geographical location, waste generation, population size and presence of the “core city” – a city with around or more than

1,000,000 residents, which has a stronger economy. Table 5.1 provides a comparison of waste management contributions and number inhabitants for chosen areas.

Table 5.1 – Waste generation and demographic data for established geographical Areas[37][7]

	The total population in 2018	Waste accountable for in 2018, %	Waste collected in 2018, million tonnes	Urban population in 2018, %
Area 1 (4 municipalities+ Kyiv city)	8160486	25,14%	2,28	83,68%
Area 2 (3 municipalities)	9154772	20,66%	1,87	55,70%
Area 3 (6 municipalities	8377847	18,78%	1,70	55,61%
Area 4 (4 municipalities)	7369922	15,33%	1,39	59,70%
Area 5 (7 municipalities)	9323376	20,09%	1,82	73,85%

It is noticeable that formed areas have rather close waste collection contribution (%) and population number, but the first area still provides the biggest amount of MSW and has the highest Urban population share, because it includes the capital city of Kyiv. All of the created areas provide a decent amount of waste for supplying possible waste treatment facilities and represent both rural and urban shares of the population. Figure 5.1 shows formed areas within Ukrainian territory, with highlighted “core cities” within each area.

Figure 5.1 – Strategic territorial division of Ukraine

5.2 Evaluation of selected MSW characteristics for milestone years in Ukraine

5.2.1 Prediction of MSW morphology

In order to start strategic planning for the waste management system, it is vital to understand the morphological composition of generated waste within the observed geographical territory. Such information creates a basis for future planning, as it defines which treatment operations is possible to perform. It is not viable to incinerate food waste as it might be composted, the same goes for packaging waste that should be recycled. Moreover, since strategic planning has its aim to set the scene for the future, it is important to analyse data on waste composition in order to extrapolate observed trends and predict changes in the morphology of future generated waste. That is performed particularly for the milestone years which is set up by the strategic planning.

Unfortunately, substantial and systematic research works on the morphology of MSW in Ukraine are absent. Most of the available articles consider a small area as its scope, – a particular village or city without a global context in terms of whole country[45], [46]. Some of the articles observe whole Ukrainian territory, but only in terms of the particular waste stream, like biodegradable waste[47]. Therefore, it is challenging to provide a precise assessment of waste composition. Table 5.2 provides a comparison of available data from different sources.

Table 5.2 – Ukrainian MSW morphology according to existing sources [48], [49]

MSW fractions	2010	2012	2015
Bio waste	30	35-50%	30%
Plastics	5	10%	11%
Paper and cardboard	31	10-15%	17%
Glass	12	8-10%	6%
Metals		2%	3%
Textile		4-6%	
Construction waste		5%	
Wood		1%	
Hazardous MSW			1%
Other	33	10%	32%

It is possible to make a raw assumption about the morphological composition of MSW produced in Ukraine in 2018 based on Table 5.2. But more important, according to current strategic planning, is the future changes of such parameter for the milestone years. Some studies [50] use statistical formulation or

neural networks to assess and predict MSW morphology, but such major calculations are out of scope for the current dissertation.

However, from mentioned studies it is possible to pick up the main trend – the amount of generated waste, as well as its composition, depends on certain economic and social factors. The usual trend is – the bigger economy growth particular country shows, the further waste composition shifts towards an increase in packaging materials percentage, and a decrease in bio waste[51]. And, as a result, a reduction in the cumulative density of MSW appears. Figure 5.2 provides insight on MSW density in Ukraine in 2014-2018, presented data is not a direct measurement but calculated value based on weight and volume of collected waste in Ukraine.

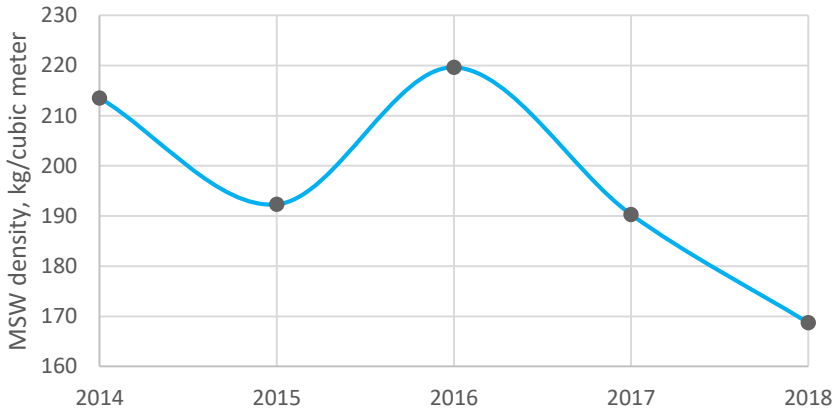


Figure 5.2 – MSW density in Ukraine, 2014-2018 [7]

The provided figure illustrates a decrease in MSW density in Ukraine over the years, which might be a result of changing in its morphology. But such rapid decrease is unlikely a systematic trend, but rather a result of different monitoring approaches for different years. Therefore, such a trend will be denied as a misleading one. Nevertheless, 170-220 kg/m^3 is a normal value for regular MSW density.

In terms of current strategic planning, morphological content of MSW is assumed to remain mostly similar over the next 12 years, as such time frame is insignificant to observe a drastic change in waste morphology. It is only assumed to sustain a 1% increase of plastics and paper fractions share, and a 2% decrease in biowaste fraction respectively, due to expected slow GDP growth trend which was observed in Ukraine in recent years[52]. Data on MSW morphology provided in table 5.3.

Table 5.3 – Prediction of Ukrainian MSW morphology for milestone years

MSW fractions		2018	2023	2026	2030
Bio waste		35%	34%	34%	33%
Packaging	Plastics	11%	12%	12%	12%
	Paper and cardboard	17%	17%	17%	18%
	Glass	6%	6%	6%	6%
	Metal	3%	3%	3%	3%
Other		28%	28%	28%	28%

5.2.2 Prediction of the amount of collected MSW

It is important to predict a waste generation in milestone years to perform further calculations. Summing up the trends observed in Chapter 4, it is visible that GDP per capita is growing for the last three years[52]. Figures provided in Chapter 4 also confirm the fact, that the decline in terms of population is not correlating with the amount of generated MSW. Therefore, an empirical formula from [48, p. 30], will be used to calculate a future waste generation. Minding provided assumptions it is calculated that:

$$G_{200i} = \left|\left(C_{200i-1} / \eta\right) \times 0{,}9\% + \left(C_{200i-1} / \eta\right)\right| \times \varepsilon \text{ [48, p. 30] (5.1)}$$

Where,

- G_{200i} – The generated amount of MSW
- C_{200i} – Collected amount of MSW
- 200_i is a year in which to MSW weight should be calculated
- η – Collection coverage in 200_{i-1} year
- ε – Collection coverage in the 200_i year
- 0,9% is an empirical coefficient from [48, p. 30], related to GDP growth

As it was mentioned, the current coverage rate of Ukrainian MSW collection is 78% of the territory, but [48] suggests that achieved rate of extension of coverage rate for Ukraine is 1% annually. Such an assumption will be used for current strategic planning. Therefore, in 2023 it will be equal to 83%, in 2026 to 86% and 90% in 2030. Having this in mind and using a formula 5.1 it is possible to calculate collected waste in baseline years.

$$C_{2023} = 10{,}101{,}407 \ \ tons \text{ (5.2)}$$

$$C_{2026} = 10,751,665 \ \ tons \quad (5.3)$$

$$C_{2030} = 11,662,307 \ \ tons \quad (5.4)$$

Applying an aerial division provided in 5.1 it is possible to evaluate the amount of MSW collected in each area. It is assumed that the percentage of collected waste by each area and their urban population share will be stable similar in the baseline years in comparison to 2018. Such data provided in table 5.4.

Table 5.4. – Projected MSW generation by Area for milestone years

	Year	Area 1	Area 2	Area 3	Area 4	Area 5
MSW collected, tonnes	2023	2,539,494	2,086,951	1,897,044	1,548,546	2,029,373
	2026	2,702,969	2,221,294	2019163	1648230	2160010
	2030	2,931,904	2,409,433	2190181	1787832	2,342958
Collected in urban areas	2023	2,125,048	1,162,432	1054757	924,482	1,498,692
	2026	2,261,844	1,237,261	1,122,655	983,994	1,595,167
	2030	2,453,417	1,342,054	1,217,741	1,067,336	1,730,274
Collected in rural areas	2023	414,445	924,519	842,288	624,064	530,681
	2026	441,125	984,033	896,508	664,237	564,843
	2030	478,487	1,067,379	972,440	720,496	612,683

5.2.3 Assumption of separate/mixed collection rates in Ukraine

As it was stated in Chapter 5, the current Ukrainian separate collection rate is 3%, but it is obvious that under such conditions it is impossible to achieve any waste management goals. So it is vital to bring a major change in a separate waste collection system and increase separate collection rates. Particular actions in that regard will be provided further in the current chapter, but in order to be able to calculate possible waste streams, a milestone separate collection numbers should be established for baseline years.

Targets provided by EC on separate waste collection is a natural choice for such case, but such targets are not numerical, but qualitative[3]. However, such a goal provided in NSWM, – 50%[5] of separate collected MSW until 2030, it will be used in current planning. Having such a milestone for the year 2030, arithmetically it requires 3,62% annual growth from starting in 2018 and will secure a 24,5% of separate collection in the year 2023, and 35,48% in the year 2026.

$$R_{separ} = \frac{(50\% - 2,9\%)}{2030 - 2017} = 3,62\% \quad (5.5)$$

$$C_{separ\,2023^*} = 2,9\% + 3,62\% \times (2023 - 2017) \approx 24,5\% \quad (5.6)$$

$$C_{separ\,2026^*} = 2{,}9\% + 3{,}62\% \times (2026 - 2017) \approx 35{,}4\% \quad (5.7)$$

$$C_{separ\,2030^*} = 2{,}9\% + 3{,}62\% \times (2030 - 2017) \approx 50\% \quad (5.8)$$

5.3 Summary of waste management goals and calculation rules for strategic planning

5.3.1 Diversion from landfill goals and calculation rules

After evaluation of general amounts of MSW to be collected in milestone years, it is appropriate to again take a look on targets provided by EU legislation in order to understand particular numbers that should be obtained as a result of following calculations. As it was mentioned above, calculations will be presented in a form of waste streams which will be obtained through a combination of available waste treatment options and their mass balance. In other words, after calculations, it will be visible how many MSW will be landfilled, recycled, incinerated or treated the other way in each of milestone years.

Naturally, it is important to set some methodological restrictions for such calculations, particularly to understand which waste stream might be counted as recycled or landfilled, and which is not. It is vital to be able to decide whether waste managing goals are achieved by the chosen combination of treatment options. Such rules and restrictions are declared in EC legislative documents [15], [17], [23] and summed up further.

Diversion from landfill target should be measured in percentage by weight in relation to all collected MSW. All EU member states should secure a 10% or less of landfilled MSW until 2035, as it was stated in[23]. However, there is a possibility to postpone such goal by up 5 years, for those countries, who landfilled 60% or more of MSW in 2013. Chapter 4 proved that Ukraine fall in such a category. So for the sake of current management planning, it is assumed that Ukraine will use this option. At the same time, those states who are using postponing option are obligated to meet the different target – secure a 25% or less of landfilled MSW by weight in the year 2035. Minding that established time frame for current planning is until 2030, it is required to adjust the mentioned goal accordingly. Arithmetically, Ukraine has to decrease its landfill rate by 4% on average annually in order to meet EC legislative targets. Therefore, in the year 2030, the landfill rate should be around 45% – this will be a landfill diversion target for future calculations.

$$R_{landfill} = \frac{(93{,}4\% - 25\%)}{2035 - 2018} = 4{,}02\% \quad (5.9)$$

$$C_{landfil2030^*} = 93{,}4\% - 4{,}02\% \times (2030 - 2018) \approx 45\% \quad (5.10)$$

Additionally, during calculations, it is necessary to stay in line with legislative “rules of calculation” in order to include the right waste streams under the definition “landfilled MSW”. Article 5a of Directive 2018/850 of the European Parliament and of the Council of 30 May 2018 “Amending Directive 1999/31/EC on the landfill of waste” states such principles:

1. “The weight of waste resulting from treatment operations prior to recycling or another recovery of municipal waste, such as sorting or mechanical biological treatment, which is subsequently landfilled shall be included in the weight of municipal waste reported as landfilled” [15]

It means that the amount of MSW which has entered a sorting facility or mechanical treatment plant cannot be categorized as diverted from landfill, but all outputs of such treatment should be allocated separately, and those which will not be further treated have to be counted as landfilled. This principle will be used in the following calculations.

2. “The weight of waste produced in the stabilization operations of the biodegradable fraction of municipal waste in order to be subsequently landfilled shall be reported as landfilled” [15]

Such principle confirms that all compost-like outputs from biological stabilization in the MBT process need to be further traced, and if the final treatment will be incineration or disposal – counted as landfilled. It is reflected in further calculations.

3. “The weight of waste produced during recycling or other recovery operations of municipal waste which is subsequently landfilled shall not be included in the weight of municipal waste reported as landfilled *“*[15]

Meaning that the waste resulted from organic valorisation or individual composting which needs to be landfilled, still might not be included in the total amount of landfilled MSW. However, in terms of current strategic planning, this rule will be avoided. Such amendment is dictated by the fact that in practical implementation mentioned waste stream might be treated through incineration and still needs to be landfilled, therefore it is important to trace such waste stream without legally possible exclusion of it.

5.3.2 Preparing for re-use and recycling goals and calculation rules

Same as in the previous subchapter, WFD establishes a postpone option in terms of re-use and recycling rates. For the milestone year of 2030, proposed by EC goal states that a minimum of 55 % of MSW should be prepared for re-use and recycled[23]. As for the calculation rules, WFD provides the following requirements:

1. “The weight of municipal waste that undergone all necessary cleaning and repair to be used again should be included in calculations as prepared for re-use”;

2. “To be considered as recycled, the particular waste stream should undergo all necessary sorting, checking and other preparation procedures and only the remained amount which goes directly to recycling operation is calculated as recycled weight.”;

3. “The amount of municipal biodegradable waste that enters aerobic or anaerobic treatment may be counted as recycled where that treatment generates compost, digestate, or other output with a similar quantity of recycled content in relation to input, which is to be used as a recycled product, material or substance.” [23].

Provided rules are adopted in current strategic planning as the amount of recycled waste will be the sum of direct recycling, input waste to organic valorisation and input waste in the biological part of mechanical-biological treatment.

5.3.3 Packaging waste recycling goals and calculation rules

Packaging waste is an important waste stream, which should be addressed by waste management planning. Like it was described previously in waste morphology provisions, packaging waste is about 38% of all MSW collected in Ukraine. However, due to the low development level of the separate waste collection system, inappropriate legislation and monitoring system, it is hard to distinguish a particular amount of collected and recycled packaging waste in Ukraine. Even harder is to distinguish particular packaging streams like glass, ferrous metals, wood, aluminum, plastics, textiles, paper, and cardboard. Which is unfortunate as EU directive on packaging waste states a clear goal on recycling of such fractions of packaging waste[17].

No later than 31 December 2025 a minimum of 65 % by weight of all packaging waste will be recycled, including: [17]

- 50 % of plastic;
- 25 % of wood;
- 70 % of ferrous metals;
- 50 % of aluminum;
- 70 % of glass;
- 75 % of paper and cardboard;

No later than 31 December 2030 a minimum of 70 % by weight of all packaging waste will be recycled, including: [17]

- 55 % of plastic;
- 80 % of ferrous metals;
- 60 % of aluminum;

— 75 % of glass;
— 85 % of paper and cardboard.

Similar to previously described aims, EC legislation provides a postponing option for member states, but only regarding particular packaging fractions, not to the overall percentage of all packaging waste. Combining that with previously discussed difficulties on distinguishing of particular packaging waste streams, it is visible that such postponing does not provide significant relief to Ukraine in terms of achieving these goals at the present time.

The calculation rules on recycling of packaging waste are similar to rules on the overall recycling rate. That is understandable, as overall recycled amount usually constitutes mainly of packaging waste stream with addition of biological treatment (which is counted as recycling under certain conditions) and recovery of metals after incineration.

Therefore, for the sake of current strategic planning, during calculations packaging material is not divided into certain streams, but is counted as general multilateral recycling. Later, in chapter with recommendations for practical implementation, a necessary set of actions for particular packaging streams is provided separately as guidance to secure the goals provided above.

5.3.4 Hazardous waste treatment goals and calculation rules

Out of all MSW produced in Ukraine, approximately less than 1% is hazardous, according to[39]. Such waste should be treated in a special way, and the main goal for a waste management planning is to extract such fraction from overall MSW stream. Goals provided by Waste framework proves this point, as the main goal is to establish by January 2025 a separate collection for hazardous waste fractions produced by households and to ensure that they are treated appropriately and do not contaminate other municipal waste streams[3].

Therefore, for current strategic planning and its calculations, hazardous MSW stream will not be included but will be discussed as a part of separate collection recommendations.

5.4 Numerical evaluation of Ukrainian future waste streams

As all calculation rules, there is a possibility to evaluate future waste streams in Ukraine. In order to perform that, Annex II provides a description of waste treatment technologies to be used in Ukraine. Sucha

description contains a cornerstone feature for calculations – mass balances of waste treatment technologies. These waste treatment technologies include: incineration, organic valorization, individual(home) composting, mechanical-biological treatment and sorting plants. Such balances used to calculate the rest fractions and valuable outputs from waste treated at respective facilities, see Annex II.

Conceptually such numerical evaluation is based on previously provided projected waste generation, separate collection rate and desired goals for three milestone years. The ultimate goal is to obtain a form of waste streams which will secure mentioned goals under projected conditions. In terms of calculation, 8 separate waste streams were defined and presented in Figure 5.3.

As it was stated in 5.1, population-wise Ukraine has an urban population of 67%[37]. But in terms of waste generation, the urban share of citizens produces more MSW – highly urbanized area inhabitants may generate up to 450 kg annually, while rural population averages are between 150-250 kg/year[7][37]. Therefore, considering the date provided in Table 5.1, using a waste generation of each area and its urban population share it is possible to approximately evaluate waste generation by the urban and rural population in Ukraine. As a result, it was defined that Urban areas are accountable for 75% of all collected MSW, and the rest 25% is assigned to the Rural part.

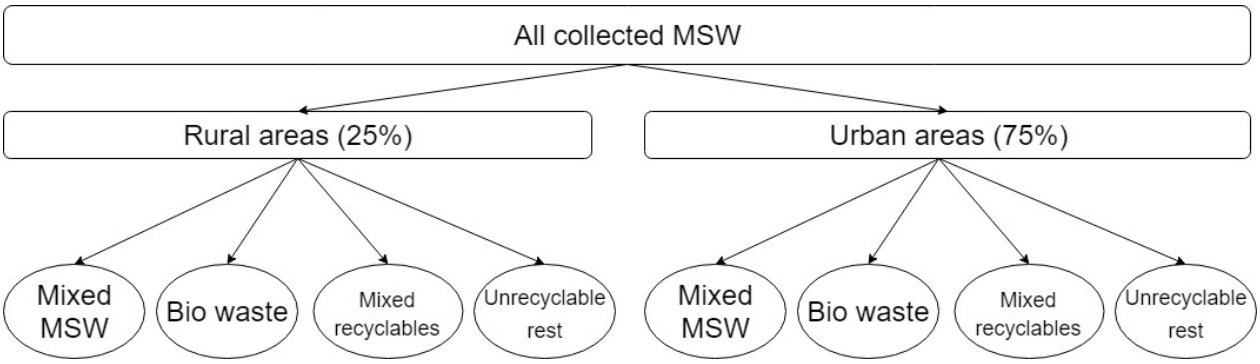


Figure 5.3 – Separate waste streams assessed in the calculation

By using provided assumptions for separate collection rate, projected MSW generation and waste morphological composition – it was possible to calculate each area contribution in terms of collected MSW. Projected amount of the waste by each stream (Table 5.5a,5.5b) was evaluated.

Table 5.5a – Predicted mixed MSW generation

	Mixed collected MSW			Separately collected MSW		
Area type	**2023**	**2026**	**2030**	**2023**	**2026**	**2030**
Urban, tonnes	5 719 922	5 209 182	4 373 365	1 856 134	2 854 567	4 373 365
Rural, tonnes	1 906 641	1 736 394	1 457 788	618 711	951 522	1 457 788
Urban, %	56,63%	48,45%	37,50%	18,38%	26,55%	37,50%
Rural,%	18,88%	16,15%	12,50%	6,13%	8,85%	12,50%

Table 5.5b – Predicted separate MSW generation

	Separately collected Biowaste			Separately collected recyclables			Separately collected unrecyclable fraction		
Area type	**2023**	**2026**	**2030**	**2023**	**2026**	**2030**	**2023**	**2026**	**2030**
Urban, tonnes	631085	705331	519717	970553	1084736	799279	1443211	1705612	1224542
Rural, tonnes	210362	235110	173239	323518	361579	266426	481070	568537	408181
Urban, %	6,25%	6,98%	5,15%	9,03%	10,09%	7,43%	12,38%	14,63%	10,50%
Rural,%	2,08%	2,33%	1,72%	3,01%	3,36%	2,48%	4,13%	4,88%	3,50%

A certain appropriate waste treatment technology was assigned to the respective waste stream through "usage coefficient" – the percentage of waste from a particular waste stream directed to particular waste treatment technology. Possible treatment technologies which were used for calculations are: sorting, incineration, organic valorisation, mechanical-biological treatment, home composting, landfilling of MSW. Therefore, mass balance of each of 8 waste streams might be represented as follows:

$$S = W_{SORT} + W_{WTE} + W_{OV} + W_{MBT} + W_{COMP} + W_{LAND} \quad (5.11)$$

$$W_i = S \times x_i \quad (5.12)$$

Where S – the amount of waste in a stream; W_i – the amount of MSW directed to particular treatment technology; x_i – treatment technology "usage coefficient" individual for each waste stream. Denotation "*i*" means particular waste treatment type – Sorting, WTE, Organic Valorisation etc.

Such "usage coefficients" introduce certain restrictions as well. It means that mentioned waste treatment technologies are available not for every waste stream discussed. Such rules reflect assumed principles of waste management in Ukraine adopted by the current Strategic Plan. The rules are the following:

- Bio-waste might only be composted at Organic Valorisation plant or at home;
- Home composting available only to "rural areas bio-waste" stream;
- Incineration available exclusively for "urban areas waste" stream;
- "Mixed recyclables" stream directed exclusively for sorting;

The further calculation process is rather trivial. Possible waste treatment technologies were assigned with appropriate mass balance coefficients. That in order to evaluate the mass of the output products from treatment plants under respective technology. Each treatment plant mass balance is represented as:

$$W_i = a_1 \times W_i + a_2 \times W_i + \ldots + b_j \times W_i \quad (5.13),$$

Where W_i – a mass of processed MSW at the certain facility; $a_{1,2,3}$ – valuable output mass coefficient; *b* – rest fraction mass coefficient. Denotation "*j*" means particular waste treatment type – Sorting, WTE,

Organic Valorisation, MBT, Landfill etc. Coefficients “a” and “b” depend on established mass balance of particular treatment technology and identical for all waste streams S which using such technology.

Therefore, the amount of waste (L_i) to landfill after each treatment operation (rest fraction) is:

$$L_i = b_j \times W_i \quad (5.14)$$

Table 5.6 provides rest fractions for each mentioned waste treatment facility type.

Table 5.6: Rest fraction mass coefficient for waste treatment technologies[53]–[57]

Treatment technology	Rest fraction (b_i)
Sorting	10%
Incineration	20%
Mechanical-Biological treatment	50%
Organic Valorisation	35,7%
Home composting	13%

It is important to mention, that rest fraction of such treatment technologies as Organic Valorisation of Mechanical-Biological treatment is possible to send for further incineration. That case the rest fraction was assigned with additional usage coefficient.

$$W_{WTE}^{/} = \left(b_{OV,MBT} \times W_{OV,MBT}\right) \times x_{WTE}^{/} \quad (5.15)$$

$$L_{OV,MBT}{}^{/} = b_{WTE} \times \left(b_{OV,MBT} \times W_{OV,MBT} \times x_{WTE}^{/}\right) \quad (5.16),$$

Where $W_{WTE}^{/}$ – the amount of rest fraction to undergo secondary incineration; $x_{WTE}^{/}$ – usage coefficient for rest fraction incineration; $L_{OV,MBT}{}^{/}$ – the amount of waste to landfill after secondary incineration of rest fraction from Organic Valorisation or Mechanical-Biological treatment process..

Provided formulas allow calculating the amount of waste underwent particular treatment and trace the outputs of such it. Summation of such numbers makes it possible to development waste stream schemes for milestone years. Figure 9 presents such a scheme for the year 2030. It is visible that some amount of MSW, particularly the rest fraction from Organic Valorisation and Mechanical-Biological treatment is directed to Incineration before landfilling.

As a result, a certain shape of waste hierarchy was obtained for each milestone year. The rest fraction was considered in calculations as well. Meaning that a final amount of landfilled waste is a summation of directly landfilled MSW and the rest fractions of waste that require landfilling after other treatment.

Figure 5.4 provides a distribution of waste by treatment options in discussed years. Such distribution may be also considered as a shape of waste hierarchy over the years. It is visible that according to strategic planning, Ukraine will not be heavily dependent on one particular waste treatment option, but waste streams

will be diversified between MBT, organic valorization, incineration, and material recycling pretty evenly. Important to remember, that “Sorting” part of the diagram is not fully accountable for respective “preparing for reuse and recycling” hierarchy part, accordingly to provided rules of calculation from WFD. Assessment on reached goals will be provided in the next subpart.

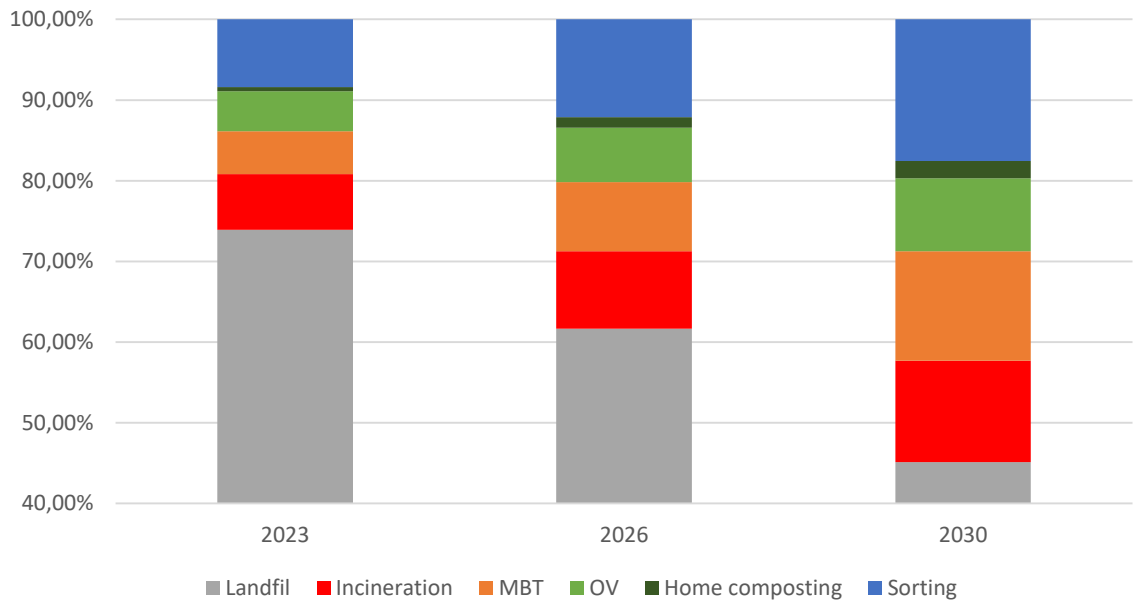


Figure 5.4 – Predicted direct distribution of MSW

It is important to note, that such distribution (Figure 5.5a) provides data on “evaluated treatment” share, meaning that it is not the amount of waste sent directly for treatment in particular facility, but the difference between inputs and outputs to it. This is the only option to provide such data in the form of 100% sum. If one to calculate waste streams from the standpoint of just inputs to respective facilities, an overall sum will be more than 100%. That caused by the fact that if the same waste stream undergoes a couple of treatment procedures, like MBT and then incineration, it will be counted twice. Figure 5.5b provides insights on the direct and indirect way of waste treatment, according to the current strategic plan. Indirect means that waste stream already underwent different treatment technology, before going to one which is observed.

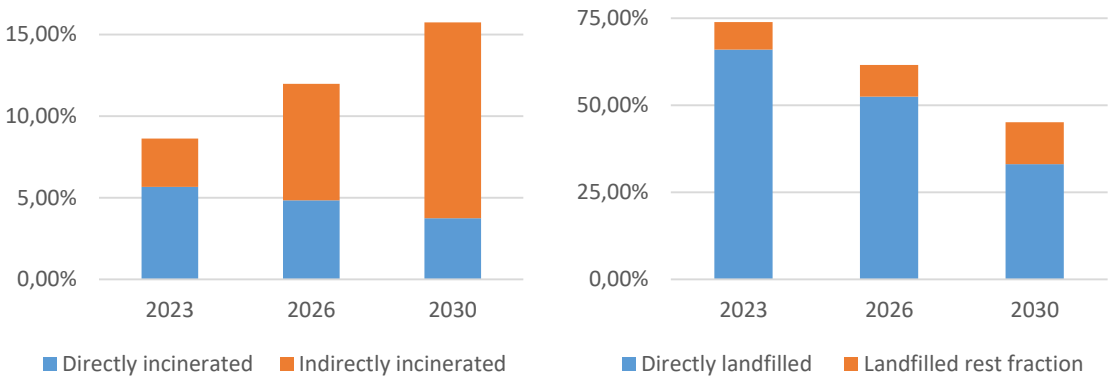
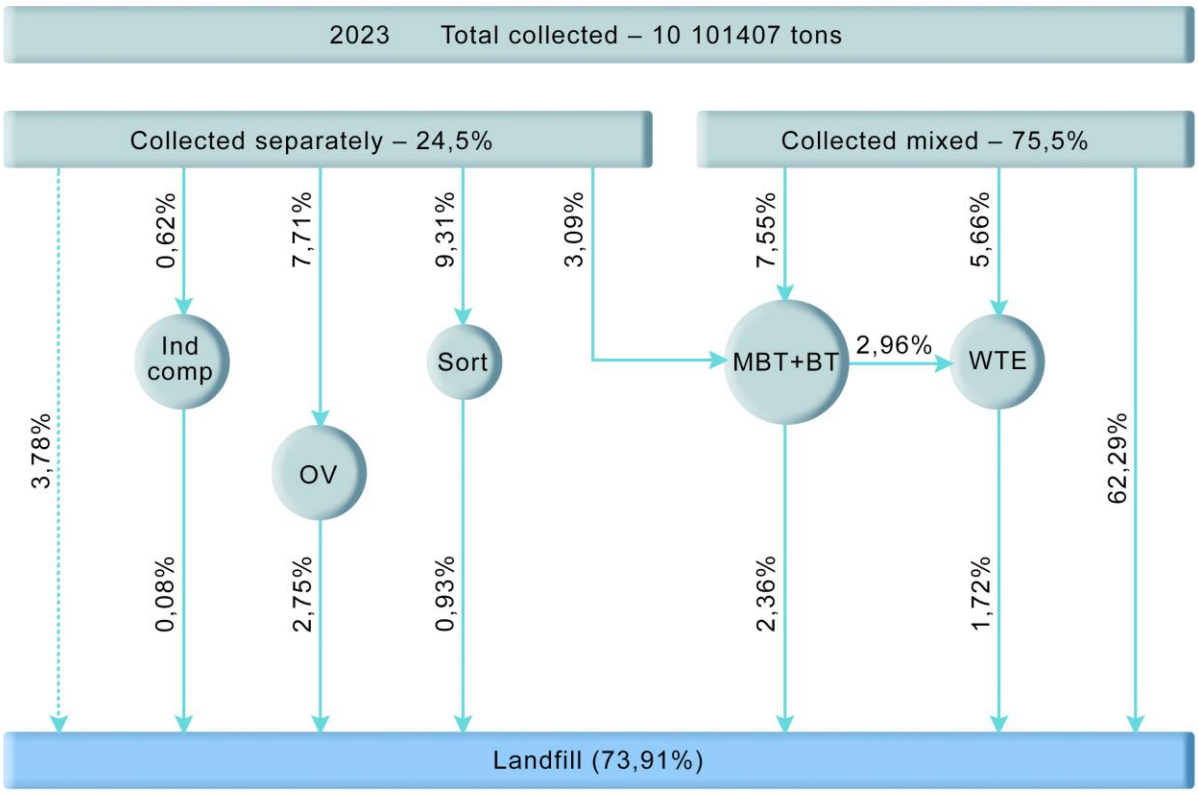


Figure 5.5(a,b) – Direct and indirect (rest) inputs to waste treatment facilities

Looking at the figure above, it is visible that waste-to-energy incineration facilities over the years will sustain an increase in terms of the treated amount of waste, but mainly due to indirect inputs, rest fractions from MBT, OV, and sorting facilities. A similar situation is with landfill rates, as direct inputs to landfill rapidly decreasing but, due to an increase in another treatment share, indirect or rest fraction inputs are growing. The best way to illustrate the results of the current calculation is to develop a scheme of waste streams, including rest fractions. Such schemes illustrated in Figure 5.6(a,b,c).



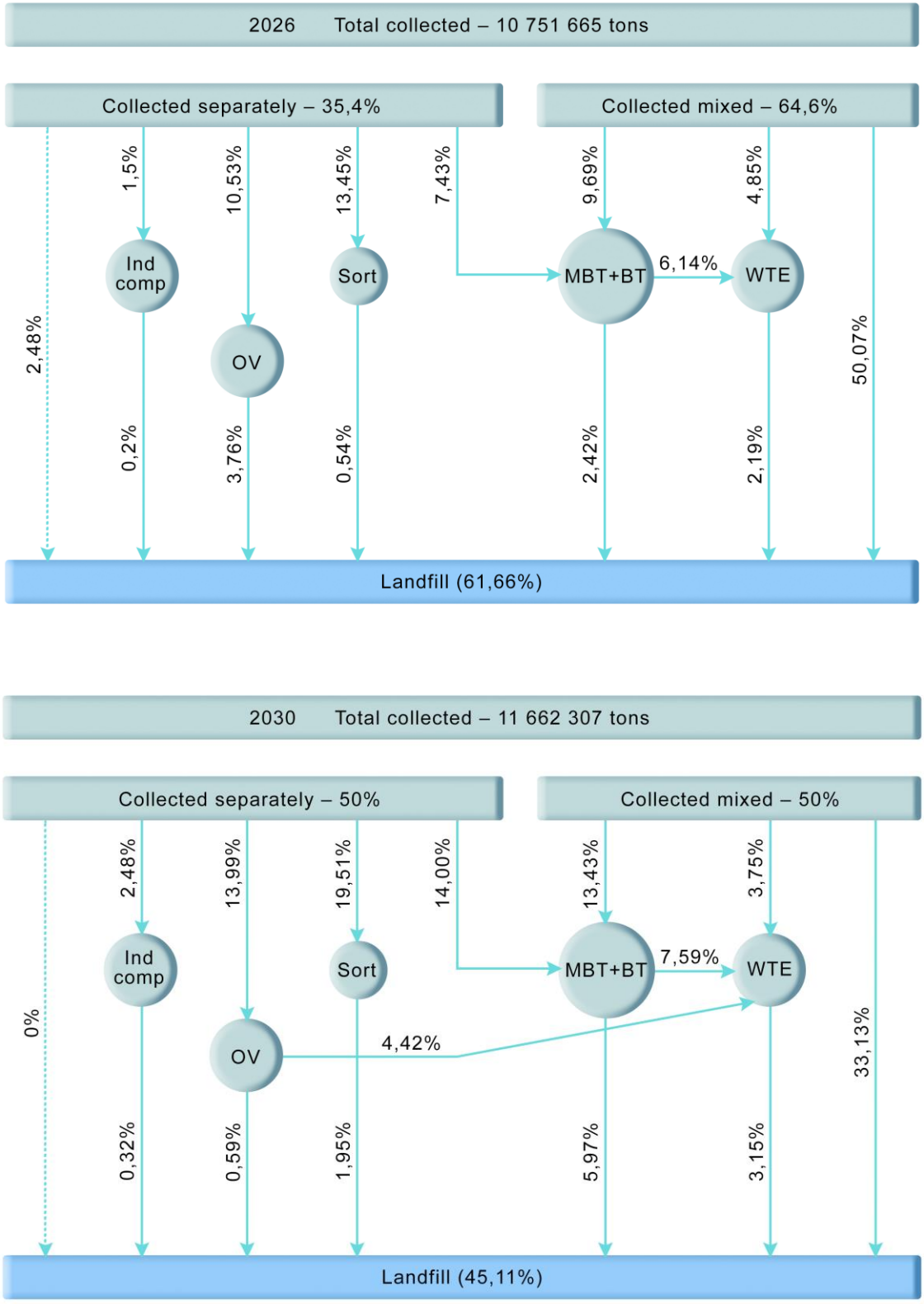


Figure 5.6(a,b,c) – Calculated waste streams for milestone years 2023,2026,2030

5.5 Evaluation of provided calculation results and stated goals compliance check

In this paragraph, particular waste streams will be extracted from calculations in order to asses if they are in line with previously approved goals. First, and the most important value, is a diversion from a landfill or a landfill rate calculated by mass. According to that, to calculate waste management target such as “diversion from landfill” it is required to calculate all disposed amount of waste from each waste stream. According to current calculation, such amount constitutes of three parts: directly landfilled waste, landfilled rest fraction from treatment, landfilled rest fraction from secondary incineration. All the mentioned components were calculated for all waste streams and summed up as follows:

$$L_{TOTAL} = \sum_{1}^{8} \left[\left(S_i \times x_{LAND} \right) + L_i + L_i^{/} \right] \text{(5.17)},$$

Where $\left(S_i \times x_{LAND} \right)$ – directly landfilled amount of waste from stream $\left(S_i \right)$, L_i – rest fraction from all used waste treatment technologies from stream $\left(S_i \right)$, $L_i^{/}$ – rest fraction from secondary incineration after each used waste treatment technology.

In 5.3.1 it was stated that such a number should be 45% or less out of all collected MSW in 2030. According to performed calculations, such parameter is equal to 45,11% in 2030, which is considered a satisfying result. Figure 5.7 provides a landfill year through milestone years, and it is visible, that in current strategic planning function is linearly decreasing by around 4% annually like it was planned. As this number was obtained in line with provided legislative requirements in terms of calculation, it is to be concluded that it is possible for Ukraine to reach EC goals on diversion from landfill for the year 2030. Of course, only if Ukraine will be able to provide sufficient treatment capacities and separate collection rates, and that population-wise Ukrainian territory will not sustain drastic changes.

Another important goal was related to reuse and preparing for recycling rate. Provided above rules of calculation for cumulative recycling allow us to count recycled amount as input to the recycling facility if rest fraction is low. Input to the recycling facility is output from sorting facility which is calculated. Additionally, as it was discussed, organic valorization treatment should be included in the overall recycling rate as well as compost output only from MBT. Figure 5.12 provides the obtained result in that regard.

$$\mathrm{Re}_{TOTAL} = \sum_{1}^{8} \left[\left(S_i \times x_{sort}^{i} \right) \times \left(1 - b_{sort} \right) + \left(S_i \times x_{OV}^{i} \right) + \left(S_i \times x_{MBT}^{i} \times a_{comp}^{MBT} \right) \right] \text{(5.18)},$$

Where Re_{TOTAL} – recycling rate; x_{sort}^{i}, x_{OV}^{i}, x_{MBT}^{i} – usage coefficient of sorting and organic valorisation and mechanical-biological treatment technologies for respective waste streams; b_{sort} – rest fraction from

sorting plant, identical for all S_i; a_{comp}^{MBT} – the percentage of compost from MBT treatment plant, identical for all S_i.

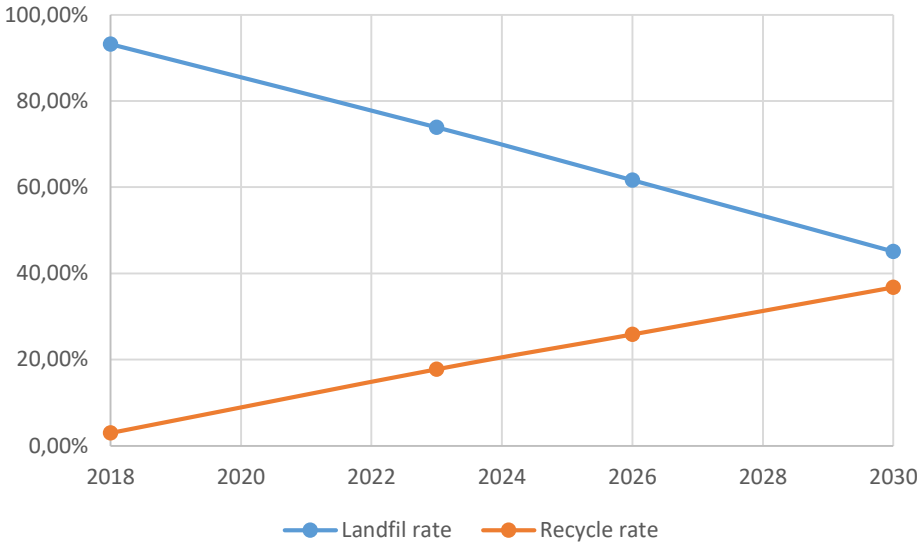


Figure 5.7 – Predicted landfill and recycling rate

Preparing for reuse and recycle rate planned for 2030 in Ukraine is 36,76% according to calculations, but the aim established by EC is 55%. Obviously, such a result should not be considered as satisfying, but it is still great progress considering a starting point of 3%. Ukraine is the second-biggest country in the EU by area, and it makes it difficult to establish high recycle rates over a given time.

It is dictated by the fact that the recycling rate does not strictly dependent on existing treatment capacities, but mainly on the development level of the separate collection system. Current strategic planning suggests ambitious progress in that regard, but still not sufficient to secure a 55% goal for recycling. It is visible from the Figure 5.12, that even such underachievement in terms of recycling will require a 12,7 times growth over 12 years, or leap from 0,27 to 4,5 million of recycled tonnes in absolute values. Considering provided insights, it is stated that obtained result for reuse and recycling is optimal, minding that the most important goal is a diversion from landfill.

Another important goal which was established – is the recycling of, particularly packaging waste stream. According to paragraph 5.2, by using a general share of packaging waste in generated MSW and the amount of recycled packaging waste, minding the calculation rules provided above, it was possible to evaluate on provided goal.

$$Pa_{TOTAL} = \sum_{1}^{8}\left[\left(S_i \times x_{sort}^{i}\right)\times\left(1-b_{sort}\right)+\left(S_i \times x_{MBT}^{i} \times a_{recov}^{MBT}\right)\right]\div 0{,}38 \quad (5.19)$$

Where Pa_{TOTAL} – packaging waste recycling rate; x_{sort}^{i}, x_{MBT}^{i} – usage coefficient of sorting and

mechanical-biological treatment technologies for respective waste streams; b_{sort} – rest fraction from sorting plant; a_{recov}^{MBT} – the percentage of recovered recyclable waste from MBT treatment plant, 0,38 – the share of packaging waste in all collected waste according to morphological composition.

Dynamic change of this parameter shown in Figure 6.13. In 2030 Ukraine, in terms of current strategic planning, will recycle around 52% of all collected packaging waste, in contrast to 70% goal established by EC. Similarly, as with total recycle rates, the obtained number is strongly underachieving in terms of EC aims but is good progress in comparison to 2018 level. Again, the problem lies not in recycling facilities, but in separate collection limitations. Indeed, there is a theoretical possibility to increase such numbers by introducing a "dirty" sorting facilities for a mixed collected fraction of MSW, but the cost-efficiency parameters of such options assumed to be inappropriate for the generally weak Ukrainian economy[48].

Another important parameter, according to WFD is a diversion of biodegradable waste from landfill. In terms of current calculations, all bio waste and paper/cardboard share of packaging waste are considered a biodegradable fraction.

$$Bi_{TOTAL} = \sum_{1}^{8}\left[\left(S_i \times x_{OV}^{i}\right) + \left(S_i \times x_{IND}^{i}\right) + \left(S_i \times x_{MBT}^{i} \times 0{,}51\right) + \left(S_i \times x_{SORT}^{i} \times 0{,}45\right)\right] \div 0{,}51 \quad (5.20)$$

Where Bi_{TOTAL} – biodegradable waste diversion rate; x_{sort}^{i} , x_{OV}^{i} x_{MBT}^{i} x_{IND}^{i} – usage coefficient of sorting and organic valorisation and mechanical-biological treatment technologies and individual composting for respective waste streams; 0,51 – the share of biodegradable waste in all collected mixed waste according to morphological composition; 0,45 – the share of biodegradable waste in all collected packaging waste according to morphological composition. Figure 5.8 provides data on the percentage of treated biodegradable waste, the rest was landfilled.

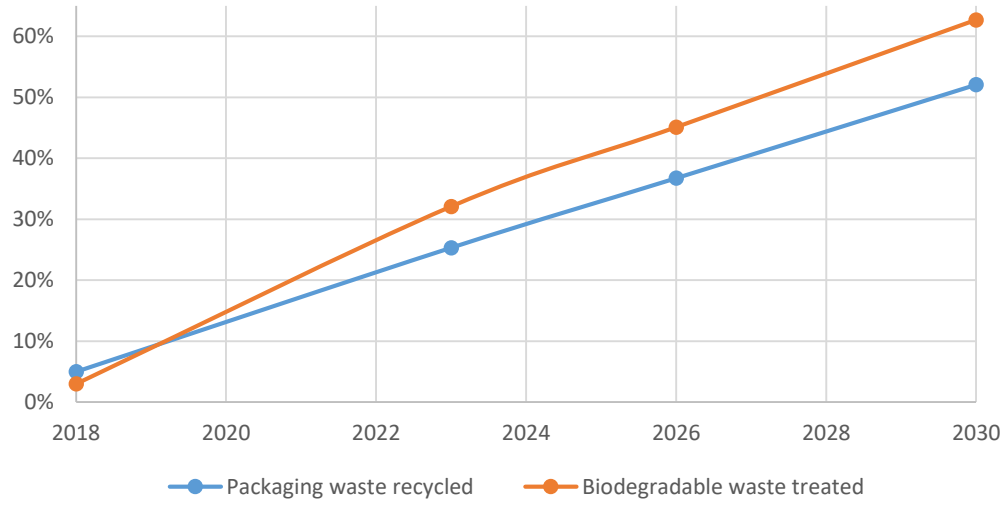


Figure 5.8 – Recycling rate for packaging waste, the biodegradable waste diversion rate

Incineration was not considered as an appropriate treatment for such waste fraction to be counted as a diversion from landfill. It is visible, that in current modelling Ukraine reaches a decent result, considering a starting point. EC legislation does not provide a precise goal in terms of percentages in such regard[15] but emphasizes that member states should ensure the increase of separate collection of bio waste, home composting rates and organic valorisation, which is included in our strategic planning.

5.6 Evaluation of required waste treatment capacities according to calculations

In the previous part, an “evaluated treatment” waste amount was described for established treatment technologies, but it does not provide us with an idea of how many treatment plants Ukraine should build. To evaluate future installed capacities should be, it is required to consider an input waste streams to each technological branch. Namely the amount of waste that certain plants will treat regardless of further processing of remained waste. Figure 5.14 provides such data for three baseline years in comparison to existing capacities in Ukraine in 2018. It is visible from the figure, that over the years share of all waste treatment technologies is growing rapidly, so, of course, such progress will require big investments in the construction of facilities.

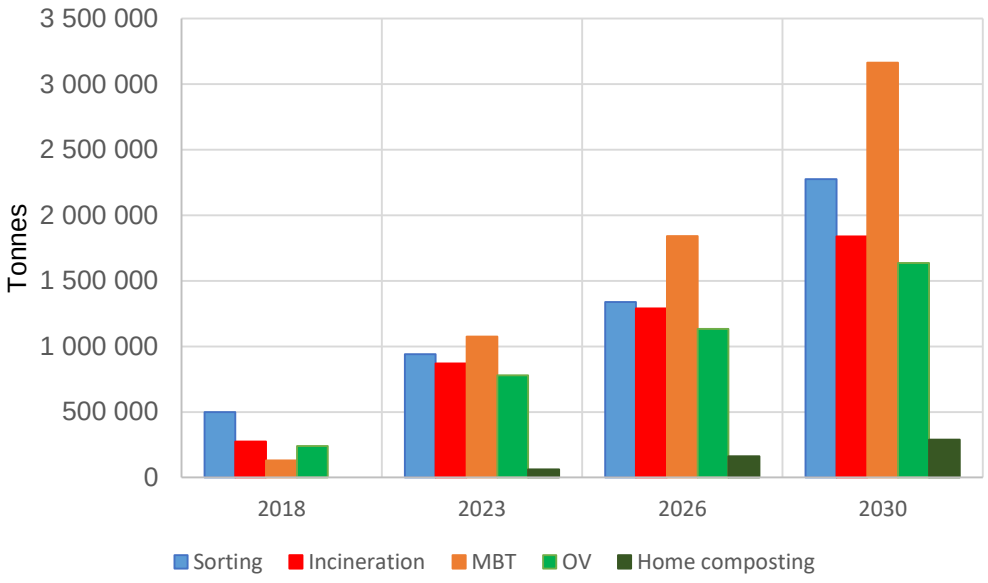


Figure 5.9 – Predicted required waste treatment capacities

Provided Figure 5.9 is rather different from Figure 5.4 due to discussed calculation features, but it provides a real comparison of waste treatment facilities from a practical standpoint. It is notable, that

according to strategic planning, in 2030 the biggest share of MSW would be sent to MBT treatment. Even though MBT treatment is of least preferable options, according to the adopted waste hierarchy, the projected amount of mixed-collected waste dictates the necessity to establish such treatment, as it is the most proven option to deal with it, avoiding low efficiency “dirty” sorting.

Required sorting capacity of separately collected MSW is also high, but such option is strictly limited by separate collection system, as it should be provided with appropriate feedstock. The same applies to organic valorisation plants, as their input is separately collected bio waste. As for waste-to-energy incineration treatment, such technology should be assessed carefully, as on a surface it is a good way to reduce the amount of landfilled MSW, but at the same time, it is a least preferable and possibly most expensive way[58]. Moreover, with the projected increase in separate collection and a possible further increase of it after 2030, it is not wise to build a lot of incineration plants, as they might not be useful in the future, or will be an obstacle to recycling rate grow. Therefore, under 16% or 1,7 million in ton annually, is considered a compromise option for such treatment. Most of the input to incineration is “rest fraction” treatment. Practical implementation of described capacities provided in the next chapter.

As it is visible from the current subchapter, stated goals are theoretically achievable or there is a possibility of decent progress in that regard for Ukraine. Conceptually, the proposed Strategic waste management plan is to create a waste management system almost from scratch. Many years Ukraine have ignored a common EU waste management trends and practices. That lead to the fact that Ukraine appeared in a situation where everything has to be created at once. Structurally, proposed solutions and actions could be divided into three directions which have to be addressed simultaneously:

- Renovate waste disposal system;
- Renovate waste collection system and introduce separate collection;
- Create a system of waste treatment facilities based on EU waste hierarchy.

The current state of all mentioned directions could be described in three statistical numbers – 95% of landfills are not in line with EU standards or in the even worse state[36]; Separate collection coverage over Ukraine is 3%[39]; Only 6% of MSW was directly treated in 2018, else landfilled[7]. At the same time, the current Strategic plan has an aim to meet at least the EU goal of diversion of MSW from landfill. Therefore, recommendations for all three mentioned directions is, naturally, ambitious, expensive and urgent.

The next subchapters contain strategic recommendations, economic instruments, possible decisions and rough calculations (where appropriate) on each of three mentioned directions and their components. Such recommendations are dictated by calculations described in Chapter 5.4. Even though the waste management system in Ukraine is not developed, there are lone bright spots there. Therefore, provided recommendations taking into account already existing useful practices of installed capacities.

5.7 Proposed practical solution – Strategic Plan for waste management

5.7.1 Practical recommendations for waste collection system improvement

Separate waste collection is a vital feature for current Strategic planning, as on whether waste was separately collected depends on its possible treatment options and, therefore, rest fractions and valuable outputs. Separate waste fractions collection directly leads to an increase in recycling rates. Since calculations of waste streams are obtained based on separate collection goals stated in 5.2.1, now it is suitable to describe the means of achievement of such numbers.

General literature provisions on such topic, state that both improvement in technical infrastructure on one hand, and public awareness, motivation on the other, are crucial to the establishment of a decent separate collection system[59]. A possible “door-to-door” collection system is usually increasing extraction of recyclables from the MSW stream and improves their quality and market value. Cost of such a collection system is higher than of other conceptual decisions, but revenues from recycling are also higher in addition to lower reject rate.

On the other hand, the system which relies mainly on “drop off” collection, when inhabitants have to bring their waste to collection points, often results in a higher level of impurities and overall low motivation to perform such actions. But that strongly depends on their working policy, meaning that such collection points are useful only if located close to potential customers, have convenient working hours and a wide variety of fractions that are acceptable there. An introduction of separate collection for bio waste results in higher recycling rates for other recyclable fractions if it is included in a “door-to-door” scheme. And, lastly, it is to be said that the overall trend for the recyclables market is shifting towards demand in higher quality materials, which makes it economically interesting to implement more advanced waste separation. [59]

5.7.1.1 The conceptual decision on the type of collection system for MSW

Cornerstone decision to be made is the type of separate collection that should be introduced for MSW. That means particularly how many containers will be included in the collection scheme and what will be a pick-up policy. Various EU member states have adopted 6,5,4,3,2,1 – container schemes for separate collection of paper/cardboard, metal, plastic, glass, bio waste and residual fraction. There is an option of co-mingled schemes, meaning that two fractions of recyclables are collected in one container, for example,

metal and plastics together. Another option is to establish a 1-container scheme for residual waste, where the rest MSW fractions are collected using a huge number of bringing points (green points). Minding European provisions[59], it is decided that metal with plastics and paper with cardboard are appropriate for the co-mingled collection, and the other fractions should have its own separate containers.

It was decided to divide Ukraine into 4 sectors by the type of household, and each was given an appropriate waste collection system. That dictated by a conceptual difference between mentioned household types, meaning that it is not viable to have the same waste collection system for village house and 16-store building in the capital. According to data provided in Table 5.7, all residents should be provided with a “door-to-door” collection service with a different amount of containers available. Individual urban houses will have the most advanced 5-container system for co-mingled collection of paper/cardboard, metal/plastic, biowaste, glass, residual waste. It is considered to be the wealthiest share of the population, who is also single-handedly responsible for its own waste management and, therefore, will be a responsible waste separator.

Multi-store houses in rural and urban areas might consist of 40-100 individual households, which means that the amount of waste from such building is relatively high, but the personal responsibility for waste separation or collection is proportionally low. In such a case, it is rather challenging to appropriately apply economic pressure on residents to increase waste separation. Organization of 5,6-container “door-to-door” collection for such households will require extensive control measures or high-end solutions to charge or penalty residents appropriately. Because of that, it was decided to introduce a 3-sack solution for this type of housing – residual waste, bio waste, mixed dry recyclables. Another strategic proposal is to introduce Bring points and Civic Amenity sites as a complementary system for extraction of source-separated recyclables with help of economical instrument discussed below.

Finally, for individual houses in rural areas, it is not viable to introduce a new “door-to-door” collection, but instead, it is advised to build a complementary system of bringing points in the residual area and put economical motivation to promote them.

Table 5.7 – Proposed waste collection schemes

Housing type	Door-to-door collection system	Complimentary collection system
Individual houses in Rural areas	1 container	Civic Amenity sites in village administration
Individual houses in Urban areas	5 containers - Paper/cardboard - Metal/plastic - Biowaste - Glass - Residual waste	Bring points in the city Civic Amenity sites
Multi-store buildings in Urban areas	3 containers - Residual - Biowaste - Dry recyclables	Bring points in the city Civic Amenity sites

Housing type	Door-to-door collection system	Complimentary collection system
Multi-store buildings in Rural areas	3 containers - Residual - Biowaste - Dry recyclables	Bring points

As EU experience goes, regarding the logistic problem of waste collection scheme – the best solution for high-quality separate collection is a door-to-door system[59], and this decision will be adopted in terms of current planning. Nowadays, Ukraine has already established such a collection system, but only for mixed waste, so the existing system will require improvements and investments in terms of collection trucks and related infrastructure.

5.7.1.2 Introduction of "pay-as-you-throw" system for waste collection

It is proposed in current planning, that in order to motivate population and improve the separate collection, it is mandatory to introduce "Pay-as-you-throw" (PAYT) system in Ukraine. Such conception means that residents will not only pay a fixed amount for waste collection, but also flexible fees based on the type of service provided, or the amount/volume of waste collected from them. Such a scheme is one of the main available economical tools to improve the separate collection, the main advantages of it include:

– Local return of investment, meaning that regular incomes from PAYT are possible to partially cover CAPEX and OPEX of the waste collection system and, therefore, contribute to its overall stability;
– Impact on household behaviour by encouraging households in their efforts to prevent waste generation, because they will pay less for less waste to be collected from them. Their waste separation efforts will have a monetary reward;
– It is a direct implementation of the "polluters pay" principle stated in WFD.

In order to establish such system, the first step should be a decoupling of waste fee form other communal service bills, like "municipal tax" or "fee based on house size", which is nowadays common in Ukraine[38]. Creating a separate position as "waste collection fee" in utility bill is crucial. Simultaneously, a system for a waste collection fee calculation based on the collected amount of weight should be introduced.

In rural areas price would be charged per residual container per week, and Civic Amenity sites will be organized in every area providing a small monetary reward for separated waste brought there. It is considered economically possible to find a margin for such monetary driver, minding the respective increase in the quality of recyclables. In the urban household, the customer will have to pay for the amount of collected different containers (for different waste fraction) per month/week. The way bigger fee would be charged for residual MSW bin so it will be an economic driver for waste separation.

A rather different picture is with highly urbanized areas in Ukraine, which usually consist of multi-store houses of 5 to 18 stores, that might include up to 500 households. It is challenging to organize a good PAYT

system there. One of the possible ways to overcome such difficulties is the introduction of specially marked bags for different waste streams. Meaning that waste will be collected only in the form of unified bags, with a different marking for different waste streams. Such bags will be sold for a certain price in a supermarket. Bags for mixed waste will have the highest price, bags for dry recyclables/bio waste will be significantly cheaper, but not free of charge. The mentioned system will need to be controlled on a level of “housing exploitation office” and local officials from each house. A responsible individual should control the quality of sorting by rejecting wrongly separated bags into “mixed amount” with appropriate fees. Cumulative provision on evaluated waste fees provided in Table 5.8.

Table 5.8– Financial aspect of proposed collection schemes

Housing type	General fee evaluation
Individual houses in Rural areas	Base fee + Moderate fee per residual container
Individual houses in Urban areas	Base fee + High fee per residual container per week + Low fee per other 4 containers per week
Multi-store buildings in Urban areas	Base fee + High price per residual bag + Moderate price for mixed recyclables bag + Low price for bio waste bag Or Individual agreement
Multi-store buildings in Rural areas	Base fee + High fee per residual price + Low price for mixed recyclables bag + Low price for bio waste bag

5.7.1.3 Recommendations regarding bring collection points system

Conceptually, bring collection system is a group of collection points (green points) which are targeting a certain waste type for centralized collection of recyclables. Such a system might be performed as a complementary or additional system to the door-to-door collection. For current strategic planning, it is proposed to target with green points primary urban areas, as it will not be targeted by separate recyclables collection door-to-door.

An average number of bringing collection points across the EU is 190 per 100,000 of inhabitants[59], which gives an approximate number of 85,000 of such points for all Ukraine. But since multi-store buildings will have only mixed recyclables collection, bring points with zero charges might become a good option for urban citizens to decrease their collection fee. Therefore, for big cities, the number of bringing points per citizen should be higher. A precise amount is out of the scope of current planning, but it will probably increase mentioned 85,000 significantly.

Nowadays, some bring collection points are in place in Ukraine, and that is one of the only ways to extract recyclables. But there are no government standards for such facilities which lead to a variety of

different container shapes, colours and markings even within one residential area of the city. Moreover, often such bring points is quickly turned into illegal dump sites, because of the lack of attention from police or governmental administration. Particular actions proposed to bringing point establishment:

- Develop a unified design for collection point for urban and rural areas;
- Collection point should be able to receive all major waste fractions separately, including WEEE, batteries;
- Calculate the needed amount and location of such points for each settlement on appropriate municipal level, with a big emphasis on technology in an urban area;
- Establish a monitoring system for collection point performance and technical state;
- Locate such points preferably near government/police offices in order to decrease the amount of illegally landfilled waste;
- Instruct the police to keep close attention to such points during their patrols, put emphasis on the proper implementation of already existing fines in that regard.

5.7.1.4 Recommendations regarding Civic Amenity sites

The nature of Civic Amenity sites is similar to bring points but more advanced. Such sites might have staff and a proper building, due to their goal – target not usual MSW fractions, but mainly WEEE, batteries, bulky waste, furniture. So the main feature of such facilities is the separation of mentioned waste from residual MSW stream. In most cities across the EU, where such facilities are in place, they still receive other 5 MSW fractions (bio waste, paper, glass, metal, plastic). In terms of current waste management planning, it is proposed to build such sites in every city with more than 20,000 inhabitants as it will be a go-to place for WEEE and other hazardous waste collection. Usually, such sites are built with sufficient parking area for receiving/shipping waste and as many containers for different MSW fractions, as economically viable.

Studies [48], [59] propose different calculation methods for the required amount of mentioned facilities, ranging from 3 sites for 10,000 people to 1 site for 20,000 residents. It is possible to assume a 3 site for 20,000 residents value as interpolated for approximation. Actual decision about the precise number of required facilities should be decided on a municipal level regardless. Therefore, by ranging Ukrainian cities by size it is possible to approximately calculate overall requirement in Civic Amenity sites.

Table 5.9 – Assessment of required Civic Amenity sites

Minimal number of residents	Maximal number of residents	№ CAs per city	№ Cities	Total CAs
20 000	100 000	3	170	510
100 000	500 000	6	36	216
500 000	1 500 000	9	8	72
Kyiv	2 800 000	15	1	15
The total required amount of Civic Amenity sites required				813

In total there are 813 facilities required in terms of assumed approximation, but some of them have

already been established. There is no accurate data on the precise amount of Civic Amenity sites in Ukraine, but the existing number is certainly not sufficient.

5.7.1.5 Extended producer responsibility scheme

Extended producer responsibility(EPR) is an economic instrument that should be adopted in Ukraine in order to facilitate the waste management principle “polluter pays”. Such approach states that producers' responsibility for reducing their impact on the environment and their products management extends over the entire life cycle of products: from the selection of materials and design to the expiry of its exploitation. "Producers" are economic entities that supply products to the market and can be direct producers or importers of products[3].

Current strategic planning considers it extremely important to fully implement the EPR scheme for packaging waste, in order to achieve recycling targets for this waste stream. In addition, taking into account the high proportion of biodegradable waste in packaging waste stream, recycling, and recycling of packaging waste will have a significant impact on the reduction of biodegradable waste from landfills.

In order to implement EPR in practice, the Ukrainian Government should obligate producers to create programs of product management. According to such programs, products after its use would be collected, recycled or disposed of in an environmentally-friendly way. Producers will be responsible (including financing) for the implementation of developed programs. For that reason, it is required to create a government body which will control all EPR system and will be empowered to influence producers.

Technically, the EPR scheme is on the legislative side of things, therefore it is impossible to provide clear practical guidance on its implementation in terms of current strategic planning. But it is strongly emphasized that such a scheme should be created as soon as possible, based on best EU practices.

5.7.2 Practical recommendations for landfill system improvement

Disposal of MSW is indeed the last preferable option in the waste management hierarchy, but it is also one of the most important in current Ukrainian waste management background. In current strategic planning, as it was discussed in the calculation chapter, even after the introduction of the new separate collection system and construction of many waste treatment plants, Ukraine will still landfill 45% of collected MSW in 2030. Therefore, it is important to provide recommendations on the improvement of landfills. As it was discussed in chapter 4, the main problems with the current landfilling system in Ukraine is an outdated, environmentally harmful landfill sites and illegal dump sites.

Dump sites is a big problem, which is not being addressed in a proper way. In 2018 there were created around 26,000 illegal dumps, and 99% of them were identified and closed[36]. The same trend goes for

previous years. It provides one with a conclusion, that even though there is a work being done to solve dump sites problem, the actions in that regard is “reactive”, and not “proactive”. As Ministry of regional development of Ukraine states, most of the illegal dump sites are created in rural areas where waste management system is not developed enough, or not working[60]. More particular obstacles may be various – insufficient waste transportation equipment, poor contracting with waste operators, corruption, etc. But the main driver for dump sites is insufficient to control and punishment system. So, the measures proposed, in terms of current planning, are on the administrative part of things, not technical:

- To straighten penalties for illegal dumping which will be distributed among residents of a particular area to promote public awareness / To shift illegal dumping into the criminal code, not administrative with appropriate punishments;
- To introduce monetary reward for information about illegal dump sites;
- Possibly create a system for identification of dump sites using satellite images;
- Introduce regular inspection of closed dump sites in order to prevent its future usage.

The second part of the waste disposal problem is an outdated conception of landfills system. Previously, most of the times, each municipality or city was able to construct its own landfill, based only on personal needs. Additionally, such landfills were not properly inspected on their environmental harmfulness or technical standards. Naturally, such landfills are not representing some established unified system, but, rather, a random amount of landfills of poor quality.

Therefore, current waste management planning suggests to start with a full and precise assessment of current landfills and simultaneously develop a new system of future “cluster” landfills. Such a system means the development of a map of “clusters” or areas with certain waste generation and population size. Based on that map, it is required to assign a landfill site with sufficient capacity to each cluster, and locate them appropriately to calculated capture radius. At the same time, it is advised to determine which currently existing landfills are in line with new “cluster” system, and might be included in it (with appropriate repair and renovation), and which should be closed permanently. Recommended action plan in that regard is the following:

- To develop and approve on a national level a new set of environmental, technical and exploitation requirements to landfills, based on respective European legislation;
- Each of 25 Ukrainian municipalities will evaluate respective capture radiuses and “cluster” landfill locations. It is important to note, that optimal clusters are not necessary will be located within the boundaries of one particular municipality, therefore such work will require inter-municipal coordination;
- Current landfills within each municipality should be inspected in order to define whether they are able to meet new environmental standards and, therefore, to be included in the new landfill system;

- To approve on a national level a set of legal financial guarantees. Such legislation will secure the fact that construction of new capacities, closure, renovation, and deactivation with further monitoring of existing landfill will be covered from the residential waste management fee;
- Until 2023 to start construction of new “cluster” landfills. It is advised in[48], that the minimal economically viable requirements for new landfills are to capture the area with at least 150,000 inhabitants and generation of at least 50,000 tonnes of MSW annually. The most optimal decision will be an area of capturing with 400,000 inhabitants. That will require a new system of around 100 landfills;
- When a new landfill will be ready to operate, the municipality should secure an environment-friendly closure of existing landfills, accordingly to developed “closure plan” for each facility;

As a result of such ambitious changes, Ukraine will have a system of 100 (the precise number should be evaluated through statistical calculations) environmentally-sound landfills, instead of 6000 mostly outdated hazardous facilities as of today.

Since Ukraine will significantly decrease the number of existing landfills, it is required to create a system of waste reloading stations. Such stations are facilities where waste transportation vehicles will drop-off waste in order to collect it into bigger shipments and further send it to “cluster” landfills or other waste treatment facilities. It is assumed that such stations are not viable to build when the distance of further transportation is less than 50 km, or where residential population covered by the waste management system is less than 50,000 people[48]. In that case, it is possible to transport waste directly using vehicles. In other word mentioned stations should be built only if their construction will help to reduce waste transportation expenses. Therefore, such an assessment should be performed on municipal or lower management levels.

5.7.3 Practical recommendations in terms of waste-to-energy facilities

According to the provided table, Ukraine has to significantly increase available capacity of waste treatment in all regards. As for the waste-to-energy share, by a strategic plan, Ukraine has to send for incineration around 1,8 million tonnes of MSW in 2030, which is almost 7 times more than it was possible in 2018. The total amount of incinerated waste in Ukraine in 2018 is 207,863 tonnes, and the total available capacity was 283,824 tonnes, which means that the load was close to only 70%[7], [42]. It means that between 2019 and 2023 Ukraine have to build and put into operation a sufficient amount of waste-to-energy facilities to process 0,87 million tonnes of MSW, which gives an additional 600 thousand tonnes annual capacity.

Table 5.10 – Required installed capacities for WTE

Required capacity	**2018**	**2023**	**2026**	**2030**
Waste-to-energy, tonnes	283 824	870 905	1 289 490	1 838 169

Since there is one existing waste to energy incineration plant in the city of Kyiv which needs modernization regardless (to be able to comply with “other treatment” according to EC regulations), it is viable to install additional incineration units to that plant, in order to increase its capacity to 500,000 tonnes annually or 1,370 tonnes per day. Additionally, other 500,000 tonnes plant needed to be built in different waste management area until 2023. That will secure a 1 million tonnes capacity, which is enough for the 2023 year, according to provided strategy. The mass burn will be a technological type of such incineration facilities, as it is only technology which might secure such amount of processed waste. A suitable place for such facility will be geographical Area 2, particularly the city of Dnipro which is home to more than a million inhabitants. Such an area as a whole, have sufficient waste generation in order to secure a sufficient waste stream for incineration.

As for the next milestone years of 2026 and 2030 – cumulative waste incineration installed capacity should be increased for another 700,000 tonnes according to strategic planning. So it is proposed to construct two new plants with a capacity of 400,000 tonnes, one in each time period. Again their locations should be at some bigger cities with great populations. Suitable candidates are cities of Kharkiv and Odessa of Area 4 and Area 3 respectively. Both of their populations are close to 1,000,000 people and there is enough MSW to feed named facilities.

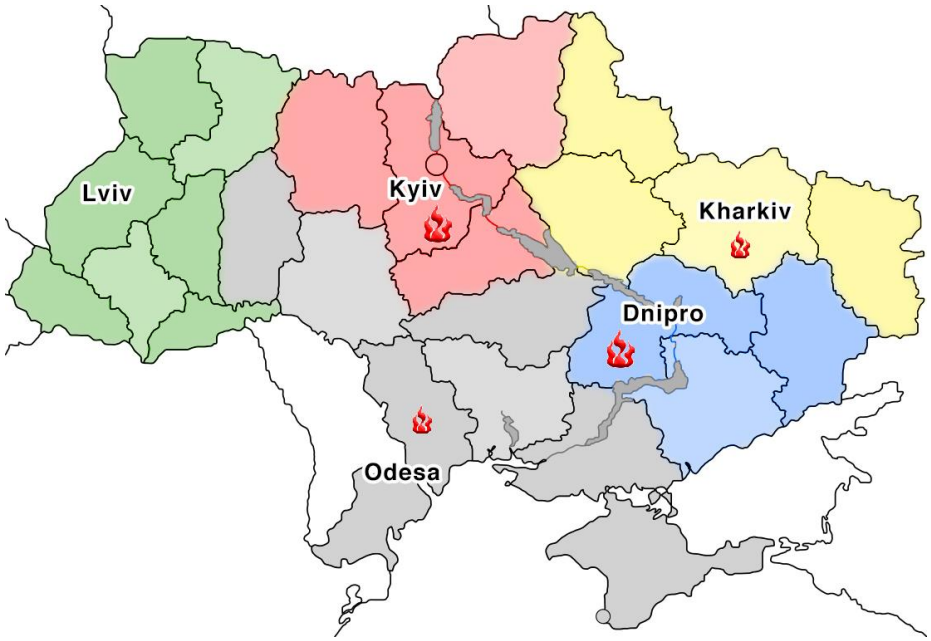


Figure 5.10 – Proposed locations for Incineration plants

Overall it is to be said that required construction projects are very expensive, and waste-to-energy facilities are not profitable in a long perspective, but it is needed measure. Moreover, in the 2030 year, such plants will only process around 16% of all collected MSW, which is acceptable from the standpoint of the waste hierarchy. In total, three new facilities should be built and one should be renovated and extended.

5.7.4 Practical recommendations in terms of Organic Valorisation facilities

In terms of current strategic planning, as it was mentioned previously, organic valorization is a technology to be used for the treatment of separately collected bio waste. That is an important waste stream, as EC states treatment of biodegradable waste (bio waste is a bigger share of it) as one of its priorities. Moreover, collection and appropriate treatment of bio waste also increase recycling rates for other waste fractions[59]. Table 5.11 shows the amount of bio waste to be treated in milestone years according to performed calculations.

Table 5.11 – Required installed capacities for Organic valorisation

	2018	2023	2026	2030
Organic valorisation, tonnes	0	778 339	1 132 312	1 635 639

As it is visible from the provided table, nowadays in Ukraine there are zero organic valorization plants in place. It is understandable as bio waste is not collected in Ukraine separately yet, and, therefore, such facilities do not have any practical value. However, since current waste management planning proposes a separate waste collection of bio fraction, there is an undeniable need in the construction of organic valorization plants. In 12 years it is planned to establish a sufficient number of plants to treat 1,64 million of tones/year of separately collected bio waste, such technological leap is not easy to make. However, looking at Figure 5.11 it is visible that some EU states achieved similar results in the past. Spain, for example, increased the cumulative capacity of its organic valorization plants from zero to 1,5 million tonnes/year in eight years.

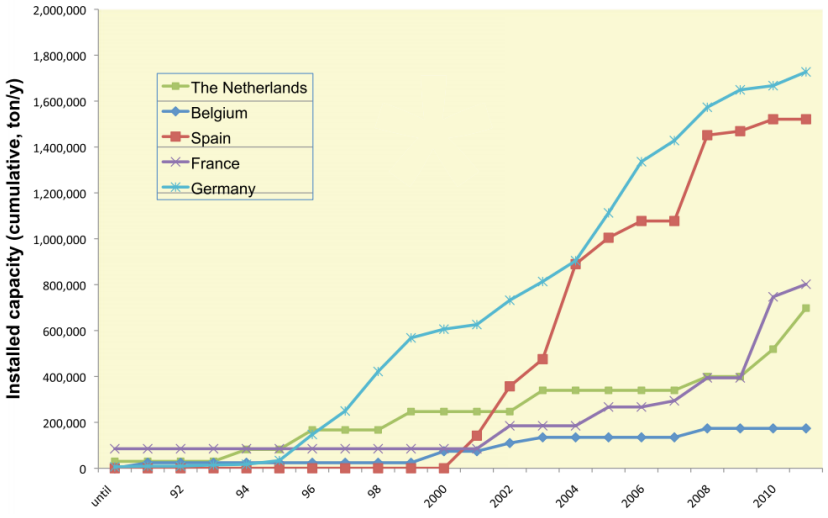


Figure 5.11 – Installed Organic Valorisation capacities in EU[61]

One of the most important decisions to make is about the size of future plants. Across European

countries there is a big variation of average organic valorisation plant capacity, average installed capacities are ranging from 10,000 to 60,000 ton/year. Spain, who showed a good example on progress in such technology have a 55,000 tonnes plants installed on average, Germany has the biggest cumulative capacity for organic valorisation, but the average plant capacity is 25,000 tonnes annually[61]. A study [62] suggests that for economic reasons plants should be at least 30,000 tonnes capacity, and preferably even 40,000 to 50,000 tonnes annually if there are no additional restrictions.

In order to implement the proximity principle, it is viable to construct organic valorisation facilities in each geographical area. Table 5.12 provides a possible building order for Ukraine. Each of that area having a "core" municipality with more than 1,000,000 inhabitants, it is proposed to construct a big organic valorisation plant there first. It is also assumed, that separate bio waste collection will have a more rapid development in such "core" municipalities than in other cities in the area. The city of Kyiv with 2,6 million residents will have a 200,000 tonnes biological treatment plant, which should be made of 3-4 combined digestion units. The rest of the "core" cities will construct 100,000 tonnes plants. In areas 2,3,5 an additional 50,000 tonnes annually plants will be simultaneously put in operation. In years 2023-2026 Ukraine would have to install 8 additional 50,000 tonnes plants in other municipalities of respective geographical areas. And from 2026 to 2030 each is will add two more plants to secure the required capacity for the year 2023.

Another important issue is siting of a particular plant, not in terms of municipalities, but in terms of precise place within the region. Biological treatment needs to utilize its useful and by-products in the correct way. Biogas, digestate or compost, extracted recyclables, and hazardous leachate should be treated in the most efficient way. Such plants may cause odour problems and require a lot of areas to be built. One of the possible decisions, supported by current waste management planning, is to use an existing landfill as a construction site. That is a possibly good decision as rest fractions from the process will be immediately correctly disposed of. A lot of landfills in Ukraine has a system of landfill gas utilization[60] which might be used for biogas resulted from organic valorisation. Such sites also have a transportation system already in place, which will help to reduce the environmental burden of newly build plants. Generally, such siting conception should be further researched.

Table 5.12 – Proposed building order for Organic Valorisation facilities

2023	**MSW share**	**Biowaste collected, tonnes**	**Plant 1, tonnes**	**Plant 2, tonnes**	**Plant 3, tonnes**	**Plant 4, tonnes**	**Plant 5, tonnes**	**Total capacity for 2023**
Area 1	25,1%	195709	200 000	–	–	–	–	200000
Area 2	20,65%	160774	100 000	50 000	–	–	–	150 000
Area 3	18,7%	146149	100 000	50 000	–	–	–	150 000
Area 4	15,3%	119331	100 000	–	–	–	–	100 000
Area 5	20%	156376	100 000	50 000	–	–	–	150 000
Total	*100%*	*778339*						*750 000*

2026	MSW share	Bio waste collected, tonnes	Plant 1, tonnes	Plant 2, tonnes	Plant 3, tonnes	Plant 4, tonnes	Plant 5, tonnes	Total capacity for 2026
Area 1	25,1%	284713	200 000	50 000	50 000	–	–	300 000
Area 2	20,65%	233891	100 000	50 000	50 000	50 000	–	250 000
Area 3	18,7%	212615	100 000	50 000	50 000	–	–	200 000
Area 4	15,3%	173600	100 000	50 000	50 000	–	–	200 000
Area 5	20%	227492	100 000	50 000	50 000	–	–	200 000
Total	*100%*	*1 132 312*						*1150 000*
2030	**MSW share**	**Bio waste collected, tons**	**Plant 1, tonnes**	**Plant 2, tonnes**	**Plant 3, tonnes**	**Plant 4, tonnes**	**Plant 5, tonnes**	**Total capacity for 2030**
Area 1	25,1%	411272	200 000	50 000	50 000	50 000	60 000	410 000
Area 2	20,65%	337859	100 000	50 000	50 000	50 000	80 000	330 000
Area 3	18,7%	307124	100 000	50 000	50 000	50 000	50 000	300 000
Area 4	15,3%	250768	100 000	50 000	50 000	50 000	50 000	250 000
Area 5	20%	328615	100 000	50 000	50 000	50 000	80 000	330 000
Total	*100%*	*1 635 639*						*1620 000*

5.7.5 Practical recommendations to in terms of Mechanical-Biological treatment facilities

As it was discussed above, mechanical-biological treatment plants will contribute 27% of planned MSW treatment capacities in 2030 in Ukraine. Such a high number is dictated by the need for the processing of mixed MSW, which will be equal to 50% out of all collected waste in Ukraine in 2030. To put such value in a global perspective, Figure 5.12 shows the share of MBT technologies in MSW generation in 2010 in Europe.

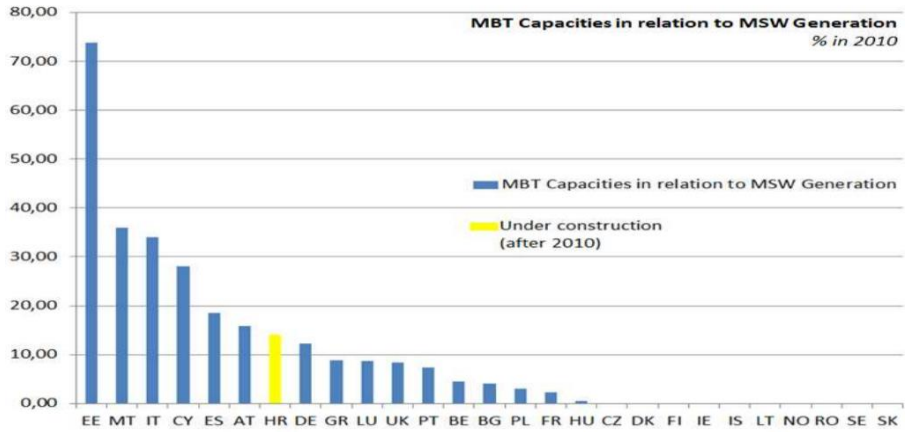


Figure 5.12 – Share of MBT capacity in relation to MSW generation of EU member states[63]

It is visible that in the current scenario Ukraine will take one of the leading positions in that regard. But it is to be noted, that overall generation of MSW in most of these countries are much bigger than Ukrainian, therefore in absolute terms, Ukraine will not have such a high position. In absolute terms, by the end of 2030, Ukraine will have to establish a sufficient amount of MBT plants to process 3 million tonnes of MSW annually.

Table 5.13 – Required installed capacities of MBT

	2023	2026	2030
Needed capacities	1 074 487	1 841 115	3 163 401

As it was mentioned in 5.4.2, MBT abbreviates a range of different waste management technologies, but in terms of current waste management planning, the emphasis is made on MBT with the anaerobic digestion system. It is dictated by the fact that over time, after 2030, Ukraine will continue to improve a separate collection, including bio waste separate collection, which means that MBT for mixed MSW after some time may not be provided with sufficient input material, as less MSW will be collected mixed. It is assumed, that having the anaerobic digestion MBTs will allow in future to treat there separately collected bio waste as well, therefore such a solution is more tempting in terms of diversification of future opportunities. Moreover, RDF type MBTs are proven to be not viable on a market.

A to performed calculations, in 2023 Ukraine should be able to treat 1 million tonnes of mixed MSW on MBT facilities. As of 2018 Ukraine has not put any MBT plants in operation[35], but fortunately, there are some plants, which are built already or on a final stage of construction[42]. In order to evaluate the needed capacities of MBT, it is required to take a look at already contracted plants. As it was mentioned in Chapter 4, cities of L'viv and Kharkiv each planning to put MBT facilities with anaerobic digestion in operation until 2020-2021. Future plants will have capacities of 240,000 and 350,000 tonnes annually respectively. The city of Rivne already has a 120,000 tonnes plant, which is still not in operation for legislative reasons[42]. Cumulatively it provides a capacity of 710,000 tonnes is already planned, which is 70% of needed capacity in terms of our strategy until 2023. But it is also important to look at the location of such facilities, meaning to which particular geographical Area such plants belong. Table 5.13 provides such data.

Table 5.13 – Available MBT plants and projected required respective capacities

	Contracted capacity 2018, tonnes	**Projected Mixed MSW 2023, tonnes**	**Projected Mixed MSW 2026, tonnes**	**Projected Mixed MSW 2030, tonnes**
Area 1		270 174	462 938	795 419
Area 2		221 947	380 302	653 435
Area 3		201 757	345 707	593 993
Area 4	350 000	164 735	282 271	484 997
Area 5	240 000 +120 000+30 000	215 875	369 897	635 557
Total	**710 000**	**1 074 487**	**1 841 115**	**3 163 401**

It is visible that Areas 1,2,3 has not contracted any MBT plants, but Areas 4,5 contracted enough plants to process all mixed MSW, as projected by our calculations, even for the year 2026. According to that, in terms of current waste management planning it is proposed to start building MBT plants in first three geographical areas immediately, but as for Areas 4,5 – construct additional small MBT capacities until 2030. Financial data provided in [64] made it possible to optimize a CAPEX and OPEX costs for different size of MBT plants, Formula 5.21.

$$M = [a*(CAPEX_{200} + OPEX_{200} \times 20)] + [b*(CAPEX_{120} + OPEX_{120} \times 20)] + [c*(CAPEX_{100} + OPEX_{100} \times 20)] + \\ + [d*(CAPEX_{60} + OPEX_{60} \times 20)] + [e*(CAPEX_{25} + OPEX_{25} \times 20)] \quad (5.21)$$

Where M is an objective function to be minimised; a,b,c,d,e – number of constructed MBT plants with 200,120,100,60,25thousand tonnes capacity respectively; CAPEX,OPEX – capital and operational expenses of MBT plants with respective capacities.

According to such optimization, it is more economically viable to build bigger MBT facilities, but the principle of proximity does not allow the concentration of all installed capacity in one place. Therefore, firstly, it is proposed to build a 200,000-250,000-tonnes plants in “core” cities of Areas 1,2,3 – Kyiv city, Dnipro city, and Odesa city. That will secure all of the named Areas with sufficient capacity to meet the year 2023. After that, until 2026 it is advised to build smaller plants in Areas 1,2,3 – with capacities 25, or 60 thousand tonnes. And until 2030 it is proposed to build a number of small capacities in lesser cities of all 5 Areas. This data is presented in Table 5.14.

Table 5.14 – Proposed building order for MBT plants

Area	Additional MBT capacity until 2023, tonnes	Projected Mixed MSW 2023, tonnes	Additional MBT capacity until 2026, tonnes	Projected Mixed MSW 2026, tonnes	Additional MBT capacity until 2030, tonnes	Projected Mixed MSW 2030, tonnes
1	250,000	270 174	100,000+2*60,000	462 938	3*60,000+ 8*25,000	795 419
2	200,000	221 947	100,000+60,000+ 25,000	380 302	5*60,000+ 25,000	653 435
3	200,000	201 757	100,000+60,000	345 707	4*60,000	593 993
Area	**Additional MBT capacity until 2023, tonnes**	**Projected Mixed MSW 2023, tonnes**	**Additional MBT capacity until 2026, tonnes**	**Projected Mixed MSW 2026, tonnes**	**Additional MBT capacity until 2030, tonnes**	**Projected Mixed MSW 2030, tonnes**
4		164 735		282 271	4*60,000+ 25,000	484 997
5		215 875		369 897	4*60,000+ 25,000	635 557
Total	1 390 000	**1 074 487**	1 955 000	**1 841 115**	3 190 000	**3 163 401**

5.7.6 Practical recommendations to in terms of Sorting facilities

Sorting facilities playing an integral part in successful waste management, as they are responsible for the preparation of MSW fractions for recycling. Total needed capacities according to provided calculations are presented in Table 5.15. Another feature of sorting plants is their relatively low capacity, in comparison to incineration, for example.

Table 5.15 – Required installed capacities of Sorting plants

Required capacity	**2018**	**2023**	**2026**	**2030**
Sorting facility	262 109	940 441	1 446 314	2 274 150

Ukraine should establish a web of sorting plants of different capacities over its territory. It is important to take a decision on which level (municipal, regional, national) such plants should be built and, therefore, managed. In other words – to build around 10 big plants or 50 smaller plants. It has been determined in[48], that the minimum capacity for new waste sorting plans with separately collected solid waste as input should be 10,000 tonnes of "dry" recyclables. For large areas of coverage (for example, cities with a population of more than 640 000 people), it may be appropriate to build waste sorting lines with a capacity of 50,000 tonnes. Waste sorting lines with a capacity of about 30,000 tonnes annually are optimal for coverage areas/clusters with a population of 250,000 to 640,000. For settlements with a population of less than 250,000, the optimal capacity is close to 20,000 tonnes annually[48]. Table 5.16 provides insights into the economic aspect of sorting capacities.

Table 5.16 – Approximate cost of Sorting facilities[48]

Sorting plant characteristics		
Plant capacity, thousand tonnes	CAPEX	OPEX/per ton
100	7,500,000 EUR	10 EUR
50	5,000,000 EUR	12,5 EUR
30	3,000,000 EUR	13 EUR
20	2,500,000 EUR	15 EUR
10	2,000,000 EUR	22 EUR

By using such Table 5.21, it is possible to evaluate the most appropriate decision on waste sorting plans construction with the help of an optimization algorithm. Based on territorial division, proposed by current planning, all MSW separately collected for recycling is divided between five areas using their evaluated MSW weight coefficient. Depending on the amount of collected recyclable waste in 2030 in each area was established a goal for the objective function. Such objective function M was a simple evaluation of capital and operational expenses for each sorting plant (by capacity) over 20 years, formula 5.22.

$$S = [a*(CAPEX_{100} + OPEX_{100} \times 20)] + [b*(CAPEX_{50} + OPEX_{50} \times 20)] + [c*(CAPEX_{30} + OPEX_{30} \times 20)] + \\ + [d*(CAPEX_{20} + OPEX_{20} \times 20)] + [e*(CAPEX_{10} + OPEX_{10} \times 20)] \quad (5.22)$$

Where S is an objective function to be minimised; a,b,c,d,e – number of constructed plants with 100,50,30,20,10 tonnes capacity respectively; CAPEX,OPEX – capital and operational expenses of sorting plants with respective capacities.

By applying a linear conjugate gradient method for optimization – the best financially wise decision always appears to be a construction of the biggest plant possible. But it was necessary to introduce restrictions – since each one of the geographical areas has only 1 city with 1,000,00 populations there was only one plant with 100 thousand tones capacity available in terms of calculations. Areas 1,2,5 were allowed to have 3 plants of 50,000 tonnes, areas 3,4 – only two of such plants. These restrictions are in line with the proximity principle. Results of such optimization are provided in Table 5.17.

Table 5.17 – Proposed building order for Sorting facilities

	MSW share	Total MSW to sort 2030, tonnes	Number of needed sorting plants with appropriate capacity			
			100,000t	**50,000t**	**30,000t**	**20,000t**
Area 1	25,1%	571 784	1	3	5	9
Area 2	20,65%	469 720	1	3	6	2
Area 3	18,7%	426 990	1	2	5	4
Area 4	15,3%	348 638	1	2	5	0
Area 5	20%	456 868	1	2	6	4
Total	**100%**	**2 274 000**	**5**	**10**	**27**	**19**

As a result, we obtained a sorting plant distribution by geographical Areas in accordance with the existing population and projected recyclables to be sorted in 2030. One of each plant of 100,000 tonnes will be located in the big 1,000,000-inhabitant city. Plants with 50,000 will be constructed in other municipal capitals in each of 5 areas as shown in Figure 5.13. To evaluate locations of the lesser capacity plants, local municipalities should carry out their own research as available information is insufficient to perform such detailed assessment. Figure 5.13 shows the possible location of 100,000 and 50,000 tonnesfacilities in Ukraine in 2030. Smaller 48 facilities should be located appropriately.

Two green points on a map indicate existing sorting plants or those which would be put in operation until 2023. In Odessa, there is a 100,000-tonnefacility under construction, and in Ternopil – a 50,000-tonneplant is operating. A number of smaller existing facilities are not shown, but the total projected capacity in 2023 as of right now, without proposed improvements, will reach only 262,109 tonnes.

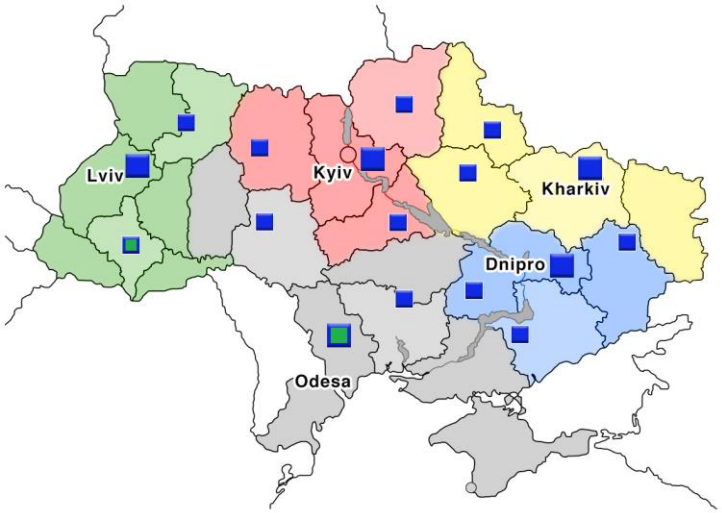


Figure 5.13 – Proposed location for Sorting facilities

It is important to note, those recycling facilities should be built according to evaluated packaging waste generation. Such number of facilities should be able to process 2,5 million tonnes of recyclables in the year 2030. Locations of such facilities are not specified, but they should be distributed among five geographical areas with an emphasis on Area 1.

As for the recycling industry, in 2018 Ukraine recovered 700 thousand tonnes of cardboard and paper products, 120 thousand tonnes of polymers, 50 thousand tonnes of PET bottles, 460 thousand tonnes of glass fibre. Nowadays there are 17 recycling companies, 39 - for processing polymers, 19 - for processing PET raw materials, 16 - for recycling glass. The separate collection system was able to secure only 40% of the existing recycling industry load. Ukraine had to import 400 thousand tonnes of waste for recycling. Based on that, it is possible to conclude that Ukraine has sufficient recycling installed capacity for the first time period under current strategic planning. After that, Ukraine would have to increase the number of existing recycling plants.

5.7.7 Practical recommendations in terms of individual composting

Individual or home composting is considered to be a secondary, but valuable tool for waste management in Ukraine. According to provided calculations, in 2030 individual composting should contribute to 2,5% of all managed MSW in Ukraine. Such number is considered ambitious because the nature of home composting process dictates a high level of responsibility and environmental awareness on personal level form potential contributors to mentioned 2,5%. Since individual composting is suitable mostly for rural areas, it was reflected in calculations. As for practical implementation, the main strategic actions for home composting implementation should include:

- Rapid realization of pilot schemes under strong support from municipalities to evaluate the best approach to home composting implementation.

- The wide informational and educational campaign provided on the level of village municipalities.
- It should be clearly explained that home compost has economic value and could be sold to a neighbour, or used by the producer to save money on fertilizers. The preferable option is to issue brochures or advertisement with solid numbers on possible savings.
- Composting equipment should not be given to a customer for free, as it will not motivate one to use it. Instead, it is possible for each responsible municipality to organize a tender and buy composters in bulk. That will secure a price, lower than the market one and will allow municipalities to sell composter to final customers with the appropriate discount.
- Another economic motivation feature might be the establishment of a discount system which is dependent on the time of composter buying. It means that the first customers willing to buy composter will get a bigger discount than the second etc.
- It is important to make sure that each composter provided in terms of such a campaign had a clear and full customer instruction.
- To secure a returning system, when a household can return composter to the municipality and get money back – it will encourage bigger population share “at least to try” such option.

In 2030, 60% of the rural population is planned to be provided with home composting equipment. There are 5,000,000 households in Ukraine living in rural areas[37]. Using a maximum one household – one composter meaning that a total number of individual composting equipment should be 3,000,000 composters. If the average price on such composter if 30-50 EUR, the total investment will be 120 million EUR, but it will be mostly covered by customers as it was discussed.

5.8 Comparison of Waste Management Plans

As it was mentioned in Chapter 2, there are certain paragraphs that should be present in any waste management plan, and such content regulated by Article 28(1) of Waste Framework Directive. It is considered appropriate to compare developed in current dissertation strategic planning on waste management and already existing planning issued by Ukrainian ministry. Table 5.23 provides such a comparison. It is visible from the table, that developed waste management planning is more in line with EU legislative requirements. It contains more information about the existing waste management background and provides more recommendations for future construction of waste treatment facilities. Moreover, it contains calculations for projected waste generation and recommendation for new waste collection schemes. According to that, developed waste planning is considered a useful document which adds value to existing Ukrainian waste management planning. To be fair, it should be noted, that regional or local waste management plans which will be developed in Ukraine in future years will probably cover its missing points.

Table 5.18 – Major WMP provisions which are required by Article 28(1)[3], [25], [26]

Indicator	Current WMP	Proposed WMP
Analysis of current waste management situation in the geographical entity concerned [Article 28(2)]	Partially	Yes
Measures suggested improving environmentally sound management at all levels of the waste hierarchy [Article 28(2)]	Partially	Yes
Assessment of possible contribution to the implementation of the 2008 Waste Framework Directive objectives, including assessment criteria. [Article 28(2)]	Partially	Yes
Quantity of waste generated by different sources [Article 28(3)[a)].	No	Partially
Quantity of waste generated (according to waste types), and evaluation of the future development of these waste streams [Article 28(3)[a)].	No	Yes
Quantity and destination of waste, according to waste types, shipped from and to the territory covered [Article 28(3)(a)].	Partially	No
Description of all existing waste collection schemes, specification of major schemes by waste types [Article 28(3)(b)].	No	Partially
Assessment of the need for new collection schemes; [Article 28(3)(c)]; specification of major schemes required, where necessary including related investments.	No	Yes
Number and capacity of major waste disposal and recovery installations already in place [Article 28(3)(b)].	No	Partially
Assessment of the need to close existing waste installations, and type of installations that need to be closed, where necessary including the related investments.	No	No
Assessment of the need for additional waste installation infrastructure and major types of installation infrastructure needed, where necessary including the related investments.	Partially	Yes
Special arrangements for certain waste streams, e.g. waste oils, hazardous waste or other waste streams addressed by specific EU legislation [Article 28(3)(b)].	Partially	Partially
Assessment in accordance with the principles of self-sufficiency and proximity (Article 16) [Article 28(3)(c)].	Partially	Yes
Measures established to assure compliance with the proximity principle.	Partially	Partially
Information and criteria for the location of all listed future disposal or major recovery installations [Article 28(3)(d)].	Partially	Yes
General waste management policies, including planned waste management technologies and methods or specific policies for problematic waste. [Article 28(3)(e)]. List of major policy priorities by waste types and by technologies.	Yes	No
Strategies for the reduction of biodegradable waste going to landfills (Landfill Directive, Article 5). [Article 28(5)]; Indication whether or not the recycling/recovery targets for biodegradable waste have been reached or will be reached within the plan — indicate the year, and major strategies applied.	Partially	Yes

6 Conclusions of Master Dissertation

In the current master dissertation, European and Ukrainian waste management legislation and planning were assessed. Present background on waste management environment and its problems were addressed for a whole territory of Ukraine, alongside with aims and goals in that regard. Based on that, it was possible to develop a new waste management plan for Ukraine on the period of 2018-2030 with a purpose to secure appropriate European goals – Strategic Plan.

Such a plan contains description and recommendations regarding two main waste management spheres – waste collection system and waste treatment technologies. Future generation of municipal solid waste and means of its possible management. Appropriate number, capacity, and geographical localization were provided for respectful technologies were it was possible. Economic and legislative recommendations were provided according to a scope of the current dissertation. Since the whole territory of Ukraine was assessed it was not possible to provide detailed guidance on each particular waste management system component, but most of them were addressed at least on a surface. In order to better understand the quality of provided planning, it is compared with an existing document using European legislation as an arbiter.

6.1 Summarised action Plan

As it was shown in Chapter 5, Ukraine has theoretical chances to complete waste management goals provided by European legislation. Considering the Ukrainian starting point in the field of waste management, it is to be concluded that there is a lot of work to be done. Gradually, step by step Ukraine needs to simultaneously improve various waste management aspects – legislation and organization, economical encouraging, technical and material base improvement, waste awareness campaigns. Indeed, such actions will require a lot of effort from key actors in the waste management field – Ukrainian Government, municipal administrations, lower administrative bodies, waste management operators, commercial waste producers and public. Following summarised action plan breaks down key actions to be performed by different waste management actors according to developed Strategic Plan.

Technical actions mainly consist of a construction plan, which is provided in Annex III. Therefore, legislative, economic and social actions are represented further. Responsible Government and private bodies should perform the following actions according to secure Strategic Plan success. It challenging to distinguish particular actors who will be responsible for providing actions, therefore it is not specified. But such actions divided based on their nature. It is considered that the pace of introduced changes will be a decisive factor for the future success of the Plan. All necessary measures of pure legislation or organizational nature shall be performed during the first time span, until 2023. It is uncertain how much time

each improvement task will take, so the provided deadline years are rather for comparison between targets order inside this strategy than actual solid deadlines. Year indicates the year where appropriate action should be implemented.

In terms of Government regulation:

- To sign a Framework Law “About waste management” and all required supporting directives (2019);
- To issue a set of guidance on waste management for lower municipal government bodies and waste management stakeholders, including assessment and renovation of existing all standards in the field (2020);
- Establish proper Government regulation in terms of licensing of waste operators and waste treatment facilities. Hold a regularly checks of their compliance with environmental standards (2020);
- Legally establish proposed separate waste collection scheme as an obligatory. Create an opportunity for local authorities and licensed businesses to sign contracts for waste collection on a transparent basis (2019);
- Establish a ban/ significant taxation on plastic bags and certain types of excessive plastic packaging (2021);
- Establish procedure of organised buying and distribution of individual composting units to the population alongside with discount system implementation. (2020);
- Develop a set of environmental, technical and exploitation requirements to landfills, based on respective European legislation (2019).

In terms of waste management planning:

- National plan on waste management should be reviewed and updated with lacking information according to Article 28, part 3 of WFD (2019);
- Regional plans should be developed in accordance with National Planning based on waste management background of each municipality (2019);
- On a regional level high attention level should be paid the following information:
    - Current waste management situation form technical, financial and legislative perspectives, including data on waste generation clusters, waste generation and morphology prediction;
    - Key actors responsible for different waste management operations;
    - Legislative, economic or social actions which planned to be implemented and their performance assessment;
    - Existing waste treatment facility status and track of existing construction work and required capacities to be installed;

- Waste collection system performance, waste collection coverage, separate collection coverage;

In terms of awareness raising:

- Initiate a nationwide campaign on raising awareness about waste management topic generally, and about approved National Strategy on Waste and its goals in particular (2019);
- Establish a special awareness campaign on individual composting for the rural population (2019);
- To issue a set of guidance on waste management implementation and reporting for lower municipal government bodies and various waste management stakeholders (2019).

In terms of economic drivers, the following practices should be implemented:

- Establish a new system of charges for waste collection which will be able to cover expenses of appropriate collectors (2020);
- Establish a new system of charges/taxation for waste landfill, which will be able to cover operational and renovation expenses of appropriate facilities (2020);
- Pay-as-you-throw system in order to support changes in the waste collection from both waste producers and waste collectors (2020);
- Extended producer responsibility for packaging waste producers, probable implementation of deposit returning system for certain products (2022);
- Implement discussed financial rewards for bringing waste in rural areas (2020);

In terms of waste management system monitoring – Ukrainian municipalities appropriate Ministry cumulatively should establish an annual unified detailed reporting on the following aspects (all 2019):

- Waste sources generated amounts, waste morphology changes
- Waste collection system performance, waste treatment system performance, waste streams maps
- Existing landfills and its state, illegal dump sites map
- Created waste bring points, civic amenity sites
- Individual composting system performance

In terms of technical actions, Strategic Plan advised the following building order for each waste management area, provided in Annex III

6.2 Recommendations for future research

As a result of the developed master dissertation, it is possible to evaluate directions for future research on the current topic. As current work contains both legislative and planning parts, it is natural to provide guidance in terms of both named directions. As it was mentioned in Chapter 3, at the time of the dissertation creation, Ukraine appears to be in an interesting position regarding waste management legislation. Framework law “about Waste Management” alongside with “National Waste Management Plan” are on final stages of approval. Therefore, future research should inspect named legislation after its final signing in order to give an ultimate quality assessment of it. It was mentioned in Chapter 4, that draft versions of named documents are not fully in line with European standards and “Association Agreement”. Therefore, it is important to check if those imperfections were addressed. After that, a number of minor legislative documents, such as separate law “about Municipal Solid Waste Management” should be developed. If according to future research, the Framework Law and NWMP would be still defined as “not compliant” to EU requirements, there is an opportunity to include lacking parts into minor legislative documents.

Simultaneously, future research work should put a major focus on waste management plans, particularly regional plans on a municipal level. Current dissertation proved that existing waste management planning in Ukraine are not fully in line with appropriate EU requirements. As it was mentioned, technically all EU member states might distribute required waste management planning parts between the number of WMPs for different administrative level. It seems like Ukraine decided to leave a major share of important statistical and planning data for lower administrative levels, avoiding its representations in both National Plan and National Strategy documents. Therefore, once developed, it is vital to address the quality of future WMPs on various administrative levels in order to make sure that Ukraine will have sufficient guidance and strategy for waste management. That is the only logical way to secure EU waste management goals and to contribute to overall environmental and health protection in Ukraine.

In terms of Strategic Planning, for future researchers, it is advised to improve calculations performed in the current dissertation. Ukraine nowadays lacks proper research works in terms of MSW morphology identification, but it is considered one of the most important information for future WMPs development. The same applies to the prediction of future MSW generation in Ukraine. The current dissertation contains an approximate evaluation of named parameters, but future researches should use more detailed mathematical models for its evaluation. Of course, that will require a more detailed MSW statistical accounting from respective Ministry. More precise evaluation of named parameters will make it possible to implement more accurate geographical division of Ukraine. A number of waste management Areas and regional distribution between them might be different after better numerical evaluation of waste generation and morphology. Also, it is recommended to widen economical and legislative tools in terms of separate collection system establishment and improvement, as it is considered the cornerstone for proper waste management system in Ukraine. Lastly, future research should evaluate the financial aspect of all provided recommendations, as it was only very briefly described in the current dissertation.

ANNEX I. Assessment of waste management planning across the EU

Thirteen of 27 reviewed WMPs achieved mark “compliant”, which means that all elements of WMPs which are mandatory according to Waste Framework Directive are indeed in place, or covered in other documents like sectoral plans. It is to be said that WMPs rated with “compliant” mark still provide very different levels of provided details.

Only one WMP was awarded “surpassing” mark, which means that particular WMP are not only compliant with all requirements of parts 1,3,5 of 28th article of WFD but also reflects the 4th part of the article – optional features like allocation of waste management responsibilities between private and public actors, evaluation on effectiveness of provided economical instruments, awareness campaigns, historically contaminated waste disposal facilities with appropriate rehabilitation measures[26].

Lastly, out of 27 WMPs assessed, 13 has been marked as “not compliant”, meaning that WMPs has not properly covered all elements required by 28 articles of WFD. It transfers to failing at least one of 18 criteria of the compliance check. Table 2.1 provides more detailed data. The analogical review carried in 2018 for 45 different WMPs gave results – 3 Surpassing, 24 Adequate(Compliant) and 18 Substandard (not compliant). Corresponding to a total of 43% of examined WMPs being partially out-of-line with Waste Framework.

Table AI.1 – Assessed compliance criteria [26]

Does the WMP include information on required elements under WFD?	WMPs rated with YES	WMPs rated with NO	WMPs rated with n/a.
Definition, type, source of municipal waste generated (Art. 28 (3) (a) WFD)	27	-	-
Waste amounts (Art. 28 (3) (a) WFD)	27	-	-
Future waste arising (Art. 28 (3) (a) WFD)	22	3	2
Existing waste collection schemes (Art. 28 (3) (b) WFD)	24	3	-
Major disposal and recovery installations (Art. 28 (3) (b) WFD)	25	1	1
Waste shipments (Art. 28 (3) (a) WFD)	20	2	5
Special arrangements (Art. 28 (3) (b) WFD)	15	2	10
Assessment of the need for new collection schemes (Art. 28 (3) (c) WFD)	25	2	-
Additional waste installations infrastructure (Art. 28 (3) (c) WFD)	22	3	2
Capacity of future disposal and major recovery installations (Art. 28 (3) (d) WFD)	17	4	6
Location criteria for site identification	23	-	4

(Art. 28 (3) (d) WFD)			
Closure of existing waste installations (Art. 28 (3) (c) WFD)	22	3	2
Description of waste policies (Art. 28 (3) (e) WFD)	27	-	-
Planned waste management technologies/ methods (Art. 28 (3) (e) WFD)	27	-	-
Policies for waste posing specific management problems (Art. 28 (3) (e) WFD)	27	-	-
Evaluation of WMP (Art. 28 (2) WFD)	27	-	-
Packaging waste (Art. 28 (5) WFD)	22	5	-
Municipal waste (Art. 28 (5) WFD)	19	8	-

As can be seen from the table, the first two criteria were satisfied by each examined WMP. However, as for “definition, type, source of municipal waste generated” Some WMPs only include a very basic description of which waste streams are included in the municipal waste stream and which are not. Others provide more precise information, such as a clear definition and the composition of the overall municipal waste stream (shares and percentages of specific waste streams of the total amount of municipal waste generated) and specify waste streams in accordance with the European List of Wastes. Projection of future waste generation was found in 22 WMPs out of 27[26].

According to research with a full assessment of 27 WMPs from 11 countries, it can be concluded that there are still major problems with the correct implementation of the waste directive regarding waste management plans creation. 13 WMPs have been rated as “not compliant”, failing to properly address mandatory elements as required by Articles 28 (1) to (3) and (5) of the WFD. The biggest compliance troubles were shown with “biodegradable municipal waste” component compliance. And for the plans that are marked as compliant with waste framework requirements – for sure that plans are fulfilling the minimum level of quality. But among them, there are major differences in provided details and often, targets and requirements based on the WFD and the connected waste legislation are not properly addressed. Information on existing waste collection streams or on progress on main targets on various waste kinds is not sufficient in a lot of cases. Only one WMP among examined provided fully sufficient info on a current state of the branch and for the planned period, together with addressing optional targets in line with a waste framework, and therefore, can be highly recommended from a good practice perspective[26].

Provided information gives a perspective on the main points of emphasis for the Strategic Plan of the current dissertation. Discussed qualitative criteria of European WMPs will be proper guidance for current dissertation. Naturally, the scope of the master dissertation does not allow to fully create a “compiled” WMP under EU regulations. But, as it was shown, even EU member states have troubles to deliver such kind of documents, so the goal is to follow the guide and satisfy as many criteria as possible.

ANNEX II. Waste treatment technologies for the Strategic Plan

In order to evaluate the waste streams for milestone years, it is vital to establish and describe types of technologies which will be used for waste treatment. In terms of current Strategic planning, technologies that will be used for diversion of MSW from landfill and establishing an appropriate shape of the waste hierarchy are the following:

- Organic valorization
- Mechanical-biological treatment,
- Waste-to-energy through incineration
- Waste sorting plants and recycling
- Individual composting

Following part presents a general description, main inputs, outputs and efficiency, justification and limitation of usage for named technological options. Based on such information it will be possible to assign a certain treatment process, or their combination, to certain waste streams and calculate the overall mass balance of waste for the milestone years.

A.1 Organic Valorisation technologies

Organic Valorisation (OV) is a general term which describes biological processing of organic fraction of MSW usually through aerobic (composting) or anaerobic digestion. According to the waste hierarchy, aerobic digestion is a recycle operation, whereas anaerobic one is possible to categorize as recycle or “other recovery” depending on the treatment of obtained gas and other resting. For the sake of current strategic planning, the term “organic valorisation” will be used to describe the biological processing of separately collected organic waste. Therefore, according to European classification, it will be counted as “recycling option”, minding that outcomes, such as compost, or compost-like outputs will be further used, in a way it is described in 5.3.2.

The process of organic valorization means the decomposition of biologically degradable waste. The main outcome products may be a biogas or compost-like outputs, biologically stabilized waste and rest fraction. Another major product is biological rest – digestate, which could be refined to the compost of fuel. To perform waste stream calculations, it is necessary to have a general mass balance of such technology in order to evaluate major outputs and rest fractions. It is possible to use paper [53], which provides a detailed mass balance of anaerobic digestion plant with compost production, fuelled by selectively collected biowaste.

Such balance is used for strategic planning calculations.

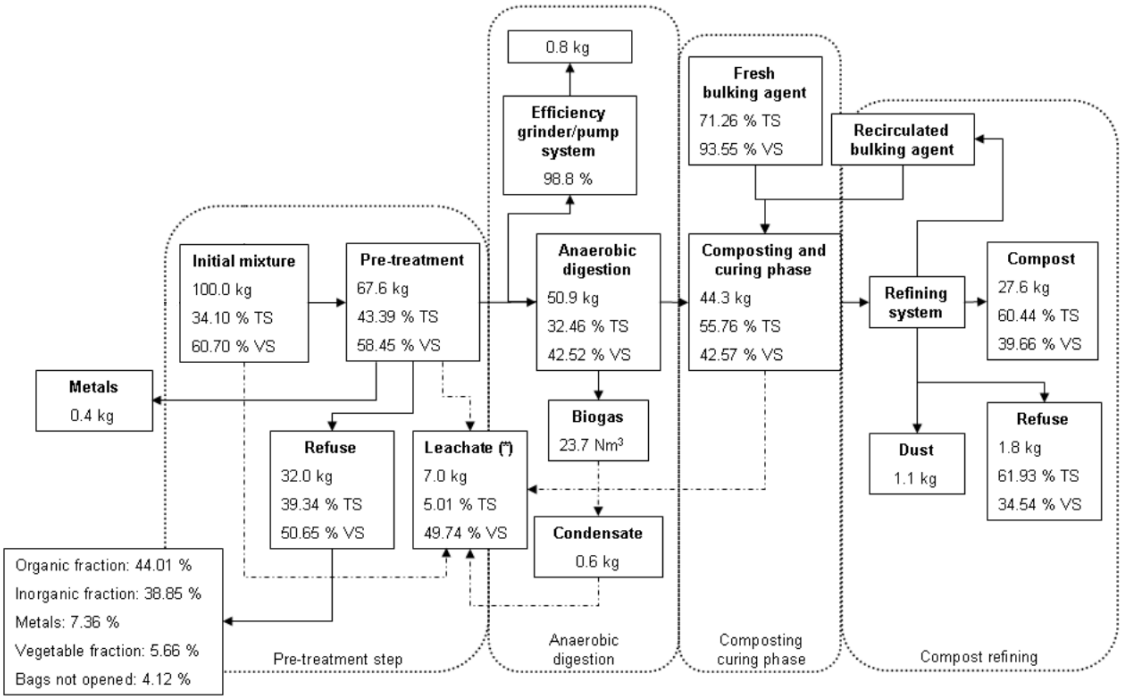


Figure AII.1 – Mass balance of Organic Valorisation Plant [53]

Values provided in Figure 5.3 correspond to the characterization of the input material on each step of the process. Calculations are made on the basis of the treatment of 100 kg of organic fraction of MSW. It is possible to simplify such a scheme into the following major outputs. The provided table is used for further waste stream calculations, particularly to the organic fraction of MSW waste stream.

Table AII.1 – Mass balance of anaerobic digestion plant

Fraction type	Leachate	Recovered metals	Compost	Atmosphere loses	Rest fraction
Percentage as of mass	7%	4%	27,6%	25,7%	35,7%

A.2 Individual composting of biowaste

Usually, individual or home composting means usage of a specified container to which a customer adds organic matter over time to produce compost. Food waste alongside with garden and other green waste is a good feedstock for a future compost output. Such feedstock naturally decomposed with some percentage of compost output. Applying high temperatures in a process allows to obtain a compost in around 3 months.

Different technological decisions are proposed by different manufacturers in terms of equipment, but the real challenge lies on the customer's shoulders. First of all, it requires a significant effort and awareness in order to correctly supply and control the process of composting itself. Secondly, such operations require individually responsible biowaste collection and separation, which have a great effect on the outcome. And lastly, even after a perfectly executed composting process, the owner should use the obtained product in the right way. It is unlikely to be able to sell gained compost, but certainly, it should be used then on the owner's farm or garden.

In terms of current strategic planning individual composting is assigned as a supporting tool for biowaste treatment in rural areas, as it is impossible to introduce a wide system of home composting in urbanized areas and big cities. As for the mass balance, a study [54] suggest the following example of Figure 5.4.

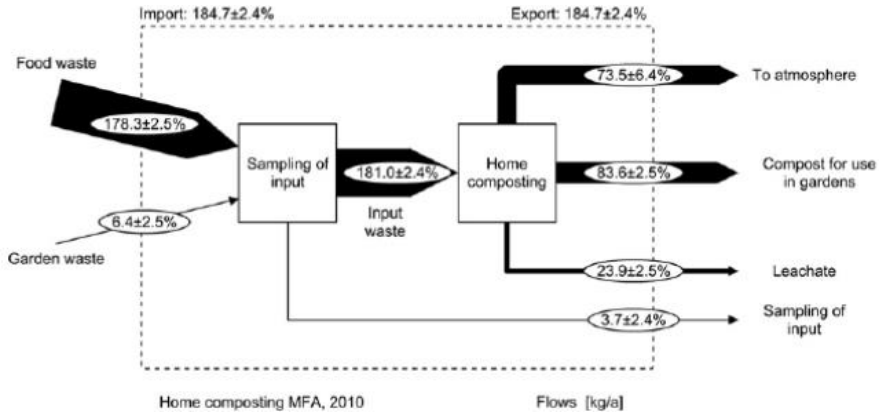


Figure AII.2 – Mass flow analysis of individual composting unit [54]

According to provided mass flow analysis, it is possible to evaluate approximate percentages to use in waste stream calculations.

Table AII.2 – Mass balance of individual composting

Fraction type	Compost	Atmosphere loses	Leachate
Percentage as of mass	46%	41%	13%

A.3 Mechanical-biological treatment of MSW

Mechanical biological treatment (MBT) is a treatment option, which is used for mixed(residual) municipal solid waste. Such a process involves both mechanical and biological treatment. Generally, MBT can be

established for a variety of purposes in many technical combinations. In relation to integrated waste management conception, an MBT system complimentary to recycling and organic valorization, but not a substitute. In relation to EU waste management directives, MBT is helpful in achieving such aims[65].

- Pre-treatment of waste going to landfill;
- Diversion of non-biodegradable and biodegradable MSW going to landfill through the mechanical sorting of MSW into materials for recycling and/or energy recovery as refuse-derived fuel (RDF);
- Diversion of biodegradable MSW going to landfill by:
  - Reducing the dry mass of BMW prior to the landfill;
  - Reducing the biodegradability of BMW prior to the landfill;
- Stabilization into a compost-like output for use on land;
- Conversion into combustible biogas for energy recovery; and/or
- Drying materials to produce a high calorific organic-rich fraction for use as RDF.

The mechanical part of the MBT process might use a variety of different tools, but usually, the main goal of it is the same – extract useful recyclables and extract biodegradable fraction for further biological treatment. The usual biological treatment is either Aerobic stabilization (composting), Anaerobic Digestion or Bio-drying[65].

In terms of current strategic planning, when mentioning MBT, it will be referred to MBT with anaerobic digestion. Anaerobic digestion is a biochemical process which took place in the absence of oxygen and results in the production of biogas. The most common approach where AD is involved is through the stabilization approach. AD in such a context would then be used as the first stage of the biological treatment which focuses on the anaerobically easily degradable waste components. The "biogas" produced during digestion is used to provide internal electrical power generation and heating requirements. Surplus electrical power (and heat) can be sold as renewable energy. The digestate is usually dewatered and treated aerobically (composted; often referred to as “maturation”). The purpose of the second stage is to further stabilize the waste, reduce the mass and reduce the odor of the material. Figure 5.5 shows such an approach

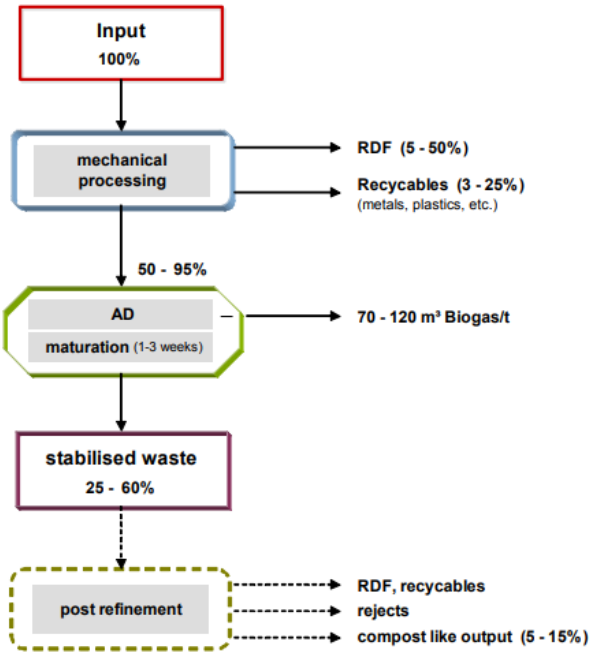


Figure AII.3 – Processing flow of typical MBT+AD plant [55]

As it was discussed in Chapter 4 RDF production is considered ineffective[43], therefore in current strategic planning emphasis will be put on biogas and compost-like outputs production. Mass coefficients table for MBT plants in Ukraine is provided below, and it is used in further calculations.

Table AII.3 – Mass balance of the MBT plant [55]

Fraction type	RDF/SRF	Recovered materials	Biogas	Atmosphere loses	Compost	Rest fraction to landfill
Mass %	5%	3%	6%	23%	10%	50%

A.4 Waste-to-energy incineration technologies

The main objective of MSW incineration is to reduce mass and volume of input waste and also make it chemically inert, while efficiently extracting thermal energy form it. An important feature of such a process is autothermic combustion, meaning that no additional fuel needed to sustain a combustion process. During such combustion there are always around 20% of residuals – fly ash, bottom ash(slug)[56]. Slug falls down during combustion and needs to be treated and landfilled, whereas fly ash needs to be firstly extracted from flue gases and then, again, treaded and landfilled. Such rest fractions may be hazardous and, therefore, require special landfilling technology.

Combustion process itself is performed at temperatures around 850-1450°C, and an important condition for such process is high enough lower calorific value of treated MSW. In terms of current strategic planning, waste-to-energy incineration technology assigned for treatment of mixed MSW. And it is important to have a mixed MSW with a minimum calorific value of 7 MJ/kg on average[58]. According to research[66], mixed municipal solid waste from Ukrainian cities is, depending on the season, may or may not be suitable for autothermic combustion. It is dictated by the moisture content of the collected waste. But there is a way to address this problem with, for example, the introduction of drying pre-processing of feedstock. Such drying may also be done with own flue gases of particular waste incineration facility to improve efficiency.

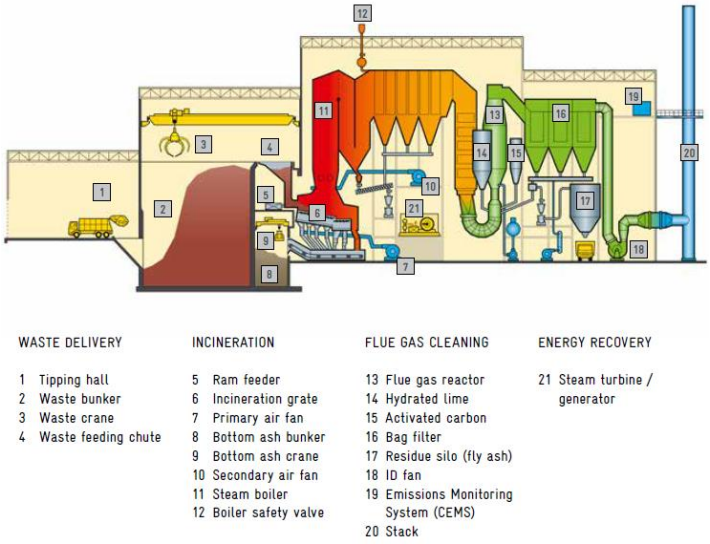


Figure AII.4 – Components of a municipal solid waste incineration plant with flue gas cleaning [56]

Usually, such facilities are demanding in operational aspects – continuous MSW supply, homogenization of feedstock, process and emission control and state-of-art flue gas treatment, appropriate disposal of residuals is required. But, probably, the most important feature of any future or existing facility of such kind is the level of its energy efficiency. According to BAT[67] provided by EC on waste-to-energy technologies, energy efficiency should exceed 0,65 in order for the plant to be counted as “other treatment”, respectfully to existing legislation. Formally, if energy efficiency is lower than 0,65 any incineration plant would be counted as “disposal” process, which makes it useless in terms of achievement of described goals. In terms of current strategic planning, all incineration facilities considered as energy efficient. The approximate mass balance used for current strategic calculations is provided in the table below.

Table AII.4 – Mass balance of typical incineration plant

Fraction type	Fly ash/residuals	Atmosphere loses
Mass %	20%	80%

A.5 Sorting and recycling technologies

Waste sorting lines are constructed to extract valuable materials from waste. There are two main types of such lines: ones are for processing separately collected waste (“clean” sorting), others have a mixed MSW as a feedstock (“dirty” sorting). Clean waste sorting facilities usually using dry components of separately collected MSW fractions – mainly packaging waste: paper, cardboard, glass, metal, and plastics. Sorting facilities could use a combination of automated and manual sorting in their workflow. Depending on the quality of the initial separate collection, the efficiency of a particular sorting facility may reach 80-90%[57], and obtained sorted fractions will have an economic value. All input materials are separated, sorted, mechanically processed and shipped to recycling facilities which can use obtained fractions for final processing. Table 5.9 presents different types of sorting operations in dependency to waste collection.

Table AII.5 – Types of waste sorting operations [57]

Type of waste collection	Sorting type
Mixed municipal waste	‘Dirty’ MRF - removing primarily metal, plastic and glass.
Mixed dry recyclables	Sorting into metal, plastic, glass, and paper for use or further sorting.
Source-separated recyclables	Fine-sorting individual material fractions

Waste sorting plants may use a variety of different sorting technologies such as waste screening, air separation, ballistic separation, film grabber, magnetic separation, eddy current separation, manual sorting, and sensor technologies. Different combinations of mentioned technologies may be used in order to obtain a particular separated waste fraction for each particular plant. Figure 5.7 shows a general workflow of average waste sorting plant.

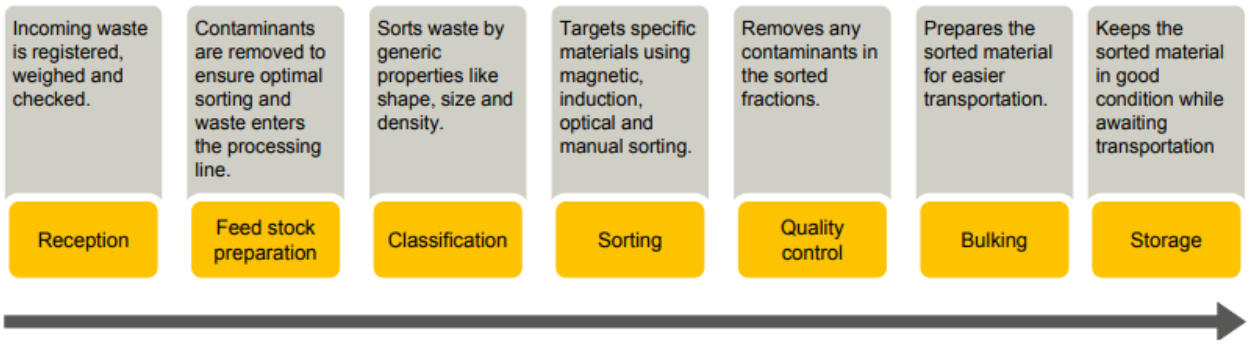


Figure AII.5 – General workflow of waste sorting facilities [57]

In terms of strategic planning for Ukraine, due to the low level of expected resource recovery, waste sorting lines for mixed "residual" waste are not considered to be an appropriate sustainable solution and do not reflect the current best practices in the EU Member States. Use of waste sorting lines to process clean "dry" recyclables, obtained after separate collection of solid waste is considered as an efficient and economically feasible option. Therefore, in provided planning, Ukraine will be using “clean” sorting technologies for mixed dry recyclables and source-separated recyclables. In order to perform calculations, an efficiency of 90% is assumed for sorting technology, which is in line with EU provisions on best practices[57].

It should be noted that sorting facilities are not sufficient for a full cycle of waste recycling, as it represents only part of the recycling chain. After sorting, obtained multilateral should undergo further treatment at the recycling industry. But in terms of current waste stream calculation, sorting plants directly receive collected recyclables, and with appointed 90% efficiency shipping them to the recycling industry. According to provided calculation rules for recycling rate, materials which entered the recycling facility (minding low rejection rate after sorting) should be considered as recycled[17]. That means that in terms of waste stream calculation – efficiency of recycling facility could be assumed as 100%. That makes it natural not to include a separate “recycling” waste stream, but calculate a recycled amount as the amount of sorted excluding rejected share.

ANNEX III. Proposed construction order for waste treatment facilities

The current annex provides cumulative construction order, as it is recommended according to the developed Strategic Plan. All five established geographical areas are represented, and such order based on the calculated collected waste within each Area for each milestone year. Such a construction plan will secure evaluated waste streams, and, therefore, established waste management goals. Data provided in Table AIII.1.

Table AIII.1 – Proposed construction order for waste treatment facilities

Capacities for Area 1	**2023**	**2026**	**2030**
Incineration, kilotonnes	200	-	-
Organic Valorisation, kilotonnes	200	100	110
MBT, kilotonnes	250	220	380
MRF, kilotonnes	150	200	200
Capacities for Area 2	**2023**	**2026**	**2030**
Incineration, kilotonnes	500	-	-
Organic Valorisation, kilotonnes	150	100	80
MBT, kilotonnes	200	185	325
MRF, kilotonnes	100	200	170
Capacities for Area 3	**2023**	**2026**	**2030**
Incineration, kilotonnes	-	500	-
Organic Valorisation, kilotonnes	150	50	100
MBT, kilotonnes	200	160	240
MRF, kilotonnes	100	150	180
Capacities for Area 4	**2023**	**2026**	**2030**
Incineration, kilotonnes	-	-	500
Organic Valorisation, kilotonnes	100	50	50
MBT, kilotonnes	-		265
MRF, kilotonnes	100	130	120
Capacities for Area 5	**2023**	**2026**	**2030**
Incineration, kilotonnes	-	-	-
Organic Valorisation, kilotonnes	150	50	130
MBT, kilotonnes	-	-	265
MRF, kilotonnes	100	180	180

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