DELIVERABLE 3.2 ENVIRONMENTAL, ECONOMIC AND SOCIAL ASSESSMENT OF MUNICIPAL SOLID WASTE MANAGEMENT IN CASE STUDY REGION D., UKRAINE

Project:

“Waste management in transition economies”

WaTra

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Economic, Ecological, Social & Technical assessment of municipal solid waste management system: a case study in D. district, Ukraine

Masters´s Thesis
Submitted in partial fulfilment of the requirements
for the degree of Graduate Engineer or Master of Science

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NOTE:

In the published version the location names were anonymised (e.g. D.district, N.region) and some figures were deleted for the reasons of data handling.

Abstract

The transition of the centrally planned economy in the former Soviet Ukraine to a liberalized market model was a challenging process. Within this transformation process the waste management sector in the Ukraine has been faced a lot of problems over the last two decades. The inadequate handling of mixed municipal solid waste posed many challenges to society.

The aim of this study was to examine the current waste management situation of the D. in Northern Ukraine and to identify possible future scenarios for the development of a modernized system. Within the study seven possible future waste management scenarios were developed and assessed by quantitative and qualitative indicators. Based on the results of the material flow analysis and identified capacities the technical configuration of the assessed scenarios includes treatment of waste via MBT plant, manual sorting lines, open-windrow composting facility and sanitary landfill. The methodological approach developed for the project "WaTra-Waste Management in Transition Economies" consists of 6 economic (Total Annual Discounted Costs of Waste Management System, Cost per tonne of formally collected waste, Revenues, Self-financing Rate, Costs as percentage of approved District Expenditures, Costs as percentage of Salary & Minimum Wage); 6 environmental (Source-separated Collection Rate, Material & Energy Recovery Rate, Landfilling Rate, Biodegradable Waste Diversion Rate, GHG Emissions); 2 social (Social Acceptance, Job Creation Potential) and 4 technical indicators (Technical Reliability, Requirement of qualified Personnel and Maintenance, Sensitivity to Quantity and Quality of input material).

The results of the economic assessment showed that many of the suggested treatment technologies are too expensive and might not be profitable unless higher waste quantities are treated or disposed or inter-municipal cooperation arrangements with other geographically appropriate municipalities are made. Furthermore, the economical evaluation revealed that current consumer tariffs must be increased over time as they are not capable to finance a modernized waste management system.

The environmental assessment revealed that in regard to moving up the waste hierarchy the best results were achieved in scenarios with more separate collected fractions and higher recycling targets. Most of the biodegradable waste could be diverted from landfill in scenario with separate collection of organics. The results of the indicator GHG emissions indicates that scenarios with high shares in recycled materials have the greatest effect on reducing GHG emissions.

The assessment of social acceptance revealed that complex scenarios with more separate fractions collected have the least beneficial results as they require a change of citizens' behaviour. Further, the assessment of the job creation potential showed that more jobs could be created in labour-intensive activities such as separate collection and recycling of waste, whereas the level of employment increased on a lower level in less labour-intensive activities such as landfilling and composting.

Finally, the assessment of the technical indicators showed that scenarios with high requirements at qualified personnel & maintenance and high sensitivity to changes of quantities and quality of input material are more complex and therefore reach lower results.

Key words: municipal solid waste management, Ukraine, waste management scenarios, environmental-, economical-, social-, technical indicators, assessment

Kurzfassung

Der Übergang von einem vormals zentral geplanten Wirtschaftssystem zu einer freien Marktwirtschaft stellte viele ehemalige Länder der Sowjetunion vor große Herausforderungen. In der Ukraine übten diese Veränderungen einen enormen Einfluss auf die Entwicklung der Abfallwirtschaft aus. Die aus dem damaligen System resultierende abfallwirtschaftliche Praxis hat auch heutzutage noch nachteilige Wirkung auf die lokale Bevölkerung und Umwelt.

Im Rahmen dieser Masterarbeit wurde das bestehende Abfallwirtschaftssystem im Bezirk D. in der Nordukraine, untersucht. Das Ziel war es, mögliche Zukunftsszenarien zur Verbesserung des gegenwärtigen Systems zu erstellen und diese anhand qualitativer und quantitativer Indikatoren zu bewerten. Basierend auf den Materialflussanalysen sowie der quantifizierten Abfallmengen wurde für die sieben zukünftigen Szenarien eine Behandlung des Abfalls mittels MBA, händische Sortieranlagen für Altstoffe, offene Mieten-Kompostierung und Deponierung nach dem Stand der Technik gewählt. Die angewandte methodologische Grundlage wurde speziell für das Forschungsprojekt „WaTra-Waste Management in Transition Economies", entwickelt. Die zukünftigen Szenarien wurden dabei anhand folgender Indikatoren im Rahmen der Arbeit evaluiert: 6 ökonomische Indikatoren (Gesamtkosten des Abfallwirtschaftssystems, Kosten pro Tonne formell gesammelter Abfall, Einnahmen, Selbstfinanzierungsrate, Gesamtkosten gemessen an kommunalen Ausgaben und am Durchschnittsgehalt & Mindestlohn); 6 ökologische Indikatoren (Sammelrate der getrennten Sammlung, Material- und Energierückgewinnungsrate, Deponierungsrate, Reduktion von organischem Material auf der Deponie, THG-Emissionen); 2 soziale Indikatoren (soziale Akzeptanz, Arbeitsplatzbeschaffung) und 4 technische Indikatoren (Technische Zuverlässigkeit, Anforderungen an qualifiziertes Personal & Wartung, Sensitivität der Anlagen gegenüber Veränderung der Menge und Qualität des Input Materials).

Die Ergebnisse der ökonomischen Bewertung zeigen, dass viele der gewählten Behandlungs – und Verwertungstechnologien zu teuer sind und möglicherweise sich nur dann als profitabel erweisen, wenn höhere Abfallmengen behandelt werden bzw. Kooperationen mit anderen Gemeinden geschlossen werden. Darüber hinaus ergab die ökonomische Bewertung, dass die derzeitigen Abfallgebühren erhöht werden müssen, da sie nicht in der Lage sind, ein modernisiertes Abfallwirtschaftssystem zu finanzieren.

Die Ergebnisse der ökologischen Bewertung ergaben, dass die besten Resultate in Szenarien mit einer höheren Anzahl an getrennt gesammelten Fraktionen und höheren Recyclingraten erzielt werden können. In Bezug auf die Reduktion von organischem Material auf der Deponie zeigten Szenerien mit getrennter Sammlung von Organik bessere Ergebnisse. Die Resultate des Indikators THG-Emissionen weisen darauf hin, dass Szenarien mit hohen Anteilen an recycelten Altstoffen die meisten TGH-Emissionen reduzieren konnten.

Die Bewertung der sozialen Akzeptanz ergab, je mehr Fraktionen getrennt gesammelt werden, desto geringer ist die gesellschaftliche Akzeptanz, da eine Änderung des Trennverhaltens erforderlich ist. Weiters konnten Szenarien mit arbeitsintensiven Technologien, wie z.B. Recycling, hinsichtlich des Indikators Arbeitsplatzbeschaffung besser bewertet werden.

Schließlich zeigte die Bewertung der technischen Indikatoren, dass Szenarien mit hohen Anforderungen an qualifiziertes Personal & Wartung, sowie hoher Sensitivität gegenüber Veränderungen des Input Materials & der Input Menge sehr komplex sind und daher tendenziell schlechter abschneiden.

Schlüsselwörter: kommunale Abfallwirtschaft, Ukraine, abfallwirtschaftliche Szenarien, ökonomische, ökologische, soziale und technische Indikatoren, Bewertung abfallwirtschaftlicher Maßnahmen

Formatiert: Englisch (Großbritannien)

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List of abbreviations

AOC	Annual Operating Costs
ABF-BOKU	University of Natural Resources and Life Sciences, Austria
AMC	Annual Maintenance Costs
AnTC	Annual Total Cost of waste management
ATPC	Annual Total Personnel Costs
B	Efficiency of CV per working day
BRU	Belarusian-Russian University, Belarus
C	Capacity of one container, m^3
Cap	Capita
CBA	Cost Benefit Analysis
CV	Collection vehicle
DNC	Data Need Catalogue
EADTEC	Equivalent Annual Discounted End-of-life Cost
EADTLC	Equivalent Annual Discounted Total Location Costs
EADTPC	Equivalent Annual Discounted Total Purchase Cost
$EATC_{subsystem}$	Equivalent Annual Total Cost of Subsystem
$EADTC_{SWMS}$	Equivalent Annual Total Costs of Solid Waste Management System
EPR	Extended Producer Responsibility
ERR	Energy Recovery Rate
EU	European Union
FE	Ferrous
GHG	Greenhouse gas
Gl	Glass
G_{rw}	Per-capita waste generation rate in rural areas

IRS	Informal Recycling Sector
K_1	Daily index of irregularity of MSW generation
K_2	Factor considering the number of containers that are being repaired and in reserve,
K_3	Fill factor of the container
K_{eux}	Factor of using CV for the provider of waste removal service
KPI	Key performance indicator
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCU	Local Currency Unit
LF	Landfill
MBT	Mechanical Biological Treatment
MCDA	Multi-Criteria Decision Analysis
Me	Metal
Mil	Million
MiWa	Minimum Wage
MFA	Material Flow Analysis
MRR	Material Recovery Rate
MSW	Municipal Solid Waste
$MSW_{form.coll.}$	Municipal solid waste formally collected
$MSW_{source\ sep}$	Source separated Municipal Solid Waste
MSWM	Municipal Solid Waste Management
N	Number of required CV
N.d.	No data available
Nr	Number
Nb	Number of containers required

NUUE	O. M. Beketov National University of Urban Economy in Kharkiv, Ukraine
Pa	Paper
PAYT	Pay as you throw
Pl	Plastic
P_{noWCS}	Number of inhabitants with no access to waste collection services
Q_{bwu}	Amount of bio-waste generated and uncollected by waste operators
Q_{Dmax}	Maximum daily amount of each type of waste components
$Q_{Subsystem}$	Waste quantities entering formal collection
RBWL	Reduction of biodegradable waste from landfill
Rev_{MBT}	Annual Revenues from recovered material of MBT – facility
Rev_{CF}	Annual Revenues from recovered material of composting facility
Rev_{SP}	Annual Revenues from recovered material of manual sorting line
Rev_{MDR}	Annual Revenues from recovered material from mixed dry recyclables
Rev_{RDF}	Annual Revenues from recovery of RDF
RDF	Refuse Derived Fuel
SalPe	Average nominal salary
S_{bwr}	Share of bio-waste in the total MSW composition
sLCA	Social Life Cycle Assessment
SS	Subsystem
T	Frequency of transportation of each type of MSW, days
TAC_{MiWa}	Total Annual Costs as % of Minimum Wage
TAC_{SalPe}	Total Annual Costs as % of Nominal Average Salary
TC	Town council
TOC	Total organic carbon
TUD	Technical University Dresden, Germany

UAH	Ukrainian Hryvnia
USSR	Union of Soviet Socialist Republics
VC	Village council
WaTra	Waste Management in Transition Economies
WEEE	Waste Electrical and Electronic Equipment
WLR	Waste Landfilling Rate
Yr	Year

1. Introduction

Over the last decades, the quantities of generated municipal solid waste (MSW) have been increased worldwide. While the waste management sector in Western Europe has been subjected to enormous legal, technical and commercial changes over the last years to handle the growing waste amounts, the Ex-Soviet countries are still lagging behind. The transition from a centrally planned economy to a liberalized market model still faces major challenges regarding the proper handling of the increasing volumes of waste produced. Failures of the waste management system lead to massive negative impacts on health, environment and economy. Therefore, former Soviet-Union countries have a high potential for improvement of their municipal solid waste management (MSWM) system.

1.1 Background and main objectives

This thesis aims to assess the MSWM system of the case study region D., located in north-eastern Ukraine by noting the current status quo and develop - based on available data - sustainable future waste management scenarios for the region. The main focus of this thesis thereby is to develop possible future waste management scenarios, present treatment- and disposal technologies used for modelling of the scenarios and to evaluate these scenarios by indicators.

Within the scope of this thesis municipal solid waste refers to household waste and wastes of similar nature and composition[1] (WFD, 2008). Construction and demolition waste and other specific waste streams like for example end of life vehicles and excavation material are not considered in the study. According to Zurbrügg et al., (2012) a sustainable MSWM system can be defined as an integrated system which considers economic, political, environmental, social and technical components. The methodological approach of this study is based on integrated waste management concept and uses most of the above listed components (6 economic, 6 ecological, 2 social & 4 technical indicators) to assess the proposed future waste management scenarios.

The methodological approach was developed within the project “WaTra – Waste Management in Transition Economies”, which supports the sustainable reformation process in Ukraine and Belarus. The project was implemented in the framework of the IMPULSE Programme financed by the OeAD (Austrian agency for international mobility and cooperation in education, science and research). This work was developed and written within this project in the time period from March 2016 until December 2017. For examination of the current system and development of future scenarios a cooperation between scientific researchers, PhD- and Master students from the Institute of Waste Management at the University of Natural Resources and Life Sciences, Vienna, Austria (ABF-BOKU); Institute of Waste Management and Circular Economy – Dresden University of Technology, Germany (TU-Dresden); Department of Occupational Health and Safety – Belarusian-Russian University,

[1] The term “wastes of similar nature and composition” can be generated for examples by: educational institutions of different levels e.g. schools, kindergartens; prison establishments; resorts; beaches; parking; shops; restaurants; cafes; institutions of culture and art etc.

Belarus and Department of Urban Environmental Engineering & Management (BRU) – O.M. Beketov National University of Urban Economy in Kharkiv, Ukraine (NUUE) was established. For that reason, several stakeholder meetings in Vienna, Austria (March 2016), Mogilev, Belarus (November 2016), Dresden, Germany (March 2017) and in Kharkiv, Ukraine (June 2017) took place. Actual waste-related and socio-economic data were provided from local authorities responsible for waste-management in D.. The main findings of this research were presented at the workshop "Scenarios for future development of waste management system in D. district" on 22.07.2017 in Kharkiv, Ukraine. The same methodological approach was used for a case study region in Mogilev, Belarus. The results of the co-study can be found in Sarokina (2018).

1.2 Structure of thesis

The thesis consists of seven chapters. Chapter 1 gives an introduction into the topic and outlines background and main objectives of this thesis.

Chapter 2 deals with an introduction of the case study region and gives an overview of the demographical and geographical characteristics of D.. Also, institutional aspects, waste generation, composition, collection, transportation, treatment and disposal as well as economic and financial data, including current tariffs of the case study region are described. Furthermore, a short description of the waste management system in former Soviet Union is provided.

Chapter 3 presents the methodological approach and methods used for this thesis. At the beginning, an extensive literature review was conducted in order to identify possible methods for the assessment of MSWM systems (chapter 3.1). After this, a data need catalogue (DNC) was developed for the collection and assessment of the existing data on location, see chapter 3.2. Further, from chapter 3.3 on the economic, environmental, social and technical key performance indicators (KPIs), which were selected and developed within the WaTra-project are presented.

Chapter 4 describes the results of the development of possible future waste management scenarios for D..

Chapter 5 presents the treatment- and disposal technologies used for modelling the scenarios. The technical configuration of the chosen technologies was developed together with the project partner TU-Dresden.

Subsequently in chapter 6, the results of seven evaluated scenarios in regard to economic, social, environmental and technical indicators are introduced.

In chapter 7 the results of the thesis are summarized and an outlook on further steps necessary to change the current system is given.

2. Decription of case study, D.

This chapter gives an overview of the demographical and geographical characteristics of the case sturdy region and a description of the waste management system in the former Soviet Union and the current waste management system in the case study region D. in Ukraine.

2.1 Geographical and demographical description

D. is located in north-Ukraine and it is one of the districts of region N (see Figure 1). The district includes one city council (city D.), 7 settlement councils and 7 village councils, including 63 localities (Stolberg et al., 2016b) .

It has an area of 900 km^2 and its population size amounts for about 98,433 inhabitants. About 71% of the whole population live in the urban area of the district (Rayon Administration D., 2016a).

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Figure 1: Location of D. district in N. region (Stolberg, et al. 2016)

The district is located in the steppe zone, climate of the district is moderately continental and the temperatures vary between 21° C in summer and -7° C in winter.

Although D.district is a rural area it has a well-developed industrial infrastructure which produces 5.4% of the industrial production of N region. The biggest companies operate in the field of electricity production, engineering and metalworking, food processing industry, construction and chemical & petrochemical industry. Small enterprises on the other hand operate in the service industry, retail sale and wholesale trade (Stolberg et al., 2016b).

The monthly nominal salary of one full-time employee is about 4,275 UAH (147€[2]) per month and the minimum wage is 3,200 UAH (110 €) per month (Stolberg et al., 2016b).

[2] An exchange rate of 1€ = 28,94 UAH was used for all calculations. Conversion rate from 03.05.2017 (Online Umrechner Euro, 2017)

2.2 Waste management in former Soviet Union

In the centrally planned economy of the former Soviet Union, waste management was not of high priority (Wohmann et al., 2017). Because of weak environmental laws and low public awareness, the rapid industrialization process lead to mismanagement of waste and natural resources (Sim et al., 2013). In the 1980s landfilling was the main method of waste disposal in the former Soviet Union. However, according to Sim et al. (2013) landfills did not fulfil any basic sanitary or environmental provisions. They were mostly not covered and presented health hazards in many areas.

Nevertheless, the amount of MSW generation was lower in the former Soviet Union in comparison to the USA or Europe and included less packing waste (Oldfield, 2005). Shortage of goods, resources and materials led to the increased efforts in reuse, separate collection and recycling of the secondary raw materials that was supported by powerful state propaganda among population. Functioning schemes for reuse and recycling of paper, metals, textiles and plastic as well as packaging waste were already implemented. However, many of the existing reuse and recycling systems stopped functioning after 1990 (Sim et al., 2013).

During the transition period from the USSR to the independent state of Ukraine, the country lost old instruments in waste management that widely stimulated efficiency in waste collection and separate collection of recyclables. Specialized waste management companies changed their main field of operation, the waste management sphere lost its significant financing and the government of Ukraine is still struggling with elaboration, adoption and implementation of the new laws regulating the waste management in the country (Stolberg et al., 2016a).

According to Wohmann et al. (2017), the economic recession and increasing decentralisation are main causes that most municipal waste treatment and disposal as well as container and collection infrastructure have not been replaced since the early 1990s and show a high degree of deterioration.

Nowadays, the standard of MSW facilities and services is still poor in Ukraine, but the country sets serious measures to adopt best practices from EU (European Union) and to establish an integrated MSWM system (GIZ, 2017). An overview of how MSW is managed and current challenges in the case study region are described in the following chapter.

2.3 Current waste management system

Managing municipal solid waste management systems is a major challenge for countries worldwide, particularly for countries in transition like Ukraine. Factors like limited financial resources, lack of adequate treatment technologies and weak legislation lead to poor waste management standards. Like many other regions in Ukraine, D. is faced with an in-effective waste management system which includes according to Stolberg et al. (2016) the following main challenges:

- Lack of reliable data related to waste quantities, composition and characteristics
- Low level of waste collection and transportation system & service coverage
- Illegal dumpsites and non-sanitary landfills

- Insufficient, unsystematic and inadequate processing of recyclables, absence of organic waste treatment
- Lack of inter-municipal cooperation arrangements
- Absence of collection of WEEE (Waste Electrical and Electronic Equipment) and hazardous waste
- Lack of clear regulations and weak enforcement of laws

In the following sub-chapter, the institutional aspects, waste generation, composition, collection, transportation, treatment and disposal as well as financial data and current tariffs of the case study region are described.

2.3.1 Institutional aspects

On national level, the basic regulatory act governing waste management in Ukraine is the Law on Waste from 05.03.1998 No. 187/98-VR. It defines legal, organizational and economic principles of activities related to the prevention or reduction of generation, collection, transport, storage, sorting, recovering, recycling and disposal, decontamination and disposal of waste produced in Ukraine (Wohmann et al., 2017).

The main regulatory authorities in the sector are the Ministry of Ecology and Natural Resources of Ukraine, Ministry of Regional Development, the State Sanitary-Epidemiological Service of Ukraine and municipal authorities (Deloitte & Touche USC, 2012).

Although the existing legal framework is yet not strong enough to cause a total paradigm shift, Ukrainian government has already undertaken steps to improve the environmental situation. One of these steps is for example the development of a “National Waste Management Strategy”. The new Ukrainian Waste Management Strategy was prepared in 2017 in collaboration with the Ministry of regional development and GIZ to coordinate all the needed steps as well as to introduce the best European practices applicable for Ukraine (GIZ, 2017; Wohmann et al., 2017).

At the regional level the sanitation plan of the settlements, the settlements improvement plan and the local programme of municipal waste management are relevant for the local city and village councils of D.. The above mentioned regional plans are an important instrument for coordination and development of organizational, technological, environmental, financial and social tasks in the sphere of management of MSW. Nevertheless, some city and village councils are still lagging behind and do not have developed a sanitation plan or a settlements improvement plan yet. Furthermore, no information could be found in the case sturdy region about programs of municipal solid waste management (Stolberg et al., 2016b). This lack of institutional documentation leads to several problems like for example improper quantity and distribution of containers for MSW collection, existence of non-sanitary illegal dumpsites, lack of clearly regulated rules for legal entities and individuals etc. To ensure environmental safety and prevention of negative impacts of waste on human health and the environment a stronger jurisdiction is a prerequisite.

2.3.2 Waste generation and waste composition

Data related to quantities, composition, characteristics and source of MSW are fundamental requirements for designing and planning a sustainable waste management system.

The generation and actual flows of the current waste streams were assessed by the local expert team of the project partner from NUUE. The data were gathered from statistical information, local studies and information from local authorities responsible for waste management in D..

The following Figure 2 shows the material flow analysis of the current waste management system of the case study region modelled in STAN. The dotted line represents the system boundaries of the study.

The system boundaries define which processes are included or excluded from the assessment of the system (International Organization for Standardization, 2006). Only waste management processes within system boundaries represent the current WM system. The unit of the mass flows is set as tonnes per year.

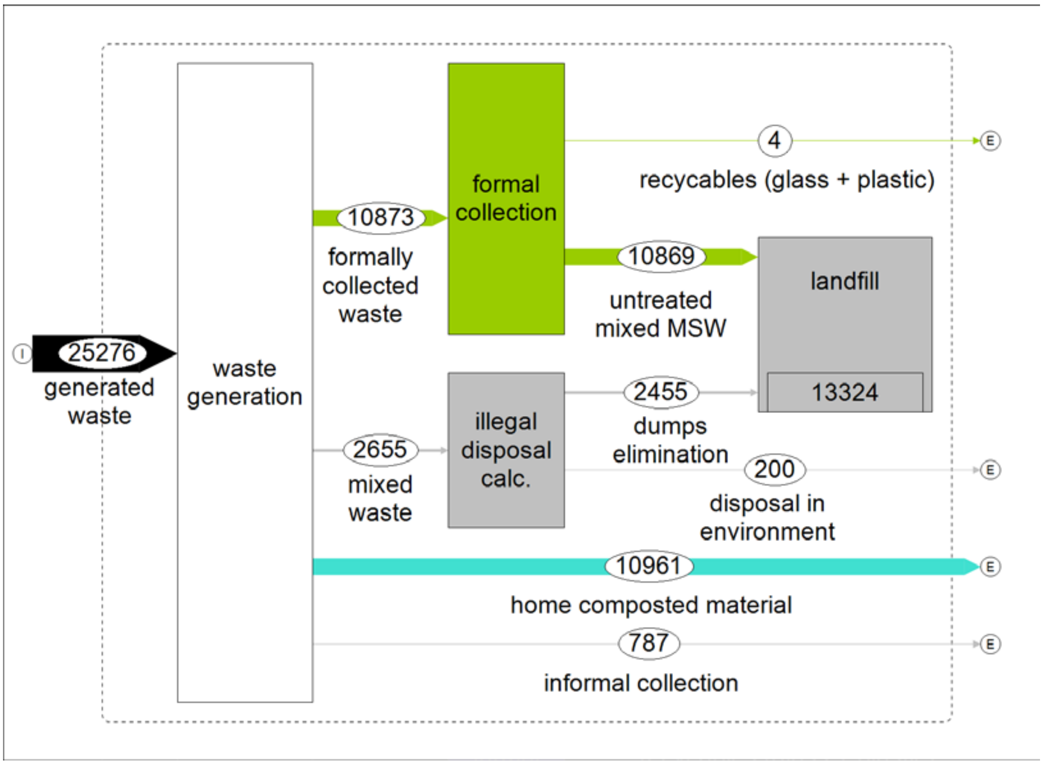

Figure 2: Material flow diagram of waste management system in 2015 [t/year]

Due to lack of reliable and available waste-related data some simplifications and reasonable assumptions had to be made for modelling the baseline scenario. All calculations and simplification are described in detail in chapter 4.2 Data availability and data uncertainties.

As shown in Figure 2 the total amount of generated waste is 25,276 tonnes per year for households and economic entities[3].

The amount of formally collected waste (10,873 t/yr) and dumps elimination (2,455 t/yr) are based on data provided by Rayon Administration (Khandogina and Abashyna, 2016a). The term “dumps elimination” means the clearance of illegal waste disposal. Illegal dumps occur, when people dispose of their waste unpermitted in the environment, instead of using authorized MSW infrastructure. Reasons for illegal dumping vary from lack of understanding of laws, or inadequacy of the existing laws to avoidance of disposal fees or proper dumping as a lack of WM infrastructure. (Hanfman, 2012; Liu et al., 2016).

Due to the lack of reliable statistical data the amount of home composted waste (10,961 t/yr), untreated mixed MSW at landfills (2,655 t/yr) and informally collected (787 t/yr) waste was calculated, for more details see chapter 4.2.

In the case study region bulky, construction & demolition and hazardous waste are not collected. Only in two town councils (P. and S. town council) separate collection of recyclables - glass and plastics - is implemented (Stolberg et al., 2016b). However, both the collection efficiency rate and the material recovery rate are very low at the moment. As a result, the amount of recyclables is also very low, therefore, room for improving the efficiency rate is available.

The amount of untreated mixed MSW at landfills results from the difference between formally collected waste, home composting and informally collected waste (Khandogina and Abashyna, 2016a).

There are no detailed, reliable studies on the waste composition for the whole district of D. However, in 2014 waste sorting analysis were made in N. region. D. city was also one of the cities where MSW composition researches were conducted. For all other settlements generalized data of average MSW composition according to results of research in identical settlements from the project partner at NUUE in Ukraine were used (Stolberg et al., 2016b). The assumed waste composition is illustrated in Figure 3.

The fractions listed in Figure 3 were chosen according to the unpublished Greenhouse-Gas-Emission-Calculation Tool from the Institute of Waste Management and Circular Economy of TU-Dresden.

The data for the fractions organic, wood, textiles, composites, pollutants, others, Fe/non-Fe metals, paper/cardboard, glass and plastic where provided by Stolberg et al. (2016) while the data for minerals and fine fraction <10mm were missing. The fraction pollutants consist of quantities from hazardous waste (means waste which display one or more of the hazardous properties) and WEEE (electrical and electronical equipment which is waste) (WFD, 2008). The fraction “others” contains the following parts: bones, leather, rubber, and residues over 10mm. The missing data for minerals and fine fraction <10mm are based on assumption of project partner from TU-Dresden (Scharenberg, 2017).

[3] The term economic entities refer to waste of similar nature and composition as MSW like for example from the following facilities: schools, kindergartens; prison establishments; resorts; beaches; parking; shops; restaurants; cafes; institutions of culture and art etc.

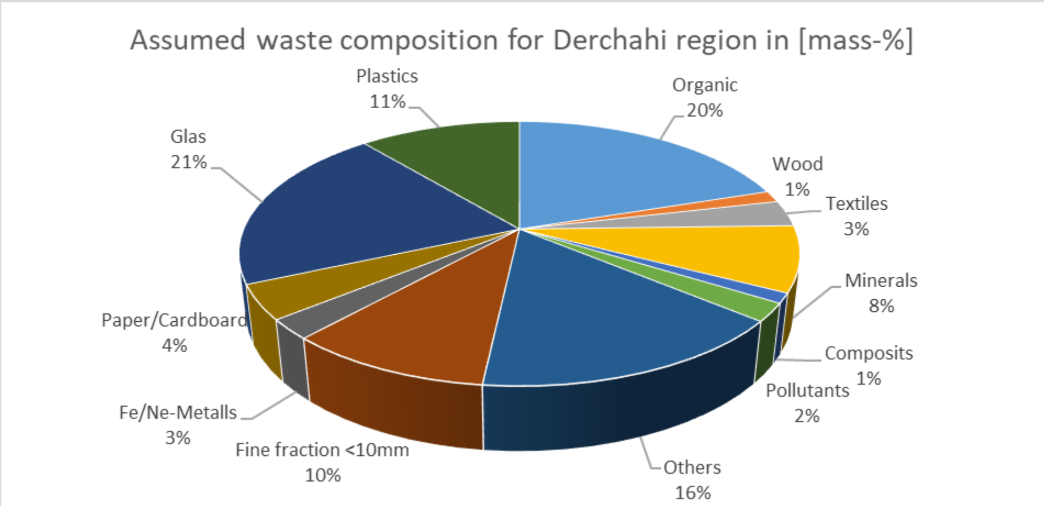

Figure 3: Assumed waste composition for D. (own application adapted after Stolberg et al., 2016; Beigl et al., 2003; Scharenberg, 2017)

As seen in Figure 3 the largest waste fractions are organics, glass and others. Although the content of biodegradable waste is higher compared to all other waste streams, a share of 20% is not typically for rural areas, where average of up to 40% could be expected. The comparatively low amount of the organics could be explained by the increased home composting rates in the private houses and relatively high fraction of “others”, which might contain biodegradable fractions as well. However, it was not possible to clearly assign the composition of the fraction “others”.

Another noticeable data is the high content of glass (21%) and the low content of paper/cardboard (4%) in the waste composition. Compared to the share of glass (6%) and paper/cardboard (17%) of MSW composition of Ukraine these two values distinguish from the national trend (GIZ, 2017).

The potential distribution of components of the MSW composition is presented in Figure 4. The figure is based on estimated assumptions form project partner at NUUE and it shows a correlation between number of citizen and amount of generated recyclables. Higher population cities (e.g. D. city, K. –L. town council (TC), P. TC) generated more waste in comparison to small city council with low population rate (e.g. T. village council (VC), P. VC).

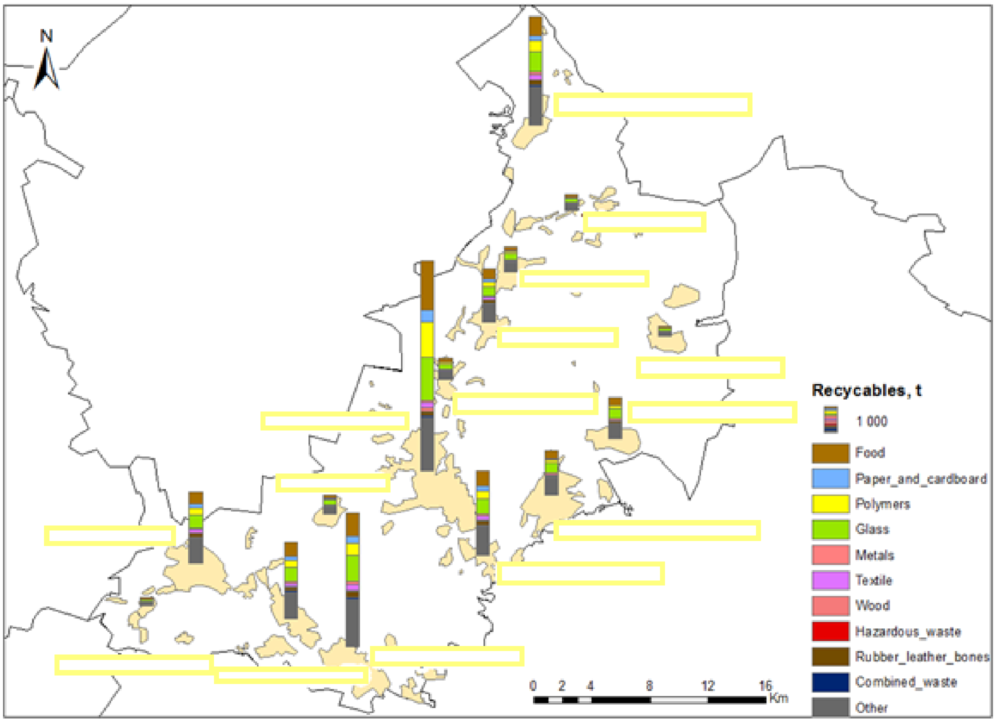

Figure 4: Potential estimation of quantities of generated recyclables and different components of MSW (Stolberg et al, 2016b)

Location names are deleted from published version for the reasons of data handling

2.3.3 Waste collection and transportation

Reliable data about the total amount of population covered with MSW services is not available. Although according to official data the waste collection system covers a big part of D. (about 90%), the real coverage is significantly lower and waste collection service is provided on an irregular basis (Rayon Adminstraion D., 2016c). A lot of discrepancies appeared in the information delivered by the Ministry of Regional Development of D., information from the Department of Housing and Infrastructure Development of N. Regional Administration and other local stakeholders. For that reason, waste collection coverage of about 40 % was assumed together with representatives from D. Rayon Administration as realistic for the case study region.

Generated waste is mostly not separated at the source but collected in one waste bin as mixed waste. The separate collection of recyclables from households is still poorly developed. Only in two town councils separate collection of glass and plastic was implemented in 2014.

At the moment, there is no separate collection or treatment of any type of hazardous household waste, WEEE or bulky waste.

540 containers (standard volume 1.1 m^3) for waste collection are installed in D.. However, the number of containers and the waste collection frequency is not enough

to provide proper MSW management services. Especially the collection and transportation in small settlements is very problematic and insufficient. Usually bags collection is done in rural areas and at private houses, container collection is applied at multi-storied buildings. However, most rural areas are lacking collection services. This is because only 17 waste collection vehicles are available for the whole district. From these 17 vehicles, a majority is outdated and does not meet the current state of the art. Another problematic factor results from the lack of contract between household and operators proving MSW services. Many citizens don't 'have contracts with operators providing MSW services and for that reason no waste collection is carried out in these areas.

2.3.4 Waste treatment and disposal

In developed countries landfilling is a highly technology oriented process in order to minimize negative impacts on the environment and human health (Shekdar, 2009; Weng et al., 2015). However, in the case study region open dumping and inadequate disposal at dumpsites are common practice. The main problems are the lack of efficient treatment and disposal facilities, poor environmental control and management practices as well as illegal dumping and disposal. The ineffectiveness of landfills can lead to negative impacts as for example landfill fires, loss of biodiversity, soil pollution, harm to human health and many more (IFC, 2012).

At the moment, there are 4 landfills on the territory of D.district (see Figure 5): D. landfill (area 13.2 hectares), V. dumpsite (area 2.8 hectares), P.dumpsite (area 5.5 hectares) and T. dumpsite (area 0.06 hectares) – the latter 3 of them do not satisfy the environmental safety standards. Whereas D. landfill is a semi-sanitary landfill. It is planned to raise the technological state of the art by constructing a landfill gas collection system, cogeneration plant, sorting line for separately collected recyclables and a leachate collection system. However, D. landfill does not belong to D., but is in property of N. oblast. For that reason, it is financed by the N. city budget and possible revenues cannot be used for D. Besides the above-mentioned landfills 4 closed dumpsites exists. However, the location and the status of the closed dumpsites are unknown (Stolberg et al., 2016b).

In order to improve the current waste management practice a programme was defined to implement the EU landfill directive requirements, to develop a system of regional sanitary landfills and to close existing waste dumpsites (GIZ, 2017).

Another uncontrolled waste stream is waste that ends up on small open dumps which occur on inappropriate areas, along the roads, river flows or other undeveloped areas. Local authorities, enterprises, organizations, institutions, students and citizens are detecting and eliminating the conducted dumps periodically (Stolberg et al., 2016b).

Beside the above-mentioned landfills and dumpsites one waste sorting facility exists in V. TC. However, the quantities entering the facility are very low due to lack of efficiency.

Figure 5: Location of landfills and dumpsites in D. (Stolberg et al., 2016b)

Figure is deleted from published version for the reasons of data handling

2.3.5 Financial data and current tariffs

In D. the MSW system is financed by the local budget, fees, subsidies and funds (Wohmann et al., 2017). The funds are basically used for maintenance and development of the MSW system like for example renovation of container fleet and trucks (Stolberg et al., 2016).

The average tariff for removal of MSW in 2015 was about 1.3 €/m^3 for population and higher (between 1.6 € - 1.9 € /m^3) for legal entities (for example commercial, institutional, etc.)[4]. The tariff structure and level differ depending on the settlement and the company which is providing waste collection and removal services. Since there is no general tariff standard for the region the fees can be charged per m^2 of housing, m^3 of generated waste (according to norms), tonnes of waste (only in one settlement established), per person in a month or per container (Stolberg et al., 2016b). Lacking jurisdiction concerning the regulation of tariffs and service payments contributes to the current poor status of the Ukrainian MSW system (Wohmann et al., 2017).

[4] An exchange rate of 1€ = 28,94 UAH was used for all calculations. Conversion rate from 03.05.2017 (Online Umrechner Euro, 2017)

3. Materials and Methodology

The following chapter describes the methodological approach and the materials used in this thesis. For fulfilling the research objectives, it was necessary to choose a mixture of methods.

The applied approach consists of the following steps:

1. Description of the baseline situation, i.e. the status-quo situation of the local MSWM system (chapter 2)
2. Development of Data Need Catalogue (DNC) – list of data needed as basis to evaluate the status quo in the case study region (chapter 3.2). The DNC aims at providing project partners on location an idea of what data need to be collected in order to carry out an assessment
3. Literature review for the development and definition of economical, ecological, social and technical indicators (chapter 3.1 & chapter 3.3)
4. Identification and determination of MSW flows, quantities and composition (chapter 2.3.2)
5. Development of possible future scenarios using Material Flow Analysis (chapter 3.4 and chapter 4)
6. Definition of waste treatment technologies for the different future scenarios (chapter 5)
7. Assessment of possible future WM scenarios with selected indicators (chapter 6)

The procedural flow of the above proposed methodology is presented in Figure 6: Procedural flowchart of methodological stepsFigure 6. The last step “development of a roadmap for implementation” is not part of this thesis. However, within the scope of the WaTra-project a roadmap including potential waste reduction/prevention strategies, information and communication strategies was developed.

The steps illustrated in Figure 6 are discussed in the following subchapters. At the beginning of this chapter the data gathering process, waste generation assessment and materials & methodology used for the selection of indicators are described.

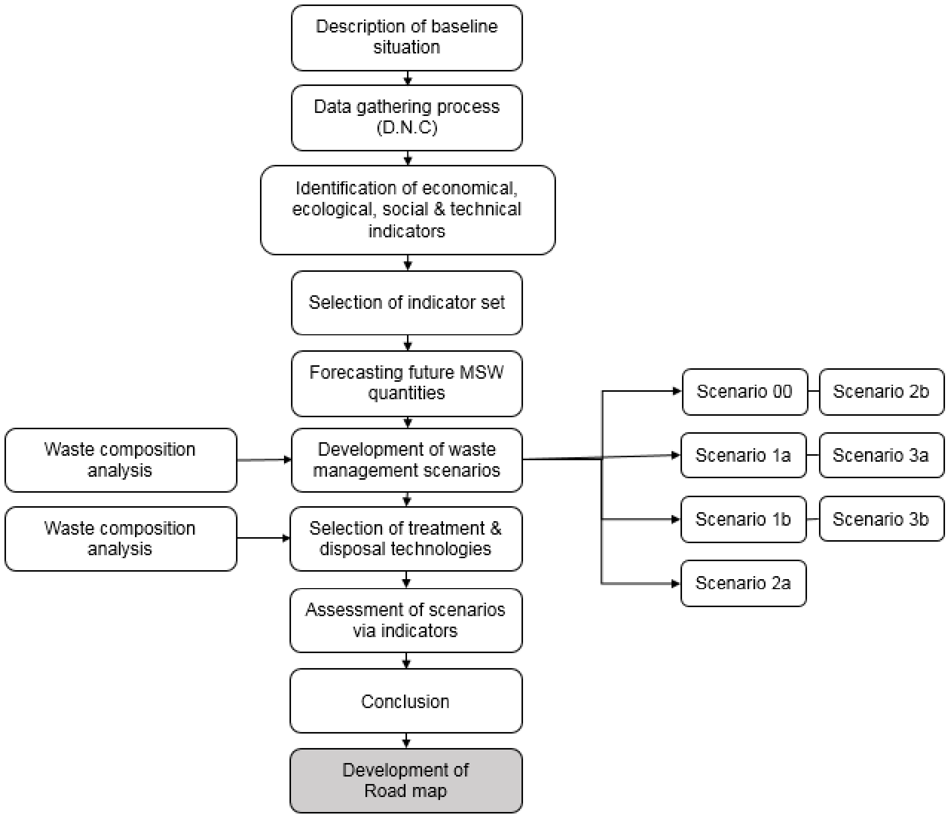

Figure 6: Procedural flowchart of methodological steps

3.1 Literature Review

One of the main goals of this study was to provide an integrated tool for assessment of different MSWM scenarios. For that reason, an extensive literature review was carried out in order to evaluate possible assessment approaches for development of the so called “Data Need Catalogue” (DNC) and for the selection of an appropriate assessment method.

In a first step, various scientific studies were screened via Science Direct database, SCOPUS database and BOKU:Litsearch database. The identification and selection of appropriate methods and tools are mainly based on literature research that was composed of articles in scientific journals and online sources from February to May 2016. The keywords used for the literature search included “waste”, “assessment” “MSW indicators”, “MSWM evaluation” “economic, ecological, social and technical assessment of MSW systems”, “integrated MSWM”. Further country-specific studies were contributed from the project partners involved in WaTra-project. Only studies reported in English and German were included in the review scope.

In a second step 53 studies were identified as relevant for fulfilling the research goals, all other studies which did not meet the requirements were not further assessed. Then the 53 chosen studies were classified to existing assessment methods. Thereby 8 different methods, namely Life Cycle Assessment (LCA), Life Cycle Costing (LCC), social Life Cycle Assessment (sLCA), Key Performance Indicators (KPI), Multi-Criteria Decision Analysis (MCDA), Cost Benefit Analysis (CBA), Simulation Models and Benchmarking methodology, were categorised.

The majority of the preselected studies applied LCA methodology for quantifying environmental impacts (Banar et al., 2008; Bovea et al., 2010; Buttol et al., 2007; Cherubini et al., 2009; Den Boer et al., 2005; Emery et al., 2006; Hermann et al., 2007; Kirkeby, et al., 2006; Kulczycka et al., 2015; Laurent et al., 2013a; Laurent et al., 2013b; Luoranen, et al., 2009; Margallo et al., 2014; Ozeler et al. 2005; Parkers et al., 2014; Reich, 2005; Tulokhonova, A., Ulanova, O., 2013; Woon and Zhou, 2015). 5 studies were using LCC for the financial and economical assessment of WM system (Martinez-Sanchez, V. et al., 2014; Reich, 2005; Woon and Zhou, 2015). 2 studies were identified, which were performing a social LCA (Aparcana and Salhofer, 2013a; Aparcana and Salhofer, 2013b). Only one study combined LCA, LCC and sLCA for assessment of the WM performance (Souza et al., 2014). However, LCA methodology should just be applied when reliable data pools are available (Karmperis et al. 2013). Therefore, life cycle based approaches were assigned as not appropriate for the given conditions.

In 6 studies the MCDM was used as a tool which uses value judgements of individual decision makers or multiple stakeholders in order to analyse and evaluate alternate solutions of a problem (Arikan, E. et al., 2015; Hanan et al., 2013; Hermann et al., 2007; Milutinovic, B. et al., 2013; Vucijak, B. et al., 2015). As MCDM can be very complicated when they take too many aspects into account and since the results can be changed when different criteria or vales are used, the MCDM was also excluded as assessment method (Karmperis et a., 2013).

11 studies were evaluating the WM system via KPI (Armijo et al., 2014; Brunner and Fellner, 2007; Cifrian et al., 2010; Cifiran et al., 2012; Den Boer et al., 2005; Emery et al., 2006; Giljum et al., 2011; Hermann et al., 2007; Rigamonti, L. et al. 2015; Shen et al., 2011). Indicators can be used to compare different processes and performances and to quantify impacts on environment and human health. As not only the environmental performance but also the entire integrated WM system (including economic, social, and technical components) can be assessed, KPI are an appropriate screening tool for scenario assessment.

Further, 5 studies were found using benchmarking to assess the performance of WM systems (Sim, 2011; Ilic and Nikolic, 2016; United Nations Human Settlements Programme, 2010; Wilson et al., 2013; Wilson et al., 2014).

CBA methodology was found in 4 studies (Pearce, 2006; Jamasb and Nepal, 2010; Karmperis et al., 2013; Weng and Fujiwara, 2011).

2 Studies were using simulation models (Armijo et al., 2014; Mutavchi, V. 2012), and the remaining 3 studies were assigned to the category “other” (Groot et al., 2011; Hervea et al., 2014; Levin and Mc Ewan, 2000). They are including carbon footprint calculations and cost effectiveness analysis.

It is crucial to underline that the pre-selected methods are not exhaustive. The evaluation might be expanded to include other methods like for example remote sensing, environmental impact assessment, environmental risk assessment or geographic information systems etc. (EEA, 2003). However, due to limitations of time, resources, and available input data no further methods were examined.

In a third step an additional screening of the preselected methods was made to choose an appropriate evaluation tool. Detailed analyses were conducted to identify possible methods for assessment of the scenarios. Since the range of methods is quite diverse, choosing a single MSWM approach or tool is challenging. One of the main aims of the study is to compare the different future scenarios based on their economic, ecological, social and technical performances. Accordingly, the selection of the most effective tool must be able to handle the limitation of given conditions like for example missing data. Therefore, not only one but a mixture of assessment methods was chosen to provide an appropriate evaluation methodology. The final method set used for the assessment is presented in chapter 3.3.

In the course of literature searching, scientific journals, books and legislative texts were used for generating topic-related general information. Further literature was applied to describe the current waste management situation in Ukraine and to develop possible alternatives for the waste management situation in D. (see Deloitte & Touche USC, 2012; EuropeAid, 2011; FCM and MEPM, 2014; GIZ, 2017; IFC, 2012; SDC and DESPRO, 2012; STAINP, 2016; Stolberg et al., 2016; UNDP, 2011; WBU, 2009; Wohmann et al., 2017; Zakhariva, 2014).

Additionally, internal information was provided through local authorities responsible for waste management in D. and the local expert team of the project partners from NUUE.

3.2 Data Need Catalogue

Appropriate decision making for the planning of future waste management systems requires accurate knowledge about the present waste management system (Letcher and Vallero, 2011).

To assess the status-quo situation of D. a so-called Data Need Catalogue (DNC) was prepared especially for the case study regions of the WaTra-project. The DNC was adapted according to questionnaires from LCA-IWM project (Den Boer, 2005). It aims to provide background information for all involved project partners and includes a qualitative description of the case study region (see Annex 1) and quantitative data collection in form of an Excel-file. More than 1,500 single indices were requested in the quantitative survey related to general, demographical, waste-related information, institutional and waste management laws, economic & cost-related data, waste characteristics & amounts, collection-, treatment- and disposal-related data, as well as data on the informal recycling sector (IRS) in MSW management.

For the data gathering process project partners co-operated with local and regional stakeholders who provided waste-related, demographic and socio-economic data. National data were obtained from reports on municipal solid waste management in Ukraine and national and international organisations like World Bank, State Statistical Service of Ukraine etc.

3.2.1 Waste Generation

The amount and composition of waste generated is the starting point for planning, operating and optimising of waste management systems (Beigl et al., 2008). Usually authorities in industrialized countries are obliged to record waste-related data as they are an important source of information (Ramusch, 2015). However, for the case study region current waste quantities and waste composition had to be assessed, due to the lack of real measured data. Therefore, a field composition study was conducted by project partner form NUUE (Stolberg et al., 2016).

Estimations and calculations about current waste quantities and composition were carried out by NUUE project partner.

The forecast of future waste quantities was conducted for the 10-years horizon until 2025 using the LCA-IWM Waste Generation Prognostic Model (Beigl et al., 2003). The prognostic tool is used for calculation of future waste quantities of cities in Europe. It provides quantitative parameters for the estimation of different waste streams and forecasts waste generation rate and waste composition. For the forecast of waste generation, the following input data were used:

Table 1: Reference data waste generation prognostic tool

Input Data	Value	Source
General		
Number of citizen	98,000	Adapted after Stolberg et al. (2016)
Reference year	2015 - 2025	Internal project requirement
Waste-related data		
Residual Waste/Mixed waste [t/yr]	13,525	Khandogina and Abashyna (2016b)
Plastic [t/yr]	3	Khandogina and Abashyna (2016b)
Socio-economic data[5]		
Population aged 15 to 59 years, [% of total population]	63.6	N. Regional Department of Statistics
Average household size, persons per household [persons per household]	2.5	N. Regional Department of Statistics
Regional infant mortality rate [per 1,000 births]	9.8	N. Regional Department of Statistics
National infant mortality rate	7.9	State Statistical Service of

[5] All social economic data are found in Khandogina and Abashyna (2017d)

[per 1,000 births]		Ukraine
Life expectancy at birth [years]	71.38	N. Regional Department of Statistics
Labour force in agriculture [% of total labour force]	15.26	World Bank Open Data
GDP per capita [international $]	7,939	World Bank Open Data

3.3 Selection of Indicators

Indicators and indices (aggregate indicators) are important tools that can be used to measure the performance of a waste management system, to compare characteristics between one or more systems, and as criteria in decision making tools (Cifrian et al., 2010; EEA, 2003; Giljum et al., 2011).

As in the previous chapter already described, many tools and methods are available and were considered for the assessment. At the beginning of the research 62 potential indicators were identified, thereof 15 economic, 25 environmental, 16 social and 6 technical indicators. However, it appeared to be difficult to develop a feasible and reliable method for the scenario assessment due to lack of input data. Therefore, the set of indicators used in this thesis were selected and adapted in particular for the WaTra-project.

The following Table 2 presents the initial list of indicators chosen for the assessment of the waste management system performance. The list of indicators was shortened in order to choose a feasible and reliable method for the scenario assessment. Only indicators marked in *green* are used for the final assessment. The excluded indicators were discarded due to lack of input material or limitations of practicability. Some indicators were included in other indicators to provide a more comprehensive decision support tool. For example, the indicators “annual operating cost”, “investment costs”, “maintenance cost” were included in the indicator “Total Annual Discounted Costs of WM system”. Furthermore, some indicators were adapted to local conditions like the initial indicator “Costs MSWM per GNP of the city” was adapted to “Annual Discounted Costs as % of approved District Expenditures”, as data of GNP of D. were not available. Also, the initial indicator “Diversion between Revenue and Expenditures of MSWM system” was adapted to “Self-financing Rate”.

Table 2: List of indicators, including initial indicators

Indicator [Unit]	Description	Source
Economic		
Costs MSWM per GNP of the city [%] => adapted to Total Annual Discounted Costs as % of approved district expenditures	Costs for MSW services as percentage of the approved district expenditures	Brunner and Fellner (2007); Den Boer et al. (2005); Panagiotakopoulos and Tsilemou (2004); UN-Habitat (2010)
Diversion between Revenue	Diversion between the financed	Den Boer et al. (2005);

and Expenditures of MSWM System => adapted to Self-financing Rate [%]	and non-financed part of the total annual costs and benefits of the WM system	Tulokhonova and Ulanova (2013); Panagiotakopoulos and Tsilemou (2004)
Revenue from recovery of materials [LCU/year]	Sum of all revenues from recovery of material eg. Recovered outputs form waste treatment plants	Den Boer et al. (2005); Emery et al. (2007); Milutinović et al. (2014); Panagiotakopoulos and Tsilemou (2004); Tulokhonova and Ulanova (2013); Vučijak et al. (2015)
Revenue from recovery of energy [%]	Percentage of the energetically recovered waste in relation to total waste generated	Den Boer et al. (2005); Panagiotakopoulos and Tsilemou (2004)
Total Annual Discounted Costs of WM System as % of nominal average salary & minimum wage	Cost of WM system per person as a percentage of the nominal average salary and the minimum wage	Den Boer et al. (2005); Panagiotakopoulos and Tsilemou (2004)
Total Annual Discounted Costs of the WM system	Total annual costs of subsystems bins and container; trucks and collection; treatment and disposal	Brunner and Fellner (2007); Den Boer et al. (2005); Hanan et al. (2013); Rigamonti et al. (2016a); Tulokhonova and Ulanova (2013); UN-Habitat (2010);
Total Annual Discounted Costs of WM system per tonne of collected waste [€/t]	Total annual costs of subsystems bins and container; trucks and collection; treatment and disposal per tonne of collected waste	Brunner and Fellner (2007); Den Boer et al. (2005); Panagiotakopoulos and Tsilemou (2004); Rigamonti et al. (2016b); Tulokhonova and Ulanova (2013)
Annual operating costs (included in indicator total costs of WM system)	Costs for raw material, energy, wastewater disposal, labour, supervision, maintenance of facilities and equipment, insurance, training programs etc.	Armijo et al. (2014); Den Boer et al. (2005); Martinez-Sanchez et al. (2015); Milutinović et al. (2014); Mutavchi (2012)
Costs for current economic damage caused by pollution of the environment	Remediation costs of polluted soils and waters	Mutavchi (2012)
Costs indicator [€/t]	Ratio between the sum of collection, treatment and disposal costs, and the amount of collected MSW	Rigamonti et al. (2016a)
Investment costs (included in indicator total costs of WM system)	Predevelopment costs, construction costs (e.g. land cleaning, buildings, equipment), connecting networks (e.g. access roads etc.)	Den Boer et al. (2005); Martinez-Sanchez et al. (2015); Milutinović et al. (2014); Mutavchi (2012); Vučijak et al. (2015); Tsilemou and Panagiotakopoulos (2006); Tulokhonova and Ulanova (2013); Woon and Zhou (2015)

Maintenance costs (included in indicator total costs of WM system)	Costs for maintenance of facilities and equipment	Martinez-Sanchez et al. (2015); Mutavchi (2012); Milutinović et al. (2014); Vučijak et al. (2015)
Minimisation of expenditures	Reduction of expenditures by optimising the utilisation of available resources within the WM system	Shekdar and Mistry (2001)
Prevented damage (costs for preventing pollution)	Costs for preventing pollution e.g. Collection and treatment of landfill gas; collection and treatment of leachate; operations at the old landfill; treatment of oil-contaminated waste; costs for research	Mutavchi (2012)
Regional value-added potential [qualitative]	Regional value-added potential created by improvement of WM system e.g. investment potential, technological knowledge, revenues, local energy production etc.	SUP (2004)
Environmental		
Biodegradable Waste Diversion Rate [%]	Amount of biodegradable waste diverted from landfill	Den Boer et al. (2005); Vučijak et al. (2015)
Energy Recovery Rate [%]	Useful recovered exergy out of the total available exergy associated with the formally collected MSW.	Rigamonti et al. (2016a); Shekdar and Mistry (2001); Weng and Fujiwara (2011)
Greenhouse Gas Emissions [t CO_2-eq per tonne formally collected waste]	Amounts of carbon dioxide emitted to the atmosphere	Scharenberg (2017); Milutinović et al. (2014); Wünsch (2013)
Material Recovery Rate [t/yr]	Ratio between the quantity of waste recycled (=brought back into the value chain as secondary raw material) and the amount of formally collected municipal solid waste	Armijo et al. (2014); Bovea et al. (2010); Brunner and Fellner (2007); Cifrian et al. (2010); Rigamonti et al. (2016a); Sim et al. (2013); Shekdar and Mistry (2001); Weng and Fujiwara (2011); Wilson et al. (2013)
Source-separated Collection Rate [%]	Amount of source- separated collected waste fractions (plastic, paper, metal, glass, organics) relative to the total amount of formally collected waste	Wilson et al. (2015); Armijo et al. (2011); Cifrian et al. (2015)
Waste Landfilling Rate [%]	ratio between waste left for disposal in landfills and formally collected waste	Desmond (2006); Cifrian et al. (2015); Shen et al. (2011)

Acidification potential [kg SO_2 eq/ton waste managed]	Acidifying pollutants (SO_2, NOx, HCl and NH_3) which have an impact on soil, groundwater, surface water, living organism and environment	Banar et al. (2008); Buttol et al. (2007); Bovea et al. (2010); Cherubini et al. (2009); Den Boer et al. (2005); Emery et al. (2007); Herman et al. (2007); Kirkeby et al. (2006); Luoranen et al. (2007); Margallo et al. (2014); Ozeler et al. (2005); Parkes et al. (2015); Souza et al. (2015)
Climate change [kg CO_2 eq./ton waste managed]	Global Warming Potential for time horizon of 100 years	Banar et al. (2008); Buttol et al. (2007); Bovea et al. (2010); Cherubini et al. (2009); Hanan et al. (2013); Kirkeby et al. (2006); Luoranen et al. (2007); Margallo et al. (2014); Parkes et al. (2015); Souza et al. (2015)
Eutrophication potential [kg PO_4^{-3} eq./ton waste managed]	Eutrophication is a phenomenon that can influence terrestrial as well as aquatic ecosystems caused by enrichment of nitrogen and phosphorus.	Banar et al. (2008); Buttol et al. (2007); Bovea et al. (2010); Cherubini et al. (2009); Emery et al. (2007); Herman et al. (2007); Kirkeby et al. (2006); Luoranen et al. (2007); Margallo et al. (2014); Ozeler et al. (2005); Parkes et al. (2015); Souza et al. (2015)
Ecotoxicity potential [1,4-dichlorobenzene equivalents/kg emission]	Ecotoxicity involves toxic impacts on an ecosystem, damaging individual species and changing the structure or function of the ecosystem range from death over reproductive damages to behavioural change	Banar et al. (2008); Buttol et al. (2007); Bovea et al. (2010); Herman et al., (2007); Kirkeby et al., (2006); Luoranen et al., (2007); Margallo et al., (2014)
Capacities of communal enterprise [number/capita]	Number of containers, recycling and collection points, recycling yards, trucks available for transport	Vučijak et al. (2015)
Controlled Disposal [%]	Percentage of total waste destined for disposal that is deposited in an environmental landfill or controlled disposal site, or any other formal treatment system, including incineration.	Brunner and Fellner (2007); Sim et al. (2013); Wilson et al. (2013); Woon and Zhou (2015)
Cumulated energy requirement [MJ/year]	Assessment if the energy required to operate the MSW management facilities and system	SUP (2004)

Human toxicity potential [1,4-dichlorobenzene equivalents/kg emission]	Fate, exposure and effects of toxic substances to human health	Banar et al. (2008); Buttol et al. (2007); Herman et al. (2007); Kirkeby et al., (2006); Luoranen et al., (2007); Margallo et al., 2014; Ozeler et al., (2005); Souza et al. (2015); Woon and Zhou (2015)
Hygienic conditions that have impact to human health [qualitative]	Risks from waste treatment facilities like for example manual sorting lines caused to human health	Vučijak et al. (2015)
Landfill volume required [m^3 $capita^{-1}$ $year^{-1}$]	Volume of landfilled required for handling MSW quantities	Brunner and Fellner (2007)
Number of necessary bins and sacks [nr.]	Number of necessary bins and sacks for provision of MSW services	Den Boer et al. (2005); Vučijak et al. (2015)
Photochemical ozone creation potential [kg C_2H_4/ton waste managed]	Measurement of substances with the potential to contribute to photochemical ozone formation	Banar et al. (2008); Bovea et al. (2010); Emery et al. (2007); Kirkeby et al., (2006); Luoranen et al. (2007); Margallo et al. (2014)
Resource depletion [kg Sb eq./ton waste managed]	Extraction of minerals and fossil fuels due to inputs in the WM system	Banar et al. (2008); Buttol et al., (2007); Bovea et al., (2010); Den Boer et al., (2005); Cherubini et al., (2009); Emery et al. (2007); Kirkeby et al. (2006); Luoranen et al. (2007); Parkes et al. (2015); Souza et al. (2015)
Recycling & recovery rate of packaging material [t/yr]	Ratio of recycled and recovered packing material to the generated amount of packaging	Den Boer et al. (2005)
Used land area [ha]	Land area required for operation of MSW management system	SUP (2004); Woon and Zhou (2015)
Volume reduction [%]	The amount of waste that remains after treatment for landfill disposal	Milutinović et al. (2014); Shekdar and Mistry (2001)
Waste Reduction [t/year]	Reduction of quantity of MSW generation	Weng and Fujiwara (2011)
Waste Generation [t/yr]	Generated MSW per capita	Beigl et al. (2003); Ilic and Nikolic (2016); Sim et al. (2013); UN-Habitat (2010); Vučijak et al. (2015); Wilson et al. (2013)

Waste Collection Coverage [%]	Percentage of population who has access to waste collection and sweeping services	Desmond (2006); Ilic and Nikolic (2016); Sim et al. (2013); Shen et al. (2011); UN-Habitat (2010); Vučijak et al. (2015); Wilson et al. (2013)
Social		
Distance to containers [qualitative]	Logistical convenience for the user = distance to containers or collection points	Den Boer et al. (2005); Tulokhonova and Ulanova (2013)
Job Creation Potential [number]	Number of new jobs created by the implementation of a given scenario. Th	BMLFUW (2015); Emery et al. (2007); EPA (2002); European Commission (2001); Hanan et al. (2013); Maletz (2017b); Milutinović et al., (2014); Murray (1999); Seldman (2002)
Odour [qualitative]	Potential of odour nuisance to the city inhabitants	Den Boer et al. (2005); Tulokhonova and Ulanova (2013); SUP (2004)
Noise [qualitative]	Sounds which cause annoyance for human beings and animals	Den Boer et al. (2005); Tulokhonova and Ulanova (2013); SUP, 2004; Weng and Fujiwara, 2011
Private Space [qualitative]	Private space consumption for waste collection inside the inhabitant's private properties	Den Boer et al. (2005); Tulokhonova and Ulanova (2013)
Social acceptance [qualitative]	Societal consensus on the planned scenario	Den Boer et al. (2005); Hanan et al. (2013); Milutinović et al. (2014)
Traffic [qualitative]	Volume of traffic, e.g. for collection of waste from bins, transport of waste to treatment facilities etc.	Den Boer et al. (2005); Tulokhonova and Ulanova (2013); SUP (2004); Weng and Fujiwara (2011)
User Convenience & Complexity [qualitative]	User convenience & complexity to the public of the waste management system is related to the number of waste fractions to be collected separately	Den Boer et al. (2005); Tulokhonova and Ulanova (2013)
Visual Impact [qualitative]	Visual impact or disturbance of waste bins and waste treatment plants	Den Boer et al. (2005); Tulokhonova and Ulanova (2013); Weng and Fujiwara (2011)
Average income of SWMS workers [LCU/SWMS worker]	Formal and informal income per occupation	Souza et al. (2015)

Final destination [qualitative]	Measure the social function of the used WM option by taking into account the recovery rate	Den Boer et al. (2005); Tulokhonova and Ulanova (2013)
Human rights [qualitative]	No child labour, formal policy against discrimination and no income difference between woman and men	Aparcana and Salhofer (2013a); Aparcana and Salhofer (2013b)
MSW workers and their relatives provided with health insurance [number]	Access to healthcare, education, environmental education and digital inclusion	Souza et al. (2015)
SWMS workers and their relatives per level of education [number]	Access to healthcare, education, environmental education and digital inclusion	Souza et al. (2015)
Risk perception [qualitative]	Public concern about risks related to waste utilization	Den Boer et al. (2005); Hanan et al. (2013); Tulokhonova and Ulanova (2013)
Working conditions [LCU; qualitative]	Average fair income according to legal framework; absence of non-agreed income deductions; regular payment for workers; Occurrence of job accidents and diseases directly related to risks of the SWMS chain	Aparcana and Salhofer (2013a); Aparcana and Salhofer (2013b); Souza et al. (2015)
Technical		
Requirement of qualified Personnel and Maintenance Requirements [qualitative]	Requirement of qualified personnel and maintenance requirements (spare parts, qualified operators etc.)	Arıkan et al. (2017)
Sensitivity to Quantity of Input Material [qualitative]	Flexibility of a technology related to changes of waste flows quantity and technical efforts for related adjustment of the technical infrastructure	SUP (2004)
Sensitivity to Quality of Input Material [qualitative]	Flexibility of technology to change of waste quality and technical effort for related adjustment of the technical infrastructure	SUP (2004)
Technical Reliability [qualitative]	Ability of a given technology to perform the desired function within a specified period of time, robustness and reliability in the practice	Arıkan et al. (2017); SUP (2004); Vučijak et al. (2015)
Autarky in the waste treatment [qualitative]	The autarchy of WM is higher in the region if all stages of WM treatment are situated within	SUP (2004)

	the region.	
Energy consumption [qualitative]	Energy consumption by technologies used for fulfilling MSW services	(SUP, 2004)

Finally, a set of 18 quantitative and qualitative indicators was chosen for the final assessment. The 6 economic, 6 environmental, 2 social (one of them consisting of 7 sub-criterions) and 4 technical indicators are described in the following chapter.

3.3.1 Economic indicators

MSWM represents a great challenge for local governments, which have the responsibility to provide the collection and adequate treatment and disposal of MSW. One of the most important issues thereby are the economic aspects in combination with available technology as they are generally the limiting factor for a properly functioning waste management system (Allesch and Brunner, 2014).

In order to measure the quantitative performance of the future waste management scenarios the following 6 economic indicators which are presented in the following subchapters were evaluated:

- Total Discounted Costs of Waste Management System
- Total Annual Discounted Costs of WMS per tonne of formally collected waste
- Annual Revenue from Recovery of Material and Energy
- Self-financing Rate
- Total Annual Discounted Costs as % of approved District Expenditures
- Total Annual Discounted Costs as % of Nominal Average Salary & Minimum Salary

The calculation of the total costs considers the:

a) Total annual costs of subsystem bins & container system
b) Total annual costs of subsystem trucks & collection
c) Total annual costs of subsystem treatment & disposal

The subsystem bins & container system includes all waste bins and containers for collection of MSW.

The subsystem trucks & collection covers all collection vehicles for the transport of the total amount of MSW collected in D..

Whereas the subsystem treatment & disposal describes all planned treatment- (MBT plant, sorting plant, composting facility, manual sorting lines) and disposal facilities (sanitary landfill) within the system boundaries of the region.

The costs of the future scenarios for all subsystems are evaluated over a time horizon of 20 years (=depreciation period). An interest rate of 11% was assumed as realistic for the current unstable economic situation in Ukraine (National Bank of Ukraine, 2016). Wherever costs were provided in local currency (Ukrainian Hryvnia -

UAH) a conversion rate of 1€ = 28,94 UAH was submitted (Online Umrechner Euro, 2017).

3.3.1.1 Total Annual Discounted Costs of Waste Management System

The total annual discounted costs calculation is based on the adapted LCA-IWM methodology (Panagiotakopoulos and Tsilemou, 2004; Den Boer et al., 2005). The methodology was developed within the research project "The Use of Life Cycle Assessment Tools for the Development of Integrated Waste Management Strategies for Cities and Regions with Rapid Growing Economies". It enables one the one hand the prediction of future waste quantities based on limited data input parameter (see chapter 4.2). On the other hand, it enables the planning and assessment of waste management strategies by comparing different scenarios. For the calculation of the Total Annual Discounted Cost of WM system the three above described subsystems (bins & container system; trucks & collection, treatment & disposal) which are described in the following section are assessed.

a) Total Annual Discounted Costs of Subsystem Bins & Container System

For the calculation of the equivalent annual discounted total costs (EADTC) of the subsystem bins & container system of waste stream i the following formula is used:

$$EADTC_{bins\,i(j)} = EADTPC_{bins\,i(j)} + EADTLC_{bins\,i(j)} + AMC_{bins\,i(j)} - EADTEC_{bins\,i(j)}$$

where,

$EADTPC_{bins\,i(j)}$ = Equivalent Annual Discounted Total Purchase Cost of bins (€)

$EADTLC_{bins\,i(j)}$ = Equivalent Annual Discounted Total Location Costs of bins (€)

$AMC_{bins\,i(j)}$ = Annual Maintenance Cost of bins (€)

$EADTEC_{bins\,i(j)}$ = Equivalent Annual Discounted Total End-of-Life Costs of bins (€)

For calculation of the Equivalent Annual Discounted Total Purchase Cost of bins the number of containers is necessary to know. This input parameter was calculated by the project partner from NUUE using the Ukrainian guidelines for organizing of the collection, transportation, processing and disposal of waste (MRD, 2010). According to these guidelines the number of containers is recommended to be determined by the following formula:

$$N_b = \frac{Q_{Д\max} t K_1 K_2}{C K_3}$$

where,

N_b = Number of containers required

Q_{Dmax} =	Maximum daily amount of each type of waste components in the settlement for which calculation is made, m^3 / day
T =	Frequency of transportation of each type of MSW, days
K1 = value	Daily index of irregularity of MSW generation; recommended is 1.4
K2 =	Factor considering the number of containers that are being repaired and in reserve, recommended value is 1.05
C =	Capacity of one container, m^3
K3 =	Fill factor of the container, recommended value is 0.9

The Annual Maintenance Costs of bins ($AMC_{bins\ i(j)}$) of stream i which are used for sector j are expressed as one percent of the Equivalent Annual Discounted Total Purchase Cost of bins:

$$AMC_{binsi(j)} = 1\% * EADTPC_{bins\ i\ (j)}$$

The Equivalent Annual Discounted Total End-of-Life Costs of bins ($EADTEC_{bins\ i(j)}$) are not considered in the calculation, because they are outside of the project´s time boundaries (lifetime of bins is >20 years).

b) Total Annual Discounted Costs of Subsystem Trucks & Collection

The Equivalent Annual Discounted Total Costs of subsystem trucks & collection of waste stream i of sector j ($EADTC_{CV\ i\ (j)}$) are calculated based on the following formula:

$$EADTC_{CV\ i\ (j)} = EADTPC_{CV\ i\ (j)} + AOC_{CV\ i\ (j)} + AMC_{CV\ i\ (j)}\ ATPC_{CV\ i\ (j)} - EADTEC_{CV\ i\ (j)}$$

where,

$EADTPC_{CV\ i\ (j)}$ =	Equivalent Annual Discounted Total Purchase Cost of collection vehicles (CV) (€/year)
$AOC_{CV\ i\ (j)}$ =	Annual Operating Costs of CVs (€)
$AMC_{CV\ i\ (j)}$ =	Annual Maintenance Cost of CVs (€)
$ATPC_{CV\ i\ (j)}$ =	Annual Total Personnel Costs of CVs (€)
$EADTEC_{CV\ i\ (j)}$ =	Equivalent Annual Discounted Total End-of-Life Costs of CVs (€)

For calculation of the Equivalent Annual Discounted Total Purchase Cost of CV the number of CV is necessary to know. This input parameter was calculated by the project partner from NUUE using the Ukrainian guidelines for organizing of the collection, transportation, processing and disposal of waste (MRD, 2010). According to these guidelines the number of CV is recommended to determine by the following formula:

$$N_{ca} = \frac{Q_{Д\max}}{B K_{вик}}$$

where,

Q_{Dmax} =	Maximum daily amount of each type of waste components in the settlement for which calculation is made, m^3 / day
N =	Number of required CV
B =	Efficiency of CV per working day, m^3
K_{eux} =	Factor of using CV for the provider of waste removal service

The Annual Maintenance Cost of CVs ($AMC_{CV\ i\ (j)}$) are expressed as percentage of the Equivalent Annual Discounted Total Purchase Cost of one collection vehicle. This means that maintenance costs are accounted as 12% of the purchase price of one CV:

$$AMC_{CV\ i(j)} = 12\% * EADTPC_{CV\ i\ (j)}$$

The Equivalent Annual Discounted Total End-of-Life Costs of CV ($EADTEC_{CV\ i(j)}$) are not considered in the calculation, because they are outside of the project´s boundaries (as lifetime of CV is >20 years).

c) Total Annual Discounted Costs of Subsystem Treatment & Disposal

Since the detailed planning of the treatment facilities for D. is outside of the project's scope, the assumptions about costs of treatment and disposal had to be made based on other studies.

Costs are usually calculated based on a waste treatment plant's capacity per year or as total costs of the plant (Mihajlovic et al., 2016). The major problems when comparing cost data are related to different construction years, countries, sizes, technologies, useful life of facility, waste composition, capacities, working conditions and material- and energy recovery-rates of the waste treatment facilities and, last but not least, highly varying levels for some cost categories (e.g. labour) (Den Boer et al., 2005). Costs for facilities in Ukrainian conditions could not be found due to the absence of such state-of-the-art treatment facilities in Ukraine. Because of the above-mentioned difficulties with data comparability and absence of realistic cost data for Ukraine, a feasible approach was to use approximated cost functions for waste treatment facilities, developed for Europe, see Table 3 (Tsilemou and Panagiotakopoulos, 2006).

Although cost curve models are only estimations and do not give exact information about the real costs in the Ukrainian conditions, they can be used as rough estimations, especially due to the fact that the technologies for treatment facilities will be most likely imported from Europe due to the absence of their local production in Ukraine.

Local decision makers need cost-related information, because they are one of the most important decision drivers. Therefore, the cost curves are a solid starting point within the scope of this work, where the overall goal is a comparative analysis of different waste management scenarios. Furthermore, the goal of this thesis is not the exact calculation of economical, ecological, social and technical impacts but rather the evaluation of parameters in order to assess and compare different scenarios. To get accurate and reals costs, the local stakeholders have to request prices from construction or engineering companies based on detailed planning of the facilities.

Table 3: Approximate cost functions for waste treatment facilities in Europe (Tsilemou and Panagiotakopoulos, 2006; Den Boer et al., 2005)

Type of treatment facility	**Suggested cost functions**		
	Investment costs (€)	**Operating cost (€/t)**	**Capacities (t/year)**
Incineration	$y = 5.000 * x^{0,8}$	$y = 700 * x^{-0,3}$	20.000≤ x≤600.000
Aerobic Mech.-Biol. Pre-treatment	$y = 1.500 * x^{0,8}$	$y = 4.000 * x^{-0,4}$	7.500≤x≤250.000
Anaerobic Mech.-Biol. Pre-treatment	$y = 2.500 * x^{0,8}$	$y = 5.000 * x^{-0,4}$	7.500≤x≤250.000
Anaerobic Digestion	$y = 34.500 * x^{0,55}$	$y = 17.000 * x^{-0,6}$	2.500≤x≤100.000
Open windrow composting	$y = 4.000 * x^{0,7}$	$y = 7.000 * x^{-0,6}$	2.000≤x≤100.000
Sanitary Landfill	y = 6.000 * x0,6	$y = 100 * x^{-0,3}$	500≤x≤60.000

As displayed in Table 3, the Total Annual Discounted Cost of Subsystem Treatment & Disposal are calculated based on total costs for investment of the treatment facility and total annual operational costs. The suggested cost functions for investment costs include: costs for site investigation, environmental assessment, hydrogeological investigation, land acquisition, engineering design + constructions costs (land cleaning, excavation, buildings and other constructions works, equipment and furnishing of facilities, technical equipment, connecting network e.g. access roads). Whereas the cost functions for operational costs include: raw material, energy, wastewater disposal, labour, supervision, maintenance of facilities and equipment, insurance, training programs etc. (Tsilemou and Panagiotakopoulos, 2006).

The cost curves were used for calculation of the cost for the MBT facility, sanitary landfill and open windrow composting facility. Investment and operational costs for the manual sorting line were available on local level.

Because of the complexity of this indicator the following Table 4 shows a summary of all input data and assumptions, calculation steps and data sources used for calculation of the indicator Total Annual Discounted Costs of Waste Management System.

Table 4: Calculation of indicator Total Annual Discounted Costs of Waste Management System

Indicator Total Annual Discounted Costs of Waste Management System Time horizon 20 years, discount rate 11%		
a) Total Annual Costs of Subsystem Bins & Container system		
Input data	Calculation	Source
Purchase costs of bins	Number of bins x purchase price of bins	Abashyna (2017)
Location costs of bins	Assumed price for construction of bins location sites	Abashyna (2017)
Annual maintenance costs of bins	1% of purchase price for bins	Khandogina and Abashyna (2017a)
b) Total Annual Costs of Subsystem Trucks & Collection		
Input data	Calculation	Source
Purchase cost of collection vehicles (CV)	Number of trucks x purchase price of CV	Khandogina and Abashyna (2017b)
Annual Operating Costs of CVs	Fuel consumption + insurance costs + road charge costs of CV	Khandogina and Abashyna (2017b)
Annual Maintenance Cost of CVs	12 % of purchase price for CV	Khandogina and Abashyna (2017b)
Annual Personnel costs of CVs	2 drivers per CV x annual costs of driver x number of trucks per scenario	Khandogina and Abashyna (2017b)
c) Total Annual Costs of subsystem Treatment & Disposal		
Treatment facility	Calculation	Source
MBT	Approximate cost curves	Tsilemou and Panagiotakopoulos, (2006); Den Boer et al. (2005)
Sanitary Landfill	Approximate cost curves	Tsilemou and Panagiotakopoulos, (2006); Den Boer et al. (2005)
Manual Sorting Line	Assumed prices for construction and workers	Khandogina and Abashyna (2017e)
Composting Facility	Approximate cost curves	Tsilemou and Panagiotakopoulos, (2006); Den Boer et al. (2005)
Cost for closure of dumps	Calculation	Source
Closure of P., V. and T. dump	Cost for mineral waterproofing layer + site planning + synthetic waterproofing layer + construction of protective screen + fine sand protective layer + drainage layer + Construction of gravel layer (30 cm) + Remediation layer + costs of design work +soil	Khandogina, O., Abashyna (2017c)

3.3.1.2 Total Annual Discounted Costs of WM system per tonne of formally collected waste

The Total Annual Discounted Cost of each WM subsystem per tonne of formally collected waste ($AnTC_{subsystem(ton)}$ is calculated (in €/tonnes) according to the following formula (Panagiotakopoulos and Tsilemou, 2004; Rigamonti et al., 2016b):

$$AnTC_{SS} = \frac{EATC_{SS\ Bins} + EATC_{SS\ Trucks\ \&Collection} + EATC_{SS\ Tretment\ \&\ Disposal}}{Q_{Subsystem}}$$

where,

$AnTC_{SS}$ =	the Annual Discounted Total Cost of each WM Subsystem (€/tonne formally collected waste)
$EATC_{SS\ Bins}$ = Subsystem	the Equivalent Annual Discounted Total Cost of Bins and Collection (€/year)
$EATC_{SS\ Trucks\ \&\ Collection}$ =	the Equivalent Annual Discounted Total Cost of Subsystem Trucks and Collection (€/year)
$EATC_{SS\ Treatment\ \&\ Disoposal}$ =	the Equivalent Annual Discounted Total Cost of Subsystem Treatment and Disposal (€/year)
$Q_{Subsystem}$ =	the Waste Quantity entering the Formal Collection System in D. (tonne/year)

In comparison to the previous indicator (Total Annual Discounted Cost of WM system) the indicator Total Annual Discounted Cost of WM system per tonne of formally collected waste is a relative indicator, which allows local stakeholders to compare the Total Annual Discounted costs with other countries or cities and can therefore be an useful tool for better understanding orders of magnitude.

Furthermore, this indicator enables the comparison of the three subsystem bins & container system; trucks & collection, treatment & disposal. Thus, it is possible to identify which of the three subsystems are major cost drivers.

3.3.1.3 Annual Revenue from Recovery of Material and Energy

In order to provide a comprehensive view on costs, also potential revenues that are generated within a MSW system have to be included in order to make considerations regarding the financial viability of a MSW system.

The indicator annual revenue from recovery of material and energy (Rev) is calculated according to the following formula (Panagiotakopoulos and Tsilemou, 2004):

$$Rev = \sum Rev_{MBT} + \sum Rev_{CF} + \sum Rev_{SL} + \sum Rev_{MDF} + \sum Rev_{RDF}$$

where,

Rev_{MBT} = Annual Revenues from Recovered Material of MBT facility (me, gl)

Rev_{CF} = Annual Revenues from Recovered Material of Composting Facility

Rev_{SL} = Annual Revenues from Recovered Material of sorting from Manual Sorting Line

Rev_{MDR} = Annual Revenues from Recovery from Mixed Dry Recyclables

Rev_{RDF} = Annual Revenues from Recovery of RDF

The unit selling prices of each recovered material or type of recovered energy were investigated on local level and presented in the following

Table 5.

Table 5: Unit selling price of recovered material in D. in year 2017

Recovered material	Unit selling price [€/t]	Source
Paper average	29	Khandogina (2017)
Plastic average	258	Khandogina (2017)
Metal average	541	Khandogina (2017)
Glass average	26	Khandogina (2017)
Compost	10	Khandogina (2017)
MBT $output_{RDF}$	10	Ministry of Republic Belarus (2016)
MBT $output_{glass}$	1	Reasonable assumption
MBT $output_{metal}$	271	Reasonable assumption

As seen in the table above most of input data could be found on the local level, however for some of the missing information like the unit selling price of RDF or MBT outputs glass and metal reasonable assumption where made together with partners of the WaTra-project. Nevertheless, prices should be regarded with caution because actual prices depend on the quality of recyclables, market fluctuations and transport costs.

3.3.1.4 Self-financing Rate

This indicator measures the diversion between the financed and non-financed part of the total annual discounted costs and benefits of the waste management system in € per person and year. The relation is calculated by comparing the total annual discounted costs of the waste management scenario (costs subsystem bins &

container system + subsystem trucks & collection + subsystem treatment & disposal) and total annual benefits (consumer fees + revenues from material and energy recovery) of the waste management system.

$$Self - financing\ Rate = \frac{Benefits_{SWMS\ fees+revenues}}{EADTC_{SWMS}} \%$$

where,

$Benefits_{SWMSfees+revenue}$ = Consumer Fees + Revenues from Material and Energy Recovery (€/person/year)

$EADTC_{SWMS}$ = Equivalent Annual Discounted Total Costs of Solid Waste Management System (€/person/year)

The calculation of annual revenues is described in the previous chapter (3.3.1.3) as well as the calculation of total annual costs (3.3.1.1). The current waste management fees are provided on local level.

The indicator was chosen to enable stakeholder to make rough estimations about eventual needed increase of current consumer tariffs and to see the breakeven point of a scenario.

3.3.1.5 Total Annual Discounted Costs as % of approved District Expenditures

This indicator measures the MSWM costs as a percentage of the income & expenditures of the D. budget (Panagiotakopoulos and Tsilemou, 2004):

$$TAC_{District\ Expenditures} = \frac{EADTC_{SWMS}}{Expenditures_{\ district}} \%$$

where,

TAC = the Total Annual Costs as % of approved District Expenditures

$EADTC_{SWMS}$ = the Equivalent Annual Discounted Total Cost of Solid Waste Management System in €

$Expenditures_{district}$ = data provided form the local budgets of D. from 27.12.2016 (Rayon Administration D., 2016b).

This indicator was selected to make it better understandable how much of the local budget is being spent on the waste management system. For local stakeholder this could be an important information to compare expenditure for the WM system with other municipal expenditures.

3.3.1.6 Total Costs of WM system as % of Nominal Average Salary & Minimum Wage

This indicator measures the cost of waste management per person as a percentage of the nominal average salary and the minimum wage in Ukraine (Panagiotakopoulos and Tsilemou, 2004):

$$TAC_{SalPe} = \frac{EADTC_{SWMS(person)}}{SalPe}\%$$

where,

TAC_{SalPe} = Total Annual Discounted Costs as % of Nominal Average Salary

$EADTC_{SWMS\ (person)}$ Equivalent Annual Discounted Total Cost of the Solid Waste Management System in €/person

SalPe = Nominal average Salary per person in €/year

$$TAC_{MiWa} = \frac{EADTC_{SWMS\ (person)}}{MiWa}\%$$

where,

TAC_{MiWa} = Total Annual Discounted Costs as % of Minimum Wage

$EADTC_{SWMS\ (person)}$ Equivalent Annual Discounted Total Cost of the Solid Waste Management System in €/person

MiWa = Annual Minimum Wage per person in €/year

The input data for the indicators are provided on local level and are presented in the following Table 6.

Table 6: Wage-related data for Ukraine

Income	Value [€/year]	Source
Average nominal salary	1,772	Stolberg et al. (2016b)
Minimum wage	1,326	VRU (2017)

Based on the results of this indicators it is possible to conclude how much of a citizen's salary will be spend for covering costs of the WM system. Local decision maker can estimate if the consumer tariffs are appropriate compared with the income of citizen or can be a burden for financially vulnerable citizen.

3.3.2 Environmental indicators

The following sub-chapters present the chosen methodology for calculating the environmental indicators.

3.3.2.1 Source-separated Collection Rate

Separate collection means the collection where a waste stream is kept separately to respect of type and nature to facilitate a specific treatment (WFD, 2008). The source-separated collection rate is defined for the project as: “The amount of source-separated collected waste fractions (plastic, paper, metal, glass, organics) relative to the total amount of formally collected waste” (Armijo et al. 2011; Cifrian et al., 2015; Wilson et al., 2015).

$$Source - separated\ Collection\ Rate = \frac{MSW_{source\ sep.}}{MSW_{form.coll.}} \%$$

where,

$MSW_{source\ sep.}$ = Source-separated Municipal Solid Waste (plastic, paper, metal, glass, organics) (t/year)

$MSW_{form.coll.}$ = Municipal Solid Waste formally collected (t/year)

In order to show possible performance options three different targets for calculation of source separated collection rate are recommended in the scope of this thesis. The targets (Table 7) are expressed as mass percentage rate for five waste streams and differ between low, high targets as well as targets for the wet-dry bin. The reference targets are based on Europe-wide investigations of collection efficiencies in different cities in Germany, France, Ireland, United Kingdom, Italy and Netherlands. They should serve as achievable estimations of separate collection targets for recyclables and organic waste.

Table 7: Recommended targets for separate collection (Den Boer et al., 2005, Pöttschacher, 2016)

Targets [%]			
Fraction	**Low**	**High**	**Dry-wet bin**
Plastic and composites	33	65	70
Glass	50	69	71
Paper and cardboard	45	74	85
Metal	60	60	81
Organics	22	51	-

The source-separated collection rate displays the quantities of recyclables collected for subsequent recycling processes and therefore can be considered as indicator showing resource recovery efforts.

WEEE and hazardous waste are outside of the system boundaries and therefore not considered in the source-separated collection rate.

3.3.2.2 Material Recovery Rate

The Material Recovery Rate (MRR) is defined as the ratio between the quantity of waste recycled (=brought back into the value chain as secondary raw material) and the amount of formally collected MSW in tonnes per year (Rigamonti et al., 2016a). It is calculated according to the following formula:

$$MRR = \frac{material_{separ.coll.} + material_{comb.residues} + material_{MBT\ plant} + compost}{formally\ collected\ MSW}$$

where,

- Material separate collection = Source separate collected material (plastic, paper, metal, glass) after sorting and recycling.
  Recycling means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes (WFD, 2008). It does not include the reprocessing of organic material
- Combustion residues = materials recovered from residues of energy recovery (e.g. incineration) are excluded, because no incarnation scenario is suggested
- Material from MBT plants = Glass and metal obtained from the sorting process in MBT and recycled afterwards; only materials with a market value are included in the calculation
- Compost = Fertiliser obtained from reprocessing of separately collected organic material in composting plants. It was assumed that compost efficiency is 1/3 of separated collected organic fraction + structure material

The source separation rate is calculated according to the previous indicator (chapter 3.3.2.1). For calculation of separation & composting efficiency and the technical recycling rate of source-separated material and MBT outputs a literature review and expert based interviews were conducted (Binner, 2012; Christensen and Damgaard, 2011a, 2011b; Maletz, 2017a; Plastic zero, 2014; Pöttschacher, 2016; Pressley et al., 2015; Tchobanoglous and Kreith, 2002; Van Eygen et al., 2017). Together with experts from ABF-BOKU and TU-Dresden the following separation efficiencies and recycling rates are assumed as basis for the calculation of material recovery rates after recycling:

Table 8: Values used for separate collection rate, sorting efficiency and technical recycling rates

Fraction	Separate Collection $Efficiency_{low}$ [%]	Separate Collection $Efficiency_{high}$ [%]	Sorting Efficiency [%]	Technical recycling rate/ Composting Efficiency [%]
Plastic	33	65	60	60
Paper	45	74	75	85
Metal	60	60	90	95
Glass	50	69	90	95
Organics	22	51	-	33
Dry wet bin plastic	-	70	50	60
Dry wet bin paper	-	71	75	85
Dry wet bin metal	-	85	60	95
Dry wet bin glass	-	81	60	95
MBT $output_{glass}$	-	-	5-12	60
MBT $output_{metal}$	-	-	1-2	80

In Figure 7 the calculation of MRR is presented for better illustration on the example of one piece of paper: if 1 piece of 1 paper is formally collected, in the end 0,46 pieces of paper can be generated after recycling (= 1 x 0,74 x 0,75 x 0,85).

As seen in Figure 7 first the separate collection targets (Table 7) are applied. Then, the sorting efficiency at manual sorting lines for sorting of paper, plastic, metal and glass is assumed (Table 8). For separately collected organics it is assumed that 33% of the collected material (including double of the input material as structure material) can be used as compost. In a third step the technical recycling rate are also considered (Table 8).

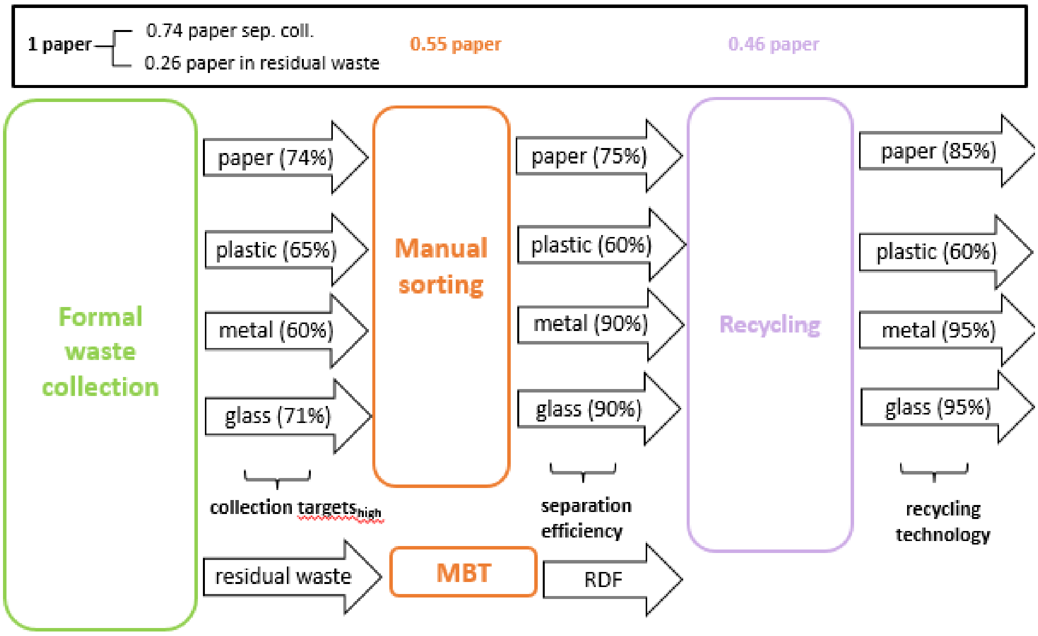

Figure 7: Difference between separate collection efficiency, separation efficiency and technical recycling rate explained on an example

3.3.2.3 *Energy Recovery Rate*

The Energy Recovery Rate (ERR) expresses the useful recovered exergy out of the total available exergy associated with the formally collected MSW. Exergy can be defined as "the maximum amount of work that can be obtained from a given, process or from a given system by reversible processes" (Gross et al., 2010). It is calculated according to the following formula (Rigamonti et al., 2016a):

$$ERR = \frac{MJ_{el} + MJ_{th} * \left(1 - \frac{T_a}{T_{ml}}\right) + MJ_{indirect}}{MJ_{available}}$$

where,

MJ_{el} Net electricity recovered out of the MSWM system, e.g. from combustion/gasification process, landfill gas utilization (expressed in MJ)

MJ_{th} Net heat recovered out of MSW management system, e.g. from combustion/gasification process, landfill gas utilization (expressed in MJ)

$(1 - \frac{T_a}{T_{ml}})$ Carnot factor describes an ideal reversible cyclic process involving the expansion and compression of an ideal gas and its efficiency

$MJ_{indirect}$ Exergy flow associated with products with an energy contend which are not directly used for energy production e.g. RDF co-combustion of RDF in coal fired power plant or cement kilns used as fuel-substitution (expressed in MJ per mass)

$MJ_{available}$ Total available exergy associated with the formally collected MSW

The heating values used for calculation of the total caloric value are presented in the following Table 9:

Table 9: Heating values for different waste fractions (Wünsch, 2017)

Fraction	Heating value [MJ/t]
Organic	5,000
Wood	14,000
Textiles	14,000
Minerals	0
Composites	19,450
Pollutants	3,000
Others	8,000
Fine fraction <10mm	4,000
Fe/non-Fe Metals	0
Paper/Cardboard	11,000
Glass	0
Plastics	31,000

The amount of $MJ_{indicrect}$ is a product of multiplication of the total heating value of RDF with the efficiency of incineration in cement kiln (99%) and amount of RDF produced. The total heating values of RDF are calculated by the Emissions-Calculation Tool from TU-Dresden by multiplying the amount of organic, wood, textiles, composites, pollutants, others, fine fraction over 10mm, Fe/non-Fe metals, paper/cardboard, glass and plastic in each scenario with the net calorific values of each scenario. Further, the $MJ_{available}$ is the product of the 11 above listed fractions contained in the formally collected waste multiplied with the heating values in Table 9.

3.3.2.4 Waste Landfilling Rate

The Waste Landfilling Rate (WLR) is defined for the WaTra-project as the ratio between waste left for disposal in landfills and formally collected waste (Cifrian et al., 2015; Shen et al, 2011; Desmond, 2006). The term waste left for disposal includes residues from manual sorting plants, open windrow composting and MBT residues. Residues from combustion and recycling are not included in the calculation.

$$WLR = \frac{MSW_{landfilled}}{MSW_{form.coll.}}$$

where,

$MSW_{landfilled}$ = Total landfilled Municipal Solid Waste (t/year)

$MSW_{form.coll}$. = Municipal Solid Waste formally collected (t/year)

A MSWM system aiming at optimised use of resources should have an indicator that is low.

3.3.2.5 Biodegradable Waste Diversion Rate

The Biodegradable Waste Diversion Rate is defined as the amount of biodegradable waste diverted from landfill in comparison with the biodegradable waste formally collected in the year 2015 (assumed as a reference year) (Vučijak et al., 2015). The reduction of biodegradable waste from landfill (RBWL) is calculated according the following formula (Den Boer et al., 2005):

$$1 - RBWL = \frac{QBiodLF}{QBiod_{2015}} = \frac{\sum \ WF_i\,(LF)\ x\ Biod_i}{\sum \ WF_i\,(2015)\ x\ \ Biod_i}$$

where,

QBiodLF Quantity of biodegradable waste which is landfilled according to a given scenario in tonnes per year

$QBiod_{2015}$ Quantity Biodegradable waste generated in 2015 in tonnes per year

WF_i (LF) Quantity of waste fraction which is landfilled in the considered scenario in tonnes per year

$Biod_i$ Biologically degradable portion of i fraction of waste in % (see Table 10)

WF_i (2015) Quantity of i waste fraction (bio waste, paper or wood, residual waste etc.) formally collected in 2015 in tonnes per year

The default data on biodegradability of different waste fractions is adopted after Den Boer et al., (2005) and presented in Table 10.

Table 10: Default characteristics of residual waste adapted after Den Boer et al. (2005)

Fraction	Biologically degradable organic dry matter [%]
Organic	100
Wood	50
Textiles	60
Minerals	0
Composites	58
Pollutants	25
Others	60
Fine fraction <10mm	88
Fe/non-Fe metals	0
Paper/Cardboard	98
Glass	0
Plastic	5

The RBWL shows the improvements of a scenario to move sufficient biodegradable waste from landfills to recycling or other treatment option and therefore cut climate relevant GHG emissions.

3.3.2.6 Greenhouse Gas Emissions

For calculation of the greenhouse gas (GHG) emissions [CO_2-eq per tonne formally collected waste] the following formula according to the unpublished Emissions-Calculation-Tool developed at TU-Dresden was used (Wünsch, 2013):

$$GHG_{SWMS} = GHG_{MBT} + GHG_{LF} + GHG_{CK} + GHG_{TR}$$

where,

GHG_{SWMS} = Total Greenhouse Gas Emissions from SWMS (CO_2-eq per tonne formally collected waste)

GHG_{MBT} = Greenhouse Gas Emissions emitted by MBT (CO_2-eq per tonne formally collected waste)

GHG_{LF} = Greenhouse Gas Emissions emitted by Sanitary Landfill (CO_2-eq per tonne formally collected waste)

GHG_{CK} = Greenhouse Gas Emissions emitted by Cement Kiln (CO_2-eq per tonne formally collected waste)

GHG_{TR} = Greenhouse Gas Emissions emitted by Treatment of Recyclables (CO_2-eq per tonne formally collected waste)

The following assumptions and data were used for the model:

Table 11: Assumptions and input data for calculation of indicator GHG emissions

Assumptions and input data	Source
CH_4 has a 28 times higher greenhouse gas potential than CO_2	IPCC et al. (2013)
N_2O has a 310 times higher greenhouse gas potential than CO_2	Scharenberg (2017)
Greenhouse gas substitution factors for material recovery in t CO_2 eq. /year: • Iron 1.2 • Aluminum 15.2 • Copper 4 • Minerals 0.004 • Paper/Cardboard 0.3 • Glass 0.5 • Plastics 0.85	Wünsch (2017)
55% of the total landfill gas is methane	Scharenberg (2017)
All RDF produced is co-incinerated in a cement kiln with an efficiency of 99%	Wünsch (2013)
In cement kilns 100% natural gas is substituted	Scharenberg (2017)

In the TU-Dresden GHG emissions tool, emissions are calculated only for the MSW treatment processes, emissions from collection and transport of waste are not considered since they usually make insignificant share of emissions in waste management system in comparison with treatment (<8%, Mohareb et al., 2011). For waste management scenarios in D. district the GHG emissions from following MSW treatment processes are considered: MBT, landfilling, cement kiln and treatment of recyclables. Emissions from composting are not included in the calculations in the tool, however their impact can be counterbalanced with GHG credits obtained by application of compost on land (substitution of other types of fertilisers by compost) (Linzner and Mostbauer, 2005).

A WM system that produces little greenhouse gas emissions will have a lower number in comparison to WM system which emit higher amount of GHG. For more detailed information concerning methodology and calculation of greenhouse gas emissions within the scope of the WaTra-project see Scharenberg (2017).

3.3.3 Social indicators

The three pillars of sustainability are a framework of the parts economic, environmental and social sustainability (German Parliament, 1998). Social sustainability is therefore an integral part of waste management. It is defined according to Den Boer et al. (2005) as the ethical performance of waste management system towards society. This means MSW systems must be planned and managed responsibly towards society and respect citizens' as well as employees' rights.

For the impact assessment of waste management system towards society a mixture of indicators was used. The indicator "Social Acceptability" (chapter 3.3.3.1) is a qualitative indicator based on expert interviews from ABF-BOKU and TU-Dresden. The indicator consists of seven subcategories (odour, visual impact, user convenience & complexity, distance to container, private space, noise). Whereas, indicator "Job Creation Potential" (chapter 3.3.3.2) is a quantitative assessment based on literature research.

3.3.3.1 Social Acceptance

For measuring the social acceptance a list of relevant subcategories was adapted after Den Boer et al. (2005). The subcategories are socially significant attributes, which are assessed by experts (UNEP, 2009). This method was chosen to gain information from experts with a solid background in waste management. Therefore, in the investigation process of the thesis four written evaluations of experts from ABF-BOKU and TU-Dresden were made.

For the assessment of the social acceptance the relevant experts had to fill in an Excel-file which was prepared especially for the WaTra-project. The relevant subcategories were classified under three different subsystems.

As already described in chapter 3.3.1 subsystem bins & container includes all waste bins and containers for collection of MSW. Additional for this indicator the collection of waste in rubbish bins at home is also included in this subsystem.

The subsystem trucks & collection covers all collection vehicles for the transport of the total amount of MSW collected in D..

Whereas the subsystem treatment & disposal describes all planned treatment- and disposal facilities within the system boundaries of the region.

Table 12 shows which subsystems have an impact on the assessed indicators. Subsystems marked with an X have an impact on a certain indicator. Subsystems without mark have no or negligible impact.

Table 12: List of social criteria for assessment of indicator social acceptance adapted after Den Boer et al. (2005)

	Subsystem		
Social Acceptance Criteria	**Bin & Containers system**	**Collection & Transport**	**Treatment & Disposal**
Odour	**X**		**X**

Visual impact	X		X
User Convenience & Complexity	X		
Distance to container	X		
Private space	X		
Noise	X	X	X
Traffic		X	X

Each social subcategory criterion is compared by the experts with the existing baseline scenario and is classified over five levels from the best situation to the worst situation. A mark (ranking from -2 to +2) is assigned to each criterion for all different future scenarios. The marks are defined by the social sustainability level: 2 means that the scenario changes in the best positive way in comparison to the baseline scenario, 0 means no changes are expected, and -2 shows that the scenario changes in the most negative way in comparison to baseline scenario. Based upon the expert survey results a mean value is calculated for each criterion of every scenario.

The definition of each criterion is adapted from various studies and is presented in the following section.

Odour

Criterion odour describes the potential of odour nuisance by a given subsystem to the city inhabitants. Intensity of odours generally increases in scenarios with separate collection of bio waste. The appearance of odour usually undermines social acceptance for a given scenario (Tulokhonova and Ulanova, 2013; Den Boer et al., 2005).

Visual Impact

This criterion measures the visual impact of waste bins and waste treatment plants. It takes into account the visibility the MSWM system. A negative impact on the criterion is caused by an increase in the number of containers and other waste storage facilities used for collection of individual waste components. The visual effects of the subsystem treatment & disposal also depends on the existence of waste management companies in urban areas (Tulokhonova and Ulanova, 2013; Den Boer et al., 2005).

User convenience & complexity

User convenience & complexity to the public of the waste management system is related to the number of waste fractions to be collected separately. The most convenient system for the public is the existing waste collection system with one waste bin only. More recycling-oriented scenarios include the separate collection of more waste fractions, this requires an increased number of different bins. More bins can cause more time for the separate collection and inhabitants have to change their behaviour, which is often perceived as inconvenient. A higher number of separated waste fractions leads to less understandability and acceptability of bins & collection system by the public (Tulokhonova and Ulanova, 2013; Den Boer et al., 2005).

Distance to containers
This criterion measures the logistical convenience for the user which means the distance to containers or collection points. The system is perceived as convenient to the user the shorter the distance to the containers is (Tulokhonova and Ulanova, 2013; Boer et al., 2005).

Private space
Private space consumption is concerned with space occupied by the waste bins & collection system inside the inhabitant's private properties. A higher number of separately collected waste fractions causes higher private space consumption due to the higher amount of waste bins and may therefore undermine acceptability of MSW services (Tulokhonova and Ulanova, 2013; Den Boer et al., 2005).

Noise
The criterion noise is described as sounds which cause annoyance for human beings and animals. Increased mean sound level is caused by additional waste management activities e.g. transport or treatment of waste, filling of containers, increased traffic (SUP, 2004; Tulokhonova and Ulanova, 2013; Den Boer et al., 2005).

Traffic
The criterion traffic is described by the volume of traffic, e.g. for collection of waste from bins, transport of waste to treatment facilities Increased traffic can have various effects like blocking the streets, increase of emissions, noise and odours (SUP, 2004; Tulokhonova and Ulanova, 2013; Den Boer et al., 2005).

3.3.3.2 Job Creation Potential

The indicator Job Creation Potential measures the number of new jobs created by the implementation of a given scenario. The number of employees is related to 10,000 tonnes yearly turnover for a certain part in the WM system e.g. sorting, landfilling, composting. Evaluation of new jobs created in the waste management sector was conducted based on literature research (BMLFUW, 2015, 2015; EPA, 2002; European Commission, 2001; Maletz, 2017b; Murray, 1999; Seldman, 2002). Data from literature include only employees which are directly involved in active waste management actives like for example truck driver, container management etc. Indirect jobs created like for example administrative or security staff are not included in the number of employees.

For the number of jobs created in manual sorting lines and number of truck drivers a reasonable assumption was made for the case study together with project partners from NUUE.

It can be concluded from literature that more recycling-oriented WM systems create more jobs, whereas disposal-oriented systems create less jobs.

3.3.4 Technical indicators

As for the technical criteria, it was proposed to use four indicators for the evaluation of efficiency and appropriateness of the treatment and disposal technologies:

- Technical Reliability
- Requirement of Qualified Personnel and Maintenance Requirements
- Sensitivity to Quantity of Input Material
- Sensitivity to Quality of Input Material

The technical evaluation of the scenarios was conducted by experts from ABF-BOKU and TU-Dresden. For the technical assessment the same method as for the social acceptance evaluation used for was chosen in order to gain information from experts with a solid scientific background in WM. Four written evaluations of expert-based opinions were made. The experts had to fill in an Excel-file which was prepared specially for the WaTra-project. Within this Excel-file each technology used in a given scenario is assessed according to a scale from 1 to 4 (4 best score; 1worst score).

Weighting of the criteria is applied by relating the score to the treated waste amount for each waste treatment technology and scenario. Based upon the expert survey results a mean value is calculated for each criterion of every scenario. The definition of each criterion is adapted from various studies and is presented below.

3.3.4.1 Technical Reliability

This indicator evaluates the ability of a given technology to perform the desired function within a specified period of time, robustness and reliability in the practice (Arikan et al., 2017; SUP, 2004; Vučijak et al., 2015). The indicator is ranked on a scale from 1 (pretentious) to 4 (unpretentious).

3.3.4.2 Requirement of Qualified Personnel and Maintenance Requirements

This indicator evaluates the requirement of qualified personnel and maintenance requirements (spare parts, qualified operators etc.) (Arıkan et al., 2017). The indicator is ranked on a scale from 1 (high requirement) to 4 (low requirement).

3.3.4.3 Sensitivity to Quantity of Input Material

This indicator measures the flexibility of a technology related to changes of waste flows quantity and technical efforts for related adjustment of the technical infrastructure. In other words, if the input quantity changes, which effect would this have on the local WM infrastructure? With increasing waste amounts additional capacities are required, a decrease of the waste amount results in a lower capacity utilization (SUP, 2004). The indicator is ranked on scale from 1 (sensitive) to 4 (insensitive).

3.3.4.4 Sensitivity to Quality of Input Material

This indicator evaluates the flexibility of technology to change of waste *quality* and technical effort for related adjustment of the technical infrastructure (SUP, 2004). The indicator is ranked on scale from 1 (sensitive) to 4 (insensitive).

3.4 Description of scenarios modelled with Material Flow Analysis

Among other things one of the main goals of this master thesis was to support stakeholders by benchmarking the current state of WM systems and selecting best future WM options for D.. In order to fulfil this comprehensive aim, a scenario-based approach according to was chosen.

Seven future scenarios (consisting of 4 main scenarios + different sub scenario variants) were developed for a time horizon of 10 years (2015 -2025). The developed scenarios include different treatment technologies and source-separated collection rates. The chosen waste management scenarios were developed together with project partners from TU-Dresden and were reviewed with local partners during stakeholder meetings. One of the main aims was to identify range of possible differences between different scenarios and therefore possible strategic options and maximum realistic scenarios were complied.

The scenario performance evaluation takes place within specific system boundaries. Waste generation, formal waste collection, waste treatment and disposal options for residual waste, recyclables and organics are included in the system boundaries. Whereas, treatment of WEEE and hazardous waste are excluded. Recycling of recyclables is only included for calculation of the environmental indicator “MRR”, “GHG” emissions and for the social indicator “Job Creation Potential”.

The MSWM methods considered in the seven future scenarios have different priorities. Scenario 00 should fulfil only the minimum requirements as 100% collection rate, no illegal dumping and focuses on the management of MSW through state of the art landfill and MBT without treatment of recyclables. Scenarios 1a, 1b, 2a and 2b focus on source-separated collection and treatment of recyclables. Whereas scenario 3a and 3b focus on the production of high-calorific RDF (Refuse Derived Fuel) material. Hence, scenarios differ in their foci, since some are based on material recovery (1a, 1b, 2a, 2b) whereas others focus more on energy recovery (3a und 3b). In all scenarios residual waste is pre-treated in an MBT plant before landfilled at a sanitary landfill. In scenarios with separate collection of organics the implementation of an open windrow composting is suggested.

Based on the method of Material Flow Analysis (MFA) the baseline scenario and possible future scenarios for D. were developed and compared (Brunner and Rechberger, 2004). MFA is chosen as a tool because it systematically assesses the flows and stocks entering, leaving and taking place within a system defined in space and time. Thus, it allows calculating required plant capacities and residual flows, by linking waste input, products, residues and emissions (Stanisavljevic and Brunner, 2016).

Even though the MFA is a useful tool for modelling of scenarios, the lack and reliably of data constrains its applicability. Simplifications and assumptions which had to be made to overcome gaps in data availability are described separately in chapter 4.2.

4. Scenario Development

In order to show the variety of different feasible MSW management options for D. seven possible future scenarios were developed. The results and uncertainties in data gathering process are presented in the following chapter.

4.1 Future scenarios of MSW management system

The prime objective behind the development of the future scenarios was to establish possible strategic options for the development of the MSWM system. For this reason, not only organizationally realistic scenarios were compiled, but also their extreme variants (i.e. with maximum realistic values of the technical parameters - collection rates, sorting efficiencies etc.) to identify range of possible differences between alternative scenarios.

In comparison to the baseline scenario it is implied for all future scenarios that:

- **100% collection coverage** of MSW (excluding home composting and informal collection of valuable material to some extent) is guaranteed
- No untreated waste is landfilled anymore (pre-treatment in a **MBT plant**)
- A **Sanitary Landfill** which meets the environmental safety standards is built
- **WEEE and hazardous waste** are collected

One of the main problems is the limited scope of the organized collection of MSW which contributes to uncontrolled disposal. Therefore, as a first step it is necessary to extend the scope and improve the quality of the municipal collection services in the region. This approach also reflects the general objectives of the new Ukrainian Waste Management Strategy, which was released in 2017. One objective of the Strategy aims to cover 90% of the total population by organised MSW services by 2030 (GIZ, 2017). This target could be achieved by implementing all future scenarios in D..

The new Ukrainian Waste Management Strategy also identifies the lack of modern technical standards in the existing waste treatment facilities and consequential negative effects as a major problem (GIZ, 2017). In accordance with the requirements of the new Ukrainian Waste Management Strategy it is suggested in the scenarios that no untreated waste is landfilled anymore, but instead pre-treated in an MBT plant, which meets the technological standards. Afterwards the pre-treated waste is landfilled at a sanitary landfill. Further, all existing waste dumpsites are closed, because they do not fulfil any technical and environmental requirements.

For WEEE and hazardous waste a separate collection is implemented. This reflects the objective of the new Ukrainian Waste Management Strategy to implement clear provisions for hazardous waste produced by households (GIZ, 2017). However, these two waste streams are outside of the system boundaries in this study and not further evaluated.

In addition to separate collection of different waste fractions, the new Ukrainian Waste Management Strategy aims to encourage home composting in rural areas as a measure to divert biodegradable waste from landfills. It is planned to install home composting units for individual houses to promote this measure (GIZ, 2017). For that reason, the process of home composting is perceived as positive regarding proper waste management and hence included in all future scenario modelling. The amount of home composted material is based on calculations of NUUE is assumed as constant for all future scenarios. For more details see chapter 4.2.

Furthermore, it is supposed that IRS carrying out unauthorized WM activates and is diverting waste from MSW. Valuable materials are further proceeded, sold or illegally dumped. The quantities of informally diverted waste are also assumed as constant for all future scenarios and does not change.

The seven scenarios which are presented in the following distinguish concerning their main aims and emphasis. The first scenario (00) is based on the current waste management system, incorporating some technological improvements and fulfils only the above described preliminary minimum requirements. The second block of scenarios (1a, 1b, 2a, 2b) emphasizes source separate collection of different waste fractions and recycling. The third block of scenarios (3a, 3b) focuses - on producing high quality RDF material. An overview of the baseline and all investigated future scenarios, their main aim, collection efficiency and treatment infrastructure is given in the following Table 13.

Table 13: Overview of baseline and future waste management scenarios

Scenario	Basic idea & significant changes to baseline scenario	Collected waste streams	Separate Collection efficiency	MSW treatment infrastructure
Baseline	-	Residual waste, very small amounts of glass and plastic	Status quo	• 3 dumpsites • Current inefficient waste sorting facility
00 No recycling, sanitary landfill & MBT	• 100% collection coverage	Residual waste	-	• MBT • Sanitary landfill
1a - Recycling$_{low}$ [pl, gl]	• 100% collection coverage • Separate collection of 2 recyclable fractions	Plastic, glass	Plastic 33% Glass 50%	• MBT • Sanitary landfill • 3 manual sorting lines
1b - Recycling [dry-wet bin]	• 100% collection coverage • Separate collection of residual waste and dry recyclables in a two-bin system	Glass, plastic, metal, paper	Plastic 70% Metals 81% Glass 71% Paper 85%	• MBT (including a module for sorting of dry-wet bin) • Sanitary landfill
2a - Recycling$_{high}$ [pl, gl, me, pa]	• 100% collection coverage • Separate collection of recyclables in different bins	Plastic, glass metal, paper	Plastic 65% Glass 69% Metal 60% Paper 74%	• MBT • Sanitary landfill • 3 manual sorting lines
2b - Recycling$_{high}$ [pl, gl, me, pa, org]	• 100% collection coverage • Separate collection of	Plastic, glass metal, paper, organics	Plastic 65% Glass 69% Metal 60% Paper 74%	• MBT • Sanitary landfill • 3 manual sorting lines

	recyclables in different bins • Separate collection of organic waste		Organics 51%	• Open windrow composting
3a - RDF - Recycling$_{low}$ [me, gl]	• 100% collection coverage • Separate collection of metal and glass	Glass, metal	Metal 60% Glass 50%	• MBT • Sanitary landfill • 3 manual sorting lines
3b - RDF - Recycling$_{low}$ [me, gl, org]	• 100% collection coverage • Separate collection of metal and glass • Separate collection of organics to reduce moisture of residual waste	Glass, metal, organics	Metal 60% Glass 50% Organics 22%	• MBT • Sanitary landfill • 3 manual sorting lines • Open windrow composting

4.1.1 Scenario 00 – No recycling, Sanitary Landfill and MBT

This scenario is based on the current waste management system, incorporating some basic improvements. It represents the management of MSW through organization of sanitary landfilling and MBT without separate collection and treatment of recyclables.

The basic idea behind this scenario is to fulfil only the minimum requirements as 100% collection coverage, disposal at a sanitary landfill and pre-treatment of residual waste in a MBT plant. However, separate collection and treatment of recyclables are not considered in this scenario. The material flow of this scenario is shown in the following Figure 8.

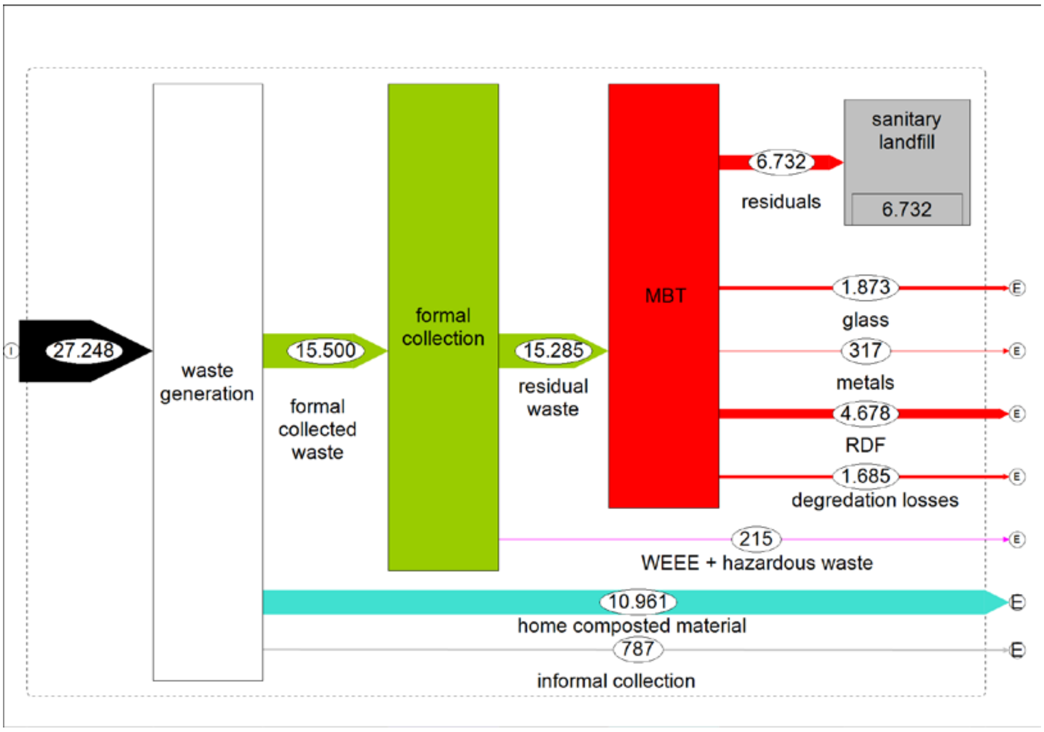

Figure 8: Material flow diagram of scenario 00 - No recycling, sanitary LF and MBT

As seen in the figure above, in this scenario, no untreated waste is landfilled. Illegally disposed of waste is collected formally and landfilled at the new sanitary landfill.

The formally collected residual waste is treated in a MBT facility and the residues are landfilled afterwards.

In comparison to the baseline scenario, WEEE and hazardous waste are formally collected and treated afterwards. The treatment of WEEE and hazardous waste are outside of the system boundaries and therefore not subject to the scope of this work. However, it is compulsory that the treatment of WEEE and hazardous waste meets the environmental & technical standards and causes no negative effects for the environment or human health. As a consequence of mismanaging these waste flows the public and workers' health as well as the environment can be adversely affected (Nowakowski, 2016).

The future waste quantities for all scenarios are based on the calculations of waste prognosis tool according to Beigl et al. (2003). An overview of all waste quantities for all scenarios is given in Annex 4.

4.1.2 Scenario 1a – Recyling$_{low}$ [gl, pl]

One of the major obstacles for developing an effective waste processing industry results from the fact that the tradition of separate collection lacks in Ukraine. Although, there are several waste sorting lines for sorting glass, paper, metals and plastic their efficiency is very low due to the lack of proper separate collection (Deloitte & Touche USC, 2012).

Therefore, in this scenario a source separation system with an efficiency of 33% for plastic and 55% for glass is implemented (Den Boer et al., 2005). The efficiency of a given recyclable is defined for all recycling-scenarios as the amount of source-separated material in relation to the total amount of that material in the formally collected waste. The non-separated material is included in the residual waste (Larsen et al., 2010).

As illustrated in the material flow diagram in Figure 9 the recyclables obtained from source separation are re-sorted in a manual sorting line and after processing they are sent to recycling facilities. This step is outside of the system boundaries (except for indicator MRR, GHG, Job Creation Potential) and for that reason not illustrated in the material flow diagram. The sorting residues from the manual sorting process are sent to the sanitary landfill.

The formally collected residual waste is pre-treated in a MBT-plant, where in the course of the mechanical separation valuable recyclables and RDF can be separated. During the biological process, the residues can be stabilized and afterwards landfilled.

WEEE and hazardous waste are formally collected and handed over to an authorized waste management company for further treatment.

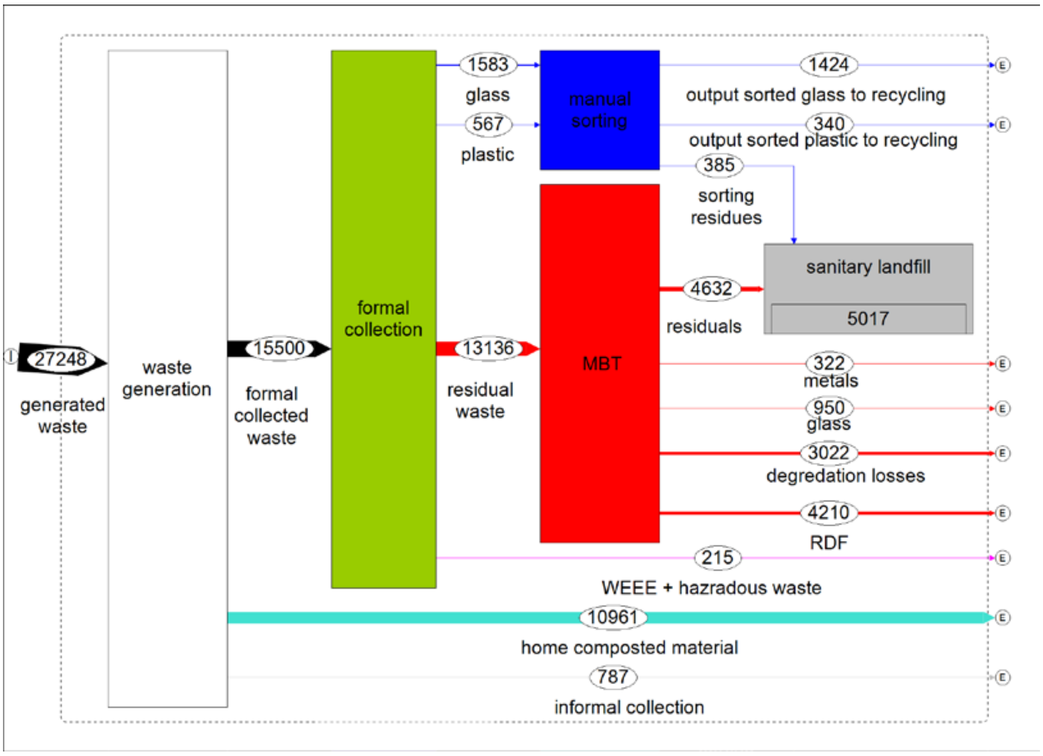

Figure 9: Material flow diagram of scenario 1a - Recycling$_{low}$ [gl, pl]

4.1.3 Scenario 1b – Recycling$_{\text{dry-wet bin}}$

This scenario puts an emphasis on the separate collection of recyclables. However, instead of collecting each different waste stream in a single bin it is suggested to implement a two-bin system. Plastic, metal, glass and paper will be collected together in one bin (=dry bin) and the remaining residuals (=wet bin) are collected in another bin.

The basic idea behind the implementation of a dry-wet-bin system is the possibility to collect plastic and so called non-packing of similar type together in one bin. The aim of this collection approach is to increase the sorting efficiency of dry recyclables and therefore to minimize the number of recyclables in residual waste. It is assumed that an easier and more user friendly separation system could lead to higher collection efficiencies (Oethen-Dehne, 2009).

The targets for the separate collection efficiency are adopted from already existing dry-wet-bin collection systems in five regions in Austria and Germany (Neunkirchen, Leipzig, Berlin, Hamburg, Karlsruhe) and are distributed on the collected fractions as following: plastic 70%, metals 81%, glass 71%, paper 85% (Pöttschacher, 2016).

After collection, the materials are treated in a MBT plant combined with sorting possibilities for the dry and the wet-bin before landfilling.

The collection and treatment process of the waste are shown in the following Figure 10:

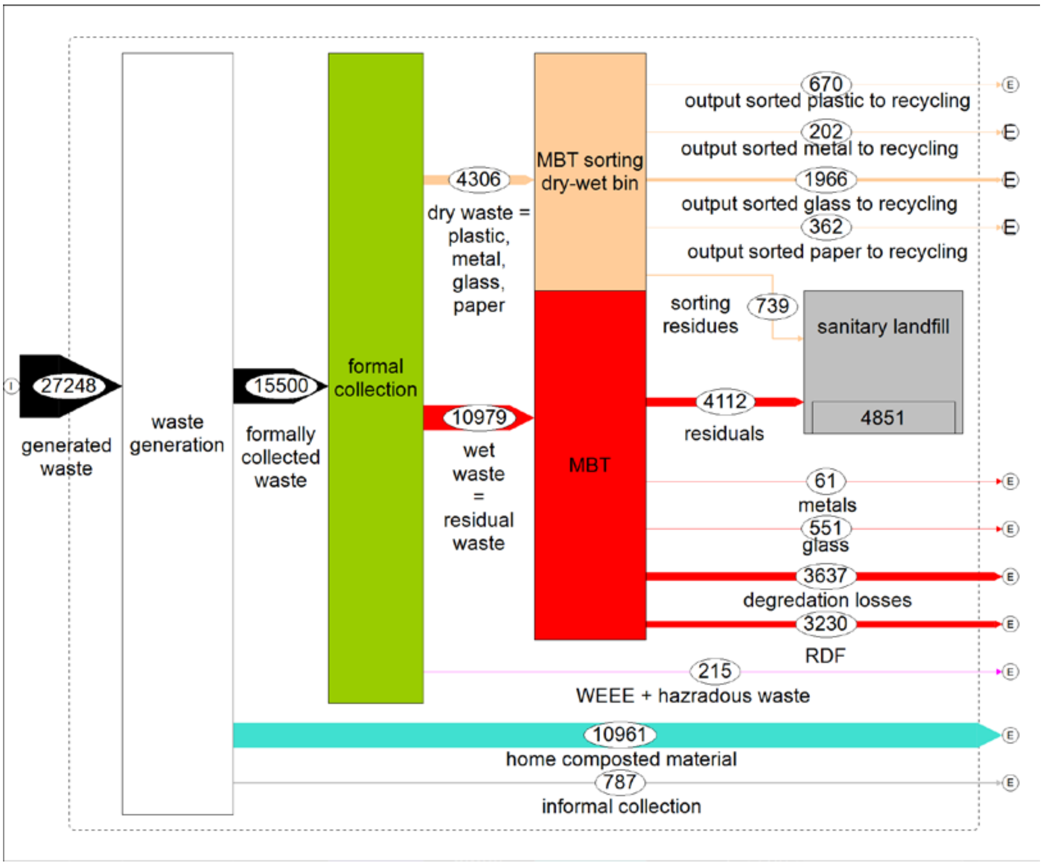

Figure 10: Material flow diagram of scenario 1b -Recycling$_{dry\text{-}wet\text{-}bin}$

As displayed in Figure 10 the recyclables (plastic, metals, glass, and paper) are collected in a one-bin-system (dry bin) and are treated afterwards in the same MBT where the residual waste is treated. After sorting out useful materials the remaining residuals from the wet and dry bin are landfilled.

WEEE and hazardous waste are formally collected and handed over to an authorized waste management company for further treatment.

4.1.4 Scenario 2a – Recycling$_{high}$ [pl, gl, me, pa]

In this scenario, a source separation system with a higher efficiency than in scenario 1a - Recyling$_{low}$ [gl, pl] was chosen. Additional to the two fractions of scenario 1a paper and metal are also collected separately. The higher source separation collection rates are as follows: plastic 65%, glass 69%, metals 60%, paper 74% (Den Boer et al., 2005).

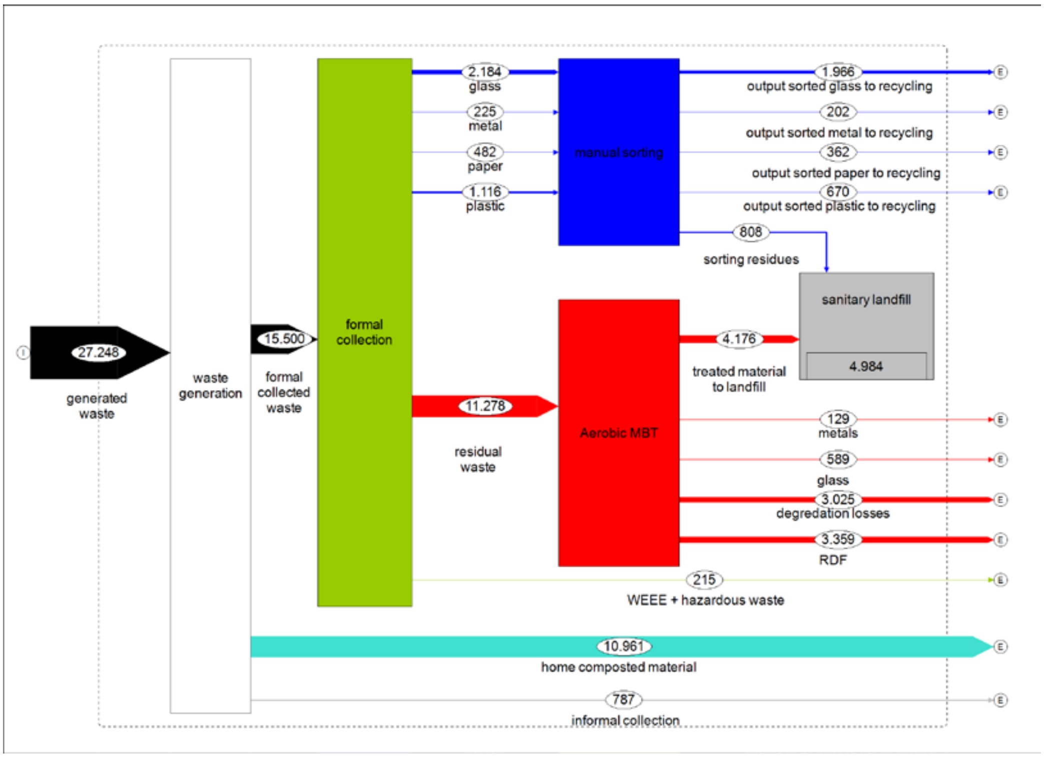

Figure 11: Material flow diagram of scenario 2a - Recycling$_{high}$ [pl, gl, me, pa]

As shown in Figure 11, the recyclables are collected separately and afterwards re-sorted at one of the three manual sorting stations. Residual waste is pre-treated in an MBT before landfilling, and valuable recyclables as well as RDF fraction are sorted out for further processing.

WEEE and hazardous waste are formally collected and handed over to an authorized waste management company for further treatment.

4.1.5 Scenario 2b – Recycling$_{high}$ [pl, gl, me, pa, org]

This scenario is similar to scenario 2a-Recycling$_{high}$, [pl, gl, me, pa] however, additional to the previous one organics are also separately collected. The separately collected organic waste is processed in an open windrow composting plant and marketable compost is produced. A detailed description of the compost process is given in chapter 5.3.

Figure 12 illustrates the material flow of this scenario. As already described in the previous chapters, recyclables are collected separately and re-sorted. The source separation rates are according to Den Boer et al. (2005): plastic 65%, glass 69%, metals 60%, paper 74%, organics 51%.

Residual waste is treated in an MBT plant and the outputs are either landfilled or further processed. Metals and glass form MBT Outputs are brought to recycling, whereas RDF is sold and used for energy recovery. WEEE and hazardous waste are formally collected and handed over to an authorized waste management company for further treatment.

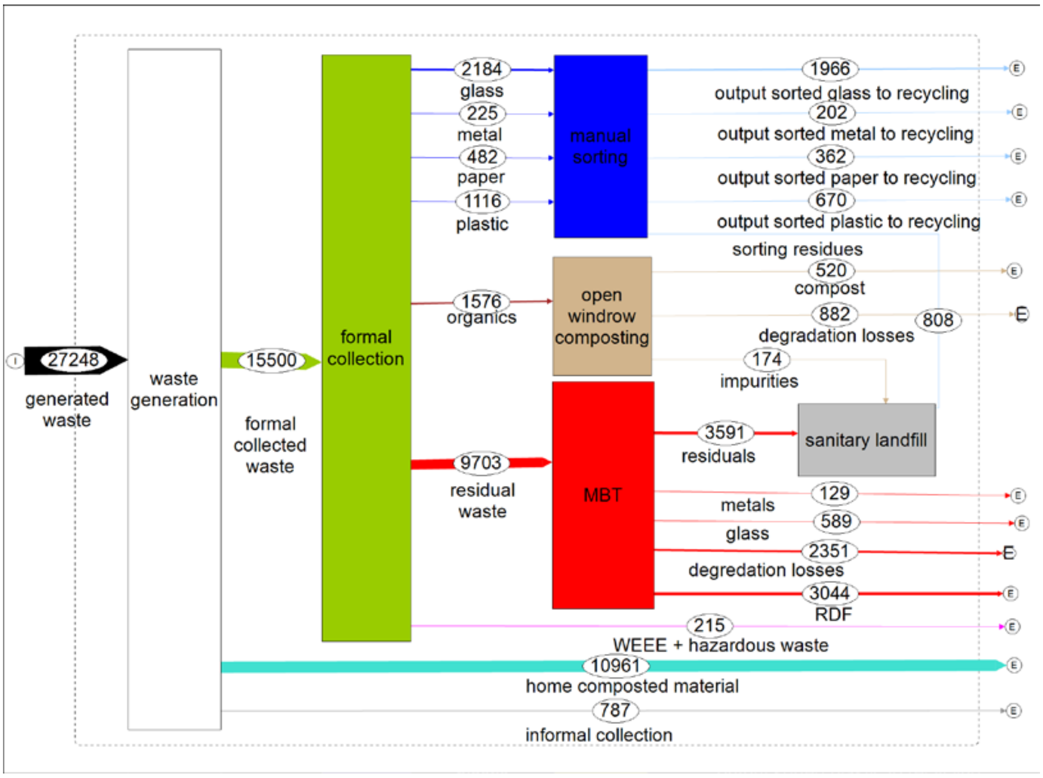

Figure 12: Material flow diagram of scenario 2a - Recycling$_{high}$ [pl, gl, me, pa, org]

4.1.6 Scenario 3a – RDF - Recycling$_{low}$ [gl, me]

RDF is a generic term to describe a fuel that has been manufactured from processing either municipal or commercial waste via mechanical biological treatment (Wise and Read, 2015). The term RDF has no strict technical definition and can include a broad variety of material that is capable of being burned. In general RDF consists largely of plastic and fibre waste combined with organic waste and it is produced by mechanical sorting, shredding and drying (GIZ, 2017).

In the previously described scenarios, the production of RDF material is also included; however, the quality and heating values of the produced materials are relatively low. As the new Ukrainian Waste Management Strategy aims to provide additional capacities for the preparation of RDF and clearly plans to take measures to encourage its use of RDF, both scenarios (3a and 3b) focus on the production of RDF with higher quality.

In order to increase the quality of RDF disruptive inert materials like glass and metals are collected separately. The source separation collection rates according to Den Boer et al. (2005) for glass are 55% and for metal 60%.

From the material flow analysis of scenario 3a-RDF - Recy$_{low}$ [gl, pl] (Figure 13) it can be seen that the formally collected metal and glass are sorted and afterwards send to a recycling plant. The sorting residues are sent to the sanitary landfill. Whereas, residual waste is pre-treated in a MBT-plant, where the higher-quality RDF fraction is sorted out and prepared for energy use. The produced RDF fraction is traded and can be co-burnt in cement kilns.

As in all future scenarios WEEE and hazardous waste are formally collected and handed over to an authorized waste management company for further treatment.

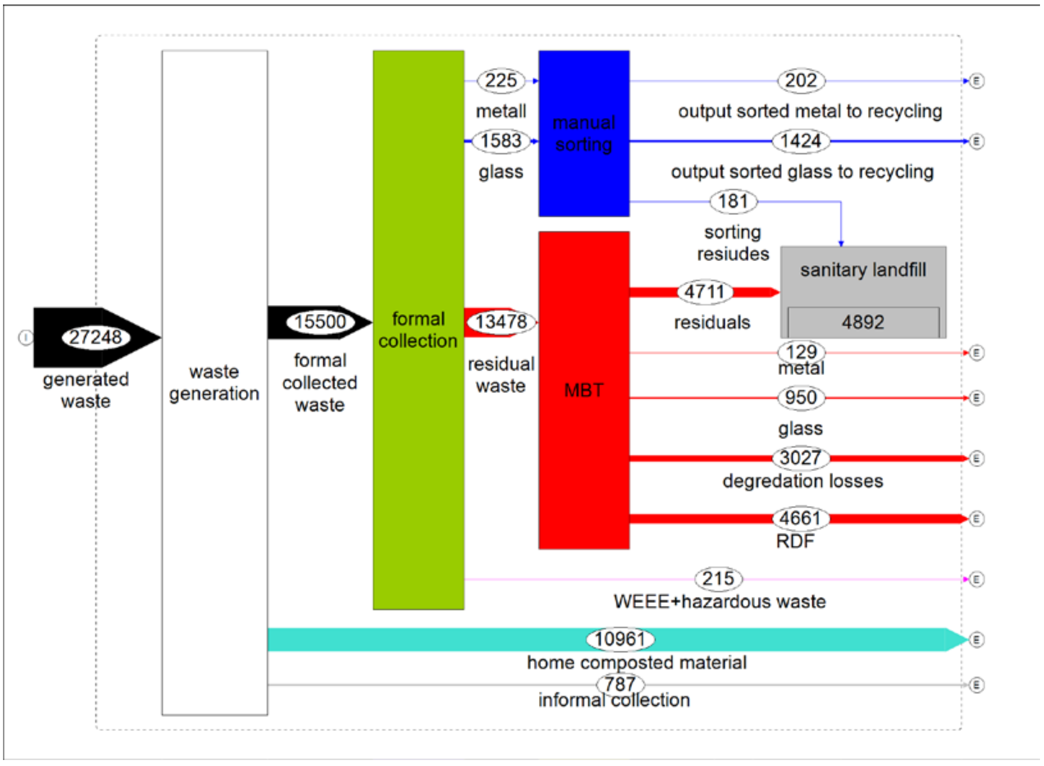

Figure 13: Material flow diagram of scenario 3a - RDF$_{low}$ [gl, me]

4.1.7 Scenario 3b – RDF$_{low}$ [gl, me, org]

Similar to the previous scenario this scenario 3b-RDF-Recy$_{low}$ [gl, me, org] also aims to produce RDF with higher quality capable for being compatible for usage in cement kilns.

Additionally, in this scenario organic waste is collected separately and prepared to be sold as compost product. This allows further reduction of the RDF moisture content and increase of its calorific value. A detailed description of the compost process is given in chapter 5.3.

The whole material flow is illustrated in the following Figure 14:

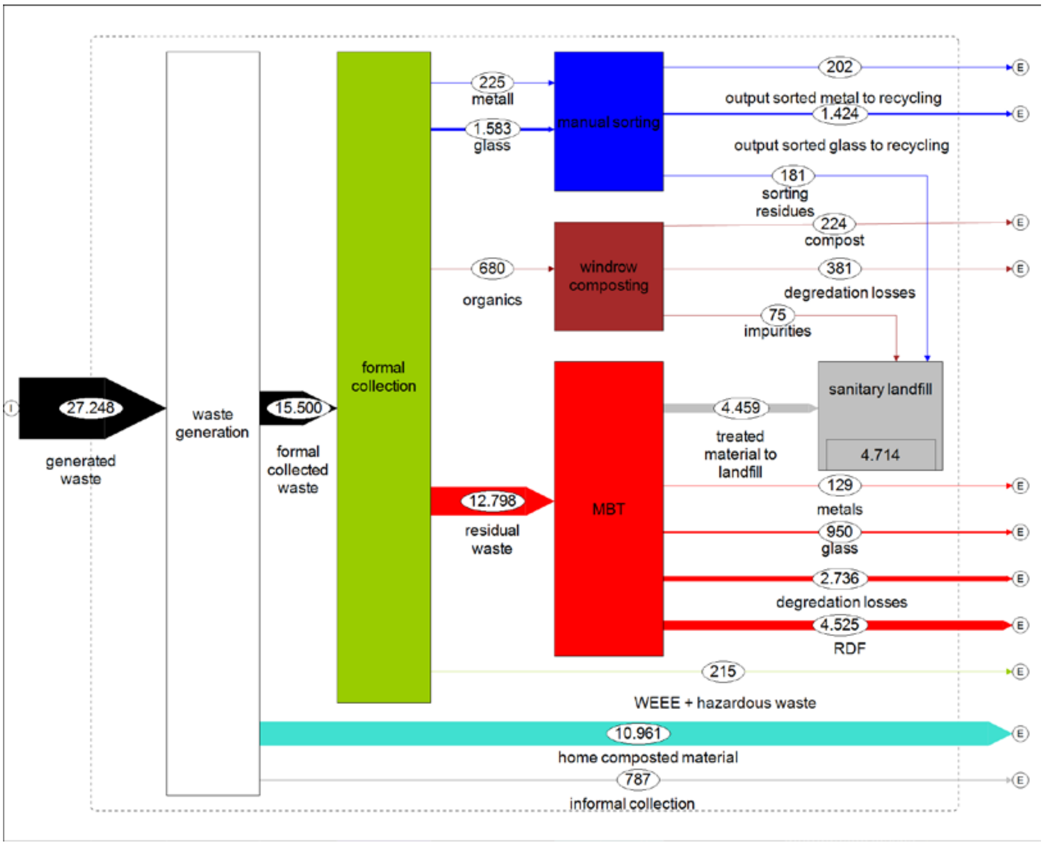

Figure 14: Material flow diagram of scenario 3b - RDF_{low} [gl, me, org]

As shown in the figure above residual waste is collected formally and pre-treated in an MBT plant which produces a higher quality RDF fraction. Metals and glass are also sorted out. The stabilized sorting residues are sent to the sanitary landfill.

WEEE and hazardous waste are formally collected and handed over to an authorized waste management company for further treatment.

4.2 Data availability and data uncertainties

Ukrainian circumstances represent a challenge because of the low level of environmental standards in WM, waste handling and waste treatment technologies. Hence, it raised the problem to gain reliable waste-related data for the modelling of the material flow analysis and calculation of the indicators. In order to gain reliable results some simplifications and reasonable assumptions had to be made in this thesis. Where possible the missing data were cross checked with literature, experts or re-calculated. An overview of the missing input data, the calculation method and (where possible) the plausibility check is summarized in Table 14.

Table 14: Summary missing data and data uncertainties

Input Data	Problem	Calculation	Verification
Waste generation baseline	No measured data available Discrepancies between collected data	Norms	Cross-check with missing data gaps
Home composting	No data available	Reasonable Assumption	Re-calculation according to Mihai and Ingaro (2016)
IRS	No data available	Reasonable Assumption	Expert interview
Mixed waste / Illegal disposal baseline	No data available	Difference between other input data	X

Data about *waste generation in baseline* was collected from Ministry of Regional Development of D., Department of Housing and Infrastructure Development of N. Regional Administration, economic entities working in the field of MSW and other local stakeholders. However, a comparison of the data revealed inconsistences between the delivered information and it was necessary to check the plausibility of the data. For that reason, local project partner from NUUE applied the Ukrainian Municipal Waste Generation Index for calculation of the waste generation in baseline.

The Ukrainian Municipal Waste Generation Index or so called “norms” is a quantitative index which enables to calculate the waste generation of region. The norm can be established on a local level for every municipality in Ukraine in case no real local data is available. In other words, the waste generation is not actually measured, (because standard methodologies for measurement of waste generation are not implemented and applied yet) but calculated. The norms are calculated per unit - for example per capita, per one place in hotel, per one m^2 of commercial and warehouse area, area of stations, parking, beaches etc. - and per time unit.

The calculation of norms was conducted by project partner form NUUE and the following units were chosen for the calculation of waste generation norms:

- MSW generated from population = m^3/year/cap
- Wastes of similar nature and composition as MSW, like for example economic entities: hospital = 1 bed; educational institutions= 1 child/student; institutions of culture and arts = 1 seat; markets = area, m^2; cafes/ restaurants = 1 seat; manufactured good stores = area, m^2

It was necessary to convert all results from m^3/year person to tonnes/year person. The following densities were used for the conversion (Khandogina and Abashyna, 2016a):

- 1 m^3 residual waste = 140 kg
- 1m^3 glass = 250 kg
- 1m^3 plastic = 18 kg
- 1m^3 metal = 70 kg

- $1m^3$ paper= 90 kg
- $1m^3$ organics = 250 kg

The waste generation rate calculated by norms resulted in 25, 276 t /yr, whereas other data from official documents were much lower and varied between 6,089 t /yr, and 11,562 t/yr. It was tried to fill this missing quantity between calculated and reported data by collecting possible data gaps. It was assumed that the following input data were not considered in local reports: quantities of home composted material (10,961 t/yr); IRS (797 t/yr); illegal disposal caused by missing collection coverage (varies between 2,528 and 15,166 t/yr). These four figures could explain to some extent the occurring discrepancies. Though the waste generation by norms is a calculated figure which does not reflect actual measured waste generation of the population. It is still a plausible assumption which had to be made in order to develop and model future WM scenarios

The *rate of home composting* (=10,961 t/yr) was estimated based on field surveys of morphology content of waste, food waste in private houses and food waste in containers in N. city (Khandogina and Abashyna, 2016a; RA N., 2006). Problematic might be, that the survey was conducted for N. city and not for D. and the that fact that no information about the season when the survey was conducted is available. To verify the plausibility of the results the amount of generated, but not collected organic waste was re-calculated according to Mihai and Ingrao (2016). The paper estimated the amount of organic waste an uncollected waste (Q_{bwu})in rural areas according to the following formula:

$$Q_{bwu} = P_{noWCS} * G_{rw} * \frac{365}{1000} * S_{bwr}$$

where,

Q_{bwu} = Amount of bio-waste generated and uncollected by waste operators [t/year]

P_{noWCS} = Number of inhabitants with no access to waste collection services

G_{rw} = Per-capita waste generation rate in rural areas [kg/inhabitant/day]

S_{bwr} (%) = Share of bio-waste in the total MSW composition

For calculation of Q_{bwu} the following input data were used:

Table 15: Estimations of bio-waste generated and uncollected

Input Data	Description	Value [unit]
P_{noWCS}	It is assumed that 60% of population has no access to regular MSW services (98,433inhab. *	59,060 t/year

	60%)	
G_{rw}	257 kg/person/year/ 365	0.7 [kg/person/day]
S_{bwr} (%)	Reasonable Assumption	70%

The re-calculation of home composting rate showed quite similar waste quantities (=10,562 t/yr) to the estimations based on Khandogina and Abashyna (2016). Therefore, the home composted amount was assumed as realistic for the case study region.

The *IRS* includes individuals or groups of people which are neither organized nor authorized by the government, but carry out waste management activities (Scheinberg et al., 2010). The amount of informally diverted waste from MSW was calculated by using the variables "percentage of urban population collecting informally", "number of working days per year" and "amount of informally collected material" (Ramusch, 2016, 2015). The results show an assumed IRS rate of 787 t/year.

Table 16: Estimation of diverted MSW from IRS

Input Data	Description	value
Percentage of urban population collecting informally	0.2% of 98,433 inhabitants	197 inhabitants
Number of working days	Number of working days excluding weekend and holidays	200 days
Amount of informally collected material	Valuable material collected by IRS	20 kg/day

The amount of *mixed waste disposed in environment* results from the difference between formally collected waste, home composting and informally collected waste (= 25,276t/yr – 10,873t/yr – 10,961t/yr – 787t/yr = 2,655 t/yr).

5. Treatment Technologies

The developed future scenarios include different MSW sorting, treatment and disposal methods. The technologies used for development of the scenarios are common in modern western and eastern European countries and are considered as state of the art. An overview of the selected technologies is given in Table 17.

Table 17: Technologies selected for the WM scenarios in D.

Technology	Input material	Output material
MBT plant (aerobic)	Mixed residual waste	Treated and stabilized organic material to landfill; RDF; low quality glass and metal
MBT plant for dry-wet bin (aerobic)	Mixed residual waste and recyclables from dry bin	Treated and stabilized organic material to landfill; RDF; low quality glass and metal; sorted recyclables (gl, pl, me, pa)
Sanitary landfill	Residues from MBT, composting, manual sorting lines	-
Composting plant	Yard and kitchen waste	Marketable compost product; impurities/residues
Manual sorting lines	Separately collected paper, glass, metal, plastic	Sorted recyclables; sorting residues

A possible technical configuration of the above listed treatment methods is described in the following chapters 5.1 to 5.4. A more detailed technical description of the different treatment technologies for D. is given in Scharenberg (2017).

5.1 Mechanical Biolgical Treatment

In the 1990s, MBT-facilities were originally conceived to reduce the amount of landfilled waste and to stabilize organic fraction. However, nowadays MBTs are additionally seen as plants for recovering of fuels and material fractions (Bilitewski et al., 2011). In other words, MBT is an alternative to incineration of mixed or residual waste prior to landfilling (Den Boer et al., 2005). The technology combines a mechanical and a biological treatment stage with the aim to minimize the negative environmental impacts of landfilling and to gain landfill volume through the extraction of metals and energy recovery (Kranert and Cord-Landwehr, 2010).

5.1.1 Process description Mechanical Biological Treatment

The mechanical treatment step takes place before the biological treatment to separate high calorific fractions and recyclables from the residual waste. Mechanical processing includes shredding, magnetic separation, sieving, sighting and homogenisation- although not all of these stages must be processed (Öhlinger and Neubauer, 2006).

The biological treatment can be aerobic (composting) or anaerobic (digestion) (Den Boer et al., 2005). During the aerobic proceeding the organic contents of the residual input material are decomposed by aerobic microorganism under air supply with the aim to stabilize the material (Öhlinger and Neubauer, 2006). The aerobic biological process is conducted for 4-5 weeks in aerated windrows (often in an indoor unit), containers or fully closed boxes. Afterwards the material is post-processed in roofed or open windrows for 9-10 weeks (Bilitewski et al., 2011). The actual duration of the process varies from plant to plant and depends on the technological parameters of the MBT (Thiel, 2007). The anaerobic treatment process is not examined further within the scope of this work, because is not proper and relevant for the MBT of the case study region.

Figure 15 presents a possible technological configuration and outputs of a MBT plant for D..

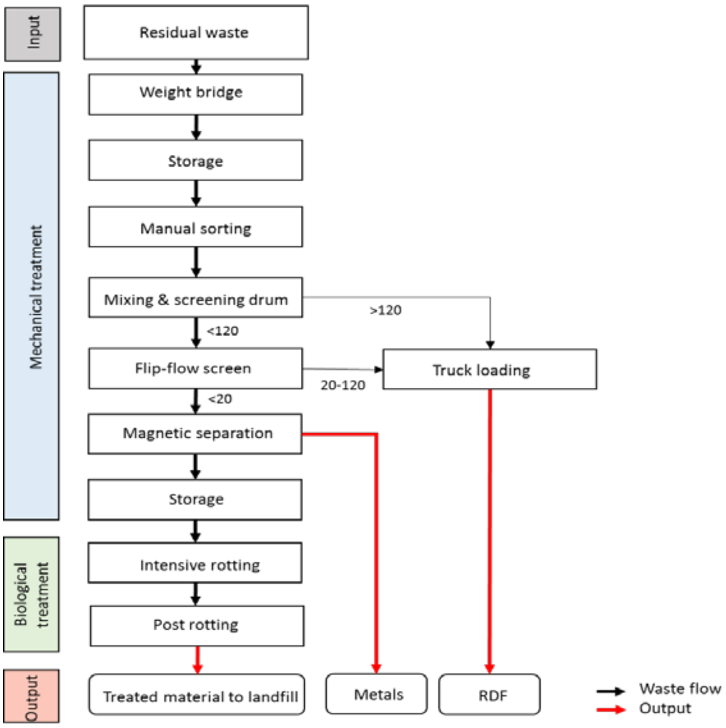

Figure 15: Flow chart of MBP plant (own application adapted after Neubauer and Öhlinger (2006)

As it can be seen in Figure 15, the mechanical treatment process starts with weighting of the input material at a weighting bridge. Then the residual waste is stored in a flat bunker, where the materials are manually sorted.

Afterwards, the material is conveyed to a mixing and screening drum where the material is screened and separated according to its size, lower and higher than 120 mm. The coarse fraction (>120 mm) is loaded at a truck and handed over to an external waste disposal company or to the cement kiln industry for thermal use. PJSC "Eurocement-UKRAINE and Zmiivska thermal power plant are large industrial enterprises near N. region which could be considered to use the produced RDF material (Khandogina, 2017). The fine fraction (<120 mm) is passed over to a flip-flow screen where the material is sieved once again and separated into fractions of less than 20 mm and 20-120 mm. The fraction with the size of 20-120 mm is also loaded at a truck in order to be further used as RDF. After size reduction, the fraction <20 mm is handed over to a magnetic separator where metals are extracted and in a last step stored in a flat bunker. However, it could also be considered to carry out the magnetic separation in a previous step. From there the material is taken as input for the biological treatment step.

Biological proceeding starts in aerated boxes where the intensive 4-5 weeks lasting rotting takes place. During this time, it is recommended to turn the material in one or two weeks with a wheel loader. After intensive rotting the material is removed from the rotting boxes via wheel loader and post processed in roofed windrows. The end product of the stabilization processes can be landfilled or is used for the re-cultivation of degraded land (Den Boer et al., 2005).

According to the waste treatment process, which was chosen for the scenario, estimate of the outputs (RDF, metals, treated material to landfill and degradation losses) is based on the research of Doedens et al., (2003); Bonnet and Viertel (2005) and adapted to the local conditions and waste characteristics. However, the actual amount of MBT outputs depend on the waste received and the real configuration of the plant (Bilitewski et al., 2011).

The chosen MBT output flows, their application and the percentage distribution are presented in Table 18. The percentage varies from scenario to scenario depending on the mass flows and treatment process of each scenario.

Table 18: Outputs of MBT plant (adapted after Doedens et al, 2003; Bonnet and Viertel, 2005)

Output	Application	Mass balance
RDF	High calorific fraction for energy recovery	30-35%
Metals[6]	Extracted recyclables for material recovery	1-2%
Glass[7]	Extracted recyclables for material recovery	4-12%
Treated material to landfill	Stabilized material for landfilling	35-44%

[6] Low quality material
[7] Low quality material

Degradation losses	Material lost through processing	11-27%

The above suggested MBT plant is applied for all future scenarios except of scenario 1b-Partly Recy$_{\text{dry-wet bin}}$. For this scenario, the MBT must be adapted for the special waste collection system. Therefore, the technical configuration of the MBT plant with included sorting of dry-wet bin is presented in the next chapter.

5.1.2 Process description Mechanical Biological Treatment including sorting of dry-wet bin

As already stated above the combined MBT plant which includes sorting of dry-wet-bin is only relevant for the future Scenario 1b-Partly Recy$_{\text{dry-wet bin}}$.

According to the waste treatment process chosen for this scenario, the MBT allows the separate treatment of waste from a two-bin collection system for dry and wet waste. However, the materials from wet and dry bin are not sorted with the same technology. The separately delivered input material is either sorted in the MBT system for residual waste or in the MBT system for dry recyclables.

An example for a possible technical configuration adapted after Öhlinger and Neubauer (2006) is provided in the following Figure 16.

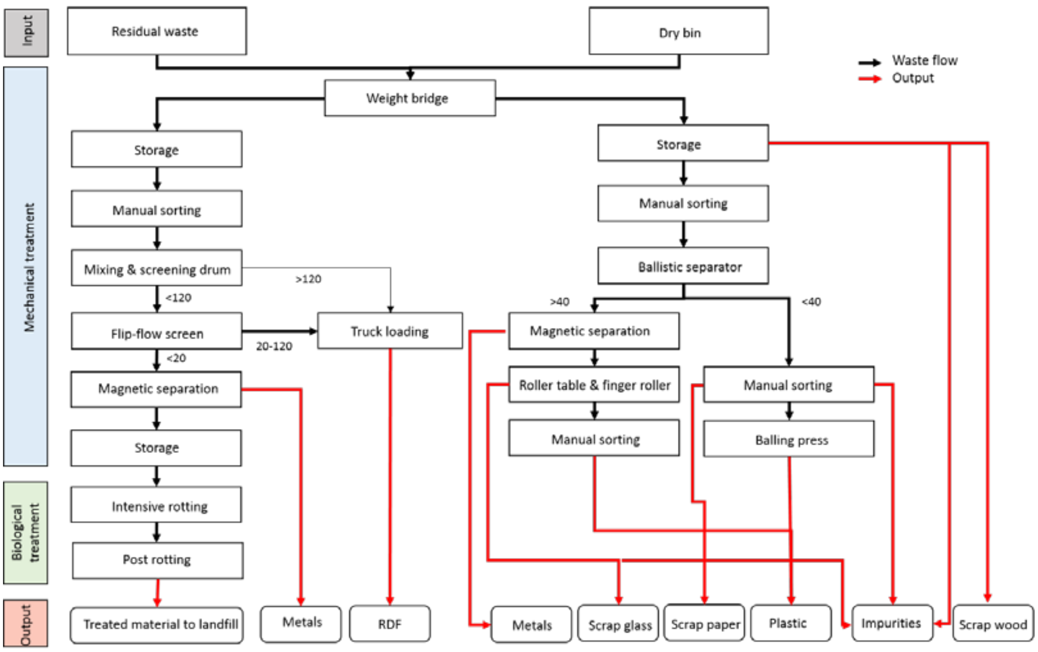

Figure 16: Flow chart of the MBT for dry-wet-bin (Neubauer & Öhlinger, 2006)

Firstly, as displayed in Figure 16 above, the incoming waste is weighted on a weight bridge and afterwards either thrown in the flat bunker for sorting of residual waste (wet bin) or for the dry-bin. The two processes for residual waste (wet bin) and dry-bin are shown separately in the figure. A detailed description of sorting process of the residual waste (illustrated on the left side of Figure 16) is found in the previous chapter.

Concerning the sorting of the dry-bin, firstly, the materials from the mixed materials are loaded from the flat bunker via overhead crane to a conveyor, where impurities are separated out manually. Subsequently, the material is passed over to a ballistic separator, where the material is sieved out to a screen cut of 40 mm and then the light and the heavy fractions are separated.

The fine fraction (<40 mm) is directly handed over to the baling press where is prepared for thermal use.

The light fraction of the coarse fraction (>40 mm) is sorted manually in a sorting carbine. Paper, plastic and impurities are sorted out during this process. The residuals of the light fraction are mixed to the coarse fraction and are baled with the baling press.

The heavy fraction of the coarse fraction (> 40 mm) from the baling separator is first transported to an over band magnetic separator for separation of FE metals. Then the material is brought to a roller table and finger roller. Glass and other impurities can be separated out with this technology. The remaining residues are transported to a sorting carbine, where plastic can be sorted out manually.

The residual light, heavy and fine fraction can be balled via balling press, foiled and handed over to an external waste disposal company or to the cement kiln industry for thermal use.

The chosen MBT output flows for the sorting process of dry and wet-bin, their application and the percentage distribution are presented in Table 19.

Output	Application	Material Stream Output
RDF	High calorific fraction for energy recovery	21%
Treated material to landfill	Stabilized material for landfilling	27%
Degradation losses	Material lost through processing	24%
Paper	Extracted recyclables for material recovery	75%
Plastic	Extracted recyclables for material recovery	50%
Glass	Extracted recyclables for material recovery	5-12%
Metal	Extracted recyclables for material recovery	1-2%

Table 19: Outputs of MBT plant with sorting of dry-wet-bin (adapted after Doedens et al, 2003; Bonnet and Viertel, 2005; Pöttschacher, 2016)

Although a considerable part of the incoming waste flows can be processed in the MBT plant, nevertheless landfilling is an unavoidable element of the waste management system. For this reason, the concept of landfilling and a brief overview of technical parameters for a possible landfill in D. are explained in the following chapter.

5.2 Sanitary Landfill

According to the waste management hierarchy, landfilling is the least preferable practice and should be limited to a minimum (GIZ, 2017). However, landfilling is a comparatively low-cost technology for the final disposal of residuals from waste treatment facilities and untreated waste. Because of the low costs and relatively low-technical requirements it is a popular technology in many countries (Shekdar, 2009).

Three out of four existing landfills in D. are unsanitary and do not have any environmental protection measures (no leachate and landfill gas collection and treatment, no protection of groundwater etc.) In accordance with the National Waste Management Plan of Ukraine and to prevent negative effects as far as possible it is recommended to build a regional sanitary landfill (GIZ, 2017).

The construction of a new sanitary landfill which meets the current technical standards is mandatory for all future scenarios. Finding an appropriate site for the new sanitary landfill is a very important decision. In Ukraine the construction of new landfills is often opposed by the public because in the past it was used to build landfills next to residential areas, water reservoirs and on areas prone to landslides (UNDP, 2011). Finding a proper site far away from the urban area may have the advantage of less public opposition. However, it also means increasing investment costs for infrastructure and transport for the local authorities (Bosompem et al., 2016). In order to avoid past mistakes, the location of a new sanitary landfill was assumed near D.city next to location of the existing landfill, because it provides optimal morphological & geographical conditions, enough space and it is not too close to residential areas. A detailed investigation of the planning and operating process of the landfill is outside of the scope of this work. Therefore detailed morphological parameters (base shape, side slopes, final cover thickness, height/depth), cell geometry (height, length, slopes), and operation parameters (waste density, working face length, cover thicknesses) are not examined (Aivaliotis et al., 2004).

Landfill concepts vary strongly from country to country, even in Europe the technological standards of landfills differ a lot (Kranert and Cord-Landwehr, 2010). In order to reduce negative effects on the environment, surface water, soil, air and human health it is suggested that the following technical parameters should be implemented as minimum requirements:

- Lifetime of landfill: 20 years (Tsilemou and Panagiotakopoulos, 2006)
- Input material: pre-treated municipal waste from MBT plant and residues from manual sorting lines and composting (hazardous waste and WEEE are not disposed at landfill sites)
- Leachate collection system must be available (appropriate management, collection, treatment and disposal of leachate)

- No gas collection system is required[8]
- TOC (Total Organic Carbon Content) ≤ 18 mass-% (Scharenberg, 2017)

Furthermore, it is assumed that all currently existing dumpsites which do not fulfil any environmental and technical standards should be closed for all future scenarios.

5.3 Composting

Composting is defined as the biological decomposition of the biodegradable organic fraction of MSW under controlled conditions to produce an end product that can be handled, stored, used or disposed without harming the environment (Golueke, 1972). Composting systems differ from low technology systems as for example simple windrow composting to high technology systems like regulated enclosed systems (Krogmann et al., 2011).

Before establishing a composting system it is necessary to clarify the following basic framework parameters: (1) selected waste to be treated & amount, (2) location (distance to neighbours is crucial), (3) delivery rhythm (capacity of storage), (4) need for know-how (e.g. space, personal, machines), (5) determine the use or disposal needs of any produced output (Binner, 2012; Krogmann et al., 2011).

Based on the above analysed framework parameters an open windrow composting was chosen for modelling of the scenarios. Advantages of this composting technology are the relatively low investment costs, personal requirements and the low waste volume needed for application in contrast to high technology systems (Amlinger et al., 2005; Tumuhairwe et al., 2009).

The specifications of the open windrow composting facility are explained below:

- Feedstock: Yard waste and other green waste; bio-waste (source-separated kitchen and yard waste)
- Design capacity: approximately 3.200 t/yr (Binner, 2017)
- Composting system: Naturally aerated static windrow composting with periodically turning of the material (Binner, 2012), An example is illustrated in Figure 17
- Process control: Hand fist test for moisture and manually measured temperatures. If the temperature declines too early and the material is too dry, windrows are turned or irrigated by tube and turned after water addition (Krogmann et al., 2011)
- Environmental controls: Distance to neighbours >300 m (Amlinger et al., 2005)
- Period of decomposition: 12-24 weeks or longer (Amlinger et al., 2005)
- Windrow geometry: 1.7 m (height), 3m^2 (cross sections), 3m (width) (Lampert and Neubauer, 2014)

[8] For large landfills (capacity > 60,000 t/yr) a gas collection system is recommended, however according to Tsilemou and Panagiotakopoulos (2006) for smaller ones (capacity < 60,000 t/yr) a gas collection system is not required. In addition, it is assumed that the gas formation potential from mechanically and biologically pre-treated waste from MBT is significantly lower than from untreated residual waste (50% of the original gas production potential) and therefore an active gas collection is not considered (Binner, 2017). Further, after treatment of material in an MBT plant only limited gas formation is expected and therefore a passive methane oxidation layer should be sufficient.

- Turning Period: Once per week or if deemed not necessary than less often (Amlinger et al., 2005)
- Description of processing sequence: Yard waste is pre-shredded to reduce the particle size and promote the breakdown of organic matter. Small amounts of organic waste are added with proper machines (e.g. mixing drum) to the pre-shredded yard waste. A high-water content at the beginning of the rotting process is recommended. The windrows are formed by a wheel loader or other suitable forming machines. The windrows are turned in regular intervals and are moistened when needed. Volume reduction due to degradation can be compensated by combining of piles. After a 6 months composting process the compost can be screened and the screen overflow is added to the fresh material (Binner, 2012; Diaz et al., 2002; Krogmann et al., 2011).

Figure 17: Example of open windrow composting, aerated piles (Binner, 2008)

An example for a possible technical configuration is adapted after Diaz et al. (2002); Kranert and Cord-Landwehr (2010); Krogmann et al. (2011) and is provided in Figure 18.

As a first step like illustrated in Figure 18 yard and kitchen waste are delivered to the composting facility and can be stored before further treatment. In the pre-processing step impurities, such as stones, glass, metals, plastic bags or other oversized items can be removed by a trommel sieve, magnetic separator or by manual sorting (Scharenberg, 2017). The better the pre-treatment step is carried out, the better the compost quality and hence the product value is achieved. The amount of impurities in the whole composting process is about 11% (Binner, 2017).

The decomposition or rotting process is the main part of the composting process. The step includes the intensive rotting and the post rotting phase. Afterwards the compost is post-treated to remove impurities or other residuals. The rejects of this sorting process are landfilled. The end-product of this process is a marketable compost product.

With the above described composting system odour emissions cannot be captured and are released to the environment without filtration. For that reason a minimum distance of 300 meter to the nearest neighbour is obligatory (Amlinger et al., 2005).

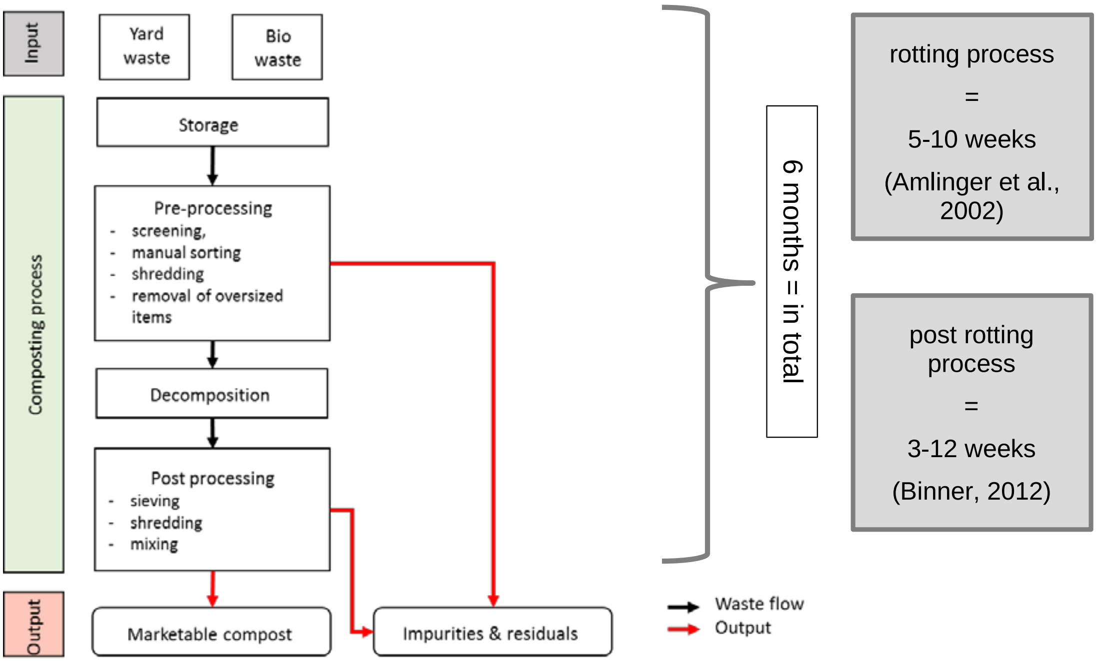

Figure 18: Flow chart of composting process (own application adapted after Diaz et al. (2002); Kranert and Cord-Landwehr (2010); Krogmann et al. (2011)

An effective control of the main influencing process parameters is obligatory for a successful composting process without negative environmental effects. The commonly used process parameters include: biodegradability, moisture content, oxygen content, material structure, particle size and aeration, temperature and hygiene, nutrients and pH-value (Binner, 2012; Kranert and Cord-Landwehr, 2010; Krogmann et al., 2011). Since the composting process can be complex the above mentioned parameters have to be observed and monitored in order to achieve a marketable end product (Kranert and Cord-Landwehr, 2010).

5.4 Manual Sorting Lines

A manual sorting line is an important component for the waste management system of D. as it functions as a link between the municipal waste collection program and the final disposal. It is suggested to implement three small manual sorting lines for the re-sorting of separate collected recyclables. In consultation with the stakeholders it was decided that the manual sorting lines could be located near S.town, D.city and P.town council. The geographical distribution is shown in the following Figure 19. The possible locations of the manual sorting lines are marked with a red cross.

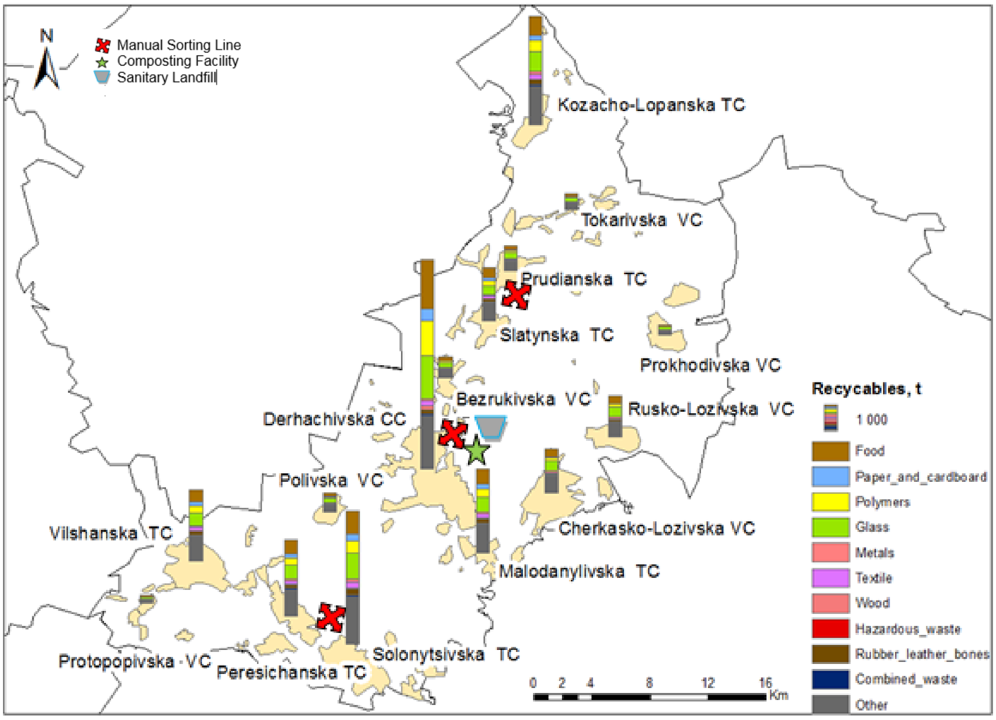

Figure 19: Possible locations of the manual sorting lines (Stolberg et al., 2016)

While automated sorting systems require a higher technology level, the ability of humans to recognize and separate materials is a very low level technology and easy to handle (Tchobanoglous and Kreith, 2002). For the case study region, it was decided to keep the sorting technology as simple as possible. Therefore, at these manual sorting lines separate collected recyclables (paper, metal, plastic and glass) will be sorted in order to produce eventually a higher quality material. For the sorting process several manual sorting techniques can be used (Bilitewski and Härdtle, 2013):

- Positive sorting: Materials to be sorted are examined
- Negative sorting: contaminants are removed from the material to be recovered.

After the manual sorting step, the fractions are transported to the final recycling facilities for further treatment.

6. Indicator Assessment

The following chapter presents the main findings of the indicators assessment and it is divided into four subchapters. Based on the results of the material flow analysis and identified capacities of the waste treatment and disposal facilities, the seven previously discussed scenarios were evaluated by 6 economic (chapter 6.1.1), 6 environmental (chapter 6.1.2), 2 social (chapter 6.1.3) and 4 technical (chapter 6.1.4) indicators. Where possible the results are compared with provisions from the new Ukrainian Waste Management Strategy to control if the aims set out in the strategy could be reached in a scenario.

6.1.1 Economic assessment

The first block of 6 indicators assesses the economic performance of all seven future waste management scenarios of D.. The main findings are discussed in the following subchapters.

6.1.1.1 Total Annual Discounted Costs of Waste Management System

The total costs of a waste management system are a significant factor for examination of the economic feasibility of each scenario. As already described in chapter Materials and Methodology the indicator consists of three subsystems: bins & container system, trucks & collection and treatment & disposal.

Total Annual Discounted Costs of Subsystem Bins & Container system

For calculation of the costs of the subsystem bins & container system, the Equivalent Annual Discounted Total Purchase cost, the Equivalent Annual Discounted Total Location Costs of bins and Annual Maintenance Cost of bins are required.

The Equivalent Annual Discounted Total Purchase Cost of bins ($EADTPC_{bins\ i(j)}$) are calculated by multiplying the number of bins of waste stream i which are used in sector j with the purchase price of bins. The number of bins (Table 20) is calculated by the project partner at NUUE according to the Ukrainian guidelines for organizing of the collection, transportation, processing and disposal of waste (MRD, 2010). The default values for purchase prices of bins are also investigated on local level from the project partner at NUUEE and are provided in Table 21.

Table 20: Total number of containers for waste stream j in D. (Khandogina and Abashyna, 2017a)

	Number of containers per Scenario						
Input Material	**00**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**
Residual waste	929	798	667	685	590	819	778
Glass		669		994	994	725	725
Polymers		1,627		3,194	3,195		

Dry waste (pl, me, gl, pa)			3,697				
Metal				715	726	726	726
Paper				552	552		
Organic					144		145

Table 21: Default values for purchase price of bins (Abashyna, 2017)

Type	Purchase Price (€ per bin)
Metallic container for residual waste	350
Metallic container for glass (open variant)	100
Metallic container for plastic (open variant)	100
Metallic container for dry recyclables of dry-wet bin (closed variant)	450
Metallic container for metal (open variant)	100
Metallic container for paper (closed variant)	450
Metallic container for organic (closed variant)	450

The Equivalent Annual Discounted Total Location Costs of bins ($EADTLC_{bins\ i(j)}$) are assumed to be 66 € for the construction of one container based on the local costs provided by Ukrainian partners (Abashyna, 2017).

Total Annual Discounted Costs of Subsystem Trucks & Collection

For calculation of the Total Annual Costs of Subsystem Trucks & Collection the Equivalent Annual Discounted Total Purchase Cost of CVs, Annual Operating Costs of CVs, Annual Maintenance Cost of CVs and the Annual Total Personnel Costs of CVs are required.

The Equivalent Annual Discounted Total Purchase Cost of collection vehicles ($EADTPC_{CV\ i\ (j)}$) are calculated by multiplying the number of collection vehicles for a given scenario with the purchase price of the trucks, see Table 22.

The calculation of number of collection vehicles for the transportation of MSW was carried out by the project partners of NUEE for each of the proposed scenarios based on methodological recommendations of organization of collection, transportation, processing and disposal of waste (MRD, 2010). As seen in Table 22, it varies from scenario to scenario depending on the amount of collected recyclables and the number of waste fractions in a given scenario. The purchase price of a collection vehicle is investigated on local level and is assumed as approximately 80,000 € for every scenario (Abashyna, 2017)

Table 22: Number of collection vehicles per scenario and default values for purchase price of collection vehicles (Khandogina and Abashyna, 2017b)

	Number of Collection Vehicles per Scenario						
Input Data	**00**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**
Total nr. of CV per scenario	6	8	8	10	13	8	10
Purchase Price (€)	80,000	80,000	80,000	80,000	80,000	80,000	80,000

The Annual Operating Costs of CVs ($EADTLC_{CV\ i\ (j)}$) are defined as expenses for managing MSW on a daily basis (Boskovic et al., 2016). According to this definition the costs for fuel consumption, insurance and road charge per collection vehicle and year are considered, see Table 23. To estimate the costs for fuel consumption the total travelled km per collection vehicle and year were calculated by the project partners at NUUE. The costs for full-comprehensive insurance and the road charge were also available on local level.

Table 23: Summary of total travelled km of collection vehicles, insurance and road charge per CV and year (Khandogina and Abashyna, 2017b)

	Scenario						
Input Data	**00**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**
Total travelled km per year per CV (km/yr)	119,280	180,804	169,200	277,404	412,404	158,760	293,760
Insurance per CV (€/yr)	1,700	1,700	1,700	1,700	1,700	1,700	1,700
Road charge per CV (€/yr)	7	7	7	7	7	7	7

The Annual Total Personnel Costs of CVs ($ATPC_{CV\ i\ (j)}$) of the subsystem trucks & collection are the sum of the annual costs (salary and overheads) of all required collection vehicles drivers and collectors and all reserve collection drivers and collectors. The input data was provided on local level and it was assumed that 2 workers are required per CV and the annual costs of one CV worker are 2,424 €/year (Khandogina and Abashyna, 2017b).

Total Annual Discounted Costs of Subsystem Treatment & Disposal

The Total Annual Costs of Subsystem Treatment & Disposal cosnsits of the Total Annual Discounted cost for the MBT plant, sanitary landfill, composting facility and manual sorting lines. Additionally, also the costs for closure of current dumps are considered in the subsystem treatment & disposal. It is recommended to close the following three dumps P., V. and T., because they do not meet any environmental requirements. The cost of closure and design work are calculated based on State Standard of Ukraine by the project partners from NUUE and are summarized in Table 24. For calculating the costs for closure of dumps values obtained according to satellite images were used. Further, expenses for closure of dumps were assessed by the local project partner. Thereby the following cost factors were considered: cost for mineral waterproofing layer, site planning, synthetic waterproofing layer, construction of protective screen, fine sand protective layer, drainage layer, construction of macadam gravel layer (30 cm), remediation layer, costs of design work and soil (Khandogina and Abashyna, 2017c).

Table 24: Overview closure of dumps (Khandogina and Abashyna, 2017c)

Name of dump	Total costs (€)
P. dump	1,170,400
V. dump	589,560
T. dump	14,470

The results of the Total Annual Discounted Costs of the three above described subsystems per scenario are presented in Table 25 and illustrated in Figure 20.

Table 25: Results of indicator Total Annual Discounted Cost of MSWM system

	Scenario						
Indicator	**00**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**
Investment costs [10^6€]	8.1	8	9.9	8.4	9.6	7.9	8.7
Ann. operating costs [10^6€/year]	1.5	1.6	1.7	1.8	2.5	1.6	2.0
Tot. ann. disc. costs [10^6€/year]	2.4	2.5	2.8	2.7	3.6	2.5	3.0

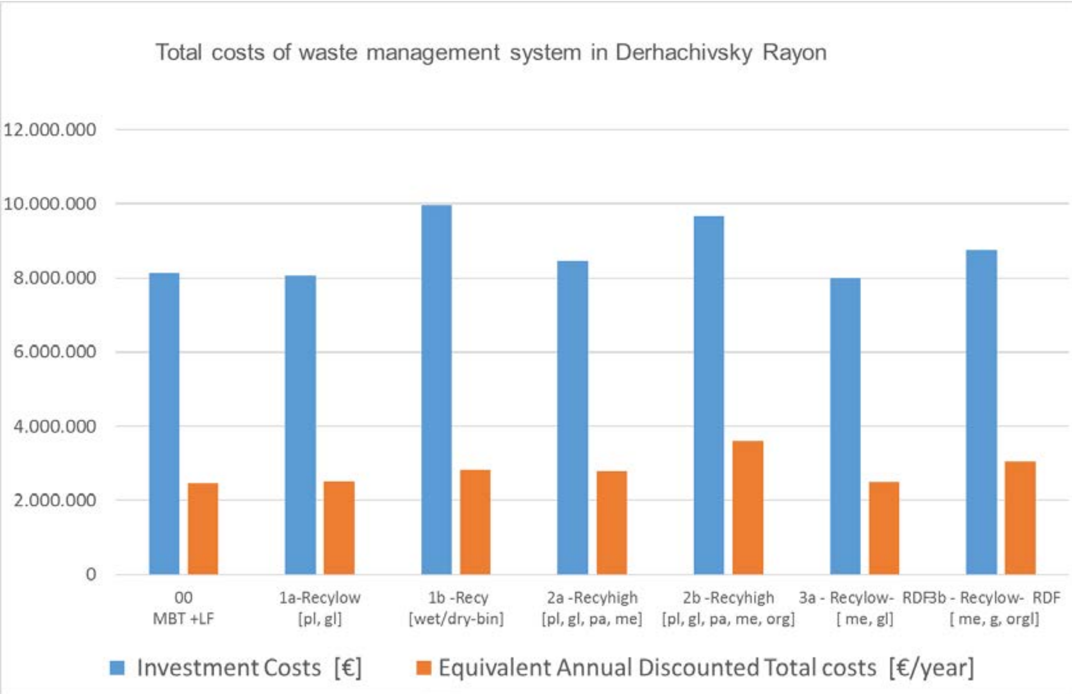

Figure 20: Total Costs of Waste Management System

The figure above shows the investment costs (blue bar) and the equivalent discounted[9] annual total costs (orange bar). As seen in Table 25 estimated investment costs for scenarios range between 8 million € (scenario 1a) and 9.6 million € (scenario 1b).

The high variations of investment costs in the scenarios depend on:

- Different treatment and disposal facilities suggested for a given scenario (see Table 13)
- Waste quantities entering the treatment and disposal facilities (see Annex 4)
- Number of collection vehicles (see Table 22)
- Purchase price of containers (see Table 21)

The first three points, mentioned above cannot be influenced, as they are depending on waste composition and on provisions of scenario specifications. However, a possibility could be to consider cheaper or used containers, as this would have a big influence on the total costs of this subsystem.

In comparison to the investment costs the equivalent annual discounted total costs range between 2.4 million €/year (scenario 00) and 3.6 million €/year (scenario 2b).

[9] A discount rate determines the present value of future cash flows by expressing the costs and benefits that accrue over a period of time into monetary units in one period.

Reasons for the high differences in equivalent annual discounted total costs are due to:

- Difference in waste quantities entering the treatment and disposal facilities
- Differences in operational costs of treatment and disposal facilities which are depending on:
    - Total travelled km per year
    - Cost for fuel per collection vehicle
    - Personnel costs

An important issue in this regard is related to the input data available for the calculation of the operational costs. As already described in chapter materials and methodology costs for subsystem bins & container system and trucks & collection, manual sorting lines are available on local level. Whereas operational cost for MBT-plant, sanitary landfill and composting facilities are calculated with cost curves based on European price level from 2003. This makes a comparison of the operational costs difficult. To overcome these differences a yearly inflation rate of 1.6% was applied to the figures in the cost curves. Nevertheless, it has to be stated that the differences might influence the final results as in reality operational and investment costs in Ukraine might be lower due to lower salaries, lower prices for equipment and construction works etc. This fact may influence to some extent the results of scenario 1b-Recy$_{\text{wet-dry bin}}$. In contrast to all other scenarios in scenario 1b-Recy$_{\text{wet-dry bin}}$ no sorting lines are implemented because the recyclables are collected in a one bin system, which is sorted by special technological appliances at the MBT-plant. This means that the operational costs are much higher in this scenario due to the limitation of cost curves and lower in scenarios where recyclables are re-sorted in manual sorting lines. However, this does not reflect the actual circumstances, as the average costs for personnel will probably not differ significantly in sorting lines and in the MBT-plant.

Other influencing factors when looking at the results are concerning waste quantities entering the different treatment- and disposal facilities. The available waste quantities which are treated in various waste treatment facilities are relatively low. To achieve better results, it would be recommended to treat higher waste quantities. The effect of economies of scales is illustrated in Figure 21.

From Figure 21, it becomes clear that higher waste quantities lead to lower costs, whereas lower inflowing capacities cause relatively high costs. Small-scale facilities are not necessarily working cost effective. Better cost-related results can be achieved with higher waste amounts treated. For that reason, it can be suggested for D. to arrange inter-municipal cooperation arrangements with other geographically appropriate regions in order to carry out waste related activities together. The overall goal of these inter-municipal cooperation is to benefit from economies of scale due to higher overall performance efficiency. They could either organize regional waste facilities together or arrange the whole waste management system, including collection and transport together (GIZ, 2017).

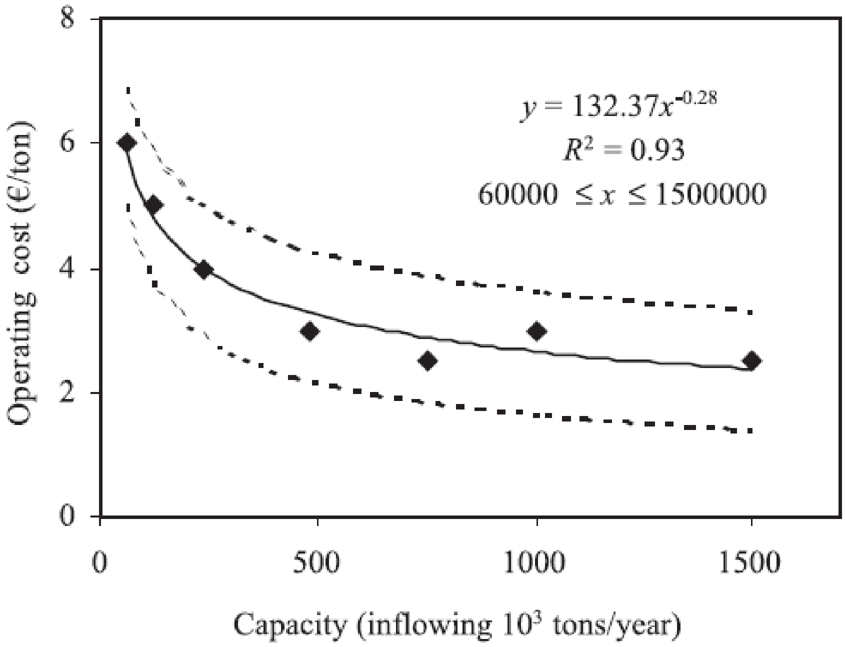

Figure 21: Economies of scales for operational costs of landfilling facilities (Dotted lines band: ± 1 standard deviation) (Tsilemou and Panagiotakopoulos, 2006)

Apart from this, the new Ukrainian Waste Management Strategy recommends a minimum capacity of about 50,000 tonnes per year and a minimum coverage of 150,000 persons for the constructions of new landfills. Both provisions could not be fulfilled in all suggested scenarios, as the maximum quantities are much lower, and the total population is 98,433 citizens. All in all, it can be concluded that this form of cooperation can be beneficial for the whole region, as the total costs can be decreased by exploiting the economies of scales advantages associated with higher waste quantities treated.

6.1.1.2 Total Annual Discounted Costs of WM per tonnes of formally collected waste

Based on the results of the previous indicator, the total annual costs of the MSWM system per tonne formally collected waste were calculated.

A comparison of the total annual costs of the MSWM system show that the costs range between 127 €/t (scenario 00) and 194 €/t (scenario 2b). The high differences between the scenarios are influenced by the costs of each subsystem. To better understand financial interrelations, the total annual costs per subsystem are presented in Table 26.

Although scenario 00-LF+MBT has in sum the lowest cost per tonne formally collected waste, it has the highest expenses in subsystem treatment and disposal. This is due to the lack of separate collection in this scenario. The total amount of waste is treated in the MBT-plant and landfilled afterwards. Because of this, costs are higher in subsystem treatment and disposal.

The highest costs per tonne formally collected waste are calculated in scenario 2b-$Recy_{high}$ [pa, me, pl, gl, org]. This is due to the separate collection of 5 different fractions. In this scenario costs for collection & transport are very high, as they correlate with the total travelled km and the collection frequency. The more fractions are separately collected the higher the cost for the subsystem collection and transport.

Table 26: Results of Total Annual Discounted Costs per subsystem

	Scenario [€/t formally collected]						
Subsystem	**00**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**
Bins & container	1	2	<u>7</u>	5	5	2	4
Collection & transport	16	29	28	50	<u>90</u>	26	52
Treatment & disposal	<u>110</u>	100	108	92	99	101	108
TOTAL:	**127**	**131**	**143**	**146**	**194**	**129**	**164**

Table 26 illustrates the big influence of each subsystem on the total costs of the scenarios. When looking at subsystem bins & containers highest costs arise in scenario 1b-$Recy_{dry\text{-}wet\ bin}$. For implementing the wet-dry bin a special container for the collection of the dry fraction was suggested, which triggers the investment costs of this scenario. Another type of container with lower purchase price per unit would decrease the total investment costs of this scenario significantly.

Regarding subsystem collection and transport the results indicate a strong influence of the waste collection route. As D. is a broad rural area, the travelled distance for waste collection are very large. Therefore, prices for fuel, trucks and maintenance are increasing the more fractions have to be separately collected.

When it comes to subsystem treatment and disposal the waste quantity entering the waste treatment facilities plays an important role for cost level.

All in all, when comparing the total cost per formally collected waste with other cities (see Table 27), the costs are much higher in D.. The cheapest scenario (scenario 00 = 127 €/t) is three times higher as the cheapest scenario in Table 27 (Wroclaw= 39 €/t). Whereas the cost of the most expensive scenario (scenario 2b =194 €/t) are exceeding the costs of the most expensive scenarios in the compared European cities (Xanthi = 140€/t). The economic assessment of this indicator again shows the importance of economies of scale. Due to the low waste quantities treated in each scenario, the financial analysis indicates that many of the suggested treatment technologies are too expensive and might be considered only when either D.´s economic position becomes stronger or inter-municipal cooperation arrangements are established.

Table 27: Costs in € per tonne of collected waste in different European cities (Den Boer et al., 2005)

City	Costs [€/tonne]
Kaunas (Lithuania)	56 - 94
Nitra (Slovakia)	99 - 119
Reus (Spain)	95 - 121
Wroclaw (Poland)	39 - 71
Xanthi (Greece)	52-140

6.1.1.3 Annual Revenue from the Recovery of Material and Energy

Beside the costs of a MSWM system, also the revenues play a very important role for enhancing financial sustainability. For assessing the financial viability of the different scenarios revenues from recovery of material (plastic, glass, metal, paper, compost from source separation and MBT output$_{glass\ /\ metal}$) and revenues from selling of RDF (MBT output$_{RDF}$) were evaluated. The uncertainties of markets for recovered materials and compost make the evaluation of the economic feasibility difficult to assess. Therefore, the economic assessment of revenues is based on current prices or assumed values, and does not consider changing price trends for recyclables.

The results of this assessment show that scenarios with higher recycling rate and more separately collected fractions have in comparison higher revenues, see Table 28. The revenues from recovered material and energy vary between 87,444 €/year and 561,114 €/year. Scenario 1b-Recy$_{dry\text{-}wet\ bin}$ achieves the highest revenues, followed by scenario 2a-Recy$_{high}$ [pl, gl, me, pa] and scenario 2b-Recy$_{high}$ [pl, gl, me, pa, org]. Revenues from selling of RDF are only forecasted in RDF scenarios 3a and 3b, as it is assumed that only these two scenarios produce valuable material for selling.

Table 28: Annual revenues from recovery of material and energy

	Scenario [€/year]						
Revenues	**00**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**
Recyclables	87,644	212,498	561,114	378,798	378,798	182,046	182,046
Compost					4,941		2,131
Energy (RDF)	0	0	0	0	0	46,613	45,254
Total	**87,644**	**212,498**	**561,114**	**378,798**	**383,739**	**228,659**	**229,431**

The cost-revenues assessment is restricted to data availability. The provided quantitative data from local project partners and assumed prices for some output streams represent only a snapshot in time. It has to be noted that the methodology is incapable of reflecting actual prices. The above presented values are not absolute, they can change depending on the waste quantities entering the treatment facilities and quality of each fraction and market conditions (prices fluctuations, demand for the product). Nevertheless, the results can be used as rough estimations and for the relative comparison between the developed scenarios.

6.1.1.4 Self-financing Rate

The indicator self-financing rate reflects the cost recovery of the evaluated scenarios. The results of this assessment are summarized in Figure 22. The green bar in Figure 22 represents the financed parts (=revenues) of the system and the red bar the non-financed part (=costs - revenues). Self-financing rate is expressed in the green box as diversion between the financed and non-financed part of each scenario in percent.

Benefits are assumed as financial revenues from material (recyclables sold) and energy recovery as well as fees charged from citizens (or the public). No additional budget financing or subsidies were taken into account. Whereas, the non-financed part is associated with the total annual discounted costs of the WM system minus revenues generated.

As the current consumer tariffs differ depending on settlement/city, company providing services for waste collection as well as on local tariff systems an average tariff of 1,6 €/m^3 [10] was assumed. The term consumer tariff is used for fees charged by the municipalities from citizens and legal entities. Due to simplification for calculation a conversion rate of 1 m^3 = 140 kg was used for all MSW streams. The evaluation of this indicator gives a relative magnitude based on current assumed fees and does not consider increased future fees.

The results in Figure 22 show, that the lowest self-financing rates are achieved in scenario 00-LF + MBT and the highest self-financing rate can be calculated for scenario 1b-Recydry-wet bin. The reason for that is the missing separate collection of recyclables in scenario 00 and therefore no revenues from material and energy recovery can be achieved. In comparison to that, scenario 1b-Recydry-wet bin has an appropriate cost-revenues diversion, where the financed part is highest among all scenarios (26 % of the total annualised costs are financed by revenues out of selling recyclables, energy and the fees). Due to highest revenues from selling of materials combined with lower total annualised discounted costs, better results can be achieved in scenario 1b-Recydry-wet bin than in scenario 2b-Recyhigh [pl, gl, pa, me, org], where 5 fractions are collected separately.

The results indicate the importance of appropriate cost revenue relation. Although scenario 2b-Recyhigh [pl, gl, pa, me, org] has the highest separate collection rate and relatively high benefits, the self-financing rate is low due to the high costs for waste treatment facilities and waste collection services. Under favourable conditions the revenues from material and energy recovery can contribute positive to the self-financing rate. An appropriate mixture of high benefits and low costs is necessary to achieve a high self-financing rate.

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[10] An exchange rate of 1€ = 28,94 UAH was used for all calculations. Conversion rate from 03.05.2017 (Online Umrechner Euro, 2017)

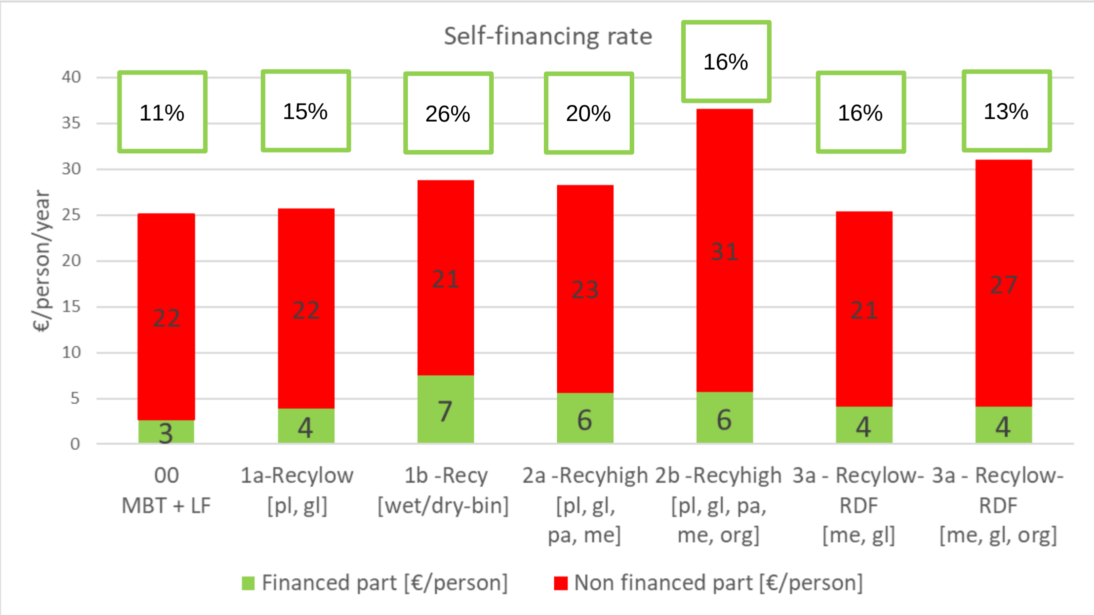


Figure 22: Self-financing rate of future WM-scenarios

Nevertheless, the self-financing rates are quite low as no scenario manages to outweigh its costs. In order to achieve better results, it is necessary on the one hand to increase the current consumer tariffs (see chapter 6.1.1.6) and on the other hand to establish extended producer responsibility schemes (EPR). EPR requires producers to create an infrastructure for collection and management of their products. The aim of this concept is to shift some parts of the costs to the manufacturers of the product. In most of the European countries EPR-schemes have been introduced successfully and the new Ukrainian Waste Management Strategy also suggests the implementation of EPR for packaging waste, WEEE batteries and end-of life vehicles by 2022 (GIZ, 2017). This measure will not only contribute significantly to the increase of the self-financing rate, but it might also encourage producers to reduce the amount of packing material used and to consider the life cycle of their products.

6.1.1.5 Total Annual Discounted Costs as % of Rayon Expenditures

Modern waste management systems in developed countries are often very expensive and therefore one of the most challenging issues for municipalities. Recent data show that 3-15% of the total municipal budget are spent on solid waste management (UN, 2010).

Comparing the results in Table 29 with these figures we see that the total annual discounted costs as percent of rayon expenditures are between 13 and 19%. In both cases the current costs of most of the scenarios exceed the typical range of 3-15%.

Table 29: Total Annual Discounted Costs as % of Rayon Expenditures

	Scenario [%]						
Indicator	**00**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**
Costs as % of regional expenditures	13	13	15	15	19	13	16

As the current standard of the waste management system is very low, rising costs are unavoidable. With higher technological complexity of the proposed scenarios an increased complexity occurs in the financing requirements. There is not only a greater need for initial capital investment for various treatment and disposal facilities, but also the costs for collection and container system will rise. The affordability of such increased technological standards might be problematic for D.. Increasing the current fees might be one option to avoid rising rayon expenses, see chapter 6.1.1.6. However, an increase of the current fees will not provide the up-front initial capital investment expenditure which is necessary for construction of the waste management infrastructure (GIZ, 2017). Several options are available to finance the waste management system. With regard to recommendations by the new Ukrainian Waste Management Strategy some of these options are presented in the following Table 30:

Table 30: Possible options for financing of solid waste management systems (GIZ, 2017)

Source of financing	Description	Purpose
Loan	The Government of Ukraine, Ukrainian commercial banks and internat. financial institutions provide construction loans for a project, typically short-term investment, which are not interested in the permanent project financing	Construction of waste MBT-plant, sanitary landfill, manual sorting lines
Grants	Grants from international or bilateral donors may be used for partial financing	Information and awareness-raising campaigns Rehabilitation and closure of unsanitary landfills and dumps
Environmental Fund	Environmental Protection fund is a special reserve state or regional fund to pay for publicly owned projects in the environmental area	Programs for rehabilitation and closure of unsanitary landfills and dumps Construction of MBT-plant, sanitary landfill, manual sorting lines
Public Private Partnership	Partnership between public and private sector companies in order to carry out waste related activities together	Design, building, operation and financing of a project

Choosing from these options will involve consideration of several issues, like time for implementation, ownership, procurement options and risk allocation (Tchobanoglous and Kreith, 2002). The decision for the best financing options must be taken by the responsible authority; it might go even above the level of D., involving both local and regional stakeholders.

6.1.1.6 Total Annual Costs as % of Nominal Average Salary and Minimum Wage

In modern waste management systems, a well-designed and functioning fee scheme should recover some of the arising costs. However, the existing low fees are not able to cover the current expenditures. As already stated before one necessary step for financing the new waste management system is the increase of current consumer tariffs. If the proposed scenarios were implemented the current costs per person as percentage of the nominal salary would be between 1.4% (scenarios 00-LF + MBT; 1a-Recy$_{low}$ [pl, gl]; 3a-RDFRecy$_{low}$ [me, gl]) and 2.1% (scenario 2b-Recy$_{high}$ [pl, gl, pa, me, org]), see Table 31. An increase of the current tariffs would still be affordable (except in scenario 2b), as according to international recommendations, the fees should not exceed 1% of the household income (=2 working people). This means scenario 2b is higher, whereas the scenarios can be classified as affordable (GIZ, 2017; Wilson et al., 2013). To cover the total costs it would be necessary to increase the current fees between 4 and 9 times or to look for alternative financing options (see Table 30). However, this measure must be implemented over a time to avoid putting disproportionate pressure on the local population.

Table 31: Total annual costs as % of nominal average salary and minimum wage

	Scenario [%]						
Indicator	**00**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**
Costs as % of nominal average salary	1.4	1.4	1.6	1.6	2.1	1.4	1.7
Costs as % of minimum wage	1.9	1.9	2.2	2.1	2.8	1.9	2.3

Furthermore, the total annual discounted costs as % of the minimum level were investigated. In comparison to the results of nominal average salary the percentage rises to 1.8% (scenario 00-LF + MBT) and 2.7 % (scenario 2b-Recy$_{high}$ [pl, gl, pa, me, org]). Such an increase could be perceived as inappropriate for economical disadvantaged citizens. Still, the increase of fees will be necessary to enhance the effectiveness of MSWM services and to cover the costs. To avoid disproportionate pressure on economically vulnerable citizens it could be considered to either offer support by subsidies or to implement PAYT (pay as you throw) - schemes.

PAYT schemes charge households based on the amount of waste they generated, weight or volume of waste, frequency of collection or the level of segregation at source (GIZ, 2017). The purpose of such a system is to influence household behaviour by rewarding decreased waste generation. The former tax-based system is replaced by a service based system, where the users pay depending on the services they use. PAYT is usually applied to residual waste as it intends to cross finance separate collection of recyclables by a higher charge of mixed waste (BiPro and CRI, 2015). Although PAYT schemes are a good measure to minimise overall waste production and divert recyclables from residual waste, it should be kept in mind, that waste tourism can occur as result of implementing this type of charging. If the PAYT - schemes is not accepted by the citizens it might happen that the generated waste is either moved to neighbouring communities or illegally dumped (Morlok et al., 2017). All in all, designing PAYT systems in MSWM services is a complex issue and requires a lot of planning. As the methodological approach for PAYT is still in development for Ukraine, it might not be applicable at the moment.

In the end, probably a mixture of slightly increasing consumer fees over the time, revenues from material and energy recovery, establishment of ERP for packing waste & WEEE and other possible sources of financing (chapter 6.1.1.5) could cover the total costs.

6.1.2 Environmental assessment

The environmental impacts have been calculated for all future scenarios. The results of the calculated 6 assessed indicators are presented in the following subchapters.

6.1.2.1 Source-separated Collection Rate

Although MSW represents only a relatively small portion of the total available waste (incl. waste from demolition, industrial sources etc.) it´s one of the most challenging issues for collection authorities all over the world (Letcher and Vallero, 2011). Several barriers like citizens' behaviour (Timlett and Williams, 2008; Tonglet et al., 2004), insufficient ability of space (Martin et al., 2006; Williams and Kelly, 2003), waste collection costs, collection requirements for different waste streams, design of collection routes (Letcher and Vallero, 2011) etc. are influencing the performance of municipal waste collection.

Municipalities often concentrate on optimizing the system by offering technical equipment to citizens, like proper bin and container systems. Nevertheless, the realistic estimation of achievable rates of source-separated collection quantities of recyclables is difficult to assess. In order to show possible performance options three different targets for calculation of source-separated collection rate are recommended in the scope of this thesis, see Table 7.

The results of the separated collection performance based on these targets are presented in the following Figure 23:

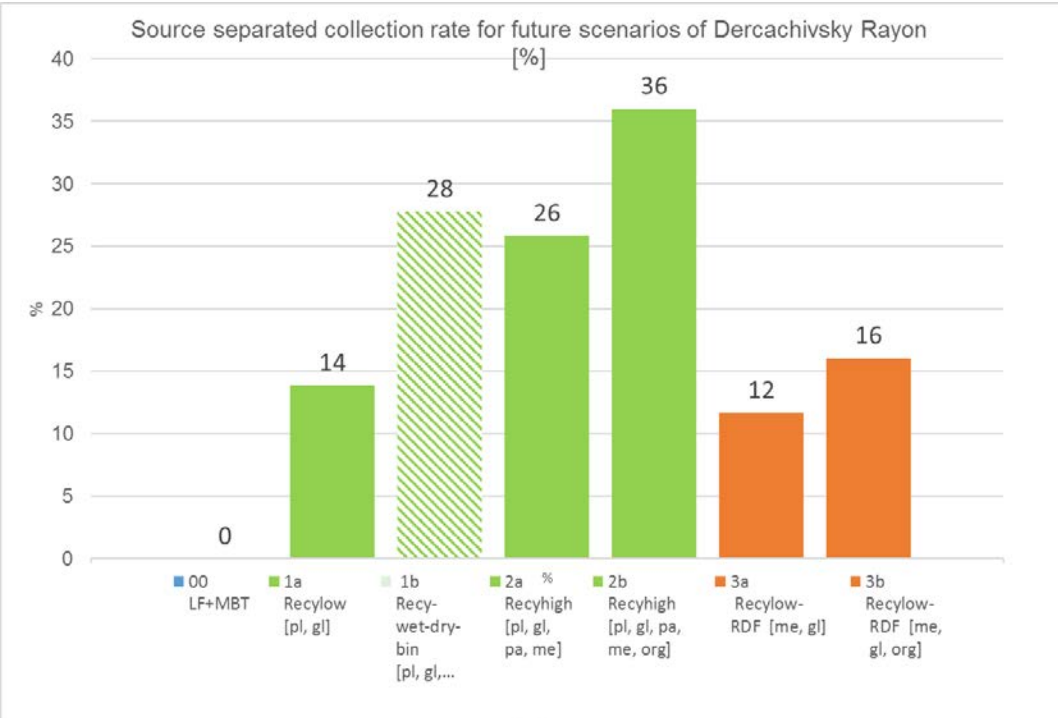


Figure 23: Source-separated collection rate for future WM scenarios

As seen in the above illustrated figure, scenarios with higher collection targets (scenario 1b, 2a, 2b) have the highest collection performance in comparison with low target scenarios (scenario 1a, 3a, 3b). In scenario 00 no recyclables are separately collected and therefore the collection rate is set at zero. Scenario 2b-Recy$_{high}$ [pl, gl, pa, me, org] is ranked as best scenario, because beside the highest collection rate all 5 waste fractions are separately collected.

However, not only the separate collection targets have an influence on the collection performance, also the waste composition is a crucial factor. Comparing scenario 1a and 3a it becomes apparent that the difference in the separate collection rate is not only due to *collection targets*, but also resulting from different *waste composition* and the thereof available waste quantity of waste fractions. Although it might seem that scenario 3a has higher collection targets (60% metal, 50% glass), nevertheless scenario 1a (50% glass, 33% plastic) has in the end a higher separate collection rate. This is because the quantities of metal are much lower in the waste composition of D. in comparison to the plastic quantities. Consequently, in the end the separate collection rate is higher, because more plastics are collected (in scenario 1a) than metals (in scenario 3a).

It is not possible to compare the results directly with provisions from the new Ukrainian waste management strategy as the new strategy does not provide source-separated collection targets for each waste fraction. The strategy requires only an increase of the source-separated collection of dry-recyclables (plastic, glass, metal, glass). Up to 53% of the total Ukrainian population shall be covered until 2030 with a separate collection. This target should be reached by extending the separate collection also in smaller towns and settlements.

Not only the coverage of source-separated dry-recyclables should be increased, but also the implementation of a so called two-bin system shall be taken into consideration. The two-bin system introduced in the new Ukrainian Waste Management Strategy corresponds to scenario 1b-Recy$_{dry-wet}$ [pl, gl, me, pa] where one container will be dedicated for collection of dry recyclables (plastic, glass, metal, glass) and another container will be provided for the collection of residual waste.

The separate collection of organics (like suggested in scenario 2b and 3b) is so far not considered as a main objective in the new waste management strategy. It is proposed to develop so called collection centres, where garden waste such as tree pruning can be collected. However, most of the organic fraction remains in the residual waste. Only in some small pilot projects the separate collection of the biological waste fraction will be tested in order to determine possible best practice options for Ukraine. Nevertheless, it is not planned to implement the separate collection of organics so far. For that reason, scenario 2b and 3b might not be interesting from the standpoint of separate collection rates, but still play an important role when it comes to material recovery, waste landfilling and biodegradable waste diversion rate.

After the separate collection of the different waste streams, the collected materials are re-sorted manually and send to recycling. The results of these processes are presented in the next chapter.

6.1.2.2 Material Recovery Rate

According to the waste framework directive one of the main goals of MSWM should be shifting waste management up the waste hierarchy by reducing waste disposal and instead focus on waste prevention, reuse, recycling and recovery (WFD, 2008).

Currently, municipal waste recycling in Ukraine is very low. However, in order to achieve higher material recovery rates the new Ukrainian Waste Management Strategy tries to set targets to improve quantity and quality of secondary raw materials captured from the MSW stream and to encourage home composting in suburban and rural areas (GIZ, 2017).

Within this thesis the material recovery rate is not described separately for each waste fraction, but aggregated for different processes (see chapter 3.3.2.2). Also, the amount of home composted material is not included in the material recovery rate. Figure 24 represents a comparison of the share of source separated collected waste (excl. WEEE & hazardous waste), output recyclables after sorting, MBT-recyclables (gl, me) after sorting and recycling, output recyclables after recycling and output organics after composting process.

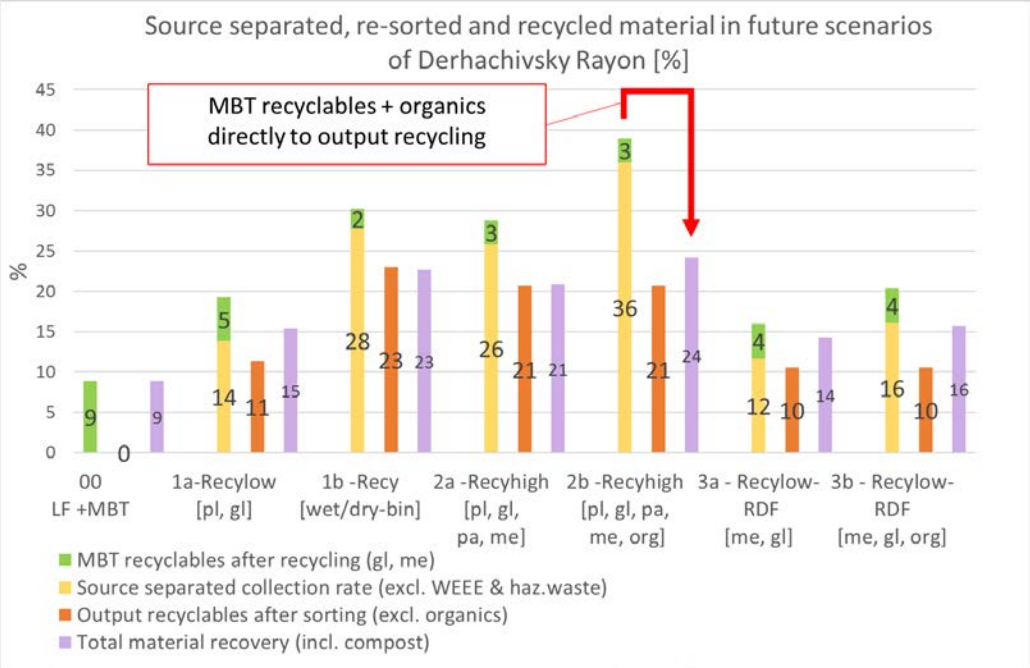


Figure 24: Source separated, re-sorted and recycled material in future WM scenarios

The figure above illustrates how much material is left after different treatment procedures and technologies. The green bar represents the MBT recyclables (glass, metal) after sorting and recycling. The orange bar indicates how much material is left after sorting of recyclables and sent to recycling. The total material recovery rate is shown in the purple bar and it shows material recovery after recycling (taking into account technical material recycling rates (Table 8) as well as composting of separately collected organics.

Results from source-separated collection rate (yellow bar) are already discussed in the previous chapter. The second bar (orange) indicates that after source separation the material is manually re-sorted. Just after the sorting performance materials are send to recycling. The amount of MBT recyclables after recycling (green bar) is calculated by the GHG-emissions tool from TU-Dresden. MBT recyclables are not sent to the manual sorting lines, because the separation of valuable materials is performed in the MBT plant. For that reason, the amount of MBT recyclables after sorting is not included in the orange bar. The reference values used for calculation of source-separated collection rate, separation efficiency, composting efficiency and technical recycling rates are shown in Table 7 and Table 8.

The total material recovery rate (purple bar) is linked to the source-separated collection rate. Clearly, scenarios with low source separate collection rates (scenario 00, 1a, 3a, 3b) have lower material recovery rates in comparison with scenarios with higher separate collection targets (scenario 1b, 2a, 2b). The total material recovery rate includes MBT recyclables directly after recycling, as well as the outputs of re-sorted recyclables after recycling process and the amount of compost produced after treatment of organics in an open windrow-composting.

By 2030, an overall material recovery rate of 15% should be achieved according to the new waste management strategy. This target could be fulfilled in all scenarios except in scenario 00-LF + MBT (only 9%) and scenario 3a-RDF-Recy$_{low}$ [me, gl] (only 14%). The failure to achieve the target in scenario 00 could be explained by the missing separate collection of recyclables. In case of Scenario 3a the reason for the failure is due to the relatively small amount of source-separated materials. Scenario 1b-Recyc$_{dry\text{-}wet\ bin}$ and 2b-Recycling$_{high}$ [pl, gl, me, pa, org] reach far higher targets, than suggested in the waste management strategy. However, when looking at these results it should be kept in mind, that the results of total material recovery rate are depending on the technical recycling rates chosen for each waste stream (see Table 8). As the actual technical recycling rates used for calculation of the 15% target are unknown, results can change if other input data are used.

Last of all, the possible impact of the IRS and the inclusion of home composted organic material should also be considered when discussing the results of material recovery rates.

As the informal collection activities have an influence on the formally collected waste quantities it is inevitable to address this issue when planning future waste management of D..

The selection and implementation of appropriate measures could include the following options:

- Formalization of the informal sector by employing the informer collectors as formal workers in the municipal waste management system (Aparcana and Salhofer, 2013b)
- Installation of underground container to limit access to recyclables (GIZ, 2017)
- Clarifying the ownership of MSW by enforcement of legislation (GIZ, 2017)

The modernization process of the waste management system is often driven by the wish to be modern and to reach a “Western or European” level of waste management system. Thus, it can happen that the livelihood activity of waste pickers becomes criminalised when local authorities deny or restrict access to landfill or containers

(Scheinberg et al., 2006). The focus on getting waste pickers out of the waste management system rather than identifying them as possible stakeholder group can result in further conflicts of interest and might not solve the current problems. Therefore, it is crucial for the development of the new waste management system rather to choose inclusion (=usage of knowledge and experience of the informal sector) than exclusion (=focus on large-scale technologies and exclusion of excluding knowledge) of the informal sector and the thereof resulting consequences or problems (Ramusch, 2015).

Like the IRS also home composting activities have a high influence of MRR as huge quantities of organic material are diverted from the municipal waste stream. However according to the new Ukrainian Waste Management Strategy, it is recommended to encourage the implementation of home composting in suburban areas (GIZ, 2017). For that reason, it can be proposed to establish home composting as a reasonable recycling option of organic material in D..

6.1.2.3 Energy Recovery Rate

Beside the material recovery rate also the energy recovery rate can be an interesting indicator for measuring the environmental performance of a MSWM system. Like the material recovery rate energy recovery is also linked to gaining sustainable benefits from natural resources by reducing primary resource consumption (Tchobanoglous and Kreith, 2002). In this case fossil fuels should be replaced as primary resources.

The indicator is calculated as a ratio between MJ_{el}, MJ_{th}, $MJ_{indirect}$ and $MJ_{available}$. It expresses the useful recovered exergy out of the total available exergy. The chosen approach for measuring the energy recovery rate allows the comparison of different MSW management scenarios aiming to achieve an objective way for monitoring the performance of each scenario (Rigamonti et al., 2016a). As neither heat nor electricity are produced out of the MSW processes in our considered scenarios, these two values are considered as zero. Values for $MJ_{available}$, $MJ_{indirect}$ and own energy consumption are presented in Table 32.

Table 32: Energy-related key parameters for future scenarios

	Scenarios						
Input Data	**00**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**
$MJ_{indirect}$ [MJ]	70 Mil.	57 Mil.	37 Mil.	40 Mil.	38 Mil.	72 Mil.	71 Mil.
Net calorific value of RDF [MJ/kg]	15	13	11	12	12	15	16
$MJ_{available}$ [MJ]	116,031,590						
Energy Consumption [MWh]	5 Mil.	4 Mil.	3 Mil.	3 Mil.	3 Mil.	4 Mil.	4 Mil.

The results of the calculations are presented in form of a bar diagram in Figure 25. The best performance is achieved in both RDF scenarios 3a and 3b due to the high total calorific value produced in the MBT plant. Scenario 00 shows second best results after the two RDF scenarios. This is because of the huge quantities entering the MBT plant, as no separate collection is conducted in this scenario. For that reason, more quantities of plastic, paper and other value material for RDF production are available and therefore the energy recovery rate is higher. All in all, the three scenarios lead to similar results and nearly the same ERR. The remaining scenarios have all relatively low energy recovery rates.

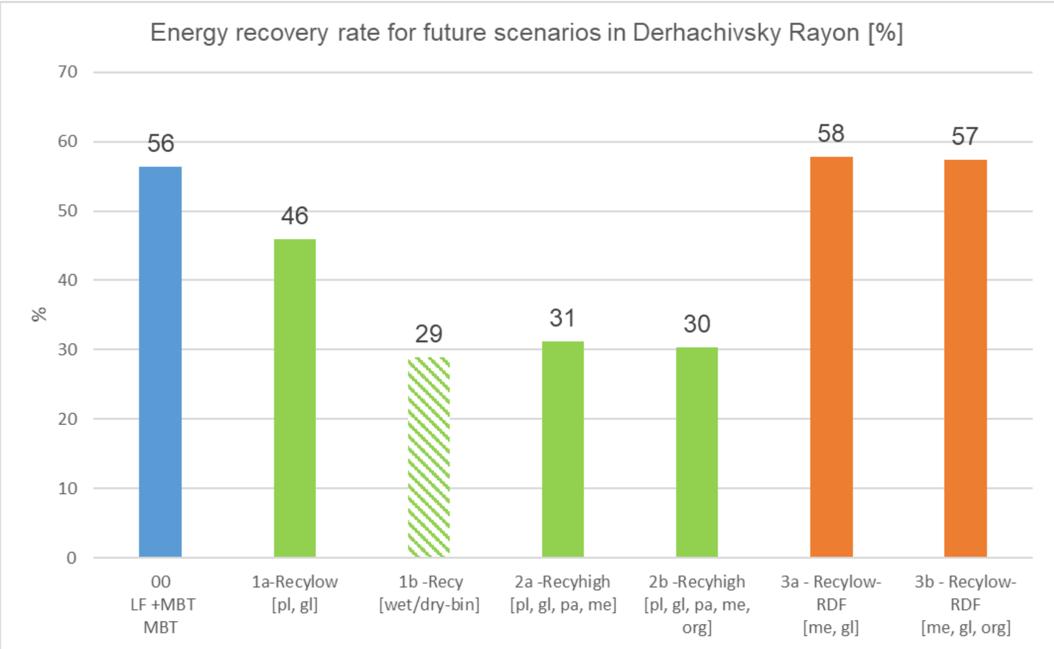


Figure 25: Energy recovery rate for future WM scenarios

The results are highly dependent on the calorific values of the produced RDF material and waste quantities entering the MBT-plant. The calorific values differ from scenario to scenario – the lowest calorific value can be found in scenario 2b (12 MJ/kg) whereas the highest calorific value is achieved in scenario 3b (16 MJ/kg). In comparison to that calorific values ranging between 11 – 18 MJ/kg can be found in other European cities (European Commission 2003, McDougall et al., 2003, Vattenfall Europe New Energy Ecopower, 2010). Depending on the calorific values the new Ukrainian Waste Management Strategy classifies the produced RDF in different classes from 1 to 5 (see Table 33).

Based on this categorization the material produced in scenario 3a, 3b and 00 can be classified as RDF class 3. As it is quite challenging to produce high-quality material the RDF produced in all other scenarios are able to achieve only class 4. It might happen that this material will not be accepted by cement kilns due to its low calorific values. However, it has to be kept in mind that all above presented results are based on calculations and may vary in reality. In order to gain a representative sample, it would be necessary to carry out a full waste composition analysis and to examine other parameters as chlorine and mercury content.

Table 33: Classification of RDF quality classes in Ukraine (GIZ, 2017)

	class				
	1	2	3	4	5
Calorific value [MJ/kg]	≥25	≥20-25	≥15-20	≥10-15	≥3

6.1.2.4 Waste Landfilling Rate

Currently D.´s MSWM practice is totally reliant on landfilling. However, 3 of the 4 existing landfills do not meet any proper environmental safety standards and can therefore have a serious impact on health and safety of the citizens and the environment. An objective of the new Ukrainian Waste Management Strategy is to close such non-complaint landfills or dumpsites and to provide a network of disposal facilities which are complaint with the EU Landfill Directive, 1999/31/EC. Both provisions could be fulfilled in all suggested future scenarios, as it is planned to close all current dumpsites and to build a new sanitary landfill. The amount of landfilled waste at the sanitary landfill is shown in Figure 26.

The different landfilling rates presented in Figure 26 are due to the variation in source separate collection targets of materials and different treatment options of organic waste. In other words, a general increase in material recycling and composting leads to a reduction in the percentage of MSW landfilled.

The large difference between the first bar (scenario 00 LF + MBT) in comparison to all other bars indicates the influence of different treatment options of recyclables. In scenario 00-LF + MBT no separate collection is performed and therefore the landfilling rate is higher than in all other scenarios. Whereas in scenarios with higher source-separated collection performances the landfilling rate is lower.

Although there is no legally binding limit on landfilling the new Ukrainian Waste Management Strategy clearly states as one of the main objectives to move up the waste hierarchy towards recycling and recovery and away from sole reliance on landfilling. None of the suggested scenarios is solely reliant on landfilling, as the formally collected residual waste is always pre-treated in a MBT-plant. However, a less significant portion of MSW can be diverted from landfill in scenario 00 – LF + MBT in comparison to all others.

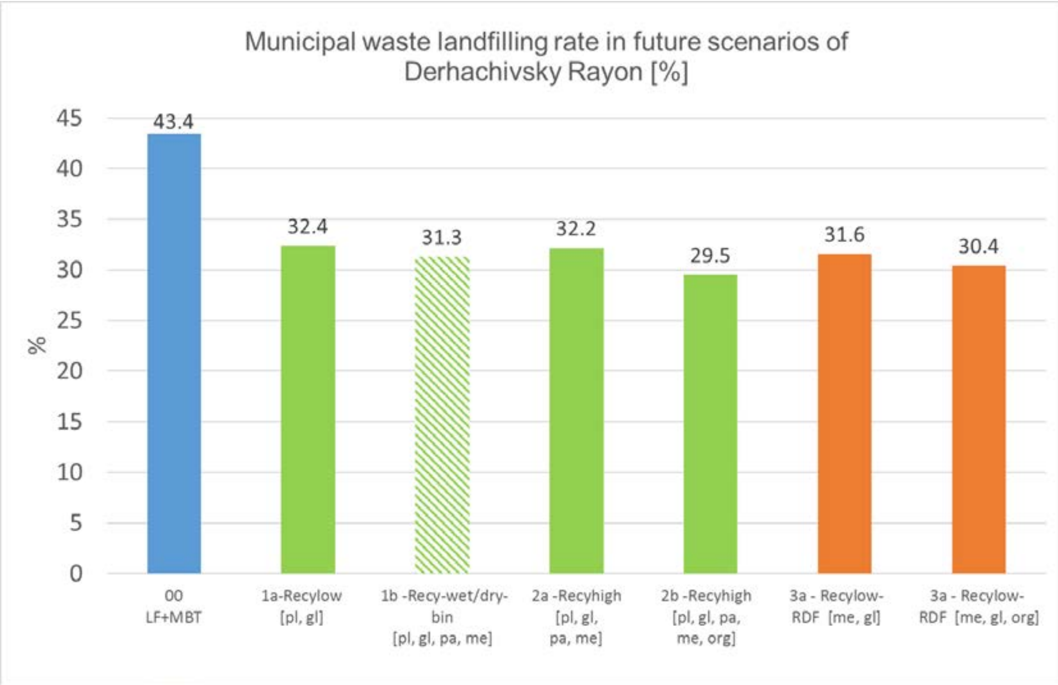


Figure 26: Municipal waste landfilling rates for future WM scenarios

Furthermore, the figure above shows that scenarios with separate collection and treatment of organics (scenario 2b-Recy$_{high}$ [pl, gl, pa, me org]; scenario 3b-RDF-Recy$_{low}$ [me, gl, org]) have a decreasing landfilling rate, because more valuable material can be diverted from the residual waste stream and is sent to further treatment procedures.

Besides the above-mentioned points which influence the landfill rate the reduction of the waste volume to be landfilled to a minimum still remains one of the biggest challenges in Ukraine. A recent study from the European Environment Agency (2013) which compared the waste management strategy in 32 European countries revealed that landfill tax can correlate with the amount of waste sent to landfill. The higher the costs of landfilling the more waste is treated via recycling and composting. But not only taxes can influence the amount of MSW sent to landfill significantly, also other factors can contribute to shifting up the waste hierarchy. The quantity of landfilled waste can be also determined by stronger waste policy, bans of landfilling biodegradable waste, mandatory separate collection schemes for recycling of municipal waste types, changes in gate fees charged by landfill sites and the available capacity of landfills used (European Environment Agency, 2013).

The new Ukrainian Waste Management Strategy tries to implement a step-wise increase of the current landfill tax in order to shift waste away from landfilling. The current landfill tax of 0.14 €/t will be increased up to 3 €/t in 2023 (GIZ, 2017). The suggested landfill tax is very low compared to the EU average (of 18 member states) of 33€, ranging from 3 € in Bulgaria and 107 € in the Netherlands (Bio Intelligence Service, 2012). For that reason, it is planned to assess the stimulatory effect and if necessary the landfill tax well be further increased in the period of 2023 to 2030.

As already mentioned above not only the landfill tax plays an important role in terms of reducing the rate of landfill disposal, but also bans of landfilling biodegradable waste can contribute significantly to this goal. Therefore, the following indicator calculates how much biodegradable waste can be diverted from landfill in each scenario.

6.1.2.5 Reduction of Biodegradable Waste Landfilling

Landfilling is ranked lowest in the waste hierarchy, nevertheless it remains still the most common waste treatment method in Ukraine.

When untreated MSW is sent to landfill the biodegradable fraction produces methane. The released gases contribute to global warming, acidification and human toxicity. Additionally, a substantial amount of nitrogenous and phosphorus compounds is released by the biodegradable fraction. When biodegradable waste is diverted from landfills a significant reduction of negative environmental impacts can be obtained (Sharma and Chandel, 2017).

In the European Union, the Landfill Directive, 1999/31/EC aims to reduce the amount of biodegradable waste diverted from landfill relative to the quantity generated in 1995. By 2006 the landfill rate had to be reduced to 75% of the amount generated in 1995, declining to 50% by 2009 and 35% by 2016 (EC, 1999). Currently, there is no legally binding rate for the diversion of biodegradable MSW on landfill in Ukraine. However, a national strategy in regard to the provisions in the EU Landfill Directive is being prepared at the moment (GIZ, 2017).

To assess the compliance with the EU Landfill Directive it is necessary to analyse available information from 1995. Because of lack of data from 1995 the biodegradable waste diversion rate was calculated with available data from 2015. Based on the waste composition it was investigated, how much biodegradable waste can be diverted from landfill in each scenario.

First the quantity of biodegradable waste which is landfilled according to a given scenario was calculated. Therefore, the output of MBT material sent to landfill, sorting residues and composting residues were multiplied with their biologically degradable portion (see Table 10) and summed up. In a second step, the quantity of each waste fraction which is landfilled in 2015 was multiplied by its biologically degradable portion to gain the quantity of biodegradable waste generated in 2015. The input data for quantity of waste fraction which is landfilled in baseline scenario are based on quantities from formal collection (10,873 t/year) and dumps elimination (2,455 t/year).

Figure 27 shows the results of biodegradable waste diversion performance of each future scenario in %. The landfill scenario (scenario 00 – LF+MBT) has the lowest biodegradable waste diversion rate in comparison to all other scenarios. From the total available biodegradable quantity generated in 2015 only 10% can be diverted. The remaining 90% are still dumped at landfills. In all other scenarios, the 75% and the 50% target could be fulfilled. Scenario 2b even nearly achieved the target set out for 2016 – a reduction to 35% of the amount which was generated in 2015.

The results show that almost all future scenarios are able to move sufficient biodegradable waste from landfills to recycling or other treatment options. Significant increase is visible in scenario 2b-Recy$_{high}$ [pl, gl, pa, me, org] and scenario 3b-RDF-

$Recy_{low}$ [me, gl, org]. This indicates that most biodegradable waste can be diverted in scenarios with separate collection and treatment of organics.

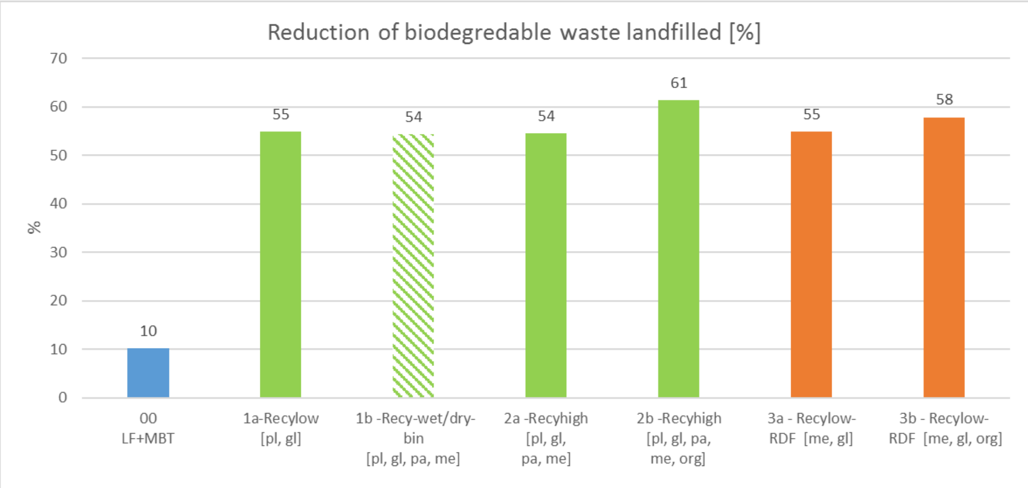


Figure 27: Reduction of biodegradable waste landfilling of future WM scenarios

6.1.2.6 Greenhouse Gas Emissions

Disposal and treatment of waste produces GHG-emissions, which contribute to global climate change. The global GHG emissions resulting from waste management activities are about 3 to 4% of anthropogenic GHG emissions (IPCC, 2006). As climate change has become an important political priority and countries worldwide struggle to address their carbon footprint, waste sector activities represent an opportunity to mitigate GHG emissions if the right measures are taken.

Within this thesis an evaluation of GHG emissions levels for the seven future scenarios was made. As already described in chapter 3.3.2.6 the GHG-emissions are calculated with the unpublished Emission-Calculation-Tool of TU-Dresden (Wünsch, 2013).

The results displayed in Table 34 and Figure 28 are indicative of the amount of GHG-emissions that may be emitted by the seven analysed future scenarios. They should not be assumed to be exact, due to assumptions and limitations necessary in the Emissions-Calculation-Tool from TU-Dresden (see chapter 3.3.2.6). Results include GHG-emissions which are released through waste treatment as well as avoided GHG-emissions from material recovery and fuel substitution. The positive values represent emissions released to the environment or resources, while all avoided GHG-emissions are shown in negative values. The released and avoided GHG-emissions can be balanced, and these net emissions are shown in the last column.

Scenario 00-LF+MBT shows the maximum GHG emissions (5,177 t of CO_2, eq.) owing to high emissions of methane and carbon dioxide, followed by scenario 1a. Fewer net emissions occur in both RDF scenarios 3a and 3b with an amount of 2,188 t of CO_2, eq and 1,139 t of CO_2, eq. respectively. The scenarios with highest material recovery rates (1b, 2a, 2b) can avoid most of the GHG-emissions compared to all other scenarios.

Table 34: GHG-emissions of future WM scenarios

Scenario	released GHG emissions [t CO_2 -eq. /yr]	avoided GHG emissions [t CO_2 -eq. /yr]	GHG net emissions [t CO_2 -eq. /yr]
00 LF + MBT	8,801	-3,624	5,177
1a-$Recy_{low}$ [pl, gl]	7,823	-3,780	4,043
1b - Recy [wet/dry-bin]	6,499	-8,948	-2,449
2a - $Recy_{high}$ [pl, gl, pa, me]	6,678	-7,173	-495
2b - $Recy_{high}$ [pl, gl, pa, me, org]	5,646	-7,163	-1,518
3a - RDF - $Recy_{low}$ [me, gl]	8,854	-6,736	2,118
3b - RDF - $Recy_{low}$ - [me, gl, org]	8,409	-7,270	1,139

This result indicates that scenarios with high shares in recycled materials also have the greatest effect on reducing GHG emissions. This is due to the fact that production emissions are reduced through feeding recycled material instead of virgin material to production processes (Mohareb et al., 2008). In other words, recycling can offer substantial GHG emissions savings though limiting resource consumption and energy savings (ISWA, 2009).

Highest emissions recognized by the Emissions-Calculation tool result from emissions of final waste disposal. The largest part ascribes to methane emissions from anaerobic decomposition of organic material. A possible measure to mitigate methane emissions would be to capture methane emissions and subsequently combust it for energy production purposes. However, the suggested disposal facility for D. has no gas collection system due to the low amount of waste and the stabilized input from MBT material. Therefore, active extraction of methane is not possible for this case study.

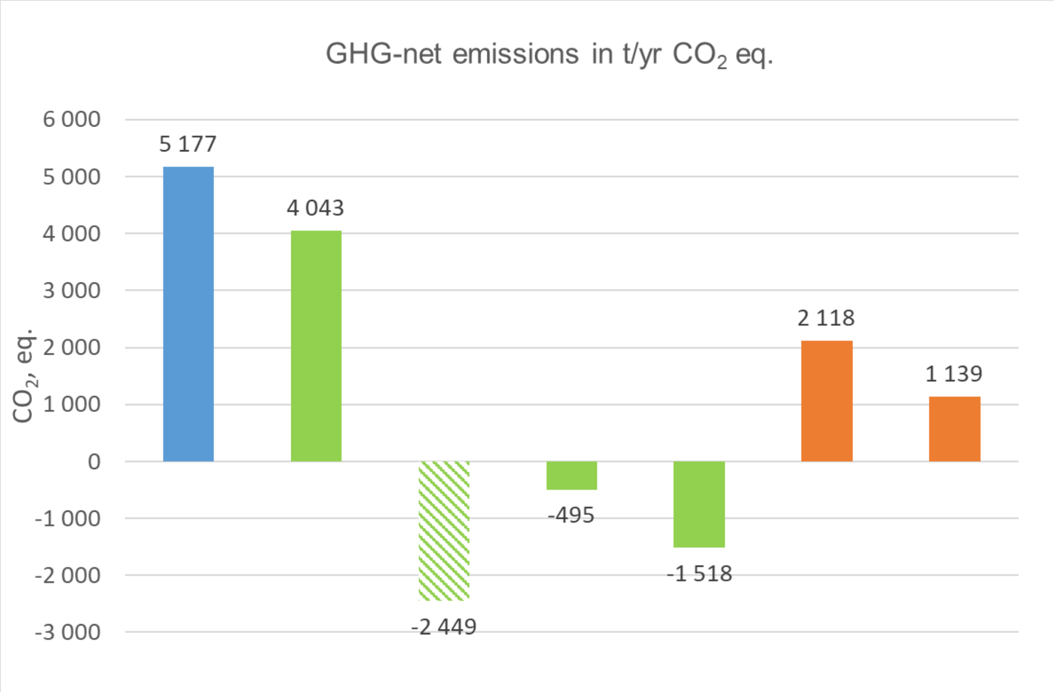


Figure 28: GHG-emissions of future WM scenarios

When looking at the results the following conclusions can be drawn:

- Variations occur because of differences in material recovery quantities and quantities treated in MBT and sanitary landfill
- A higher MBT input and higher landfill input will release more GHG emissions (Scharenberg, 2017)
- Fewer emissions will be released, with a smaller organic fraction in the waste composition (Scharenberg, 2017)
- Emissions from composting are not included in the calculations in the tool, however their impact can be counterbalanced with GHG credits obtained by application of compost on land (substitution of other types of fertilisers by compost) (Linzner and Mostbauer, 2005). Hence, the net emissions in scenario 2b and 3b could differ in reality
- Most GHG-emissions are avoided in scenarios with higher material recovery rates

A detailed climate relevant GHG balance for every scenario is available in Annex 5, more details about GHG-balance within the scope of WaTra-project is provided from TU-Dresden in Scharenberg (2017).

The project partner form NUUE evaluated the above described environmental indicators (except indicator GHG) also for the baseline scenario, see Table 35 (Stolberg et al, 2016b). Compared to the results of the baseline indicators it can be concluded that all future scenarios can improve their performance drastically.

Table 35: Comparison of environmental performance of baseline and future scenarios

	Scenario							
Indicator	**Baseline**	**00**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**
Separate collection rate [%]	0	0	14	28	26	36	12	16
Material recovery rate [%]	0	9	15	23	21	24	14	16
Energy recovery rate [%]	0	56	46	29	31	30	58	57
Landfilling rate [%]	100	43	32	30	32	29	31	30
Red. biod. waste landfilling [%]	0	10	55	54	54	61	55	58
GHG [$tCO_{2\ eq\ /yr}$]	n.d.	5,200	4,000	-2,500	-500	-1,500	2,100	1,100

6.1.3 Social assessment

Social sustainability in terms of waste management means that MSW system must be socially acceptable, distribute benefits and disadvantages equally between citizens and perform its social function of safe waste handling (Den Boer et al., 2005). In order to evaluate if the seven future scenarios are planned in accordance with the requirements of social sustainability the indicators "social acceptability" and "job creation" were measured. The results of both indicators discussed in the following sub-chapters.

6.1.3.1 Social Acceptance

Social Acceptance is a qualitative indicator, which is difficult to measure. For that reason, the quantification of this indicator is based on 4 expert interviews with experts from ABF-BOKU and TU-Dresden.

The obtained assessment values for the social acceptance of the different future scenarios are presented in Figure 29. The results in Figure 29 are provided for each evaluated sub-criterion. In order to make the comparison of the different scenarios easier, the expert-based results are aggregated. This was done in two steps:

1. creation of arithmetic average of all waste management stages within one subcategory
2. creation of arithmetic average of all subcategories for all experts

Based on the average values of the expert assessment a ranking of the seven scenarios was elaborated (see Table 36). Rank 1 indicates the scenario with most positive foreseen social effect, whereas rank 6 indicates the worst effect. Two scenarios (1a and 3a) have reached the same score and have therefore the same rank.

Table 36: Results of Social Acceptance ranking

	Scenario						
Indicator	**00**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**
Social acceptance [ranking]	1	3	2	4	6	3	5

From the results in Figure 29 follows that almost all subcategories lead to decreasing social acceptability. The main reason for this is that in comparison to status-quo where almost no separate collection is carried out, "doing nothing" can bring "better" results than improving the current system. Inhabitants have to change their behaviour, complexity rises, and this is often perceived as negative. Only the sub-category "distance" gains a positive score for all scenarios, as more containers will be installed and therefore the distance to the containers will become shorter.

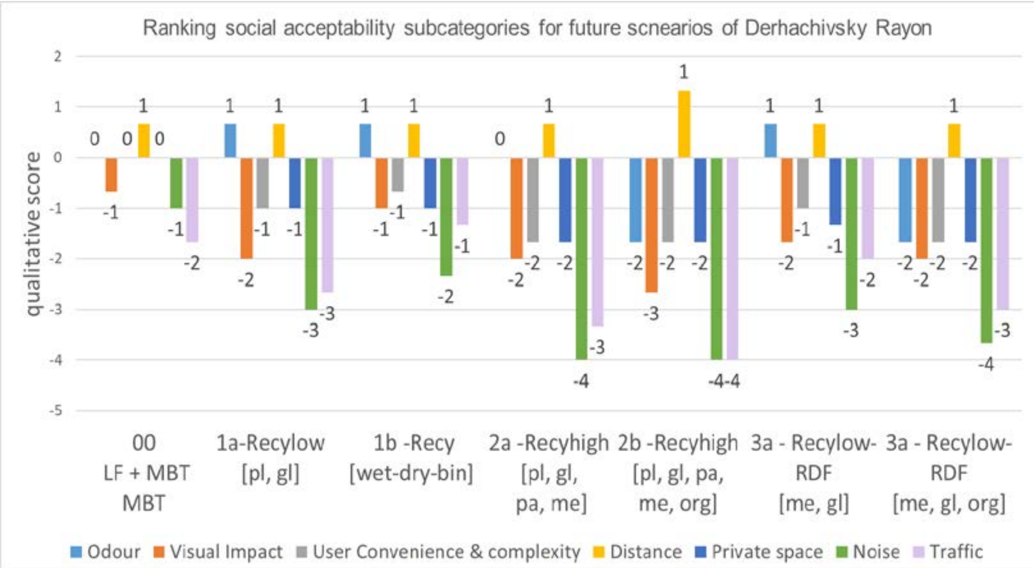


Figure 29: Results of ranking social acceptance for future WM scenarios

According to the results, scenario 00-LF + MBT has the best score, followed by scenario 1b-Recy$_{\text{wet-dry bin}}$, scenario 1a-Recy$_{\text{low}}$ [pl, gl] and scenario 3a-Recy$_{\text{low}}$ – RDF [me, gl] with the same score. Scenario 2b -Recy$_{\text{high}}$ [pl, gl, pa, me, org] and scenario 3b-Recy$_{\text{low}}$ – RDF [me, gl, org] achieve the lowest social acceptance, although they indicate a clear improvement of the whole waste management system. Especially the categories noise, traffic and visual impact are ranked very low. Reason for this could be that e.g. main sound level rises, when more containers are installed and emptied, volume of traffic is higher, because of higher collection frequencies and an increase of containers and waste treatment- and disposal facilities is perceived as negative. Based on the results it can be concluded that more complex scenarios with more separate collected fractions have the least beneficial results.

However, when looking at the results it should be considered that a negative social acceptance does not mean, that improving the waste management system would be disadvantageous for citizens. The results only indicate that a change of the current situation could be perceived as negative. It is important to communicate changes of the current system in order to reduce the negative perception. Information about objectives of the new systems, clear instructions about separate collection, intervals and organisational aspects etc. can increase the motivation (Bilitewski and Härdtle, 2013).

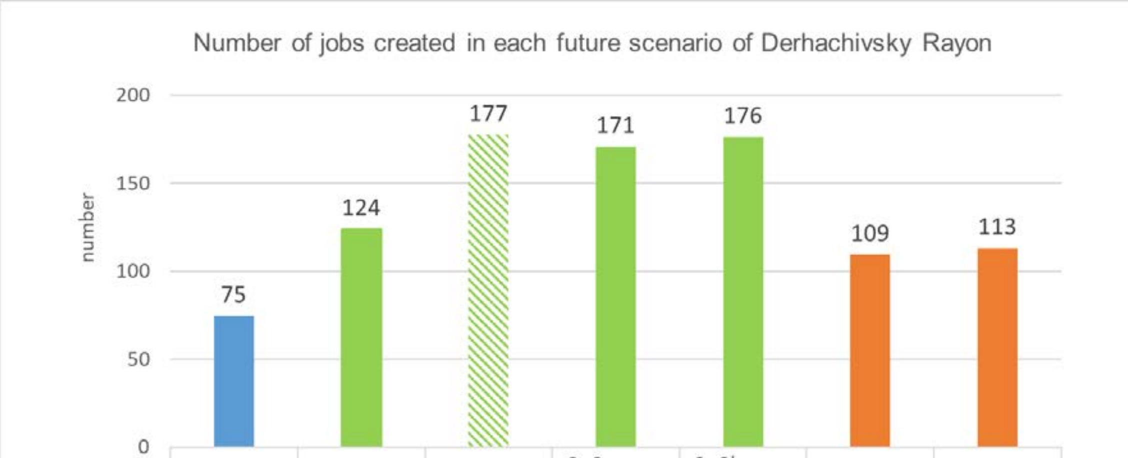
Furthermore, it should be kept in mind that the resulting assessment reflects opinions of the interviewed experts. The scoring of the social indicators is highly subjective and might not be reproducible if more or other experts would be reviewed. Another influencing factor might also be the choice of experts. Only experts with a scientific background conducted the review. If other stakeholder groups like NGO, politicians, local citizens were included, the final results could differ as the perception of odour, visual impact, noise and traffic are subjective and difficult to measure.

6.1.3.2 Job Creation Potential

This indicator measures how many jobs could be created if a given scenario is implemented. The methodology for estimating potential future jobs is based for some stages of the MSW system on available literature data. Therefore, it should be taken into consideration that jobs might also be created outside the three subsystems bin & container system, collection & transport and treatment & disposal. Jobs could also be created e.g. in a recycling company or industry using recyclables (e.g. paper mill). This means that the number of jobs presented in Figure 30 includes also jobs which are created outside of D..

For calculation of the Job Creation Potential and arithmetic average of number of jobs based on literature data in a certain WM treatment stages or subsystems was created. In a second step the number of jobs was applied relating to the quantities of waste treated in a certain WM treatment stage or subsystem. This step was necessary because literature values for job creation are often based on an annual turnover of 10,000 tonnes. However, the annual turnover of subsystems in D. are lower than 10,000 tonnes. Therefore, it might happen that due to low quantities e.g. in composting facilities according to the calculation only 1 job is created although a composting plant will most likely not be able to operate in reality with one employee only.

The number of truck driver correlates with the number of trucks in each scenario. It was assumed that one truck requires two workers: one driver and one person for emptying the containers (Khandogina and Abashyna, 2017b).



	00 LF + MBT	Sc 1a-recy [pl, gl]	Sc 1b -recy [wet/dry]	Sc 2a -recy [pl, gl, pa, me]	Sc 2b -recy [pl, gl, pa, me, org]	Sc 3a RDF [me, gl]	Sc 3b RDF [me, gl]
Jobs created	75	124	177	171	176	109	113

Figure 30: Results of number of jobs created from future WM scenarios

Based on the results in Figure 30 it can be concluded that for more labour-intensive activities such as separate collection and recycling of waste the level of employment is higher than in less labour-intensive activities such as landfilling and composting.

Therefore, scenarios 00-LF + MBT, scenario 3-RDF-Recy$_{low}$ [me, gl] and 3b-RDF-Recy$_{low}$ [me, gl, org] have a lower employment quantity. Whereas in scnearios with high rates of separate collection and treatmen of recyclables the number of jobs created is much higher.

These results should be regarded as conservative theoretical estimates not as targets. They are based on literature data and therefore actual jobs created might differ from these results. Nevertheless, this indicator gives an order of magnitude to the potential for job creation in waste management.

6.1.4 Technical assessment

The procedure of technical assessment evaluated the four indicators: Technical Reliability, Requirement of Technical Personnel and Maintenance, Sensitivity to Quantity and Sensitivity to Quality of input material entering a treatment or disposal facility. In order to make the comparison of different scenarios easier, the expert-based results are aggregated within the indicator. This means that the final results are presented as aggregated ranking for all four indicators and not separately for each one. The aggregation procedure was done in the following steps:

1. creation of total score achieved within a scenario for all four indicators
2. creation of arithmetic average of indicators for all experts

Based on the average results of the expert assessment the ranking of the scenarios was conducted (see Table 37). Rank 1 indicates the scenario with best achieved score, whereas rank 7 indicated the worst possible score.

Table 37: Results of technical assessment

	Scenario						
Indicator	**00**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**
Technical assessment [ranking]	5	3	7	1	2	4	6

Figure 31 shows the results of the aggregation for the four indicators of the technical assessment. The highest value is achieved in scenario 2a-$Recy_{high}$ [pl, gl, pa, me], whereas the worst performance is achieved in scenario 1b-$Recy_{wet/dry\text{-}bin}$. A reason for this might be that in comparison to all other scenarios the recyclable fraction in scenario 1b is sorted mechanically in the MBT - plant and not in the manual sorting lines. The MBT-plant which includes sorting of the wet-dry bin has higher requirements on technical personnel and maintenance and it is more sensitive to changes in quality and quantity of input material than the manual sorting procedure, which has very low requirements and a low level of sensibility.

All other scenarios have quite similar mid-ranging results. The reason for the similar score might be due to uncertainties of the expert-based reviews. When looking at the results it is important to keep in mind that the resulting assessment reflects opinions of the participating experts and are not necessarily factual. In the further evaluation of the indicator it became evident that results among single indicators differ from expert to expert significantly. However, the creation of an arithmetic average reversed these differences. The resulting inability to measure and understand components of the final technical assessment indicates that the validity of this indicator is not comparable with the other indicators. It is not possible any more to conclude which factors are decisive for the final results therefore it is recommended to treat the technical assessment with caution, as results are tainted with uncertainty and might change if other or more experts would be interviewed.

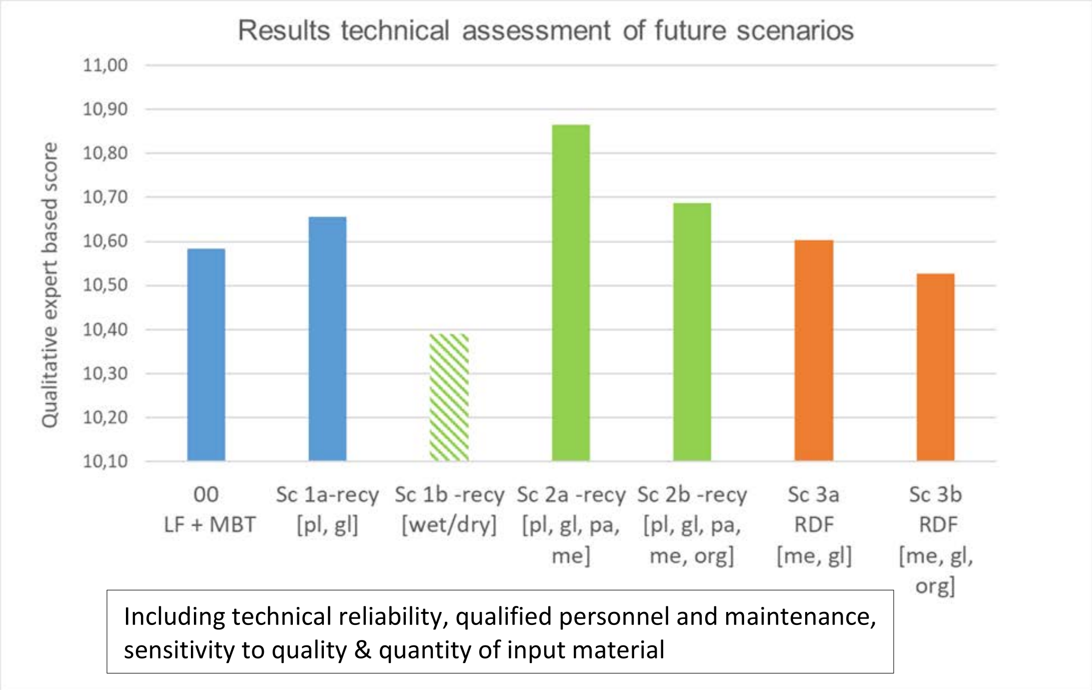


Figure 31: Results of technical assessment for future WM scenarios

7. Conclusions and Outlook

Municipal solid waste management represents a great challenge for local governments all over the world. Especially economies in transition such as former Soviet Union countries are still lagging behind to transform the obsolete current practise into modernized high-technical standard system. In order to support the sustainable reformation process in Ukraine seven possible future scenarios were developed for the case study region and were assessed by a mixture of quantitative and qualitative indicators.

An extensive literature review marked the beginning and was conducted aiming to develop a DNC for assessing the status quo of the waste management system in the model region D.. It soon became apparent that a good data basis of the status quo is mandatory to develop the future scenarios. However, data availability and reliability has been a challenging factor. Waste-related data were not always available and therefore some reasonable assumption concerning waste generation, home composted material, informal collection activities, untreated mixed MSW to landfill and disposed waste in environment/wild dumps had to be made. Furthermore, a lot of other general, social-economical, organizational, institutional, economic & cost-related data, as well as collection-, treatment- and disposal-related data were collected. Most of the used data were cross-checked, but as a lot of data were gathered from a wide range of local stakeholders and partners it was not always possible to verify all of the used input data. Thus, data insecurity cannot be excluded to a full extent.

In the second part of the thesis a methodological approach was developed for measuring the performance of a waste management system. In a first step, 62 potential indicators were identified, thereof 15 economic, 25 environmental, 16 social and 6 technical indicators. In a further iterative process, the list of indicators was shortened in order to choose a feasible and reliable indicator set for the scenario assessment. Finally, a set of 18 quantitative and qualitative indicators was chosen for the final assessment.

An essential part of the thesis was the determination of feasible waste management options for D.. As preliminary minimum requirements, it was implied for all future scenarios that 100% collection coverage of MSW (excluding home composting and IRS) is guaranteed; no untreated waste is landfilled anymore (pre-treatment in a MBT plant); a sanitary landfill which meets the environmental safety standards is built and WEEE and hazardous waste are collected. In the scope of this work seven scenarios with three different emphases were developed. The first scenario (00) is based on the current waste management system, incorporating some technological improvements and fulfils only the above described preliminary minimum requirements. The second block of scenarios (1a, 1b, 2a, 2b) emphasizes source separate collection of different waste fractions and recycling. The basic idea behind the four recycling scenarios was to show different collection and possible performance options with higher and lower source-separated collection targets. The third block of scenarios (3a and 3b) focuses on producing high quality RDF material, which can be co-burnt in e.g. cement kilns.

In chapter five, technologies used for modelling of the scenarios were presented. The possible technical configuration of each treatment- and disposal plant was developed together with project partner from TU-Dresden. All proposed technologies are common in modern western and eastern European countries and are considered as state of the art. First, it is suggested for all seven scenarios to pre-treat residual waste in a MBT-plant and to construct a regional sanitary landfill. In one scenario, the MBT-plant is combined with a treatment system for sorting of dry-wet bin. Second, in scenarios with separate collection it is recommended to implement three small manual sorting lines for the re-sorting of separate collected recyclables. In two scenarios with separate collection of organic fraction the implementation of open windrow-composting is suggested. Lastly, the final disposal of residues from MBT-plant, composting, and manual sorting lines ends up in a sanitary landfill. Owing to the small quantities entering the MBT-plant and sanitary landfill the small-scale facilities will probably not work cost effective enough. Better cost-related results could be achieved with higher quantities by exploiting the economies of scales advantages associated with higher waste amount treated. For that reason, an implementation of a MBT-plant and sanitary landfill only for D. might not be recommendable. Also, according to the new Ukrainian Waste Management Strategy, a source separation of organic waste is not considered as a feasible option for Ukraine at the moment. For that reason, the implementation of composting facilities for separated collected organics might not be applied. Nevertheless, they are a possible option for treatment of green waste, as the new Ukrainian Waste Management Strategy put an emphasis on the installation of compost centres for treatment of garden and park waste.

Based on the results of the material flow analysis and identified capacities of the waste treatment and disposal facilities, the seven above discussed scenarios were evaluated by economic, environmental, social and technical indicators. The final results of the assessment are summarized in the following Table 38.

Table 38: Summary Results Economical, Ecological, Social and Technical Assessment

	Economic Assessment Final Results						
	Scenario						
Indicator	**00**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**
Investment costs [10^6€]	8.1	8	9.9	8.4	9.6	7.9	8.7
Operating costs [10^6€/year]	1.5	1.6	1.7	1.8	2.5	1.6	2.0
Tot. ann. disc. costs [10^6€/year]	2.4	2.5	2.8	2.7	3.6	2.5	3.0
Costs per ton [€/year]	127	131	143	146	194	129	164
Revenues [€]	87,644	212,498	561,114	378,798	383,739	228,659	229,431
Self-financing rate [%]	11	15	26	20	16	16	13
Costs as % of regional	13	13	15	15	19	13	16

expenditures							
Costs as % of nominal and average salary	1,4	1,4	1,6	1,6	2,1	1,4	1,7
Costs as % of minimum wage	1,9	1,9	2,2	2,1	2,8	1,9	2,3
Environmental Assessment Final Results							
	Scenario						
Indicator	**00**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**
Separate coll. rate [%]	0	14	28	26	36	12	16
MRR [%]	9	15	23	21	24	14	16
ERR [%]	56	46	29	31	30	58	57
Landfilling rate [%]	43	32	30	32	29	31	30
RBWL [%]	10	55	54	54	61	55	58
GHG [t $CO_{2eq\ /\ year}$]	5,200	4,000	-2,500	-500	-1,500	2,100	1,100
Social Assessment Final Results							
	Scenario						
Indicator	**00**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**
Social acceptance [ranking]	1	3	2	4	6	3	5
Job creation [nr.]	75	124	177	171	176	109	113
Technical Assessment Final Results							
	Scenario						
Indicator	**00**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**
Technical assessment [ranking]	5	3	7	1	2	4	6

The economic assessment of the scenarios showed that many of the suggested treatment technologies are too expensive and might not be profitable unless higher waste quantities are treated or disposed. For gathering of higher waste quantities, it is suggested to establish inter-municipal cooperation arrangements with other geographically appropriate municipalities. Furthermore, the economical evaluation revealed that current consumer tariffs must be increased over time as they are not capable to finance a modernized waste management system.

The results of the environmental assessment showed on the one hand the importance of citizens' behaviour and waste composition when it comes to source-separated collection efficiency, material and energy recovery rate. The not negligible influence of the informal collection activities and the necessity to address these issues when planning a new waste management system, was revealed. Moreover, the results indicated the importance of different waste treatment options when it comes to landfilling and biodegradable waste diversion rate. In regard to moving up the waste hierarchy the best results were achieved in scenarios with more separate collected fractions and higher targets. Most of the biodegradable waste could be diverted from landfill in scenario with separate collection of organics.

The assessment of social acceptance revealed that complex scenarios with more separate fractions collected have the least beneficial results as they require a change of citizens' behaviour. When implementing the new waste management strategy, it is important to recognize the need and willingness of local population and to plan educational and awareness rising programmes to facilitate behavioural changes. Further, the assessment of the second social indicator showed that more jobs could be created in labour-intensive activities such as separate collection and recycling of waste, whereas the level of employment increased on a lower level in less labour-intensive activities such as landfilling and composting.

Finally, the assessment of the technical indicators showed that the best ranking score could be achieved in scenario 2a-$Recy_{high}$ [pl, gl, pa, me], whereas the worst performance is achieved in scenario 1b-$Recy_{wet\text{-}dry\text{-}bin}$. This can be explained by the fact that in scenario 1b dry fraction is sorted in an MBT plant which has – in comparison to manual sorting lines - higher requirements on technical personnel and maintenance and it is more sensitive to changes in quality and quantity of input material. All other scenarios have quite similar mid-ranging results. Further, from the results of the technical assessment it appeared that evaluating qualitative indicators might lead to some extent to uncertainties, because of method insecurities. The results of the assessment reflect opinions of the participating experts, that not necessarily are factual. With rising number of experts or inclusion of other expert groups the results might change. For that reason, the results of the technical assessment have to be treated with caution.

All in all, when looking at the results it can be concluded that a paradigm shift from the current system mostly based on landfilling to material or energy recovery is needed. Some further challenges that should be addressed are:

- Education and awareness rising to stimulate a change of citizens' behaviour
- Adaption of current legislation and policy towards compatibility with EU-requirements
- Improvement of all current waste management subsystems (container, collection, treatment, disposal)
- Implementation of extended producer responsibility schemes
- Adoption of current fees and establishment of adequate financing system
- Integration of informal sector

- Strengthen accuracy and availability of data and statistics
- Increase effectiveness of monitoring and evaluation procedures

The assessment of a whole waste management system is a multi-faceted and highly complex problem with no single solution. Finding an appropriate strategy might be difficult due to the huge diversity of influencing factors. The development of an appropriate waste management system is a long-term project that can become a burden for the whole region and economy. However, a transformation of the current situation is needed. The results of the economic, ecological, social and technical assessment can be used to assist and guide local stakeholders and decision makers to develop a modernized and environmentally friendly waste management system based on local needs and priorities.

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9. Annex

Annex 1 Data Need Catalogue – Qualitative description

Descriptive overview of the existing MSW management system in Case Study Region

- The following document aims at a **qualitative description** of the prevailing waste management system in the target region. Goal is to provide background information for all involved project partners to get a first idea how the municipal solid waste is managed in the respective region. Some of the information asked for is quantitative, but where not asked explicitly for numbers, please give a brief text description.
- Please provide a text description of **municipal solid waste management** system (WM) in the city separately for Case Study City and District (if separate data are available).
- Questions to be covered are listed below. For providing detailed data/numbers please use the attached Excel File.
- To the extent possible, please provide the required data for the time period indicated below. Compare arrangement of the WM system in the past and describe changes during the last two decades. Provide analysis of weaknesses and strengths and examples of successful practices (in the past and today).
- **Time period to be covered:**

  - Before 1990
  - after 1990 (~1990-2005)
  - actual situation (~2005-2015).

- **Policy and legal framework:**
  - o Main provisions of the national framework waste management law, existing (or planned) national WM policies, target indicators for WM system.
  - o Is there an existing strategy or plan for waste management at the city/region level? Is there a planning requirement or mandate? Describe main provisions and target indicators.

- Describe any incentives/plans to approach EU WM standards (e.g.EU-UA Association agreement etc.)
- Are laws and regulations for WM sufficient (do they cover all necessary issues, are sanctions severe enough)? How well does enforcement of these regulations function?
- Presence and enforcement of local regulations supporting waste prevention / re-use and recycling
- Assessment of compatibility of the current status quo of the WM process (from waste generation, collection, prevention, re-use, recycling to waste treatment and disposal) with legal requirements.

- **Institutional and organisational arrangement:**
  - Is solid waste management the responsibility of one legal body or are tasks divided over several departments? Please name institutions / departments / stakeholders on the state, regional and municipal level, and their roles and responsibilities.
  - Does the municipality have the authority to contract private enterprises? Describe the involvement of state and private companies in WM activities (collection, treatment, recycling, landfilling)
  - Influence of political stability on effectiveness and operation of WM system

- **Technical aspects**:

– Are there reliable data available:
  - On the real waste generation rate (municipal solid waste, household waste), if yes: how measured (estimated at the landfill, waste separation analyses etc.). If no data available, provide data for other regions.
  - On the waste composition at the level of generators (or at other estimation levels)
  - Seasonal specifications / variations in both waste generation and composition
- Quantities of waste collected (formally and informally), treated, recycled and disposed of;

- What system elements (technological components ranging from collection, separation, treatment, final disposal etc.) are in place in municipal waste management at present? Please describe certain facilities, their capacities and what they do. Please describe the collection system, what types or collected, bins used, frequencies of emptying…
- Collection rate (how much waste is collected as a % of total amount generated)
- Collection (Service) coverage rate (how many people are served as a % of the total population)
- Areas not served by regular collection (which and how many)?
- What fractions are currently separately collected (e.g. certain recyclables)? What happens with these fractions?
- Existing recycling plants for processing of recyclable materials in the region, in country or outside the country (for export);
- Are there informal activities in waste collection and processing (non-authorised inhabitants living from waste picking activities)? If yes, where are these activities taking place (e.g. street picking, landfill only etc.).
- Number of litter bins in commercial areas
- Performance of waste processing (e.g. sorting etc.), recycling / treatment (e.g. composting) and disposal plants (e.g. incineration, landfill) (amount processed as % of design capacity)
- Assessment of the efficiency and state of the collection system and equipment, the disposal and treatment facilities, including their state, capacity and performance their remaining life and compliance with international and national laws.

- **Environmental aspects:**
- Current environmental impact of the existing WM system (any available quantitative or qualitative data on emissions from landfills, treatment plants etc.)
- Controlled disposal rate (% of waste collected which is disposed of in a sanitary or controlled landfill)
- Description of waste disposal on landfills and uncontrolled dumps

- Hazardous waste collection and disposal (% of hazardous waste generated which is collected and treated appropriately; describe collection and treatment system for hazardous waste)
- Recovery rate (how much waste is recycled/reused by government and private sector (formal and informal) as % of total amount generated)

- **Financial-economical aspects**:
- general description of economic situation (population average income, GDP etc.)
- describe and provide numbers for WM financing sources: waste fees for population and commercial clients, landfill/treatment plants gate fees, taxes, state/local budget subsidies etc.); level of cost sharing by other stakeholders (%).
- How are fees / tariffs for waste management services calculated and incurred?
- Are there financial incentives at national / local level in waste management? If yes, please describe.
- Level of cost recovery (revenues generated through waste collection fees and taxes as percentage of total costs of waste management)
- Investment and operational costs of waste management (costs/ tonnes). If possible divided into collection, landfilling, treatment operations etc.;
- Cost estimates for new/planned waste management infrastructure projects.
- Describe existing market for recycled materials, prices for main recyclables.

- **Demographic background and social performance**

– Are there reliable data available on:
    - o Number of inhabitants and future prospection
    - o Number of districts and per district: size [km2] and number of inhabitants
    - o Zoning of the city in terms of: where are residential areas, commercial, industrial areas, where are major waste management facilities located (e.g. if available, please provide a map)
    - o Information on seasonal / daily variations regarding population: e.g. tourists, commuters

- Who are the stakeholders in waste management in your city? Who has an interest in waste management or is affected by it? What type of activities do these stakeholders carry out? Does the municipality co-operate with these stakeholders?
- Are there social institutions/NGOs active in the field of environment and waste management?
- Is there sufficient skilled and educated staff for waste management?
- How are the working conditions for waste management workers (uniforms, gloves, low loading height, extra allowance for risks incurred, health insurance, health services)?
- People's culture, behaviour, and involvement in the process of waste management, satisfaction with the existing WM system, acceptance of technologies.
- Policy, budget and activities for environmental awareness-raising
- Examples of successful waste prevention strategies.
- Existence of policies to promote waste prevention, (safe) reuse and recycling

- **Summary:**

Reviewing, analysing and summarizing main actual and future problems and challenges at different stages of solid waste management (source separation, collection, transfer, recycling, disposal, and post-disposal operations) according to the main dimensions listed above – legislation, institutional, technical, environmental, economic, social.

Annex 2 Overview waste quantites of senarios

Input Material in tonnes/year	Base-line	00 LF+MBT	1a - $Recy_{low}$ (gl, pl)	1b – Recy-dry-wet bin	2a $Recyc_{high}$ [gl, pl, me, pa]	2a $Recyc_{high}$ [gl, pl, me, pa, org]	3a RDF $Recy_{low}$ [gl, me]	3b RDF $Recy_{low}$ [gl, me, org]
Total generated waste	25 276	27 248	27 248	27 248	27 248	27 248	27 248	27 248
Formal collected waste	10 873	15500	15500	15500	15500	15500	15500	15500
Separately collected waste:								
Plastic	0[11]	0[4]	567	1 202	1 116	1 116	--	--
Metal	--	--	--	303	225	225	225	225
Glass	0[4]	0[4]	1 583	2 247	2 184	2 184	1 583	1 583
Paper	--	--	--	554	482	482	--	--
Organics	--	--	--	--	--	1 576	--	680
Total recyclables[12]		0	2 150	4 306	4 007	5 583	1 808	2 488
Residual waste		15 285	13 136	10 979	11 278	9 703	13 478	12 798

[11] Assumed for calculation: existing pilot, small-scale separate collection is neglected

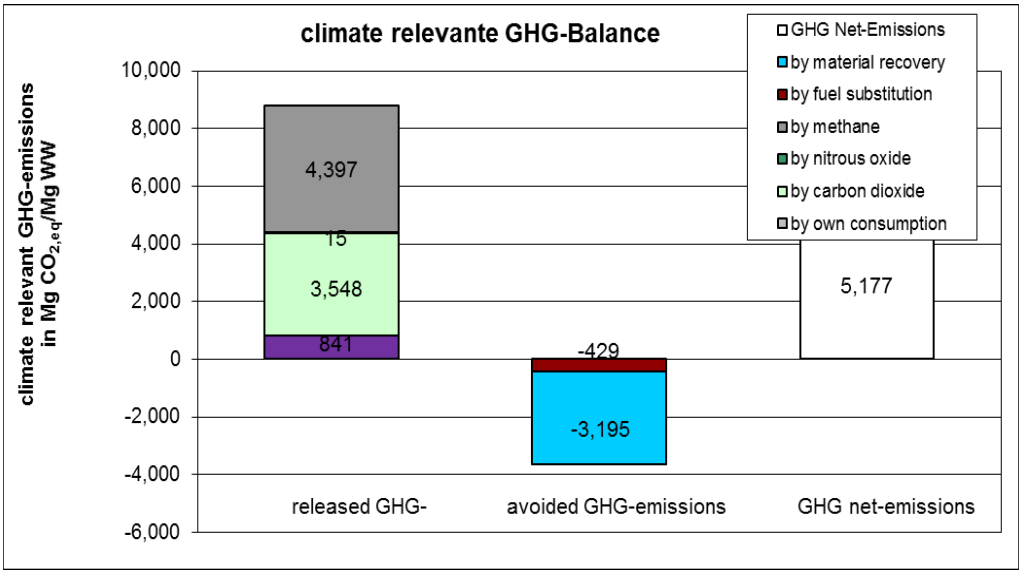
[12] Excluding WEEE & hazardous waste

Treated material in WM-facilities								
Manual Sorting	0[4]	0	2 150	0	4 007	4 007	1 808	1 808
MBT	0	15 285	13 136	15 285	11 278	9 703	13 478	12 798
Composting[13]	0	0	0	0	0	2 615	0	1 128
Landfill	10 873	6 732	5 017	4 731	4 984	4 572	4 892	4 714
Outputs								
RDF	0	4 678	4 210	3 230	3 359	3 044	4 661	4 525
Compost	0	0	0	0	0	520	0	224
Recyclables (input to recycling) -after sorting	0[4]	0	1 764	3 687	3 199	3 199	1 627	1 627
- after MBT (gl, me)	0	2 190	1271	612	718	718	1 078	1 078
Output **after** recyling	0[4]	1 377	2 384	3 516	3 225	3 225	2 218	2 218

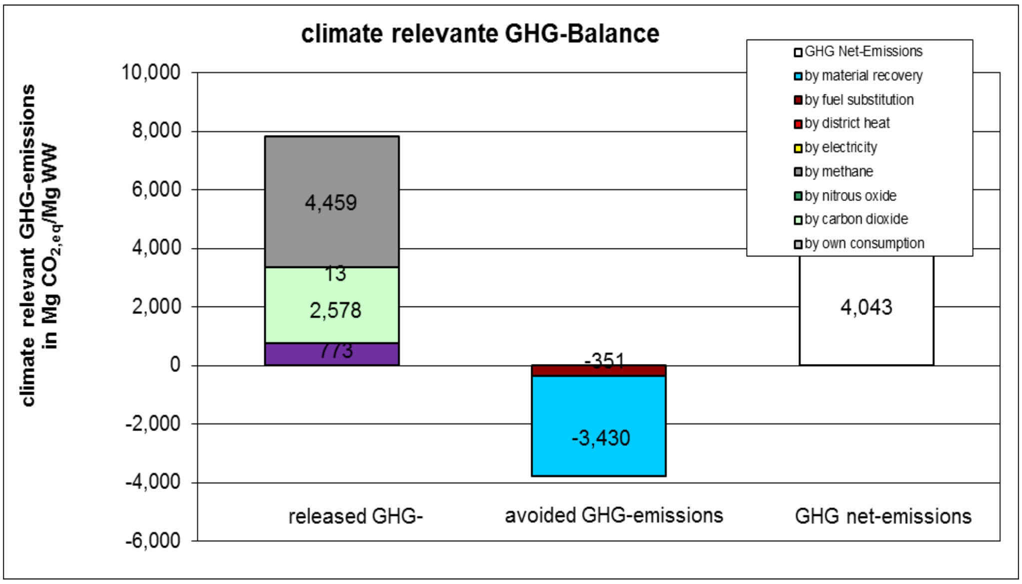
[13] Including structure material

Annex 3 Climate relevant GHG balance of all future scenarios

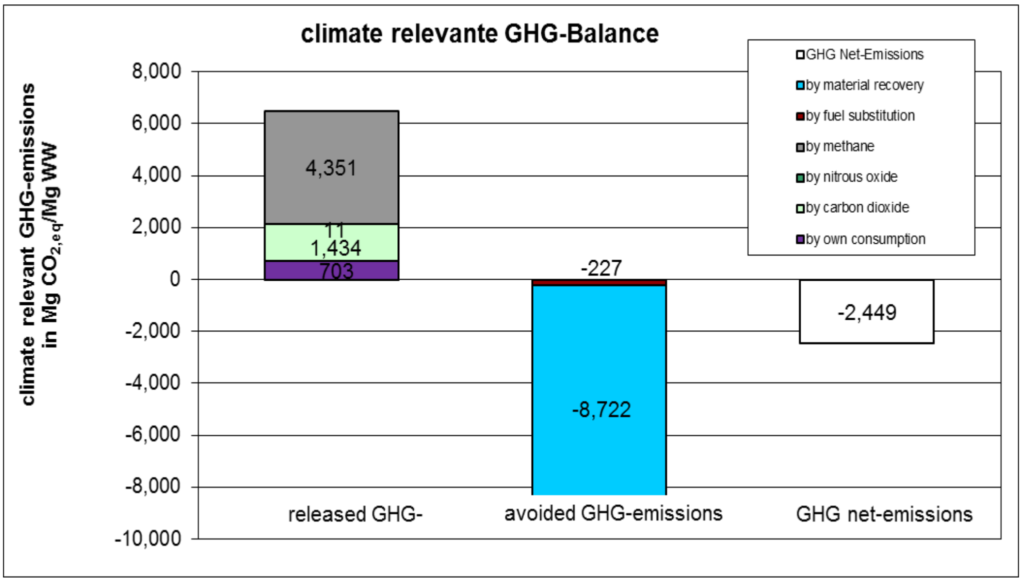
Scenario 00-LF + MBT



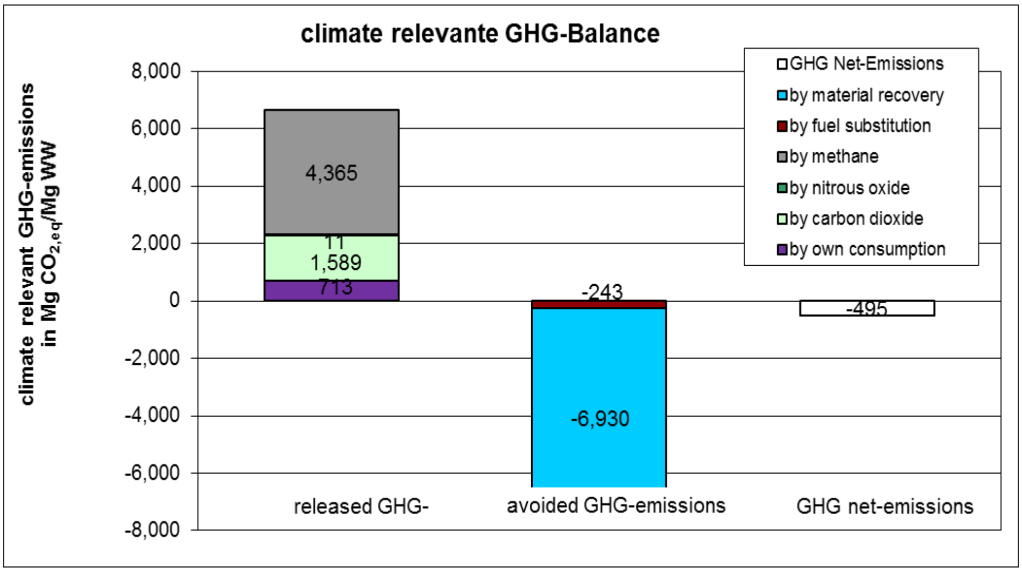
Scenario 1a-Recy$_{low}$ [pl, gl]



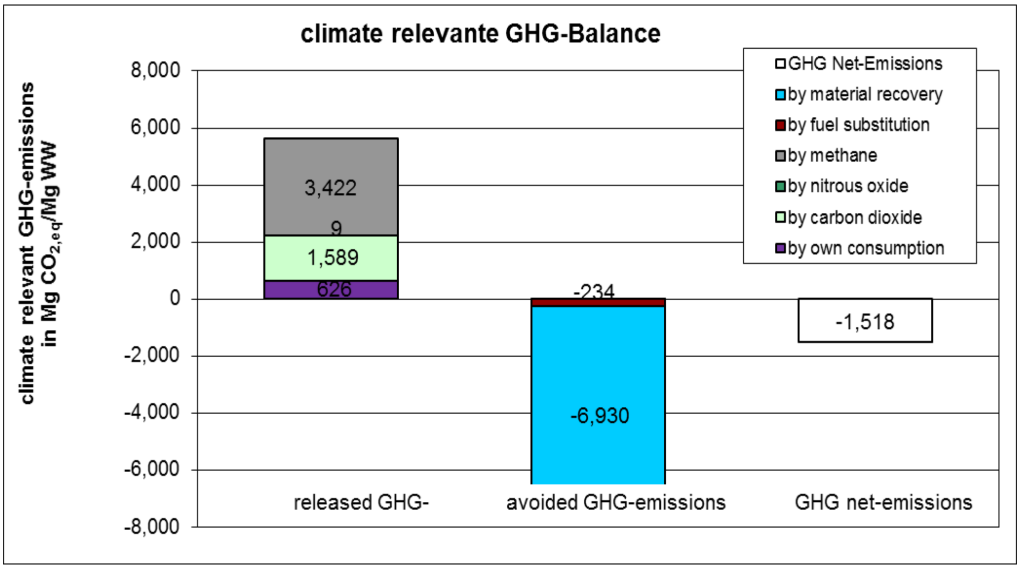
Scenario 1b-Recy$_{wet\text{-}dry\ bin}$



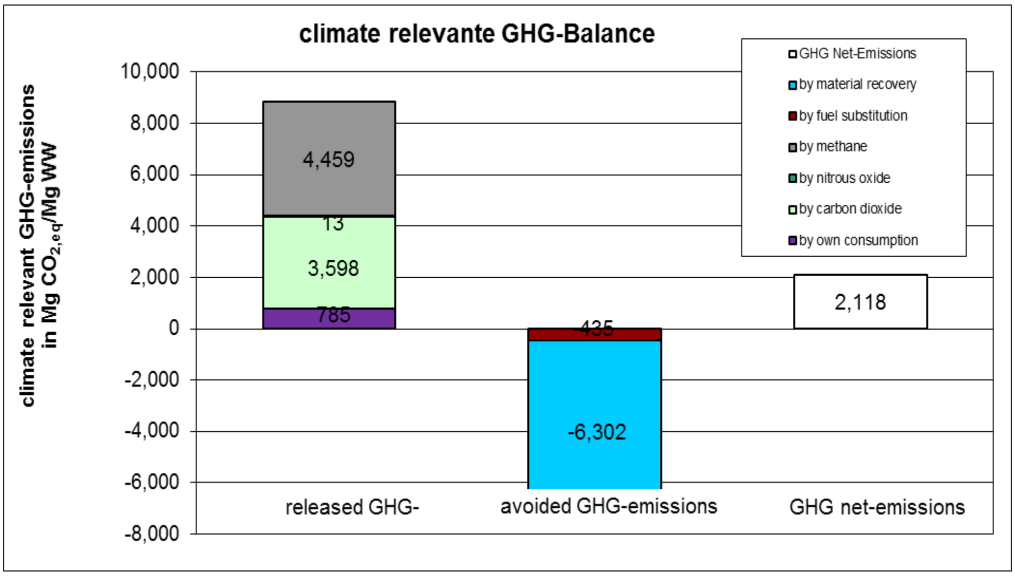
Scenario 2a-Recy$_{high}$ [pl, gl, pa, me]



Scenario 2b-Recy$_{high}$ [pl, gl, pa, me, org]



Scenario 3a-RDF-Recy$_{low}$ [me, gl]



Scenario 3b-RDF-Recy$_{low}$ [me, gl, org]