WATRA:
WASTE MANAGEMENT IN TRANSITION ECONOMIES

DELIVERABLE 3.3
ENVIRONMENTAL, ECONOMIC AND SOCIAL ASSESSMENT OF MUNICIPAL SOLID WASTE MANAGEMENT IN CASE STUDY REGION MOGILEV, BELARUS

Project:

“Waste management in transition economies”

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Ecological, Economic, Social & Technical Assessment of Municipal Solid Waste Management System: Case Study from Mogilev, Belarus

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

submitted by
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Abstract

Belarus experiences a difficult transition period from centrally planned economy towards a liberalized market model. The waste management industry in Belarus as well experiences a challenging transformation process. Especially, the treatment of mixed municipal solid waste is an issue for the society. Thus, this master thesis aims to capture the current waste management situation in Mogilev, and aims to develop possible future scenarios regarding a modern waste management system. This master thesis provides five waste management scenarios that are benchmarked by quantitative and qualitative indicators. The technical configuration of these scenarios is based on the results of the material flow analysis and determined capacities. The technical configuration includes treatment of waste in an anaerobic digestion plant, sanitary landfill, manual sorting lines, open-windrow composting facility, incineration plant and MBT plant.

This master thesis was written within the project “WaTra - Waste Management in Transition Economies”. The methodological approach of this project includes benchmark indicators, that are six economic (Total Annual Discounted Costs of Waste Management System, Total Annual Costs per ton of Formally Collected Waste, Revenues from Materials and Energy, Self-financing Rate, Costs as percentage of approved City Expenditures, Costs as percentage of Minimum Wage); six environmental (Source-separated Collection Rate, Material & Energy Recovery Rate, Landfilling Rate, Biodegradable Waste Diversion Rate, GHG Emissions); two social (Social Acceptance, Job Creation Potential) and four technical indicators (Technical Reliability, Requirement of qualified Personnel and Maintenance, Sensitivity to Quantity and Quality of input material).

The outcome of the economic assessment presents the proportion of costs within the scope of scenarios with different technologies. Furthermore, the assessment revealed that the consumer tariffs have to be increased steadily to finance a modern waste management system. The assessment based on the environmental indicators showed that the waste management system achieves best results in scenarios with advanced separate collection of specific fractions and higher recycling targets. Also good results are achieved in scenarios with full energy recovery, because the incineration plant avoids more GHG emissions compared to landfilling (even with pretreated waste). Moreover, the social assessment demonstrates that scenarios with advanced collection of separate fractions call for a change of social behaviour, and thus, most probably will hardly gain social acceptance. Additionally, scenarios with labour-intensive technologies such as separate collection and recycling of waste benefit job creation. Scenarios with demand for qualified stuff and maintenance, as well scenarios with increased sensitivity to quantity and quality changes of the input material, reached lower results in the technical assessment due to complexity.

Key words: Belarus, municipal solid waste management, waste management scenarios, economical-, environmental-, social-, technical indicators, assessment, transition countries, material flow analysis.

Kurzfassung

Weißrussland durchlebt eine schwierige Übergangsperiode von einer Zentralplanwirtschaft zu einem liberalisierten Marktmodell. Auch die Abfallwirtschaft in Weißrussland erfährt einen herausfordernden Transformationsprozess. Insbesondere die Behandlung der gemischten kommunalen Abfälle stellt ein Problem für die Gesellschaft dar. Die vorliegende Masterarbeit erfasst die aktuelle Abfallwirtschaftssituation in Mogilev und zielt darauf ab mögliche Zukunftsszenarien mit einem modernen Abfallwirtschaftssystem zu erstellen. Die vorliegende Masterarbeit erstellte fünf Abfallwirtschaftsszenarien, welche anhand quantitativer und qualitativer Indikatoren bewertet wurden. Die technischen Ausstattungen in diesen Szenarien basieren auf den Materialflussanalysen und der quantifizierten Abfallmengen. Die technischen Ausstattungen beinhalten die Behandlung des Abfalls mittels Mechanisch-Biologischer Behandlung, manuelle Sortieranlage für Altstoffe, offene Mieten-Kompostierung, Verbrennungsanlage, Biogasanlage und Deponierung nach Stand der Technik.

Die Masterarbeit wurde im Rahmen des Forschungsprojektes „WaTra - Waste Management in Transition Economies“ verfasst. Die angewandte methodische Grundlage enthält Indikatoren anhand deren die Bewertung der Szenarien stattfand. Diese sind sechs ökonomische Indikatoren (Gesamtkosten des Abfallwirtschaftssystems, Kosten pro Tonne, Einnahmen, Selbstfinanzierungsrate, Gesamtkosten gemessen an kommunalen Ausgaben und am Mindestlohn); sechs ökologische Indikatoren (Erfassungsgrad der getrennten Sammlung, Material & Energierückgewinnungsrate, Deponierungsrate, Reduktion von organischem Material auf der Deponie, Treibhausgasemissionen); zwei soziale Indikatoren (soziale Akzeptanz, Arbeitsplatzbeschaffung) und vier technische Indikatoren (Technische Zuverlässigkeit, Anforderungen an qualifiziertes Personal & Wartung, Sensitivität Menge & Qualität).

Die Ergebnisse der ökonomischen Bewertung zeigen die Verhältnisse zwischen den Kosten verschiedener Szenarien und verschiedener Technologien. Zusätzlich zeigen die Ergebnisse, dass die Abfalltarife kontinuierlich erhöht werden müssten, um ein modernisiertes Abfallwirtschaftssystem zu finanzieren. Die Ergebnisse der ökologischen Bewertung ergaben, dass Szenarien mit mehr getrennt gesammelten Fraktionen und höheren Recyclingzielen die besten Resultate erzielen. Die Bewertung der sozialen Kriterien ergibt, dass Szenarien mit umfassender getrennter Sammlung von spezifischen Fraktionen ein Umdenken in der Gesellschaft verlangen, und daher voraussichtlich weniger gesellschaftliche Akzeptanz genießen. Zudem fördern Szenarien mit arbeitsintensiver Technologie, wie z.B. getrennte Sammlung und Recycling, die Arbeitsplatzschaffung, während Szenarien mit weniger arbeitsintensiven Tätigkeiten, wie Deponierung, Kompostierung oder Verbrennung, weniger Beitrag zum Beschäftigungsgrad leisten. Szenarien mit Bedarf an qualifizierten Personal und technischer Instandhaltung, aber auch Szenarien mit höherer Anfälligkeit gegenüber quantitativen und qualitativen Änderungen des Inputmaterials, erzielen schlechtere Ergebnisse in der technischen Bewertung aufgrund ihrer Komplexität.

Schlüsselwörter: Belarus, kommunale Abfallwirtschaft, abfallwirtschaftliche Szenarien, ökonomische, umweltrelevante/ökologische, soziale und technische Indikatoren, Bewertung, Transformationsland, Materialflussanalyse.

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List of abbreviations

AOC	Annual Operating Costs
AMC	Annual Maintenance Cost
AnTC	Annual Total Cost of waste management
ATPC	Annual Total Personnel Costs
BRU	Belarusian-Russian University, Belarus
Bel SRC «Ecology»	Belarusian Scientific Research Centre «Ecology»
Cap	Capita
CV	Collection vehicle
DNC	Data Need Catalogue
EADTEC	Equivalent Annual Discounted End-of-life Cost of bins
EADTLC	Equivalent Annual Discounted Total Location Costs of bins
EADTPC	Equivalent Annual Discounted Total Purchase Cost of bins
$EATC_{subsystem}$	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
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_{use}	Factor of using CV for the provider of waste removal service
KPI	Key performance indicator
LF	Landfill

LCV	Lower calorific value
MBT	Mechanical Biolgocal Treatment
Me	Metal
Mil	Million
MNREP	Ministry of Natural Resources an Environmental Protection
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
Pa	Paper
PAYT	Pay as you throw
Pl	Plastic
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 sorting collection point
Rev_{MDR}	Annual Revenues from recovery from mixed dry recyclables
Rev_{RDF}	Annual Revenues from recovery of RDF
RDF	Refuse Derived Fuel
SAE	Special Automobile Enterptises
SalPe	Average Nominal Salary
SRM	Secondary Raw Materials
sLCA	Social Life Cycle Assessment
SS	Subsystem

TACSalPe	Total Annual Costs as % of Nominal Average Salary
TOC	Total organic carbon
TUD	Technical University Dresden, Germany

1. Introduction

A challenge for urban areas in many countries is handling of solid waste, as the generation of municipal solid waste (MSW) increases every year worldwide. Many Western European countries faced the challenge by implementing legal, technical and commercial adaptations of their waste management sector. However, European and other economies in transition experience difficulties of proper handling the increasing volumes of generated waste. This failure of waste management systems has negative impacts on economy, environment and health. As post-Soviet transition economy, Belarus also faces the challenge of increasing quantities of solid waste generated by residents and business, as well as problems of waste sector transformation from socialistic to market conditions.

This thesis was written within the project “Waste management in transition economies” (WaTra), implemented from 2016 to 2018 under the IMPULSE Program financed by the OeAD (Austrian Agency for International Mobility and Cooperation in Education, Science and Research). The project is a collaborative effort of scientific researchers, as well PhD- and Master students from the Institute of Waste Management at the University of Natural Resources and Life Sciences in Vienna, Austria (ABF-BOKU); Institute of Waste Management and Circular Economy at the Dresden University of Technology in Germany (TU-Dresden); Department of Occupational Health and Safety at the Belarusian-Russian University in Belarus (BRU) and Department of Urban Environmental Engineering & Management at the O.M. Beketov National University of Urban Economy in Kharkiv, Ukraine (NUUE).

1.1 Background and Main Objectives

The objective of this thesis is to develop a comparative methodological framework to determine proper solid waste management systems for a specific region. This thesis captures the current status quo and develops future waste management scenarios for the Belarusian town Mogilev as a case study city. The research question here is, what are the potential waste management concepts improving the waste management system in Mogilev from socio-economic, technical and ecological perspective.

The comparative methodology framework covers solid waste that refers to households and to waste of similar nature and composition. “Waste of similar nature and composition” means waste generated by educational institutions of different levels, penal institutions, vacation and health resorts; beaches; parks; shops; restaurants and cafes; cultural and art institutions, etc. (WFD, 2008). Specific waste streams like construction and demolition waste are not covered in this study.

The integrated waste management concept is used as methodological approach for this thesis that includes six economic, six ecological, two social and four technical indicators, described in the following chapters. The thesis uses waste-related and socio-economic data provided by the local partner (BRU) and local authorities. The comparative methodology framework was developed within WaTra project jointly with my colleague Monika Dobreva who applied this approach for the case study region in Derhachi district in Ukraine (Dobreva, 2018).

1.2 Structure of the master thesis

The thesis consists of seven chapters:

Chapter 1 outlines the background of this thesis and main objectives.

Chapter 2 describes the case study region. It gives an overview of the demographical and geographical characteristics of Mogilev. Moreover, this chapter constitutes the current MSW management system.

Chapter 3 incorporates the methodological approach and methods of the research work. It starts with the literature review and applied method of data collection. As well, this chapter describes the selected indicators.

Chapter 4 highlights future waste management scenarios and its outcomes.

Chapter 5 provides an overview of selected treatment technologies in future scenarios.

Chapter 6 provides results for five evaluated scenarios according to economic, environmental, social and technical assessment.

Finally, Chapter 7 combines the results of this master thesis and draws conclusions.

2. Description of Case Study City

In the following chapter, the demography and geography of the case study region are reviewed, outlining the current waste management in Mogilev city.

2.1 Demographical and Geographical Description

Mogilev, the third largest city in the eastern part of Belarus, the centre of one of the country's main economic and industrial regions (Mogilev region), was founded in 1267. It occupies the territory of 118.5 sq.km.

Population of the city in 2014 was 374,655 people. Almost half of the population (46%) lives at the outskirts of the city in the private houses (Skryhan et al., 2016).

Figure 1: Map of Belarus

Mogilev climate is moderately continental there with mild winters and rather warm summers. The average temperature varies from 4.4 °C in January on the south-west to -8 °C on the north-east and from 17.0 °C to 18.8 °C in July correspondingly.

Industrial and scientific enterprises, built there after the World War II, made Mogilev one of the main economical centres in Belarus. Crane factory, car, tractor and chemical plants created forceful industrial basis (Skryhan et al., 2016).

The average monthly salary in that area consists 2,300,000 BYN in 2015 which is approximately 114 EUR (National Statistical Committee of the Republic of Belarus, 2017; Skryhan et al., 2016). The exchange rate used for 2015 was 1 EUR = 20,139 BYN[1] (National Statistical Committee of the Republic of Belarus, 2017).

2.2 Description of the Current MSW Management System and Key Issues.

Global growth of production and consumption brought the problem of handling the municipal solid waste to the new level. For the number of reasons countries like Belarus, with transitional economy and very low standards of waste management, were challenged even more. That happened because of limited financial resources, lack of adequate recycling technologies, inefficient legislation. Mogilev is no exclusion of that trend, and faces the following obstacles in that sphere:

Data and information gaps exist due to lack of reliable data on the amount and composition of waste, and due to insufficient information on illegal landfills and extend of unregistered circulation of secondary material resources (SMR). These gaps exists furthermore, due to different measuring units or dissimilar terminology,

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[1] On 1st July 2016 a national redenomination of the BYN took place with a ratio 1 to 10,000. For further calculation, respectively for calculation of data at a later time a corresponding exchange rate was used for this time period.

general data inconsistencies, or inconsistency of the reported data. Additionally, personal relationships, credibility and trust limit the access to local database and increase the information gaps (Skryhan, 2017a).

The regulatory and institution gaps in municipal solid waste (MSW) management include (Skryhan, 2017a):

- the lack of established behaviour patterns of separation the MSW among the locals;
- the deficit of legal norms guiding the e-waste handling;
- declarative nature of certain provisions of the regulations;
- insufficient involvement of local representatives of public organisations in the development and approving process of legislative initiatives;
- absence of clear separation of powers in the sphere of waste management.

The shortage of production capacity and lack of technology for processing of some particular waste (e.g., electronic), as well as an inefficient system of collecting secondary sources should be considered as technical gaps of MSW management. Cross-subsidisation, tariffs that do not meet the level of costs, scarcity of institutionalised instruments providing financial incentives to reduce generation, sorting and recycling of MSW are to be noted among the financial gaps of MSW management.

The monitoring gaps are associated with the opacity of the current procedures of reporting on performance results and monitoring compliance with obligations. (Skryhan, 2017a)

2.2.1 Legal and Institutional Framework of Waste Management.

Main priorities and the goals of the state policy in the sphere of waste management are described in the following documents.

Strategy on Environmental Protection in the Republic of Belarus for the period up to 2025 outlines the standards and purposes of environmental protection. The most relevant targets to waste management are following:

- full involvement population into the process of separate collection of MSW;
- to set up by 2016 the separate waste collection and disposal system for WEEE and hazardous waste;
- provide full coverage of urban and rural population with scheduled and regular household waste collection service;
- extraction of at least 70 percent of recyclable materials from the total generation of these waste;
- equip MSW landfills with facilities and equipment protecting environmental pollution until 2015.

Strategy on Organisation of Efficient Collection and Utilization of Recyclables 2011 - 2015:

- separate collection of recyclable materials, sorting in sorting points (in the towns with the population of 20-50 thousand people) and sorting facilities (in the towns with the population of 50-100 thousand people);
- construction of waste treatment facilities in all larger towns;
- boost the number of buy-back network;
- implement tariff models, full cost recovery tariffs for the population;

- encourage investment in the local waste management system;
- enhance competitiveness in the supply of waste management services.

Waste Management Law defined the basic principles of waste management which meet the international standards, e.g.:

- Operation of municipal waste disposal facilities without environmental protection measures starting from January 1, 2015.

Extended producer responsibility. The Extended producer responsibility was first introduced back in 2002 and finalised in the Decree # 313 «On some issues about consumption waste» on July 11, 2012. Article 1.6 of the Decree articulates that accumulated funds from producers and importers are directed to compensate separate collection costs in case of utilization in Belarus. Furthermore, they are directed to construct sorting and utilization facilities.

Main documents that regulate waste management in Mogilev district and the city are “Norms” and city (district) program. The «Norms» of MSW generation for Mogilev city were adopted in 2001 and for Mogilev district in 2015. The document specifies the amount and the composition of generated waste depending on the type of the house (modernised or not) and the time of the year. The norms fix the absolute maximum of waste generation for the city and the district and serve as the background document for calculating the landfilling permits at the territorial offices of MNREP (Ministry of Natural Resources and Environmental Protection) and for taxation and fees calculation. Annual procedure of the development of regional and city (district) program on separate waste collection and collection of recyclables takes place basing on the national program. This program provides indicators to modernize equipment of Housing and Public Utilities (HPU) organisations. The program for solid waste processing is adopted by local self-governing authorities and describes the step-by-step procedure of handling the MSW: the location of temporary storages, scheduled waste removal, logistics and the number of containers and trucks, etc. (Skryhan et al., 2016).

2.2.2 Waste Generation and Waste Composition

Sources of household solid waste and similar waste generation are citizens (multi-story apartments and private households), organizations and plants, garage cooperatives and garden cooperatives. Statistical data provided by BelSRC “Ecology”(Belarusian Scientific Research Center «Ecology») include total amount of generated waste, total amount of collected waste, as well as amount of landfilled waste an (Skryhan et al., 2016). SRM data are tracked separately to total amount of generated waste, because according to the legislation in Belarus recyclables are not considered as waste. Unfortunately, this approach to statistical recording does not provide data on generated waste, in particular garbage thrown away into the environment, as well garbage stored respectively landfilled in illegal dumps (Skryhan et al., 2016).

The present waste management situation in Mogilev is represented by the Baseline Scenario in Figure 3. A local expert team of the project partner at the BRU assessed generation and flows of present waste streams. The data was collected from statistical sources, local studies and from local authorities. The waste management estimation in Mogilev for 2015 is taken as a model for the Baseline Scenario (Skryhan et al., 2016).

A closer look at the background of statistical data reveals some issues that should be taken into account. In the official data “generated waste” is always equal to “collected waste”. However, SRM flows are tracked separately to total amount of generated waste, because according to the legislation in Belarus recyclables are not considered as waste. Official figure on “generated waste” also does not include garbage littered into the environment, landfilled in illegal dumps, common practice of home-composting or backyard-burning in the private sector, as well as informally collected waste. Therefore, this approach to statistical recording does not provide realistic data on waste generated at household level.

A local expert team of the project partner BRU conducted estimates of waste generation in Mogilev using “waste generation norms” and estimated flows of present waste streams based on various data collected from statistical sources, local studies, from local authorities and waste operators.

The waste streams estimates in Mogilev for 2015 is taken as a model for the Baseline Scenario and is shown in Figure 2 (Skryhan et al., 2016).

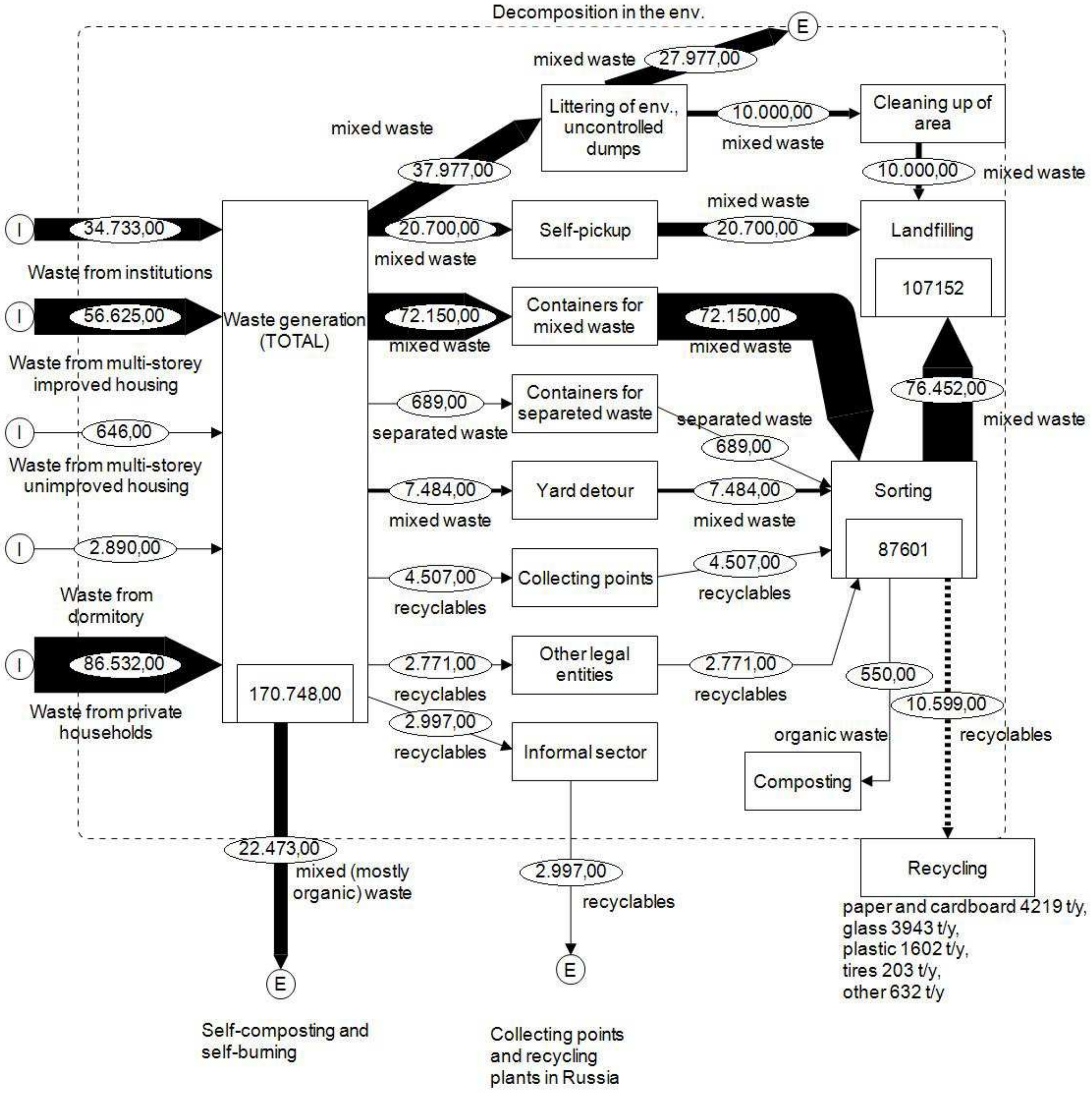

Figure 2: Waste streams of Mogilev in 2015 [t/year] (Skryhan et al., 2016)

Figure 3 illustrates simplified material flow analysis of present waste management system. The charts were developed using software STAN (Brunner and Rechberger, 2004). The dotted rectangle represents system boundaries of the investigated case study city and defines processes included in the system assessment. All scenarios include only waste management process flows within system boundaries. Home composting, informal sector, WEEE & hazardous waste are not taken into account in the scenarios assessment. Tons per year are set as a unit of mass flows.

The modelling of the Baseline Scenario requires some simplifications. Furthermore, assumptions have been done due to lack of reliable waste-related date. Chapter 3.8.1 describes the simplifications and calculations done related to the Baseline Scenario.

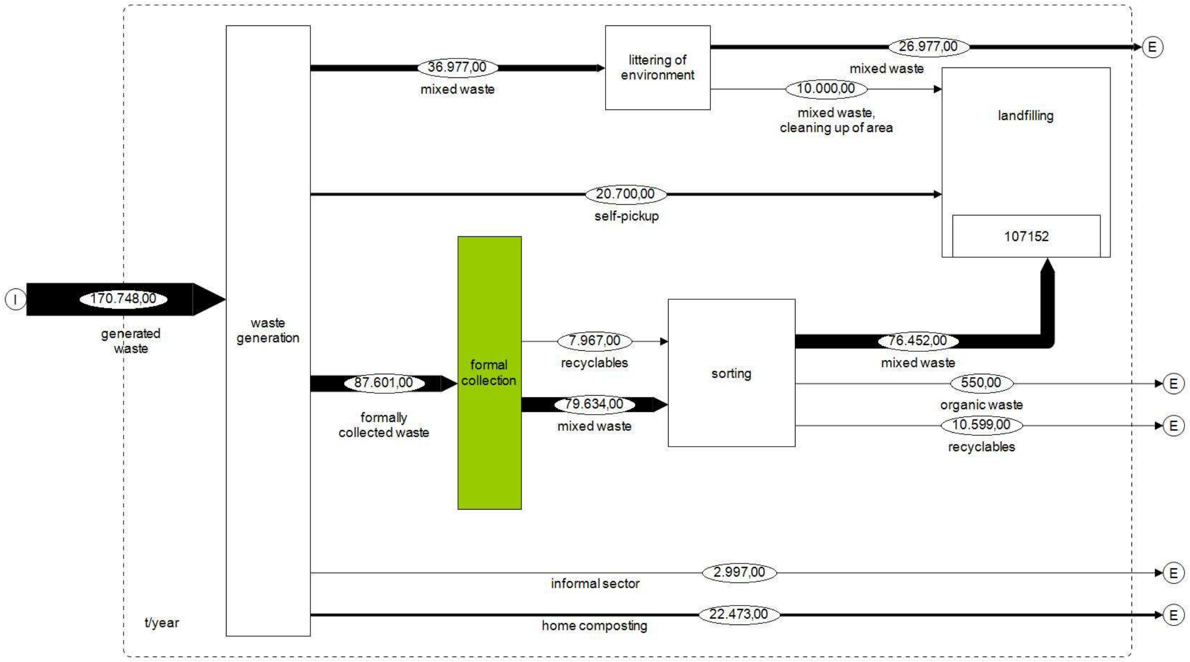

Figure 3: Material flow diagram of Baseline Scenario in 2015 [t/year]

Figure 3 demonstrates the existing waste streams in Mogilev city in 2015. The total amount of generated waste is 170,748 tons per year for household, economic entities[2]. The amount is calculated in compliance with estimated norms, which define the upper level of generated waste amount (Skryhan et al., 2016).

Waste composition

Today there is no verified and complete data about the waste composition in the city of Mogilev. Based on consolidated data, which was provided by the representatives of SAE (Special Automobile Enterprises), Figure 4 on the composition of waste in Mogilev as a percentage of total waste amount was compiled (Skryhan et al., 2016).

This data on waste composition is based on the investigations of SAE of the waste in the yard containers, therefore the recyclables collected in the collection points or by informal sector are not included here.

The structure of the waste composition components was selected in order to be harmonized with the Waste Forecast tool (Beigl et al., 2008) and the "Greenhouse-

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[2] The term economic entities refers to facilities of educational, financial, culture and art, health care, hospitality, entertainment, food service, as well as commerce institutions.

Gas-Emission-Calculation Tool” provided by the Institute of Waste Management and Circular Economy of TUD (Wünsch, 2013).

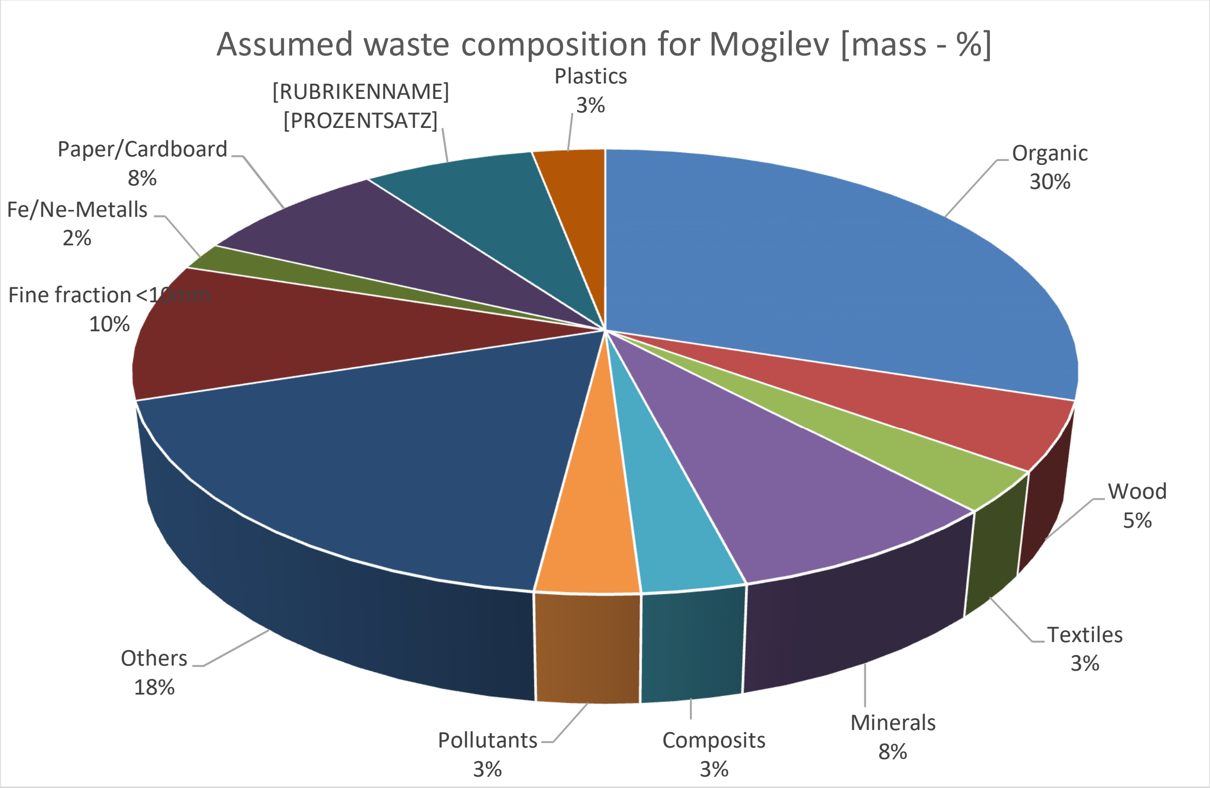

Figure 4: Assumed waste composition for Mogilev (with changes and amendments according to (Beigl et al., 2003; Scharenberg, 2017; Skryhan et al., 2016)

Data on the amount of organics, wood, textiles, composite materials and other like FE/NE metals, paper/cardboard, glass and plastic were supplied by local partner BRU (Skryhan et al., 2016). Missing data on minerals and fine fractions (<10 mm) was assumed based on the previous investigations of the project partner TUD (Scharenberg, 2017).The waste containing hazardous substances, electronics and electric equipment (WEEE) comprises the fraction pollutants (WFD, 2008). Fraction «others» includes bones, leather, rubber and the residuals (>10 mm).

Organics, fine fractions, and «others» constitute the most of waste, as it is shown in the Figure 4. On the contrary, the content of paper (8%), glass (7%) and plastic (3%) is negligible. It should be noted that Mogilev composition data quantitatively differs from the official data on waste composition on the national level (Skryhan et al., 2016). Comparing the shares of glass (13%), paper/cardboard (28%), and plastic (28%) in the composition of MSW at the national level, one may see the higher difference compared to those in Mogilev (Skryhan et al., 2016). The explanation can be found in the fact that analysis of the waste components was carried out at the final stage of waste collection in the SAE facilities. Presumably, the actual content of recyclable fractions in the household waste is much higher, yet too little data is available to support or refute the abovementioned suggestion. Therefore, it has to be kept in mind that this waste composition does not reflect composition of waste generated at household level. However, since the SAE as municipal operator has access only to the waste collected in its installed containers, this waste composition was assumed as appropriate for the purpose of the study.

2.2.3 Current Management of Municipal Solid Waste

Separate collection, sorting and recycling.

Municipal solid waste collection in Mogilev can be performed in several ways (Skryhan et al., 2016):

- “container use” – collection in yard containers in multi-story residential area by municipal company (SAE);
- “yard detour” – collection in detached housing areas and rural settlements. Residents prepare boxes or bags with waste at roadsides for MSW collection on particular day once a week by municipal company (SAE);
- “self-pickup” – residents or legal entities bring waste to the landfill on their own;
- collection of recyclables by legal entities with further transportation to the municipal sorting plant of SAE.

The Baseline Scenario assumes a full 100% collection coverage. However, comparison of data on collected waste and waste generation estimated by norms shows that only about 60% of the generated waste (108,000 tons/year) is collected by official waste collection system. Remaining waste is littered or illegally dumped, composted or burned at home, or collected by informal sector. Paper, glass and plastic are collected separately in designated yard containers or at collection points and delivered for after-sorting to the sorting plant “ZUBR”. The collection efficiency rate and the material recovery rate are very low at the moment.

In 2008 the separate waste collection system in the Mogilev region covered on average 45,8% of urban and 14,4% of rural population (Skryhan et al., 2016). Separate waste collection in containers is organised in the whole city, but the number of collected fractions and collection efficiency varies between the districts. Paper, glass and plastic are collected separately, but the overall collection rate in containers is low at around 0,6% of the collected waste. Collection points run at higher collection efficiency – 6,7% of waste is collected as recyclables (paper, glass, polymers, PET and films, WEEE, textiles) at 46 collection points (Skryhan et al., 2016). Two state companies run separate collection points for scrap metals. Only a small amount of hazardous waste and WEEE are currently collected, the collection system is under development – starting with 2016 state-run facility collects WEE and batteries directly from households and enterprises (Skryhan et al., 2016).

Treatment and disposal.

Currently, the status quo of Mogilev`s treatment and disposal facilities is as following (Baseline Scenario):

1. sorting plant “ZUBR” with two lines of manual sorting and total capacity of 90.000 tons;
1. semi-sanitary landfill that does not comply to technical and environmental standards (outside of the city);
2. Old small-scale composting plant (current throughput of 550 tons per year) is operating since 1980s, processing mixed waste and using worms for composting process (Skryhan et al., 2016).

Home composted material and informal collected waste are included in the system boundaries, as well as formally collected waste.

As reliable statistical data is not available the amount of illegally disposed, informally collected and home composted waste was calculated. The amount of home composted material was estimated by an expert at the BRU according to field studies of morphology content of food waste in private houses (Skryhan et al., 2016).

The informal sector in waste management consists of private sector enterprises and individuals participating in waste management services, but those activities are not contracted, taxed, financed, not organized by a formal solid waste authority (Scheinberg et al., 2010). It is known that informal collection is taking place in Mogilev, the recyclables (especially metals) are usually transported and sold in Russian Federation, as purchase prices are higher there. According to investigations of Ramusch (Ramusch, 2016a), it was estimated that 2,997 tons of recyclables are informally collected (under assumption that 0.2% of population in Mogilev and suburbs collect 20 kg of waste per day during 200 working days per year).

At the moment Mogilev has one major landfill, located 20 km from the city with a total area of 19.6 hectares. Currently, one of the two sections of landfill is already full. The second section had begun to be filled in recently. Thus, the landfill can freely and safely operate for the next 4 to 5 years (Skryhan, 2016).

Illegal dumps are a result of unpermitted dispose of waste into the environment, instead of using authorized MSWM infrastructure. Lack of enforcement of environmental laws and environmental consciousness of population, as well as lack of WM infrastructure are reasons for illegal dumping (Hanfman, 2012). It was estimated that about 36.977 tons of mixed waste per year are illegally disposed into the environment, and about 10.000 tons of these illegal dumps are cleaned up every year (Skryhan, 2016).

Main problems of waste management that have been named by stakeholders are: exhaustion of existing landfill capacities; large volume of untreated organic waste; inefficient separate waste collection; absence of waste treatment facilities in Mogilev.

Financial data and current tariffs.

The MSW system in Mogilev is financed through public means, fees and subsidies (Skryhan et al., 2016). The fees for MSW collection, removal and treatment are approved by local executive authority in accordance with the “norms” of MSW generation per person. Hence, the financial contribution of consumers for MSW removal and treatment is based on the MSW generation “norms”, but not on actual waste quantity going to landfills. Practically, two options exist to cover costs for removal and treatment of MSW. First, increasing tariffs for waste removal and landfilling. Second, increasing the amount of waste generation per person allowed by “norms” (Wohmann et al., 2017).

On average the tariff for MSW removal in Mogilev in 2015 was 3.4 EUR/m^3 for private persons and around 6 EUR/m^3 for legal entities (Skryhan et al., 2016).

3. Method

The chapter ‘Method‘ describes the methodological approach and references used for this thesis. To meet the research objectives a mixture of diverse methods and tools was chosen covered in following steps:

1. Development of DNC (Data Need Catalogue), a list of data required for evaluation of the status-quo in Mogilev (Chapter 3.2). The DNC provided local project partners and stakeholders an overview of data required for further assessment.
2. Report on the status-quo situation of the MSW management system in Mogilev is described in the baseline situation (Chapter 2).
3. Review of literature to define economic, social and technical indicators for further assessment of waste management scenarios (Chapter 3.1). In addition to the literature review, discussions from project meetings in Vienna, Austria (March 2016), Dresden, Germany (March 2017), and meeting with local stakeholders (municipalities, waste operators, NGOs and universities) in Mogilev, Belarus (November 2017) were fed into this thesis.
4. Documentation and definition of current MSW flows, corresponding quantities and compositions, as well as calculation of future MSW flows using Waste Forecast Tool (Chapter 3.8).
5. Development of future waste management scenarios and their representation using Material Flow Analysis tool STAN (Chapter 3.8 and 4).
6. Selection of waste treatment technologies of future waste management scenarios (Chapter 5).
7. Evaluation of future scenarios by means of selected indicators (Chapter 6).

Supplementary, the WaTra-project developed a roadmap for potential waste reduction and prevention, as well as information and communication strategies.

3.1 Literature Review

The goal of this study was to suggest different waste processing options for the city Mogilev and provide an assessment of the effectiveness and sustainability of those waste management scenarios using set of indicators. The first step on this way was to study existing literature, to range the methods of evaluating the effectiveness of the WM system in terms of reliability and applicability for the project. Finally, the task was to identify economic, social, environmental and technological indicators suitable for evaluation of efficiency and sustainability of the WM system.

At the initial stage of the research, the scientometric databases At the initial stage of the research, the scientometric database like Science Direct, SCOPUS, BOKU:Litsearch were chosen to be the hunting tool for the sources of appropriate literature. Articles from scientific magazines and online sources over the period from February to May 2015 were used as the base for the research due to relative mobility in reporting.

The keywords used in the searching engines included but not limited to (search was conducted in the studies in English and German languages): “integrated MSWM”; “waste management”; “sustainability assessment”; “assessment”; “MSW indicators”; “MSWM evaluation”; “economic, ecological, social and technical assessment of MSW systems”.

The pool of 53 literature sources was estimated as corresponding to the objectives of the research project. Afterwards, the selected sources were classified in accordance with the used methodology for assessment of the environmental, economic and social impact of waste management. Generally, there are many different methods of such assessment, e.g. Life Cycle Assessment (LCA), Life Cycle Costing (LCC), social Life Cycle Assessment (sLCA), Key Performance Indicators (KPIs), Multi-Criteria Decision Analysis (MCDA), Cost-Benefit Analysis (CBA), Simulation Models, Benchmarking methodology and others.

As it turned out, most of the studies used LCA method to assess the quantitative impact on the environment (Banar et al., 2009; Bovea et al., 2010; Buttol et al., 2007; Cherubini et al., 2009; den Boer et al., 2005; Emery et al., 2007; Hermann et al., 2007; Kirkeby et al., 2006; Kulczycka, et al., 2015; Laurent et al., 2014a, 2014b; Luoranen et al., 2007; Margallo et al., 2014; Ozeler et al., 2005; Parkes et al., 2015; Reich, 2005; Tulokhonova and Ulanova, 2013; Woon and Zhou, 2015). Next four studies used the LCC technique to calculate the financial and economic indicators of the efficiency of the waste system management (Martinez-Sanchez, et al., 2014; Reich, 2005; Woon and Zhou, 2015). Another 2 studies used the methodology of the social LCA (Aparcana and Salhofer, 2013a; Aparcana and Salhofer, 2013b).

Another study complemented the methodology of LCA with LCC and SLCA to assess the effectiveness of WM (Souza et al., 2015). It must be said, that the LCA methodology has one significant drawback: in case of an insufficient data for analysis, the results of research based on this technique cannot be considered reliable (Karmperis et al., 2013). Another drawback is that the methodology is quite complicated, results of the assessment might be difficult to understand and to interpret by local stakeholders for the local conditions. For this reason, all the sources using the life cycle methodology were excluded from the pool of the literature to be further analysed.

Further, it was discovered that five sources have used the value judgments of experts, senior officials or shareholders as an analysing tool for possible alternative solutions to the problem of WM (MCDA) (Arıkan et al., 2017a; Hanan et al., 2013; Hermann et al., 2007; Milutinović et al., 2014; Vučijak et al., 2016). MCDA is not always effective if one needs to take into account too many aspects; especially if any of the criteria is unstable, then the results can be ambiguous. Due to complexity of this method of evaluation, it was excluded as a potential assessment method (Karmperis et al., 2013).

The 10 sources used the KPI methodology in their studies of WM (Arıkan et al., 2017a, 2017a; Armijo et al., 2014; Brunner and Fellner, 2007; Cifrian et al., 2012, 2010; den Boer et al., 2005; Emery et al., 2007; Giljum et al., 2011; Hermann et al., 2007; Rigamonti et al., 2016a; Shen et al., 2011). The key indicators work good while analysing different stages of the WM process, as well as for indexing its impact on the environment, human health and economy. Since the KPI methodology allows to describe the reactions of the environment as well as to analyse comprehensively the entire system of WM (including economic, social and technical components), it is considered to be acceptable for the project.

The following 5 studies used benchmarking to assess the effectiveness of WM system (Sim et al., 2013; Wilson et al., 2014; Wilson et al., 2013; Ilic and Nikolic, 2016; United Nations Human Settlements Programme, 2010), however this method is commonly used for analysis of results in comparison with a reference value (benchmark) or for comparison of WM systems between each other.

The application of the CBA methodology was found only in 4 studies (Jamasb and Nepal, 2010; Karmperis et al., 2013; Pearce et al., 2006; Weng and Fujiwara, 2011). Two more studies used method of simulation and considered carbon dioxide emissions along with an analysis of economic efficiency (Armijo et al., 2014; Mutavchi, 2012) together with the last 3 studies which were assigned to the category “other” (Groot, 2011; Herva et al., 2014; Levin and McEwan, 2000).

It’s fair to say, that the above listed methods are not exhaustive. However, other assessment methodologies like assessment of environmental impact, ecological risk assessment (EEA, 2003) were omitted from the consideration as inappropriate for the objectives of this study.

Finally, the analysis of the selected literature sources was carried out to identify the most appropriate methodology in accordance with the peculiarities of the project. It must be remembered that one of the objectives of this project was to compare different possible outcomes of the waste management scenarios based on real economic, environmental, social and technical conditions. The assessment method should be effective and simple, consider the local features such as lack of input data, providing results informative and understandable for local stakeholders. Apparently, not a single assessment method may provide the reliable result alone in this situation, hence, it was decided to use a combined approach with elements from two methods – MCDA and KPI – to analyse the WM system in Mogilev. The set of the possible appropriate quantitative and qualitative indicators has been selected from the above literature. Afterwards, the list of indicators was refined/narrowed in the discussion with local stakeholders, where they ranked indicators according to the importance and local priorities. The final list of selected indicators is described in chapter 3.3.

3.2 Data Collection

The special Data Need Catalogue (DNC) was compiled to document the situation in the waste management sector at the beginning of the project. The Catalogue was compiled based on the survey used in the LCA-IWM project (Boer, 2005) and included two parts: description of the qualitative aspects of the case study region (see Annex 2) and quantitative database in Excel format. The quantitative survey included more than 1,500 individual indexes reflecting general statistics, demography, waste management laws and strategies, cost related data, the characteristics and quantity data on waste collection, processing and disposal, as well as data on the informal recycling sector (IRS) in the management of MSW. Although, many questions could not be answered due to the lack of information, the report “Waste Management in case study region: Mogilev city and Mogilev district” (Skryhan et al., 2016) and Excel database compiled by local project partner BRU based on the DNC has become a practical guide and source of input data and information for members and partners of the project.

In order to re-create the basic legal background on this issue the legislation of the Republic of Belarus was used. Bulletin of the State Statistical Service of Belarus, World Bank, state reports of the Republic of Belarus on municipal solid waste management contain national-level data of study subjects.

Due to the contacts and efforts of the local partner BRU, access to insider information from local authorities and waste operators, intimately involved in the waste management in Mogilev, and groups of local experts played an important role in clarifying the data and forming a realistic picture for the study implementation. City and regional activists, interested in the positive development of the project and the city, were involved in data collection process. They provided precious information about real waste management situation in the region, demographic and socio-economic indicators for the city of Mogilev.

3.3 Selection of Indicators for Assessment

The literature review provided many tools and methods to assess waste management systems. At the outset of research for this thesis 62 potential indicators were identified, 15 economic, 25 environmental, 16 social and 6 technical indicators. All these indicators are presented for reference in the thesis of Monika Dobreva “Ecological, Economic, Social & Technical assessment of municipal solid waste management system: a case study in Derhachivsky region, Ukraine (Dobreva, 2018).

It was impossible to develop a scenario assessment based on such an extensive number of indicators, therefore it was necessary to exclude some indicators due to lack of data and practical limits. Some indicators were combined into complex indicators: for instance, the indicator ‘Total Annual Costs of WM System’ is a sum of indicators annual operating cost, investment costs and maintenance cost. Then again, some indicators were adapted to provide meaningful decision tool for local stakeholders. For instance, the original indicator ‘Costs of MSWM per GDP of a city’ was modified to ‘Annual costs as percentage of approved City Expenditures’, since data on the city GDP was not available.

Finally, a mix of different economic, environmental, social and technical performance indicators was chosen to evaluate future scenarios. Table 1 lists selected indicators to assess waste management system performance in Mogilev. Table 1 consists of six economic, six environmental, two social and four technical indicators that are further described in the following chapter.

Table 1: List of indicators chosen for assessment

Indicator [Unit]	Description	Source
Economic		
Total Annual Costs of the WM System [€]	Sum of total annual costs of MSWM per subsystems a) bins and containers; b) trucks and collection; c) 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 Costs of WM System per ton of Formally Collected Waste [€/t]	Sum of total annual costs of MSWM related to ton of collected waste	Brunner and Fellner, 2007; Den Boer et al, 2005; Panagiotakopoulos and Tsilemou, 2004; Rigamonti et al., 2016b Tulokhonova and Ulanova, 2013
Total Annual Costs as % of City Expenditures [%]	Costs of MSW services as percentage of the annual city expenditures (budget)	Brunner and Fellner, 2007; Den Boer et al, 2005; Panagiotakopoulos and Tsilemou, 2004; UN-Habitat, 2010
Total Annual Costs of Waste Management System as % of	Cost of WM system per person as a percentage of the nominal	Den Boer et al, 2005; Panagiotakopoulos and

Nominal Average Salary [%]	average salary	Tsilemou
Annual Revenue from Recovery of Materials [€/year]	Sum of all revenues from recovery of material, e.g. 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
Annual 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
Self-financing Rate [%]	Diversion between revenues and expenditures of MSWM system or share of the MSWM costs that can be self-financed by revenues (from recovery of materials, energy and current fees)	Den Boer et al, 2005; Tulokhonova and Ulanova, 2013; Panagiotakopoulos and Tsilemou, 2004
Environmental		
Biodegradable Waste Diversion Rate [%]	Percentage 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 collected MSW.	Rigamonti et al., 2016a; Shekdar and Mistry, 2001; Weng and Fujiwara, 2011
Greenhouse Gas Emissions [t CO_2-eq]	Amount of greenhouse gases emitted to the atmosphere from all processes in the MSW system	Scharenberg, 2017; Milutinović et al., 2014; Wünsch, 2013
Material Recovery Rate [%]	Ratio between the quantity of waste recycled (=brought back into the value chain as secondary raw material) and the amount of 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 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
Social		
Job Creation [number]	Number of new jobs created by the implementation of a given scenario.	BMLFUW, 2015, 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 Boe et al., 2005; Hanan et al., 2013; Milutinović et al., 2014
Traffic [qualitative]	Volume of traffic associated with WM system, 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
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 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	Arıkan et al., 2017; SUP, 2004; Vučijak et al., 2015

	time, robustness and reliability in the practice	

3.4 Economic Indicators

Local governments face MSWM as a challenge, as they are responsible to provide collection, appropriate treatment and disposal of MSW. Financial resources together with modern technologies are a main limiting factors for a progressive waste management system. During discussions with local decision makers economic indicators, especially costs, were indicated as the most important decision criteria.

Following chapter describes and evaluates six economic indicators measuring quantitative performance of future waste management scenarios.

- Total Annual Discounted Costs of WM System
- Total Annual Discounted Costs of WM System per ton of Formally Collected Waste
- Annual Revenue from Recovery of Material and Energy
- Self-financing Rate
- Total Annual Discounted Costs as % of approved City Expenditures
- Total Annual Discounted Costs as % of Nominal Average Salary

3.4.1 Total Annual Discounted Costs of Waste Management System

For the calculation of the Total Annual Costs of WM System an approach of the LCA-IWM methodology was used (den Boer et al., 2005; Panagiotakopoulos and Tsilemou, 2004). Calculated total costs include costs of the following WM subsystems:

$$TADC_{WMS} = EADTC_{bins\ i(j)} + EADTC_{CV\ i\ (j)} + EADTC_{TD\ i\ (j)}$$

where,

$TADC_{WMS}$ = Total Annual Discounted Costs of Waste Management System

$EADTC_{bins\ i(j)}$ = Total Annual Discounted Costs of Subsystem Bins & Container

$EADTC_{CV\ i\ (j)}$ = Total Annual Discounted Costs of Subsystem Trucks & Collection

$EADTC_{TD\ i\ (j)}$ = Total Annual Discounted Costs of Subsystem Treatment & Disposal

The Baseline Scenario contains already an existing container system. Thus, merely additional number of containers in future scenarios needs to be calculated. For this reason, bins and containers subsystem shows preliminary collection of definite amount of waste over a definite time period, which includes transportation of waste to a treatment facility.

Similarly, trucks and collection subsystem includes only new additional collection vehicles that will be needed to transport the total increased future amount of MSW in Mogilev.

Treatment and disposal subsystem includes all treatment facilities that are planned in each scenario (e.g. MBT plant, incineration plant, anaerobic plant, composting facility), as well as disposal facilities (sanitary landfill) within city system boundaries.

The cost estimates for the above mentioned subsystems (bins and container system; trucks and collection, treatment and disposal) are described and assessed in the following section to allow the calculation of the ‘Total Annual Discounted Costs of WM system’.

Costs of all subsystems in future scenarios are estimated over a depreciation period of 20 years. On the basis of data from the National Bank of the Republic of Belarus (2017) a discount rate of 11% was used for calculations. Costs figures provided in the local currency have been converted at a rate of 1 EUR = 2,30 BYN (BYN – Belarus Rubel) (National Bank of the Republic of Belarus, 2016).

a) Total Annual Discounted Costs of Subsystem Bins & Container

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

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 (€)[3]

The number of required containers is important to know for the calculation of purchase and location costs of bins. In the Baseline Scenario waste containers for different fractions already exists, therefore it was decided to calculate the additional amount of containers required for the future increased waste volumes. In the following Table 2 overview of existing containers in Mogilev in 2016 is presented.

Table 2: Bins for temporary storage of MSW in 2016 (Skryhan et al., 2016)

Region	Type of waste	Number of bins	Bin capacity
Mogilev city	**Residual waste**	1,858	0.75 m^3
		220	1.1 m^3
		150	360 l
	Separate fractions:		
	Paper and cardboard	445	1.1 m^3
	Glass	751	1.5 m^3
	Plastic	626	1.1 m^3

Ukrainian “Guideline for organization of collection, transportation, processing and disposal of waste” (MRD, 2010a) was used for calculation of waste collection system in both case study regions of the WaTra project - in Ukraine (Dobreva, 2018) and in Mogilev. According to this guideline, the number of containers is determined by the next formula:

The number of containers is determined by the next formula:

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[3] $EADTEC_{bins\ i(j)}$ are not considered in the calculation because they are outside of the project system boundaries.

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

where,

Nb = 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

K_1 = Daily index of irregularity of MSW generation; recommended value is 1.4

K_2 = 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

K_3 = Fill factor of the container, recommended value is 0.9

The Annual Maintenance Costs for bins in a specific sector [j] of stream [i], expressed as [$AMC_{bins\ i(j)}$] is assumed to be 1% of the Equivalent Annual Discounted Total Purchase Cost of bins, which is shown in the next quotation (Panagiotakopoulos and Tsilemou, 2004):

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

Due to an expected lifetime of bins over 20 years, the Equivalent Annual Discounted Total End-of-Life Costs for bins (EADTEC bins i(j)) are outside of the project time boundaries and excluded from the calculation.

b) Total Annual Discounted Costs of Subsystem Trucks & Collection

The equation for the calculation of the Total Annual Costs of the subsystem ‘Trucks and Collection’ of waste stream [i] of sector [j] is:

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

where,

$EADTC_{CV\ i\ (j)}$ = Total Annual Discounted Costs of Subsystem Trucks & Collection

$EADTPC_{CV\ i\ (j)}$ = 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 (€)

The number of CV is required for calculation of the ‘Equivalent Annual Discounted Total Purchase Cost of CV’. Currently in the Baseline Scenario collection trucks are available, however, many of these trucks are obsolete and inefficient in terms of waste compression. Thus, it was decided to assume replacement of all trucks and calculate the number of new trucks handling future waste amounts, while existing trucks are not taken into account. It is not within the scope of the study to calculate mileages and routes for collection vehicles based on exact location of collection points. Therefore, only approximate calculation of CVs was conducted based on the following formula:

$$N_{ca} = \frac{Q_{Dmax}}{BK_{use}}$$

Where,

N_{ca} = Number of required CV

Q_{Dmax} = Maximum daily amount of each type of waste components in the settlement for which calculation is made, m^3 / day

B = Efficiency of CV per working day, m^3,

K_{use} = Vehicle utilization factor for the provider of waste removal service, recommended value is 0.8

The estimation of the Annual Maintenance Cost of CVs, expressed as $AMC_{CV\ i\ (j)}$, is defined as a percentage of the Equivalent Annual Discounted Total Purchase Cost of a collection vehicle, and assumed to be 12% of the purchase price for one CV (den Boer et al., 2005).

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

Due to an expected lifetime of CV over 20 years, that is outside of the project's boundaries, the Equivalent Annual Discounted Total End-of-Life Costs of CV ($EADTEC_{CV\ i(j)}$) are not part in the calculation.

For the calculation of Annual Operation Costs local information and assumptions are used and are shown in Table 3 and Table 4.

Table 3: Calculation assumption of Annual Operating Costs of CVs (€)

Key parameters	**Value**	**Unit**
Price for fuel	1	€/l
Fuel per km	0.48	l
Operation days	208	day/truck and year
Number of workers	3	No./truck
Staff costs per year (1 worker), assumption for 2025	11,658	€/yr
Staff costs for 1 truck per year	34.975	€/yr
Operation costs and depreciation	1.500	€/yr
Total operating costs for one truck (without fuel)	36.475	€/yr

The actual planned truck route distance is not known for future scenarios. Thus, the truck route of future scenarios was estimated based on available data from Vienna. The population density in both cities is roughly similar, with 4,502 habitants per km² in Vienna and 3,210 habitants per km² in Mogilev. Hence, this comparability between Mogilev and Vienna makes the estimation of truck route distance in future scenarios possible (Belarusian-Russian University, 2015; MA 23, 2017). Table 4 presents the route distance required to collect one ton of MSW in Vienna (MA 48, 1999).

Table 4: Route distance for collection of one ton of MSW in Vienna

MSW	Km/t
glass	7.76
plastic	40.98
paper	5.82
metals	36.87
residues	6.09
organic	11.99

c) Total Annual Discounted Costs of Subsystem Treatment and Disposal

Rather than to provide a detailed technical and commercial planning of a specific treatment facilities for Mogilev, the present study aims to develop, evaluate and compare different scenarios for waste treatment.

The total costs of a plant are related to its waste treatment capacity per year. Furthermore, the costs of operation varies depending on the level of labour costs and the costs of supplies in a specific region (Le Bozec, 2004). Unfortunately, viable costs of state-of-the-art treatment facilities in Belarus are not available as these facilities do not exist in this country at the moment. Due to this lack of reliable data for Belarus, a cost function for waste treatment facilities, developed by Panagiotakopoulos and Tsilemou for the Western Europe has been used as an approximation, as summarized in Table 5 (Panagiotakopoulos and Tsilemou, 2004).

Notwithstanding the limitations, like not-country-specific approach of this method, the results can be used as a solid estimation. It is most likely that technologies for such treatment facilities will be imported from Western Europe at the estimated cost level as these technologies are not produced locally.

However, it must be remembered that this thesis does not deliver an exact calculation of economic impacts, but rather approximate values that would allow to see the difference between scenarios. In order to get accurate costs of a waste management facility local stakeholders need to run a detailed technical planning.

Table 5: Cost functions for waste treatment facilities in Europe (den Boer et al., 2005; Panagiotakopoulos and Tsilemou, 2004)

Treatment technology	Suggested cost functions

	Investment costs (€)	**Operating costs (€/t)**	**Capacities (t/y)**
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
	y = 3.500 * x0,6	$y = 150 * x^{-0,3}$	60.000≤x≤150.000

Costs for Mechanical Biological Treatment facility, Incineration, Anaerobic Digestion, Open Windrow composting facility and sanitary landfill are estimated based on specific function shown above in Table 5.

The 'Total Annual Discounted Costs of Subsystem Treatment & Disposal' sum total initial investment costs and total annual operation costs of a treatment facility. Investment costs functions consist of: costs for site investigation, environmental assessment, hydrogeological investigation, land acquisition, engineering design and constructions costs (land cleaning, excavation, buildings and other constructions works, equipment and furnishing of facilities, technical equipment, connecting network e.g. access roads). Operation cost function consists of: raw material, energy, wastewater disposal, labour, supervision, maintenance of facilities and equipment, insurance, training programs (Tsilemou and Panagiotakopoulos, 2006).

3.4.2 Total Annual Discounted Costs of WM System per ton of Formally Collected Waste

Panagiotakopoulos and Tsilemou deliver the equation for the Total Annual Discounted Costs per ton of Formally Collected Waste ($AnTC_{subsystem(ton)}$) for a specific WM subsystem (Tsilemou and Panagiotakopoulos, 2006).

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

where,

$AnTC_{SS}$ = the Total Annual Discounted Costs of each WM Subsystem (€/ton formally collected waste)

$EATC_{SS\ Bins}$ = the Equivalent Annual Discounted Total Costs of Subsystem Bins and Collection (€/year)

$EATC_{SS\ Trucks\ \&\ Collection}$ = the Equivalent Annual Discounted Total Costs of Subsystem Trucks and Collection (€/year)

$EATC_{SS\ Treatment\ \&\ Disposal}$ = the Equivalent Annual Discounted Total Costs of Subsystem Treatment and Disposal (€/year)

$Q_{Subsystem}$ = the Waste Quantity entering the Formal Collection System in Mogilev (ton/year)

While the previous indicator ‘Total Annual Discounted Costs of WM system’ shows the total costs, this indicator provides relative figure that allows comparison between cities, regions and countries. Thus, the indicator ‘Total Annual Discounted Cost of WM system per ton of formally collected waste’ is a useful tool to understand scales. Furthermore, this indicator enables link and identify the major costs between three subsystems: bins & container system; trucks & collection, treatment & disposal.

3.4.3 Annual Revenue from Recovery of Materials and Energy

The presented WM systems generate potential revenues that have to be accounted for in addition to the financial costs. The indicator ‘Annual Revenue from Recovery of Material and Energy’, expressed as (Rev) provides this information and is defined as a sum of all potential revenues (Panagiotakopoulos and Tsilemou, 2004).

$$Rev = \sum Rev_{IF} + \sum Rev_{ADF} + \sum Rev_{MBT} + \sum Rev_{CF} + \sum Rev_{SF} + \sum Rev_{MDR} + \sum Rev_{RDF}$$

Where,

Rev_{IF} = Annual Revenues from Recovered Material and Energy of Incineration facility

Rev_{ADF} = Annual Revenues from Recovered Material and Energy of Anaerobic Digestion facility

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

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

Rev_{SP} = 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

Table 6 list of selling prices for recovered material and type of recovered energy.

Table 6: Selling prices for recovered material and type of recovered energy

Recovered material	Unit selling price	Source
Paper average	89 [€/t]	Ministry of Republic Belarus, 2016a
Plastic average	149 [€/t]	Skryhan, 2017b
Metal average	426 [€/t]	Skryhan, 2017b
Glass average	30 [€/t]	Skryhan, 2017b
Compost	10 [€/t]	Reasonable assumption based on Khandogina, 2017
MBT $output_{RDF}$	10 [€/t]	Ministry of Republic Belarus, 2016
MBT $output_{glass}$	1 [€/t]	Reasonable assumption

MBT $output_{metal}$	213 [€/t]	Reasonable assumption
Heat	0,011 [€/MJ]	Skryhan, 2017
Electricity from incineration	96,42 [€/Mwh]	Ministry of Energy Republic of Belarus, 2017
Electricity from biogas	160,10 [€/Mwh]	Ministry of Energy Republic of Belarus, 2017

Although most of the input data were provided on the local level, some reasonable assumptions were required. This assumption for the unit selling price of compost and for the MBT outputs glass and metal were made together with the partners of the WaTra-project. As actual prices depend on the quality of recyclables, market fluctuations and transport costs, these prices should be regarded with caution.

3.4.4 Total Annual Discounted Costs as % of Approved City Budget Expenditures

The indicator 'Total Annual Discounted Costs as Percentage of approved City Budget Expenditures' places the MSWM costs in relation to expenditures of the total Mogilev city budget (Mogilev city executive committee, 2017; Demetrios Panagiotakopoulos and Tsilemou, 2004):

$$TAC_{City\ Expenditures} = \frac{EADTC_{SWMS}}{Expenditures\ _{City}}\%$$

where,

$TAC_{City\ Expenditures}$ = the Total Annual Costs as % of approved City Budget Expenditures

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

$Expenditures_{city}$ = Annual expenditures of the Mogilev City budget

This indicator shows the share of city budget spent on WM system and provides local stakeholders information to compare municipal expenditures between each other.

3.4.5 Total Annual Discounted Costs of WM System as % of Nominal Average Salary per Person

This indicator measures the cost of waste management per person as a percentage of the nominal average salary in Belarus:

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

where,

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

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

$SalPe$ = Nominal Average Salary per person in €/year.

The indicator 'Total Annual Discounted Costs of WM System as Percentage of Nominal Average Salary per Person' provides local officials an evaluation how much of a citizen's salary will be spend for covering remaining costs of a WM system in addition to the self-financing part of WM system. It means, in case a WM system has a self-financing rate of 60 % through revenues from materials and energy, how much of a citizen's salary is required to cover the rest. Moreover, it provides the basis for decision to adjust consumer tariffs to an appropriate level.

The data for the calculation is attached in Table 7.

Table 7: Nominal Average Salary for Belarus

Income	Value [€/year]	Source
Nominal Average Salary (for 2015)	4,424	National Statistical Committee of the Republic of Belarus, 2015

3.4.6 Self-financing Rate

The indicator 'Self-financing Rate' represents the level of financial self-sustainability of a system. It measures the share of 'Total Annual Discounted Costs of WM system' that can be financed by revenues of a waste management system. The equation compares 'Total Annual Discounted Costs' of the waste management scenario (costs subsystem bins & container system + subsystem trucks & collection and subsystem treatment & disposal) and 'Total Annual Benefits' (consumer fees and revenues from material and energy recovery) of the waste management system.

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

where,

Benefits$_{\text{SWMSfees+revenue}}$ = Consumer Fees + Revenues from Material and Energy Recovery (€/cap and year)

EADTC$_{\text{SWMS}}$ = Equivalent Annual Discounted Total Costs of Solid Waste Management System (€/cap and year)

Furthermore, this indicator allows stakeholders to evaluate the adequacy of current consumer tariffs, as well to see the economic breakeven point for each scenario.

3.5 Social Indicators

To evaluate the impact of waste management system on the society a mix of indicators was used. The qualitative indicator ‘Social Acceptance’ (chapter 3.5.1) is based on interviews with experts from ABF-BOKU and TU-Dresden. This indicator is composed of five criteria: odour, visual impact, user convenience and complexity, traffic, private space, as well noise. The quantitative indicator ‘Job Creation’ (chapter 3.5.2) is purely based on literature review.

3.5.1 Social Acceptance

To assess the level of social acceptance a separate list of criteria was prepared adapted after (den Boer et al., 2005). Those criteria are important in social opinion, which was also confirmed during discussions with local industry stakeholders and representatives of local authorities. The experts' opinion was involved to draw the reliable picture on the importance of these qualitative indicators in the different stages of waste management processes. Four written evaluations by experts from ABF-BOKU and TU-Dresden were performed in the investigation process of this thesis.

The set of questions regarding the assessment of social acceptance specified for the WaTra-project was composed in a tabular form and was given to the experts to fill it out. Each subcategory was evaluated by three parameters corresponding to three stages of MSWM, namely: subsystem bin & container system, subsystem collection subsystem transport, and treatment & disposal.

Table 8 describes the impact of the listed subsystems on the chosen criteria. Subsystem marked with X effects the respective criteria. A subsystem with no X mark has no significant influence.

Table 8: 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**		
Private space	**X**		
Noise	**X**	**X**	**X**
Traffic		**X**	**X**

The experts were faced with the task of comparing each social criterion in the future scenario with the existing Baseline Scenario and classifying it into five levels (scores). Each criterion got its score (from -2 to +2) depending on the future development of the situation.

The level of social stability was the benchmark for defining the ratings: rating mark of +2 means that the situation changes to a better one compared to the Baseline Scenario; rating mark of 0 means the lack of dynamics (the impact of criteria remains the same as in baseline), and rating mark of -2 indicates a negative change of the criteria in a relation to the Baseline Scenario. After processing of the survey results, the average value for each criterion obtained from all surveys was estimated.

The methodology of selection of criterion from the different studies is to be presented later.

Odour

The odour criterion reflects the likelihood of an unpleasant smell (miasma) within the framework of the subsystem. Typically, miasma appears in cases of separate bio-waste collection. The appearance of odour usually undermines social acceptance for a given scenario (den Boer et al., 2005; Tulokhonova and Ulanova, 2013).

Visual impact

This criterion characterises the degree of acceptance of the appearance of garbage bins and waste recycling enterprises, and, accordingly, their presence or absence in the area. The overabundance of containers and other storage facilities collecting individual waste components in the visibility zone affects negatively the rating of this criterion. The way the components of garbage collection and processing system look, acts on the willingness of residents to see waste-processing companies in their area (den Boer et al., 2005; Tulokhonova and Ulanova, 2013).

User convenience & complexity

It is meaningful how convenient or difficult for the residents to apply the principle of separate waste collection in their everyday life, how many garbage containers must be in the house, or at which distance the collection containers or waste collection sites are located. Practice shows that it is easier to collect garbage in one container. The recycling oriented waste management system requires the usage of several household waste containers, more time consuming management of waste, which implies changes in the behaviour of people, thus always perceived as an inconvenience. The more containers for collecting and disposing the waste are in the yard or the higher distance to the containers/collection sites, the less do people understand how to use them and are less willing to participate in separate waste collection (den Boer et al., 2005; Tulokhonova and Ulanova, 2013).

Private space

The concept of private space in this case applies to the size of the space allocated for equipping and servicing the waste collection system in peoples’ dwellings. The more fractions are to be distributed, the more space is needed for garbage containers in the household. It is not always acceptable for the MSW service consumer (den Boer et al., 2005; Tulokhonova and Ulanova, 2013).

Noise

Noise is the category that describes the unwanted annoying sound. The specific waste management activities like transportation and/or treatment of waste, emptying the containers, increased traffic, enhanced above average level of noise can be easily perceived as unpleasant and aggravating (den Boer et al., 2005; SUP, 2004; Tulokhonova and Ulanova, 2013).

Traffic

The traffic criterion reflects the movement of cars during the execution of routine waste management procedures such as collection of waste from bunkers, transportation of waste to processing plants and/or to sorting points. Increased traffic intensity may cause various effects such as blocked streets, short-term jams in the yards, increased rate of fumes emissions, raised level of noise, dispersed odours (den Boer et al., 2005; SUP, 2004; Tulokhonova and Ulanova, 2013).

3.5.2 Job Creation

This criterion reports the number of new jobs that can be created during the implementation of the future waste management scenario. The number of employees is being calculated from the need to service 10 000 tons of waste per year at any stage of the WM production chain, whether it is sorting, dumping, burning or composting. Moreover, the printed sources on this topic indicate that only directly employed workers are considered, for example, truck drivers, operators at processing points, container operators, etc. At the same time, indirect jobs such as administration, security or accounting services are not considered as newly created because of the implementation of the project. Job creation is usually considered vitally important for development of the regions, and is also very important for the Belarus and Mogilev in particular (BMLFUW, 2015; European Commission, 2001; Maletz, 2017; Murray, 1999; Sedman, 2002).

The number of employees is calculated based on the literature data about jobs creation in the European waste management sector (BMLFUW, 2015; European Commission, 2001; Maletz, 2017; Murray, 1999; Sedman, 2002). The provided number of employees refers to handling of 10 000 tons of waste per year at all stages of the WM production chain, whether it is sorting, dumping, burning or composting. According to the above mentioned literature, only the calculation of directly employed workers is considered, for example, truck drivers, operators at processing plants, container operators, etc. At the same time, indirect jobs such as administration, security or accounting services are not taken into account. Following Table 9 provides the potential number job created by a specific WM activity.

Table 9: Job creation potential in WM

Job creation potential for different WM facilities	
MSW facility	Number of jobs per 10 000 tons/year
Collection	40
MBT	10
Recycling	30
Incineration	14
Anaerobic plant	7
Composting	4
Landfill	3

3.6 Environmental Indicators

The calculation methodology of the chosen environmental indicators is described in the next chapters.

3.6.1 Source Separated Collection Rate

Separate collection means separate collection of waste streams to respect type and nature of waste in order to facilitate a specific treatment. The source-separated collection rate is defined 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., 2014; 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)

WEEE (Waste Electrical and Electronic Equipment), as well hazardous waste is outside of the system boundaries and therefore is not included in the source-separated collection rate.

Two different collection targets are defined to show possible performance options. Table 10 lists collection rates for five waste streams and two corresponding targets ("high" targets for separate bins, dry-wet bin). Below listed reference targets correspond to investigations of collection efficiencies in European cities in Germany, France, Ireland, United Kingdom, Italy and Netherland (den Boer et al., 2005; Pöttschacher, 2016). Hence, these targets reflect realistic estimations of collection rates for recyclables and organic waste. Den Boer (den Boer et al., 2005) provides two sets of possible collection targets depending on achievable collection efficiency: "low" and "high". Ambitious "high" collection targets were taken for calculations, since the aim of all of future scenarios calculated for the year 2025 was to show maximum benefits that can be achieved if state-of-the-art technologies are implemented. Targets for the dry-wet bin are taken based on experience of dry-wet bin implementation in Austria (Pöttschacher, 2016), whereas, collection efficiency targets for glass and metal fractions were slightly adapted by the project team.

Table 10: Suggested targets for separate collection (den Boer et al., 2005; Huber-Humer, 2017; Pöttschacher, 2016)

Separate collection targets [%]		
Fraction	**High**	**Dry-wet bin**
Plastic and composites	65	70
Glass	69	60
Paper and cardboard	74	85
Metal	60	60
Organics	51	-

3.6.2 Material Recovery Rate

The indicator 'Material Recovery Rate' (MRR) represents a ratio between waste recycled and formally collected MSW, in % (den Boer et al., 2005; Huber-Humer, 2017; Pöttschacher, 2016).

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

where,

- '*Material from separate collection'* is a secondary raw material - plastic, paper, metal and glass, recovered from separate collection and after going through sorting and recycling process. It does not include reprocessing of organic material.
- *'Material from combustion* residues' includes metal recovered from bottom ash of incineration plant, after their recycling.
- '*Material from MBT plants'* includes glass, metals and polymers from sorting process in MBT, after their recycling.
- *Compost* is produced from separately collected organic fraction in composting plants or obtained from digestion process in anaerobic digestion plants.

Calculation of material recovery rates can be composed of three parameters, e.g.:

*'Material from Separate Collection' = 'Separate Collection Efficiency' * 'Sorting Efficiency' * Technical Recycling Rate'*

Figure 5 illustrates the material recovery rate for 'Material from separate collection' for paper, plastic, metal and glass. The MRR is effected by three steps. First, separate collection targets are applied. Second, sorting efficiency at manual sorting plant is applied. Third, technical recycling rate at recycling plants has to be considered as well. On the example of paper, if one unit of paper is formally collected it will result in 0.46 pieces of paper recovered after recycling (1 x 0.74 x 0.75 x 0.85 = 0.46).

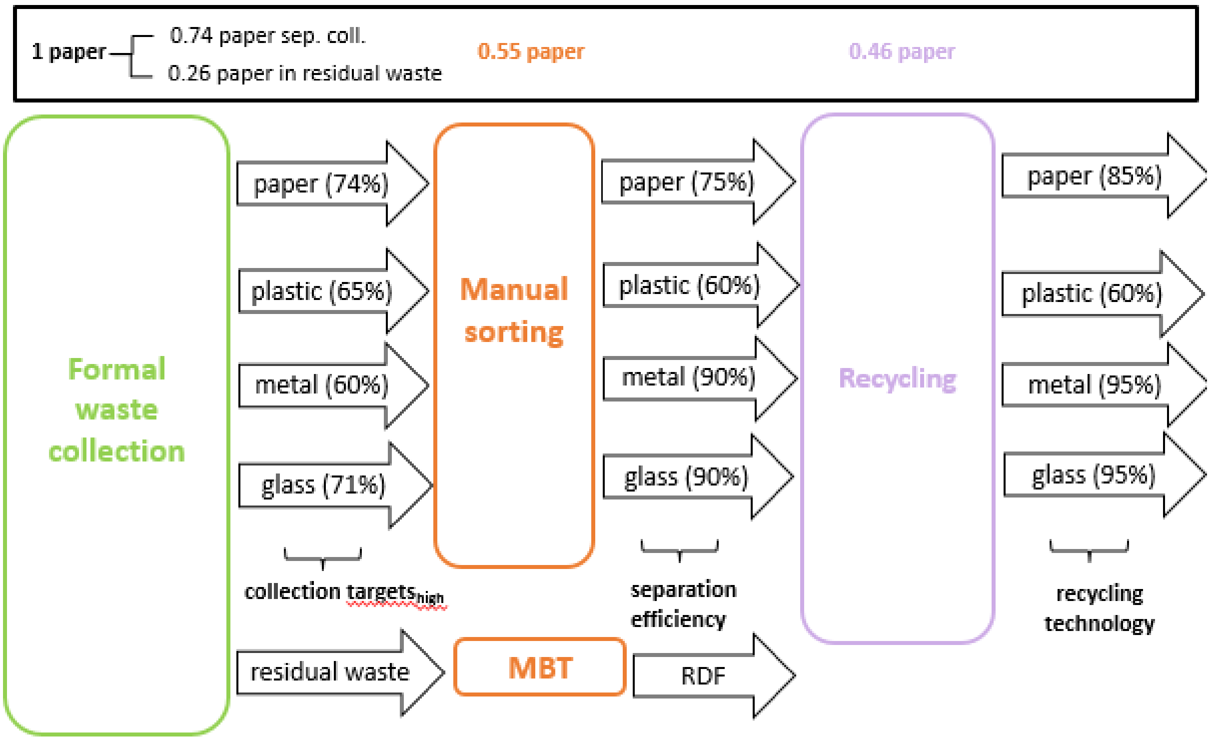

Figure 5: Difference between separate collection efficiency, separation efficiency and technical recycling rate explained on an example

Assumptions on ‘separate collection efficiency’, ‘sorting efficiency’, ‘technical recycling rate’ (of source-separated material, as well as material from MBT and combustion residues) or ‘composting rate’ of separately collected organic waste are based on literature research and expert interviews (Binner, 2012; Christensen and Damgaard, 2011a, 2011b; Maletz, 2017; Plastic zero, 2014; Pöttschacher, 2016; Pressley et al., 2015; Tchobanoglous and Kreith, 2002; Van Eygen et al., 2017).

Table 11 lists assumptions on separate collection efficiencies, sorting efficiencies and recycling rates based on literature research and on opinion of experts from ABF-BOKU and TU-Dresden. Those rates are used for the calculation of material recovery rates after recycling for the case studies in Belarus and Ukraine:

Table 11: Values used for separate collection rate, sorting efficiency and technical recycling rates

Fraction	Separate Collection $\text{Efficiency}_{\text{high}}$	Sorting Efficiency	Technical recycling rate/ Composting Efficiency
Plastic	65%	60%	60%
Paper	74%	75%	85%
Metal	60%	90%	95%
Glass	69%	90%	95%
Organics	51%	-	33%
Dry wet bin plastic	70%	50%	60%
Dry wet bin paper	85%	75%	85%

Dry wet bin metal	60%	60%	95%
Dry wet bin glass	60%	60%	95%
MBT output$_{glass}$	-	5-12%	60%
MBT output$_{metal}$	-	1-2%	80%

*Composting efficiency (Binner, 2017).

3.6.3 Energy Recovery Rate

The indicator ‘Energy Recovery Rate’ represents recovered energy used out of the total available energy containing in formally collected MSW (Grosso et al., 2010; Rigamonti et al., 2016a). Following formula describes the indicator:

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

where,

MJ_{el} =	Net electricity recovered out of the MSW management 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 (expressed in MJ), calculated by multiplying the amount of collected MSW by fractions with heating values of waste fractions.

The Carnot Factor is subject to outdoor temperatures. However, the exergetic efficiency rate does not affect the scenario analysis according to the assumption of the WaTra-project. Thus, the Carnot Factor is not used in this master thesis. Nevertheless, for a detailed and correct planning of Waste to Energy Projects surrounding temperatures and heat extraction have to be taken into account (Maletz, 2017).

Table 12 lists heating values that are taken into account in the calculation of $MJ_{available}$.

Table 12: Heating values for different waste fractions (Wünsch, 2017a).

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/Ne-Metals	0
Paper/Cardboard	11,000
Glass	0
Plastics	31,000

3.6.4 Waste Landfilling Rate

The indicator ‘Waste Landfilling Rate’ represents the ratio of waste left for disposal in landfills to formally collected waste. Since no waste is directly landfilled in any of the future scenarios, waste left for disposal contains only residues from manual sorting plants, open windrow composting and MBT residues (Shen et al., 2011). However, residues recycling are not included in the calculation. Following formula describes the indicator:

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

where,

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

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

The lower value this indicator has, the higher efficiency of resources utilisation has the MSWM system.

3.6.5 Biodegradable Waste Diversion Rate

The indicator ‘Biodegradable Waste Diversion Rate’ represents the ratio of biodegradable waste diverted from landfill to biodegradable waste formally collected in 2015 defined as a reference year (Vučijak et al., 2015). Following formula describes the indicator (Vučijak et al., 2015):

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

Where,

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

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

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

$Biod_i$ = Biologically degradable portion of i fraction of waste in % (see Table 13)

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

The default data on biodegradability for different waste fractions are adopted according to Den Boer et al. (2005) and is listed in Table 13. The indicator RBWL represents enhancement of a specific scenario in respect of biodegradable waste shift from landfills towards recycling and other treatment alternatives.

Table 13: Default characteristics of residual waste adapted according to 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/Ne-Metals	0
Paper/Cardboard	98
Glass	0
Plastic	5

3.6.6 Greenhouse Gas Emissions

The greenhouse gas emission (GHG) defined as CO2-eq per ton of formally collected waste was calculated by means of an unpublished Emission-Calculation-Toll developed by TU-Dresden : and is represented in the following formula:

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

where,

GHG_{SWMS} = Total Greenhouse Gas Emissions from SWMS (CO2-eq)

GHG_{MBT} = Greenhouse Gas Emissions emitted by MBT (CO2-eq)

GHG_{LF} = Greenhouse Gas Emissions emitted by Landfill (CO2-eq)

GHG_{CK} = Greenhouse Gas Emissions emitted by Cement Kiln (CO2-eq)

GHG_{TR} = Greenhouse Gas Emissions emitted by treatment of recyclables (CO2-eq)

GHG_{inc}= Greenhouse Gas Emissions emitted by Incineration (CO2-eq)

GHG_{ad}= Greenhouse Gas Emissions emitted by Anaerobic digestion (CO2-eq)

The TU-Dresden GHG emission tool calculates emissions only for the MSW treatment processes. However, emission due to collection and transport of waste are not part of this calculation tool because this emission share is usually insignificant in waste management systems (Mohareb et al., 2011). Following GHG emissions from MSW treatment process are considered for the waste management scenarios for Mogilev: incineration, anaerobic plant, MBT, landfilling, cement kiln and treatment of recyclables. Furthermore, emissions from composting are not part of the calculation tool. But, according to some literature data the impact of these emissions can be counterbalanced by GHG credits obtained by application of land compost (Linzer and Mostbauer, 2005), therefore emissions from composting process were assumed to be not highly significant in our MSWM system compared to other sources, and were therefore omitted.

A WM system with low greenhouse gas emissions have a low value compared with WM system with high amount of GHG. Scharenberg provides detailed information on methodology and calculation of greenhouse gas emissions within the scope of the WaTra-project (Scharenberg, 2017).

Assumptions and input data for calculation of indicator GHG emissions:

- CH4 has a 28 times higher greenhouse gas potential than CO2 (Scharenberg, 2017)
- N2O has a 310 times higher greenhouse gas potential than CO2 (IPCC et al., 2013)
- Density of methane 0.72 kg/m^3

Greenhouse gas substitution factors for material recovery kg CO2 eq./ kg recovered material (Wünsch, 2017b):

Iron	1.2
Aluminium	15.2
Copper	4
Minerals	0.004
Paper/Cardboard	0.3
Glass	0.5
Plastics	0.85

- 55% of the total landfill gas is methane (Scharenberg, 2017)
- 60% of the biogas from anaerobic digestion is methane (Wünsch, 2013)
- CH_4 has an energy content of 10 kWh (LCV - Lower calorific value = 50 MJ/kg) (Scharenberg, 2017)
- All RDF produced is co-incinerated in a cement kiln with an efficiency of 99% (Wünsch, 2013)
- In cement kilns 30% natural gas, 40% lignite coal, 30% hard coal are substituted (Wünsch, 2013)

3.7 Technical Indicators

Four technical indicators evaluate efficiency and appropriateness of chosen 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

Experts from ABF-BOKU and TU-Dresden performed the technical evaluation of the technologies used in scenarios. Similar to the social acceptance evaluation same approach was chosen for the technical assessment to gain information from waste management experts with scientific background. In total four expert surveys were performed by means of an electronic table (Excel file) prepared specifically for this project. The experts rated each of the four technical indicators for each technology used in the specific scenario with a score from 1 (worst score) to 4 (best score).

Based upon the expert surveys weighting of criteria is applied by relating the score to the treated waste amount for each waste treatment technology and scenario. As a results an average value is calculated for each criterion of each scenario. Following sections present the definition of each criterion that are adapted from various studies.

3.7.1 Technical Reliability

This indicator reflects the level of adequacy of the results of technology's operation to the predicted signs in accordance with the tasks assigned for a given period of time, its ability to cope with unforeseen circumstances and affinity to the realities of the environment (Arıkan et al., 2017; SUP, 2004; Vučijak et al., 2016). The indicator assessment scale ranges from 1 (pretentious) to 4 (unpretentious).

3.7.2 Requirement of Qualified Personnel and Maintenance Requirements

This indicator reflects on the qualification requirements for personnel and the technical conditions concerning the resources needed for the proper WM system functioning (spare parts, skilled operators, assistance services etc.) (Arıkan et al., 2017). The indicator assessment scale ranges from 1 (high requirement) to 4 (low requirements).

3.7.3 Sensitivity to Quantity of Input Material

This indicator measures the adaptability of the technology to quantitative changes in waste generation in liaison with the need to adjust the technological process. In other words, how will the increase or decrease of the amount of garbage effect the local WM system? The increasing of the quantity of waste is likely to require additional capacity, and the reduction of the quantity of waste may lead to lower utilisation capacity rates of the treatment, recycling and disposal plants, which would have also negative economic impact (SUP, 2004). The indicator assessment scale ranges from 1 (sensitive) to 4 (insensitive).

3.7.4 Sensitivity to Quality of Input Material

This indicator demonstrates the ability of technology to acclimate to qualitative changes in the overall composition of the waste and the need for technological adjustments of the system of MSWM (SUP, 2004), e.g. low quality or impurities in separately collected bio-waste easily lead to malfunction of the biogas plant, high moisture content of residual waste lowers efficiency of combustion significantly. The indicator assessment scale ranges from 1 (sensitive) to 4 (insensitive).

3.8 Scenarios modelling with Material Flow Analysis and Waste Forecasting Tool

The future waste management scenarios were developed for the long-term implementation in the year 2025. They include various technologies of waste processing and estimate the related costs of scenario implementation. Together with partners from TU Dresden various scenarios of development of the MSW system management have been worked out and discussed at meetings with local partners and stakeholders. Once the strategic aim of MSW system development has been defined, the implications of each scenario for the city of Mogilev were discussed and the most realistic scenarios were selected.

The main idea of the scenarios was to demonstrate maximum possible benefits that could be achieved in MSWM system involving state-of-the art technologies used at their optimum conditions (e.g. high source-separate collection rates, high-efficient treatment plants) and at most ambitious legal requirements and their enforcement (e.g. ban on landfilling of untreated waste, 100% collection coverage, prohibition of unsanitary landfills, 100% illegal dumping elimination). Through combination of different technologies, scenarios can be designed target-oriented, e.g. aimed at increase of recycling or at increase of energy production. In this study, we have suggested several scenarios aimed at either “increase of separate collection and recycling”, or “increase of energy production”, as well as optimised scenario combining maximisation of recycling as 1st priority and energy production as 2nd priority. Local stakeholders can compare and weigh negative or positive impacts, costs and benefits from different scenarios and select the scenario most appropriate for them depending on their national/regional problems and priorities.

The scenarios were developed location-based. Each scenario has taken into account following aspects: the accumulation/storage of waste, its collection, ways of treatment and disposal of residual waste, management of recyclables and organic waste. Treatment of WEEE and hazardous waste were not considered.

The first step for the scenarios modelling was the forecast of future waste generation. The thesis used the LCA-IWM Waste Generation Prognostic Model to forecast the waste quantities for the 10-years horizon until 2025. This forecast tool is applied to calculate the future waste quantities in European cities. It implements parameters to explain the current situation on the one side, and to examine the future amount of MSW generated per capita in Mogilev on the other side. The tool requires a broad set of influencing parameters, mainly social, economic and demographic indicators, and past waste generation factors. Furthermore, it provides quantitative parameters on different waste streams, and estimations of waste generation rate and waste composition (Beigl et al., 2003b). Based on the parameters and waste generation amount of 170,748 tons in 2015 the tool estimated an amount of 197,870 tons in 2025. This amount is the basis for the assessment of future scenarios. Following Table 14 presents a selection of main input data to the forecast tool to estimate the future waste generation.

Table 14: Reference data waste generation prognostic tool

Input Data	Value	Source
General		
Number of citizen	375,000	Skryhan, 2016
Reference year	2015 - 2025	Internal project requirement
Waste-related data		
Residual Waste/Mixed waste [t/yr]	157,354	Skryhan, 2016
Paper and cardboard [t/yr]	4,219	Skryhan, 2016
Plastic [t/yr]	1,602	Skryhan, 2016
Glass [t/yr]	3,943	Skryhan, 2016
Bulky waste [t/yr]	3,628	Skryhan, 2016
Hazardous waste [t/yr]	1	Skryhan, 2016
WEEE [t/yr]	1	Skryhan, 2016
Socio-economic data[4]		
Population aged 15 to 59 years, [% of total population]	61.7	Skryhan, 2016; Mogilev Main Department of Statistics, 2015
Average household size, persons per household [persons per household]	3.4	Skryhan, 2016; Mogilev Main Department of Statistics, 2015
Urban infant mortality rate [per 1,000 births]	2.2	Skryhan, 2016; Mogilev Main Department of Statistics, 2015
National infant mortality rate [per 1,000 births]	3.5	Skryhan, 2016; Mogilev Main Department of Statistics, 2015
Life expectancy at birth [years]	72.4	Skryhan, 2016; Mogilev Main Department of Statistics, 2015
Labour force in agriculture [% of total labour force]	9.5	Skryhan, 2016; Mogilev Main Department of Statistics, 2015

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[4] All social-economic data are found in Skryhan, 2016

At the next step, all identified scenarios were modelled using the method of material flow analysis (MFA) (Brunner and Rechberger, 2004). The MFA method was selected because of its versatility, it systematically takes into account the flow and accumulation, incoming/outgoing and ongoing processes in the specific place and particular time of the system. Thus, the method linking together the accumulation of waste products with non-processed waste and emissions, allows calculating the necessary capacity of the recycling plants and the amount of waste (Stanisavljevic and Brunner, 2014).

Despite the obvious benefits of using the MFA as a tool for modelling paths of development it is also necessary to consider the lack of data and non-reliability of some of it, which limits the scope of the method implementation.

In the following chapter the detailed description of the simplifications and assumptions that had to be taken to overcome the problem of data limitations will be given.

3.8.1 Data Uncertainties

In order to model the material flows and analyse the indicators, precise information about the current system of waste management is required, yet it is not available. A way out of this situation was found in some generalization of the situation, omission of inconsequential details and introduction of some reasonable assumptions to the study, which allowed obtaining meaningful results. To maintain the confidence level of the study, the incomplete data were cross-checked by experts, subjected to recalculation and reconciliation with the selected sources.

Statistical data regarding waste generation at the Baseline Scenario as of the year 2015 are available for the total amount of generated waste, for the total amount of collected waste, treated, recycled and landfilled waste. These statistical data are provided by the BelSRC “Ecology” (Belarusian Scientific Research Centre «Ecology», 2016). However, as described above, analysis of statistical data revealed some issues that should be taken into account. In the official data “generated waste” is always equal to “collected waste”. However, according to the Belarusian legislation, the recyclables are not considered as waste, therefore SRM is excluded from the total volume of waste generated and are to be registered separately. Official figure on “generated waste” also does not include garbage littered into the environment, landfilled in illegal dumps, common practice of home-composting or backyard-burning in the private sector, as well as informally collected waste. With that approach, it is difficult to estimate the actual amount of generated waste and related indicators (emissions to the environment, collection costs and potential income from selling of recyclables etc.).

In this local project, the partner from BRU had used Belarusian Municipal Waste Generation Index to calculate the waste generation in the Baseline Scenario. The Belarusian Municipal Waste Generation Index (so-called “norms”) is a set of quantitative data, allowing to calculate the generation of waste. For each municipality in Belarus in the absence of actual local data on waste generation, the norm can be set and approved at the local level. The normative standard for the generation of MSW is set by the Mogilev city Executive Committee. Thus, it turns out that the waste, in fact, is not measured, it is calculated according to the methodology. Norms are calculated per unit of something, such as, per capita, one place in the hotel, one m^2 of commercial and warehouse space, square, stations, parking, etc. - and per unit of time.

For the calculation of waste generation using the norms by the project partners from BRU the following units were used (Mogilev city executive committee, 2015):

- MSW generated from population = m^3/year and cap, and kg/year and cap
- Waste of similar origin and composition, for example, legal entities: hospital / hotel = m^3/year and bed, schools = m^3/year and child or student, markets = m^3/year and m^2 of area, cafes / restaurants = 1 m^3/year and space, etc.

The standard of generation of municipal solid waste for the population (norm approved in 2010):

- For housing equipped with communal facilities (centralised electricity-, heat-, water supply and sewage facilities) – 1.72 m^3/resident and year
- For housing not-equipped with communal facilities (centralised electricity, heat, water supply and sewage facilities) – 2.12 m^3/resident and year. The term inadequate housing refers to homes lacking two or more components of communal facilities.

The established annual norms of municipal waste generation were multiplied with the number of population (per type of housing) and various entities/facilities and summed up over all objects. The average density of waste has been defined for each object separately. For example: equipped houses - 182 kg/m^3, uncomfortable houses - 214 kg/m^3 and so on (Mogilev city executive committee, 2015).

According to the norms, waste generation rate for Mogilev city was estimated as high as 170,748 tons per year. It was very important to fill in discrepancy between the estimated and the statistical data on waste collection by detecting possible gaps in the data. For example, based on the literature research and “qualified guess” estimates of the project partners it has been suggested that the local reports do not take into account the following initial data:

- home composted material (22,473 tons/year);
- collection of recyclables by informal recycling sector (IRS) (2,997 tons/year);
- littering in environment (uncontrolled dumping) (36,977 tons/year).

Those numbers may explain to some extent the occurring discrepancies and they were used for the further development of the future WM scenario.
Explanation on these assumptions is provided below.

The IRS represents individuals or groups of people that are neither organised, nor sanctioned by the government, yet, operating informally in the waste management business. Using the variable “percentage of urban population collecting informally”, “the number of working days per year” and “amount of informally collected material” the number of MSW illegally recycled was calculated (Ramusch, 2016b, 2015). The obtained results show amounts of the waste handled by IRS at the rate of 2,997 t/year. Table 15 contains the used assumptions for the estimation of the IRS.

Table 15: Estimation of diverted MSW from IRS (Ramusch, 2016a).

Input Data	Description	value
Percentage of urban population collecting informally	0.2% of 374,655 inhabitants	749 inhabitants
Number of working days	Number of working days excl. weekend and holidays	200 days

Amount of informally collected material		20 kg/day

With the help of field studies of the morphology content of the waste, food waste in private households and food waste in containers in Mogilev, the level of home composting was estimated as 22,473 t/yr. This calculation was performed on following information: share of bio-waste in the composition of total MSW is 27%; the number of people living in private households is 171,882; and the amount of waste per person is 484,2 kg/yr and cap (=171,882 t/yr * 484,2 kg/yr and cap * 27%)

The amount of mixed waste littered and illegally disposed to the environment results from the difference between formally collected waste, home composting and informally collected waste, self-pickup to landfills (= 170,748 t/yr – 87,601 t/yr – 22,473 t/yr – 2,997 t/y – 20,700 t/y = 36,977 t/yr).

4. Scenario Development in Case Study City

Five possible future scenarios were developed for Mogilev. These scenarios represent some of the variety of potential MSW management options. Following sections give an overview of the scenarios and waste flows, while more detailed description of the used technologies is provided in Chapter 5.

4.1.1 Future Scenarios of MSW Management System

Limited scope of the organized collection of municipal solid waste and recyclables, like low efficiency of separate collection and sorting, insufficient number of collection bins and outdated collection equipment, is one of the main problems in Mogilev. Another major problem is inadequate landfilling and lack of treatment capacities. During the project implementation, a National Waste Management Strategy of Belarus was published.

The national strategy points to the lack of modern technical standards in the existing waste treatment facilities (The Council of Ministers of the Republic of Belarus, 2017). The National Waste Management Strategy for Belarus suggests that no untreated waste is landfilled anymore. Instead, it has to be pre-treated in an MBT plant or combusted in a waste incineration plant. Only pre-treated waste is allowed to be landfilled at a sanitary landfill. Furthermore, all waste dumpsites have to be closed as they do not meet technical requirements (The Council of Ministers of the Republic of Belarus, 2017). The National Waste Management Strategy of Belarus 2017 was published after the scenarios in this thesis have been developed. Thus, it was necessary to verify whether scenarios correspond with the national strategy. The result showed that all scenarios are in accordance with the national strategy.

Five potential scenarios were developed for Mogilev to determine the most feasible waste management system. The main goal was to show several different strategic options for MSWM system development.

In line with the National Strategy, all future scenarios foresee following basic improvements in comparison with the Baseline Scenario:

- establishment of formal collection of uncontrolled dumped waste and elimination of illegal dumpsites;
- collection of WEEE and hazardous waste;
- waste treatment before landfilling;
- construction of a new sanitary landfill in accordance with best available technology.

The scenarios are developed for the year 2015, whereas future waste quantities for all scenarios are calculated based on the waste prognosis tool developed by Beigl (Beigl et al., 2003). Waste streams for all scenarios are shown in Annex 2.

Waste quantities that are illegally dumped or littered in the environment in the Baseline Scenario are redirected to the formal collection system in the future scenarios.

A separate collection for WEEE and hazardous waste is implemented in Mogilev in future scenarios. Nevertheless, as the treatment of this waste is impossible in the city[5], it has to be transported to Minsk for further treatment in compliance with latest technology standards. However, these two waste streams are outside of the system boundaries of this study and are not further evaluated.

It was decided to retain home composting amount in all scenarios at the level of the Baseline Scenario, as it is assumed that this traditional and well-established practice will remain in the private houses in the future.

Furthermore, it is known, that IRS carries unauthorized WM activities and diverts waste from MSW in Mogilev. Valuable materials are further processed and sold, invaluable components might be illegally dumped. It is assumed that this practice will remain and in all future scenarios quantities of informally diverted waste are assumed to stay constant.

Both home-composting and informal collection streams are excluded from the system boundary and are not further considered in calculation and assessment.

Following Table 16 outlines investigated future scenarios, organization of collection and treatment infrastructure

Table 16: Overview of baseline and future waste management scenarios in Mogilev

Scenario	Scenario description	Separate collection efficiency	MSW treatment infrastructure
Baseline	100% collection coverage. Separate collection of recyclables (paper, glass, plastic, metals) in bins and collection points. Manual sorting of mixed waste and after-sorting of collected recyclables. Small-scale composting of residual waste. Non-sanitary landfilling and illegal dumping.	Paper, glass, plastic, metals[6]: total separate collection rate in bins 0.6%, in collection points ~6.7%.	• Manual sorting plant • Old small-scale composting plant • Non-sanitary landfill
0 San. LF & MBT	Elimination of illegal dumping. Organisation of sanitary LF[7]. After-sorting of recyclables.	As in baseline	• Sorting plant • Aerobic MBT • Sanitary landfill
1 MBT-Recycling [wet/dry bin]	Separate collection of residual waste and dry recyclables in a two-bin system. Residual waste is treated in the aerobic MBT	Plastic 70% Metals 60% Glass 60% Paper 85%	• Aerobic MBT (including a module for sorting of dry-wet bin) • Sanitary landfill
2 MBT - Recycling	Separate collection of recyclables in different	Plastic 65%	• Sorting plant

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[5] Treatment facilities for WEEE and hazardous waste are not available in Mogilev.

[6] Not all recyclables are accounted here, part of recyclables is collected by other channels: by enteprises, schools etc., metals are collected separately by designated state enterprises.

[7] Diversion of MSW streams from littering/dumping to formal WM system and organisation of sanitary LF is an obligatory component also in Scenarios 1-4.

[gl, pl, pa, me, org comp]	bins, after-sorting at sorting plant. Separate collection and composting of organic waste. Residual waste is treated in the aerobic MBT	Glass 69% Metal 60% Paper 74% Organics 51%	• Aerobic MBT • Sanitary landfill • Open windrow composting
3 Incineration – Recycling [pl, gl, pa, me, org comp]	Separate collection of recyclables in different bins, after-sorting. Separate collection and composting of organic waste. Residual waste is combusted in the waste incineration plant.	Plastic 65% Glass 69% Metal 60% Paper 74% Organics 51%	• Sorting plant • Incineration • Sanitary landfill • Open windrow composting
4 Incineration – Biogas - Full energy recovery [gl, me, org biogas]	Separate collection of metal and glass to increase calorific value of incinerated waste. Organic waste is separately collected and processed for energy recovery in the anaerobic digestion plant.	Glass 69% Metal 60% Organics 51%	• Incineration • Anaerobic digestion • Sanitary landfill

4.1.2 Scenario 0: Sanitary Landfill, Aerobic MBT

Scenario 0 (zero) is based on the present waste management system with incorporation of some improvements.

The essential concept of this Scenario is fulfilling minimum requirements of waste management. That means, formal collection of illegally dumped waste, disposal at a sanitary landfill and pre-treatment of residual waste in a MBT plant. The rates of separately collected recyclables (glass, plastics, paper) remain the same as in baseline, residual waste is treated in the new aerobic MBT plant.

All scenarios with MBT technology produce RDF fraction. The term RDF (Refuse Derived Fuel) describes “a fuel that has been manufactured from processing municipal and bulky waste and production with high calorific value into homogenous RDF or secondary fuels for cement kilns or power stations” (European Commission, 2003). In Mogilev RDF can be used for co-incineration at power plants or in industrial furnaces, e.g. in cement kilns for cement production.

Figure 6 shows the material flow diagram of Scenario 0.

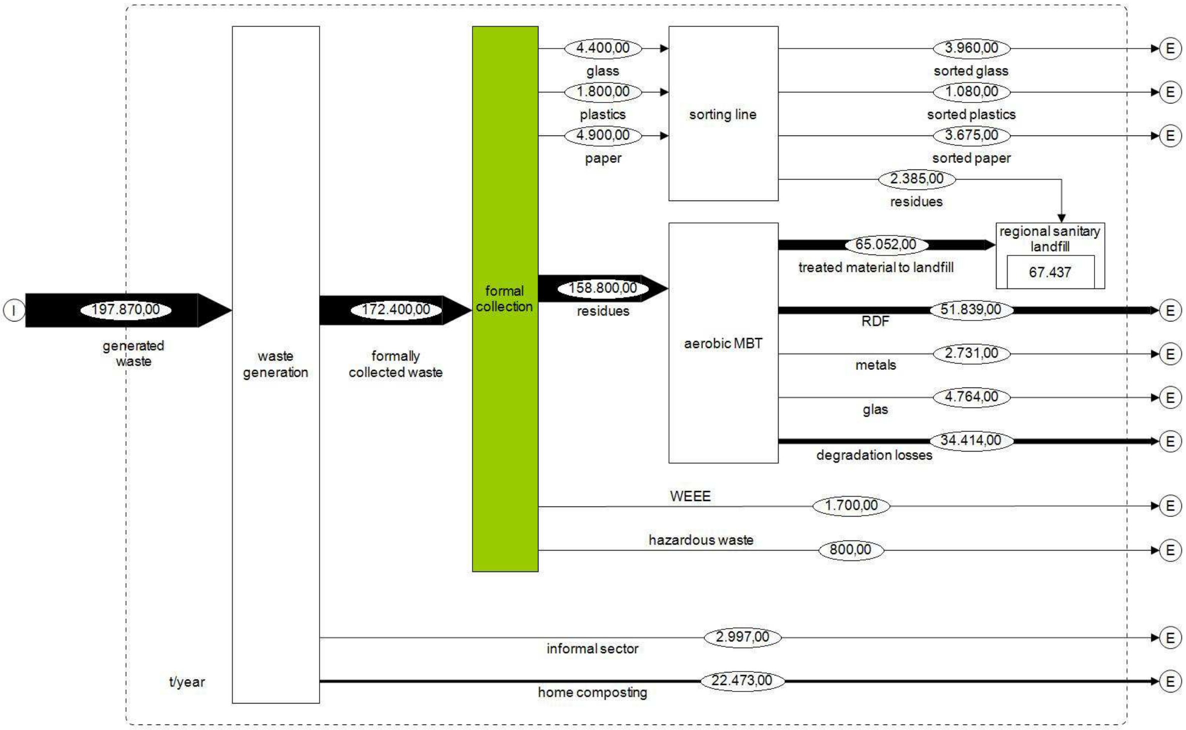

Figure 6: Material flow diagram of Scenario 0 - sanitary landfill and aerobic MBT

Figure 6 for Scenario 0 shows that recyclables are re-sorted at the existing sorting plant ZUBR (“ЗУБР“) and in the next step send to a recycling plant outside of system boundaries. The sorting residues are sent to sanitary landfill. Formally collected residual waste is treated in an aerobic MBT facility before landfilling. Valuable recyclables and RDF fraction are sorted out for further processing.

In Scenario 0 WEEE and hazardous waste are formally collected and treated in comparison to the Baseline Scenario. Treatment of WEEE and hazardous waste is not scope of this work as they are treated outside of the defined system boundaries.

4.1.3 Scenario 1: Aerobic MBT – Recycling [wet/dry bin]

Scenario 1 simplifies the separate collection system by using only two containers: wet and dry wastes are source separated into two containers and separately collected and recycled. Dry bins are used for collection of dry recyclable fractions - plastic, metal, glass and paper. Wet bins are used for collection of remaining residuals waste.

According to Pöttschacher (2016) a user friendly separation system using only one container for all types of recyclables could increase separate collection efficiency, sorting efficiency and recovery rate of dry recyclables. Thus, implementation of a dry-wet-bin collection system leads to higher efficiency of collection system and minimization of the amount of recyclables in residual waste.

Targeted collection rates for Scenario 1 were adopted from existing dry-wet-bin collection systems (source separation) in five regions in Austria and Germany (Huber-Humer, 2017; Pöttschacher, 2016):

- Plastic 70%
- Metals 60%
- Glass 60%
- Paper 85%

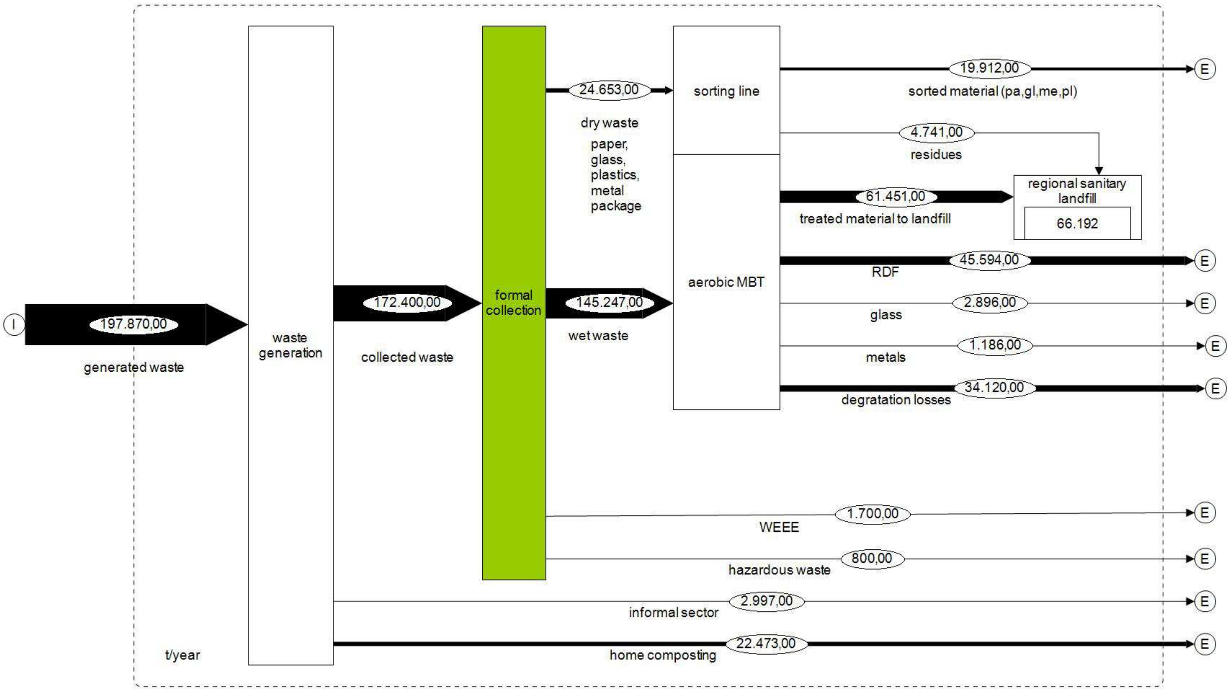

Figure 7: Material flow diagram of Scenario 1 - Aerobic MBT - Recycling [wet/dry bin]

Figure 7 shows that in Scenario 1 the manual sorting line ZUBR becomes part of the aerobic MBT plant. Recyclables - plastic, metals, glass and paper - are collected in a dry bin. They are pre-sorted in a manual line and then automatically sorted in the MBT plant.

Wet waste is aerobically treated in an MBT plant. Remaining valuable inert recyclables - metals and glass fraction are sorted out for further processing, high-calorific fraction is sorted out for production of RDF. Remaining stabilized sorting residues are sent to sanitary landfill.

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

4.1.4 Scenario 2: Aerobic MBT – Recycling [gl, pl, pa, me, org_{comp}]

Scenario 2 aims to maximize overall recycling in correspondence with the National Waste Management Strategy of Belarus 2017. Accordingly, all recyclables are collected separately to achieve high collection quality and re-sorted in the next step. Also, organic waste is collected separately to be treated in an open windrow composting plant for a production of marketable compost. This allows further reduction of the RDF moisture content and increase of its calorific value.

Figure 8 describes material flows in Scenario 2. The underlying recycling source separation rates are (den Boer et al., 2005):

Plastic	65%
Glass	69%
Metals	60%
Paper	74%
Organics	51%

Residual waste is pre-treated in the MBT plant, where high-calorific fractions are sorted out for RDF production and subsequent waste-to energy use. Formally collected WEEE and hazardous waste is handed over for further treatment to authorized waste management companies.

Additional amount of green waste, like wood chips or tree limbs, should be collected separately and added as structure material to a composting process of organic waste to improve the aeration of the windrow (Binner, 2017; Wurff et al., 2016). Chapter 5.1.3 describes a detailed description of the composting process.

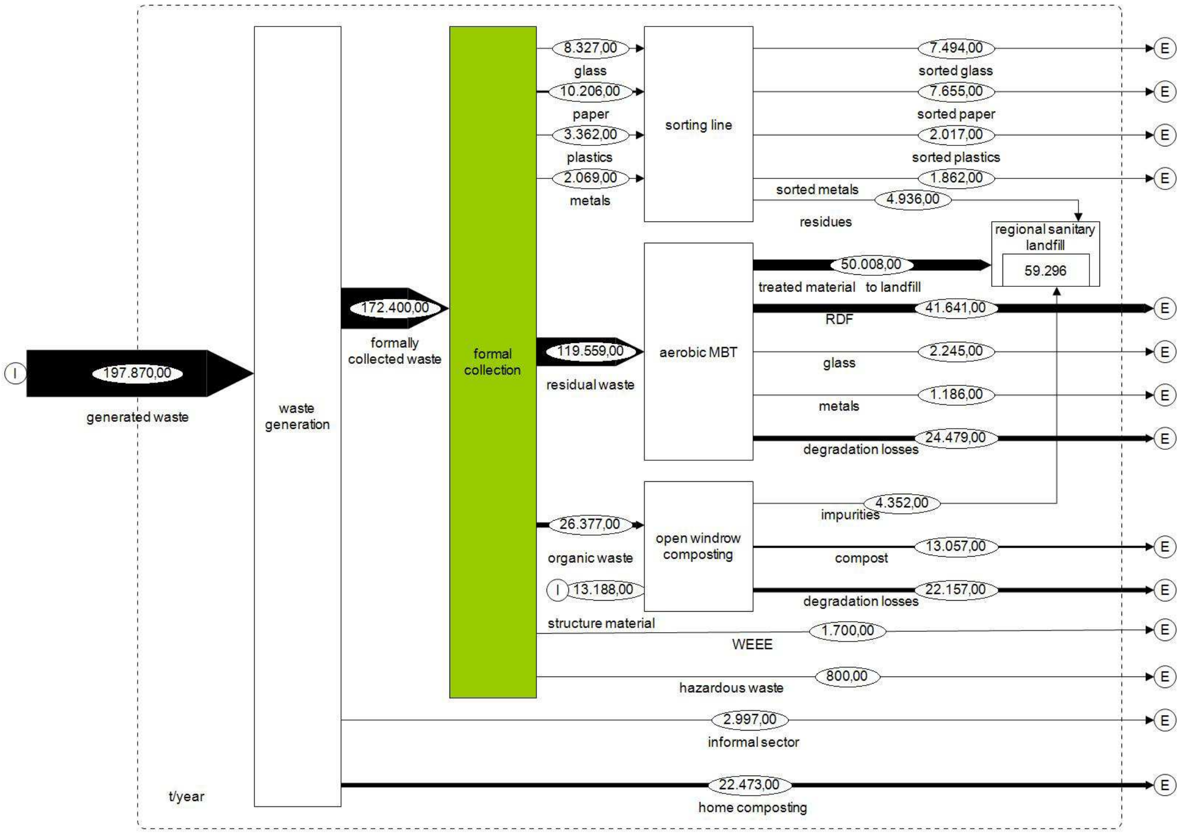

Figure 8: Material flow diagram of Scenario 2: Aerobic MBT - Recycling [gl, pl, pa, me, org_{comp}]

4.1.5 Scenario 3: Incineration - Recycling [pl, gl, pa, me, org_{comp}]

Enhancing recycling (1st priority) and energy recovery (2nd priority) are the main targets of Scenario 2.

Incineration is an effective way to reduce amount of waste and its harmful potential at the same time converting waste into energy. In comparison to other waste treatment methods, incineration has advantages, which correspond with the aims of the National Waste Management Strategy for Belarus, 2017, like: reduction of volume and weight; requirement for a smaller disposal area for ash residues compared to MSW landfill disposal, recovery of energy (Hulgaard and Vehlow, 2011; The Council of Ministers of the Republic of Belarus, 2017); destruction of organic matter and organic pollutants.

Figure 9 describes the material flows in Scenario 3. In this Scenario recyclables are collected separately at a high collection rate and quality and re-sorted. The underlying source separation rates are (den Boer et al., 2005):

Plastic	65%
Glass	69%
Metals	60%
Paper	74%

- Organics 51%

Residual waste is combusted in the municipal waste incineration plant. In Scenario 3 waste incineration generates electricity and heat. The option of energy and heat generation depends on ability of end users to utilise produced electricity and power. In most cases power can be distributed and sold via national grid, which is the most common form of energy recovery (den Boer et al., 2005), while finding the heat consumer is usually a more challenging issue. A description of an incineration process is outlined in chapter 5.1.4 (Department for Environment Food & Rural Affairs, 2013). Additionally, organic waste in Scenario 3 is collected separately to be prepared as compost for further sale. A description of a composting process is outlined in chapter 5.1.3.

WEEE and hazardous waste are formally collected to be treated by an authorized waste management company in next step.

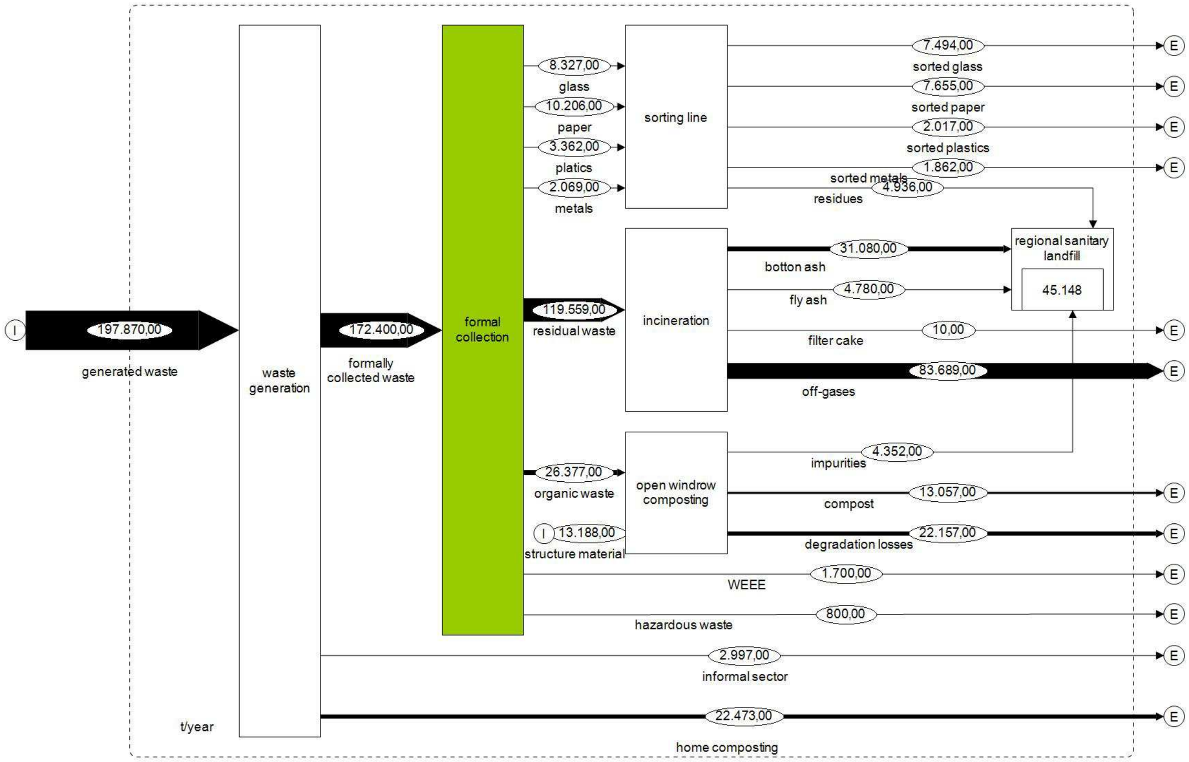

Figure 9: Material flow diagram of Scenario 3: Incineration - Recycling [pl, gl, pa, me, org$_{comp}$]

4.1.6 Scenario 4: Incineration – Recycling [gl, me, org$_{biogas}$]

Scenario 4 aims at maximisation of energy recovery from MSW as highest priority. To meet this target two most common state-of-the-art technologies are applied, particularly waste incineration plant and anaerobic digestion plant. The purpose of the anaerobic digestion treatment of biowaste is the reduction of organics and their reactivity, production of biogas, and furthermore usage of digestate as compost (Angelidaki and Batstone, 2011).

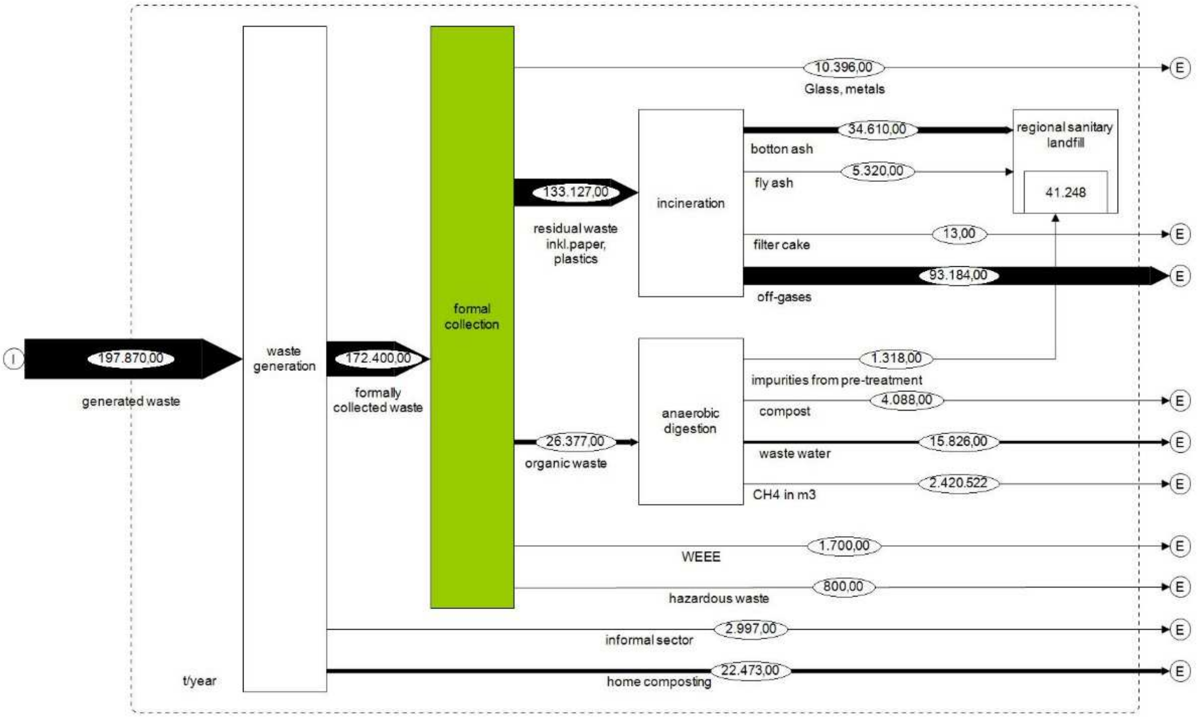

Figure 10: Material flow diagram of Scenario 4: Incineration – Recycling [gl, me, org_{biogas}]

Figure 10 shows the material flow in Scenario 4. To increase calorific value of incinerated waste inert materials (glass and metal) are collected separately in one bin. On the contrary, paper and plastic remain in the mixed waste in order to increase calorific value of the waste. Glass and metal is brought further to recycling plants and biowaste is processed for energy recovery in an anaerobic digestion plant. The assumed source separation collection rates for glass, metal and organics are shown below (den Boer et al., 2005):

- Glass 69%
- Metal 60%
- Organics 51%

Similar to all scenarios collected WEEE and hazardous waste is handed over for further treatment to authorized waste management companies.

5. Treatment Technologies

Diverse MSW sorting, treatment and disposal technologies are included in developed future scenarios. Technological solutions chosen for scenarios are state of the art and are common practice in western and eastern European Union countries. An outline of selected technologies is shown in Table 17.

Table 17: Technologies used in the future WM scenarios in Mogilev

Technology	Input	Output
Manual Sorting	Separate collected paper, glass, metal, plastic	Sorted recyclables
MBT for dry-wet bin	Mixed residual waste and recyclables from dry bin	Sorted recyclables, RDF, Stabilized material for landfilling
MBT	Mixed residual waste	RDF, Stabilized material for landfilling
Composting	Yard and kitchen waste	Marketable compost product
Incineration	Mixed residual waste	Incinerator Bottom Ash for landfilling, residues from air cleaning technologies, Electricity and Heat
Anaerobic digestion	Kitchen waste	Biogas, Marketable compost product
Landfill	Residues from MBT, composting, manual sorting, anaerobic digestion and bottom ash from incineration	-

A technical configuration of the listed treatment methods is described in chapters 5.1.1 to 5.1.6. A detailed technical description of listed treatment technologies that are chosen for Mogilev is given in the Master Thesis of Laura Scharenberg from TU-Dresden, prepared within WaTra project (Scharenberg, 2017). In her work Scharenberg conducted technical assessment of municipal solid waste management options for the Case Study Regions - Mogilev in Belarus and Derhachi in Ukraine.

5.1.1 Manual Sorting Station

Despite the overall technological trend towards automation of the sorting process, manual sorting station play an important role in future waste management system scenarios in Mogilev. A manual sorting plant is a unit with a physical removal of items from a waste stream mainly by persons (Tchobanoglous and Kreith, 2002).

Existing sorting station ZUBR with two sorting lines is already part of the Baseline Scenario. Following consultation with the stakeholders it was decided to keep this sorting station for re-sorting of separated collected recyclables in future scenarios for Mogilev. The ZUBR sorting station is in operation since 2009 with a capacity of 90.000 tons per year. This sorting capacity is sufficient for handling total amount of recyclables in all scenarios (Skryhan et al., 2016).

Use of automated separation systems is limited due to its expensive investment and high running costs, as well requirement for high technology level and for skilled stuff. A manual separation system requires lower technology level and simple to manage, as humans are able to recognize and separate materials without complex education (Tchobanoglous and Kreith, 2002).

Two methods of sorting process can be applied, positive and negative sorting. A method with sorting material of an elevated conveyor into bins under the conveyor is called positive sorting. Whether negative sorting is removal of contaminants from material intended to be recovered (Bilitewski and Härdtle, 2013). Both methods receive higher quality recyclable material like polyethylene, PET-bottles, paper, glass and metals.

Assumed sorting efficiencies for different waste fractions are given below in Table 18.

Table 18: Sorting efficiencies for different waste fractions

Fraction	Sorting Efficiency[8]
Plastic	60%
Paper	75%
Metal	90%
Glass	90%
Organics	-
Dry-wet bin plastic	50%
Dry-wet bin paper	75%
Dry-wet bin metal	60%
Dry-wet bin glass	60%

Sorted and packed recyclables are sold to other companies for further treatment. Sorted residues are compressed and transported to landfill. Chapter 5.1.1 provides more information on the sorting plant.

5.1.2 Mechanical Biological Treatment

Mechanical biological treatment (MBT) plants were first designed in the 90-is of the last century to stabilise the organic fraction and reduce the amount of the landfilled waste. They are now used to extract fuels and fractions of different materials (Bilitewski and Härdtle, 2013). MBT has two stages of waste processing - mechanical and biological; this kind of treatment decreases the negative environmental impacts of waste disposal by reduction of biodegradability of waste compounds and reduces the amount of landfilled waste by extracting metals and other fractions for production of fuel or direct energy recovery in case of anaerobic plants (Bilitewski et al., 2011).

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[8] Sorting Efficiency from already separately collected waste

5.1.2.1 Description of MBT

Prior biological treatment, the mechanical treatment of waste takes place to separate the high-calorific fractions and recyclables from the residual waste. It includes shredding, magnetic separation, sieving, and homogenization, nevertheless, going through all stages is not mandatory (Bilitewski et al., 2011).

The types of biological treatment are:

- aerobic (rotting)
- anaerobic (digestion).

The process of anaerobic treatment is not further discussed, since it is not applied in the developed scenarios.

The aerobic process is intended to stabilise the material by decomposing the organic part of the residual input material in the presence of free oxygen with aerobic organisms (den Boer et al., 2005). The processes may take place in aerated shafts, containers or boxes for 4 to 5 weeks. Subsequently, the processed material is placed to indoor windrows for another 9-10 weeks. To find out the accurate duration of the process one has to consider the industrial capacity of the particular MBT facility since they do vary a lot (Bilitewski et al., 2011; Bilitewski and Härdtle, 2013).

Figure 11 shows possible process configuration of the MBT plant for the city of Mogilev:

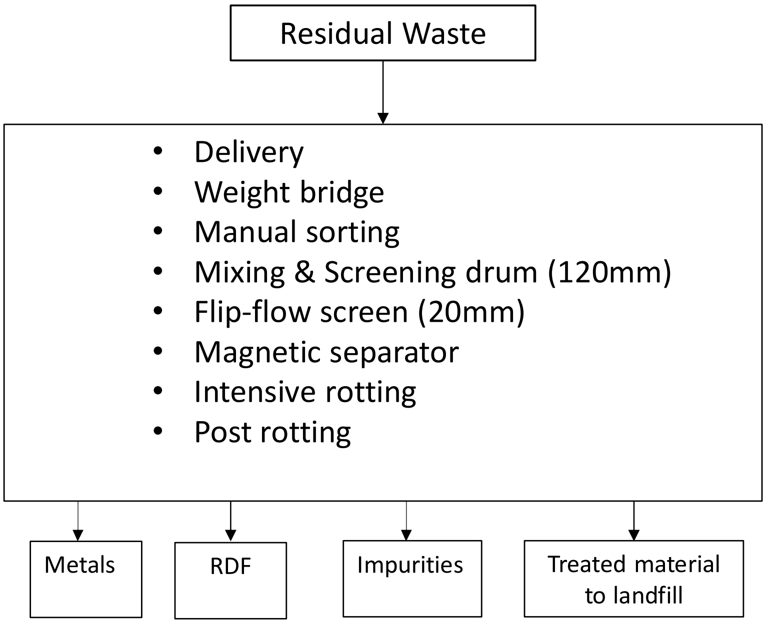

Figure 11: Technological scheme of installation of MBT (adapted after Dippert and Fenzl, 2005; Neubauer and Öhlinger, 2006)

The automatic sorting units like NIR scanners, ballistic or air separators are essential for the MBT facilities with the high yearly input of residual waste (like in Mogilev) (Scharenberg, 2017).

Minimum technical requirements imply weight measurement of the in-coming material on a weight bridge. Residual waste is then moved to a flat bunker for manual sorting. Then the material is transported to the drum for mixing and screening. There it gets sifted through and separated by fractions: smaller than 120 mm and bigger than 120 mm. The coarse fraction (> 120 mm) is outsourced to another waste processing company or to cement kilns for heat treatment. A fine fraction (< 120 mm) gets sieved again and separated into two fractions: less than 20 mm and 20 to 120 mm size particles at the screen with a reverse flow. Subsequently, the fraction measuring from 20 to 120 mm will be used as RDF. After crushing of the finest fraction (i.e. less than 20 mm), the material is moved to the magnetic separator, where the metals being extracted from, and afterwards moved to the flat bunker for storage. This material now is ready for the stage of biological treatment.

The biological treatment, which is based on simple windrow rotting, requires only basic technological equipment. The biodegrading starts with aerated windrow boxes, where the intense rotting for 4-5 weeks occurs. It is recommended to flip the material over several times with the help of wheel loader. After 4 to 5 weeks of intensive rotting, the material may be removed by the wheel loader to covered shafts. There are two possible ways to utilise the end-product of stabilising processes: to landfill it or to use it for the recultivation of degraded land (Bilitewski et al., 2011; den Boer et al., 2005; Scharenberg, 2017).

The assumption about the amount of RDF, metals, processed materials, waste disposal and the loss from processing is based completely on the literature data and thoroughly adapted to local conditions and characteristics of local waste. However, the actual composition and amount of the material output depend on the daily waste composition and the configuration of the facility (Bilitewski et al., 2011; Bonnet and Viertel, 2005).

The percentage of the MBT outputs is presented in Table 19. The percentage varies from case to case, it is affected by the input MBT waste composition in each scenario, which in turn depends on the fractions sorted out by separate collection. For each scenario exact input and MBT waste composition was calculated and used for calculation of produced outputs. The extracted glass and metals are recognized as low quality recovered materials in all cases.

Table 19: Outputs of MBT plant (adapted after Bonnet and Viertel, 2005; Doedens et al., 2003)

Output	Application	Mass balance
RDF	High calorific fraction for energy recovery	30-35%
Metals	Extracted recyclables for material recovery	1-2%
Glass	Extracted recyclables for material recovery	4-12%
Treated material to landfill	Stabilized material for landfilling	35-44%
Degradation losses	Material lost through processing	11-27%

Main technical characteristics of the proposed aerobic MBT facility assumed for calculations are provided below in Table 20 (Wünsch, 2013):

Table 20: Technical characteristics of the aerobic MBT (Wünsch, 2013)

Recovery rate	
Fe	90%
Aluminium	80%
Copper	80%

Minerals	60%
Glass	60%
Transfer rates (transfer to high caloric fraction)	
Organic	20%
Wood	80%
Textiles	80%
Minerals	5%
Composites	85%
Pollutants	10%
Others	50%
Fine fraction <10mm	5%
Fe/Ne-Metals	5%
Paper/Cardboard	75%
Glass	5%
Plastics	80%

It is proposed to use the above-mentioned facility in the future MBT for Scenario 0 and Scenario 2. In the case of Scenario 1 (dry/wet bin), the MBT should be adapted for special waste collection system. The technical configuration of the MBT facility, proposed for use in this project, for dry/wet bin sorting is presented by Dobreva (2018).

5.1.3 Composting

Composting - is the decomposition of the organic substances in usually separately collected biogenic waste by microorganisms under controlled aerobic conditions for producing high quality, humic rich composts for ultimate safe processing and usage. The composting systems differ from low-tech manufacturing systems, such as simple windrow composting, to the high-technology systems, such as fully automated closed systems (Krogmann et al., 2011).

The basic parameters of the composting system to be taken into account:

(1) the quantity and composition of waste to be processed, (2) proximity to the nearest neighbours, (3) scheduled waste supply (storage capacity), (4) the need for the adjustments (e.g. space, personal, machines), (5) assessment of the final product: disposal, industrial or agriculture usage (Binner, 2012b; Krogmann et al., 2011).

After analysing the above parameters, the open windrow composting for the simulation of Scenario 2 and Scenario 3 was selected, which assumes a natural aerated static windrow composting with the recurrent turning of the material (Binner, 2012b). The planned capacity of the facility in these cases is approximately 39,565 tons per year, of which 26,377 tons are bio-bin waste and 13,188 tons of structure materials.

About 30% of the structure material from park and garden waste is mixed with delivered waste. To reduce the size of the particles and to destruct the organic matter, green waste must be pre-grinded. After such a preparation the yard waste has to be mixed thoroughly with a small quantity of kitchen waste with the help of special machines (e.g., mixing drum). High water content contributes to the beginning of rotting. Wheel loaders or other suitable forming machines are used to form windrows. Turn over of the windrows at regular time intervals of time windrows is done and the windrows are evenly wetted with water when necessary. As the decay, the volume of the windrows decreases and the remaining matter stays in the heaps. After 6 months since the start of the composting process, the finished product is checked and its excess may be added to the fresh composting material (Binner, 2012a; Diaz et al., 2002; Krogmann et al., 2011; Scharenberg, 2017).

An example of composting system is illustrated in Figure 12.

Figure 12: Example of open windrow composting (Binner, 2008)

An example of an suitable configuration was adapted according to different studies (Binner, 2012a; Diaz et al., 2002; Krogmann et al., 2011; Scharenberg, 2017) and presented in the following Figure 13.

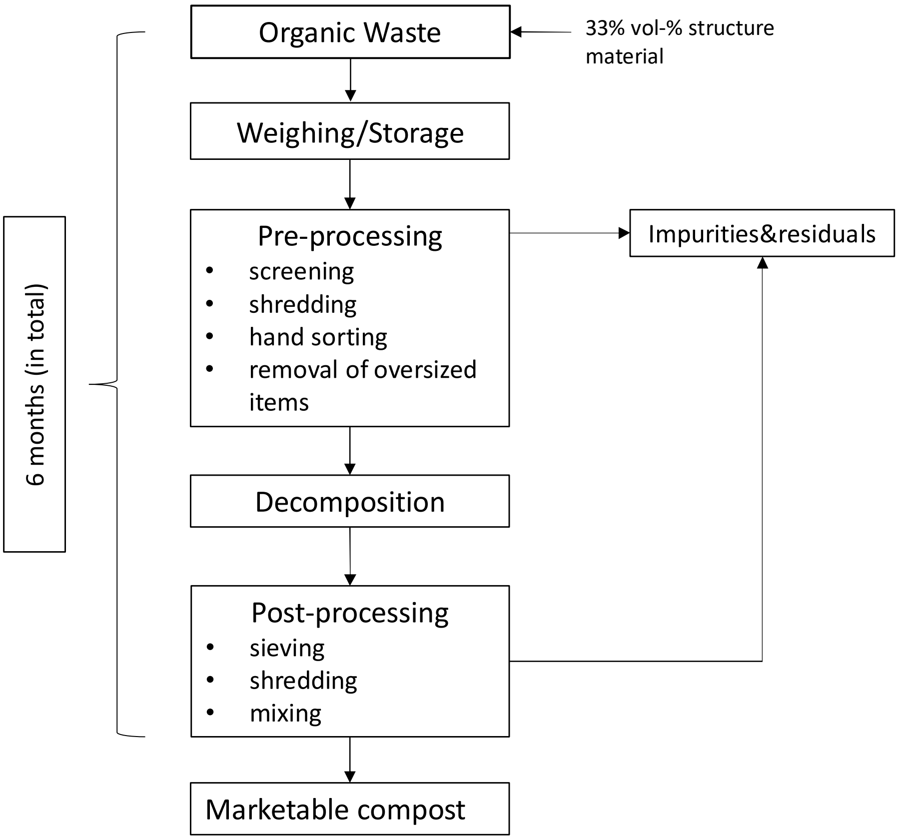

Figure 13 Flowchart of composting process (adapted after Diaz et al., 2002; Kranert and Cord-Landwehr, 2010; Krogmann et al., 2011)

Stones, glass, metal, plastic bags or oversized items must be removed at the stage of pre-treatment with the trommel sieve, magnetic separator or manual sorting. The quality of compost and its value is higher, if the better primary processing/sorting was conducted. Typically, the quantities of impurities in the initial material for composting may reach up to 11% (Binner, 2012a; Scharenberg, 2017).

The process of composting is basically rotting / decomposition. It consists of two stages - the stage of intensive rotting and post-rotting. After its finishing contaminants and unprocessed residues must be removed or landfilled. As a result, the compost comes out as a high-quality commodity.

The implementation of an effective composting process without negative impacts on the environment requires an efficient control of the main influencing process parameters. The following parameters of the process are usually subjected to control: biodegradability, moisture content, oxygen content, material structure, particle size and aeration, temperature and purity, nutrients and pH level. In respect of the technological features of the process of composting and the need to obtain high-quality marketable end-product, all the above parameters are subject to strict control (Binner, 2012a; Krogmann et al., 2011).

5.1.4 Incineration

Speaking of incineration, it should be noted its high cost compared to landfill, yet a lot of advantages in the environmental aspect may not be omitted too. The incinerated organic content of the waste produces energy and heat that can be used to generate electricity or for district heating (Bunge, 2015).

Here are the main advantages of incineration:

- maximal reduction of the waste volume;
- low pollutant and low reaction of the bottom ash;
- production of energy
- destruction of organic pollutants and disinfection

The existing disadvantages are high investment costs (provision of security requirements, for example) and problem of public acceptance (Hulgaard and Vehlow, 2011). Waste incineration plant may also become one of the city's places of interest, as for example, waste incineration plant in Vienna (Austria), which has become a local landmark and tourist attraction (see Figure 14).

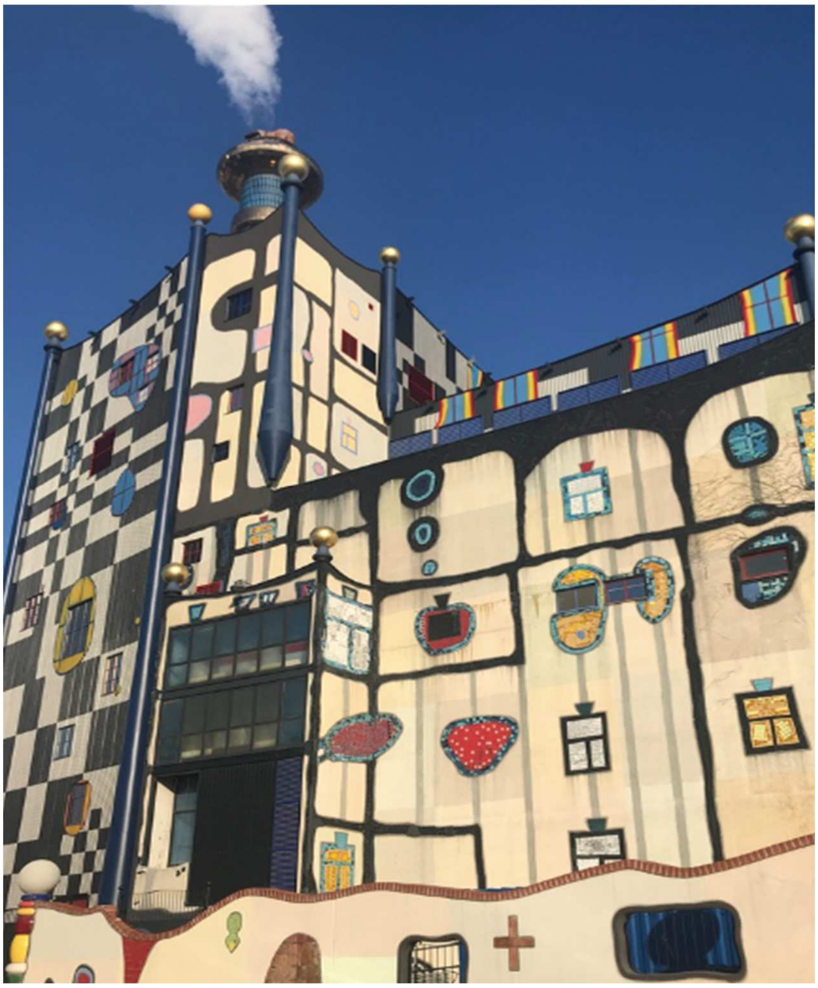

Figure 14: Spittelau WTE facility in Vienna, Austria (shoot by the author).

Different types of waste require different combustion technologies (Hulgaard and Vehlow, 2011). Approximately 90% of all mixed waste incineration facilities in Europe use the grate for the combustion of solid waste (European Commission, 2006).

Grate incineration with electricity and heat generation is suggested for the case study in Mogilev. Figure 15 shows a standard process configuration of an incineration plant.

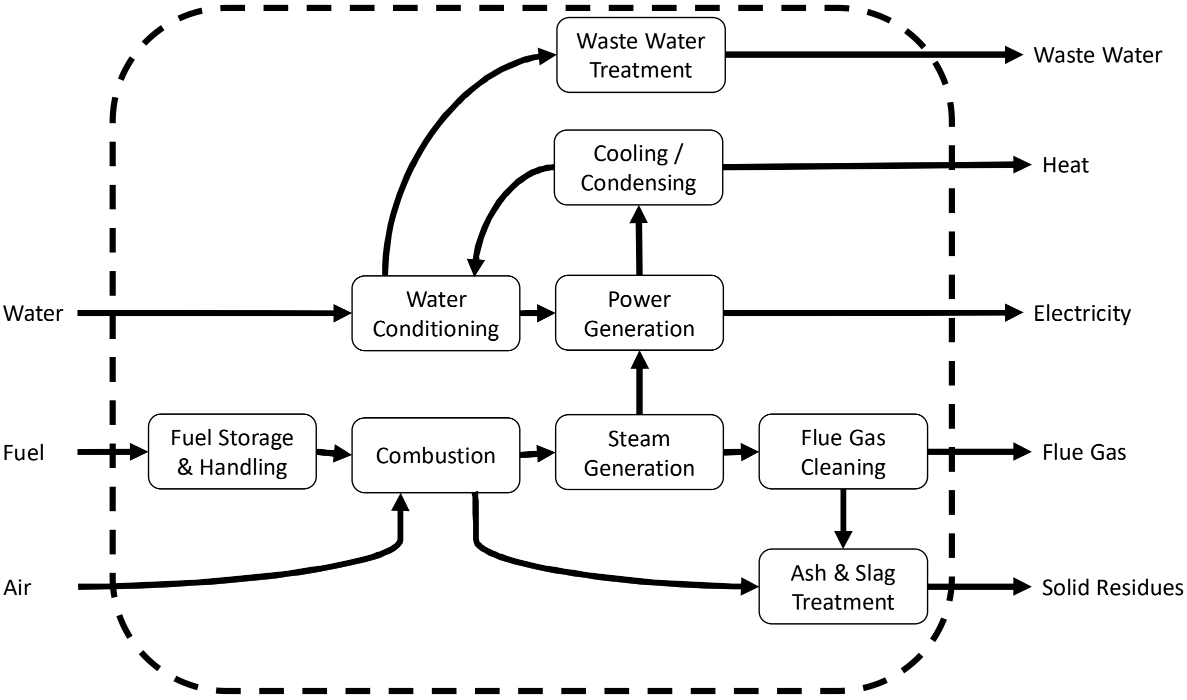

Figure 15: Incineration Plant Flow Diagram (adopted after Hulgaard and Vehlow, 2011)

Components of the facilities of waste incineration on the grate (European Commission, 2006; Umweltbundesamt, 2002):

- delivery bunker
- incineration grate,
- bottom ash discharger,
- incineration air duct system,
- incineration chamber,
- auxiliary burners,
- energy recovery system,
- flue gas cleaning.

The grate-firing is a continuous process (24 hours), while the waste delivery takes place only in daytime. For consistent supply of furnaces with the processing materials, there is a huge underground bunker built on the most plants. It is equipped with a grapple crane and is also used for mixing and homogenization of the waste to maintain constant calorific value. Incinerating of waste takes place under the temperature between 850° - 950°C. As the movement of the grate, ash falls down and hits the bottom of the ash chamber located below. The flue gases arise in the secondary combustion chamber during burning at a temperature reaching up to 850 - 1000°C. Later, they are getting cooled to 200-400°C in the special boiler. Throughout the whole process the superheated steam (max 40 bar, 400°C) being produced, which drives the turbines to produce electricity (Bilitewski and Härdtle, 2013; Department for Environment Food & Rural Affairs, 2013; Hulgaard and Vehlow, 2011)

The combustion on the grate must meet the following requirements (Scharenberg, 2017):

- Quality of input material: LCV (Lower calorific value) = > 6,5 MJ/kg and <12 MJ/kg grain size < 300 mm.

It is always beneficial to have an external user that can utilise thermal energy and to supply electricity to the public power system.

The solid residues (ashes) are an output of the incineration process. The Table 21 below presents the percentage of main products of the combustion process considering the recovery of materials and energy production (Bunge, 2015; Scharenberg, 2017; Umweltbundesamt, 2002):

Table 21: Products of combustion technologies (Department for Environment Food & Rural Affairs, 2013)

Outputs	State	Quantity of original waste amount	Comment
Bottom Ash (BA)	Solid residue	26%	Potential use as non-biodegradable, non-hazardous waste for disposal
Metals (ferrous and non-ferrous)	Requires separation from MSW or BA	1%	Sold for re-smelting
APC residues (incl. fly ash, waste water)	Solid residue/ liquid	4%	Hazardous waste for disposal
Emissions to atmosphere	Gaseous	Represents ~70%	Cleaned combustion products

Main technical characteristics of the incineration plant assumed for calculations are listed below in Table 22 (Wünsch, 2013):

Table 22: Technical characteristics of the incineration plant (Wünsch, 2013)

Parameter - Waste Incineration plant	
efficiency of incineration [EF]	0.97
concentration N_2O in mg/Nm^3	2
flue gas volume in Nm^3/t Input	5,500
electrical net efficiency	10%
thermal net efficiency	35%
fuel oil in % of thermal input	2.0%
natural gas in % of thermal input	0.5%

5.1.5 Anaerobic digestion

Anaerobic digestion involves the oxygen-free processing of biodegradable organic waste using microorganisms accompanied by release of biogas. This technology allows to recycle organic solid waste and thus contribute to reducing carbon dioxide emissions (Jansen, 2011).

The advantages of anaerobic digestion are:

- production of energy;
- contribution to the reduction of greenhouse gas emissions, saving practically all the nitrogen from the feedstock in organic or ammonium form;
- digestate contains significant amount of nutrients can be used in agriculture as fertilizer. It produces energy, which can later be used on the spot.

Depending on type of the input material, the anaerobic digestion system can have different technological schemes (Jansen, 2011):

- dry/wet digestion
- thermophilic/mesophilic digestion
- one-stage/ two-stage digestion
- one-phase/two-phase digestion

Wet mesophilic two-step digesters are proven in the recovery of organic substances from MSW.

Figure 16 shows the process plan of the anaerobic digestion system. Post-rotting (composting) begins after the anaerobic digestion phase is over. Coupling anaerobic digestion with composting in a single technological process has proved its efficiency, as reported by the Witzenhausen-Institut (Witzenhausen-Institut für Umwelt, Abfall und Energie, 2012).

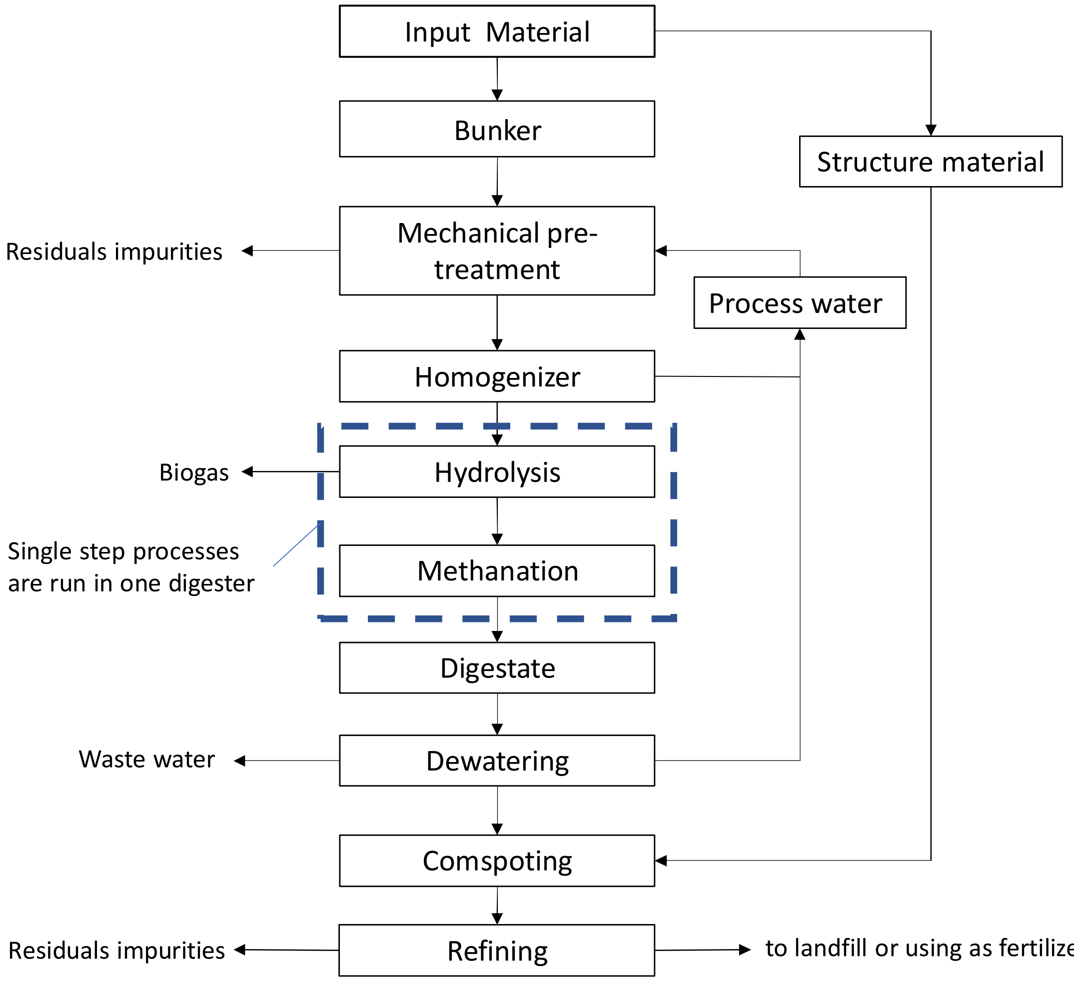

Figure 16: Draft plan of an anaerobic digestion plant (adapted after UBA, 2014)

Based on German practical experience, anaerobic digestion plant for biodegradable waste from MSW can produce up to 80-140 m^3 of biogas from one ton of biomass[9] with the methane concentration of 50-60%, which corresponds to 50 - 80 m^3 of natural gas (Scharenberg, 2017). Depending on the degree of enrichment/purification, biogas can be used either for heating, or for electricity production (200 - 300 kWh from a ton of waste), or as a motor fuel for internal combustion engines.

Wet mesophilic two-step digesters with an internal combustion engine for electricity and heat production was chosen for Mogilev case study.

Depending on the original composition and type of the biodegradable organic matter, the percentage of raw outputs can fluctuate dramatically. Following outputs composition is assumed for the selected digestion system in this thesis (Bilitewski and Härdtle, 2013; Jansen, 2011):

- impurities from pre-treatment 9 mass-%,
- wastewater 55 mass-%,
- digestate 20 mass-%,
- biogas 15 mass %.

Main technical characteristics of the anaerobic digestion plant assumed for calculations are listed below in Table 23 (Wünsch, 2013).

Table 23: Technical characteristics of the anaerobic plant (Wünsch, 2013)

Anaerobic Plant	
Target water content input fermentation	90%
Fraction of methane by volume	60%
Methane slip by transfer of fermentation residues to composting in Vol.-% CH$_4$	1%
Methane slip Power unit	0.5%
Electrical net efficiency Power Unit	35%
Thermal net efficiency Power Unit	12%
Fermentation of low caloric Fraction	**Specific Gas Yield in Nm^3/Mg oTS**
Organic	500
Others	100
Fine fraction <10mm	450

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[9] dry matter

5.1.6 Landfill

The existing waste management hierarchy rates the landfilling as the least preferred practice which should be avoided as much as possible. Comparative cheapness and relatively low technological requirements to such a way of disposal of non-recyclable residues from the reprocessing waste make it very popular in many countries though (Shekdar, 2009).

Construction of a new sanitary landfill that meets minimum requirements of modern engineering standards was assumed mandatory for all scenarios. An important and difficult task is to find a suitable place for the construction of a new landfill, which would meet not only environmental requirements but also the requirements of citizens. Location of landfills outside the city will increase the investment costs for infrastructure and transport costs for local authorities (Bosompem et al., 2016).

It is assumed that existing non-sanitary landfill and all currently existing dumpsites in and around Mogilev, which do not fulfil environmental and technical standards, should be closed for all future scenarios.

International standards for the construction of waste disposal sites have many technical and engineering requirements to that kind of facilities like the shape of the base, the side slopes, thickness of the final cover, height/depth, geometry of the cells (height, length, slopes) and the operating parameters - density of waste, length of the working surface, intermediate cover (Aivaliotis et al., 2004). However, the detailed description of the planning, building, and operation of the landfill is beyond the scope of this study, therefore only following basic parameters are addressed:

- The lifetime of the landfill: 20 years (Tsilemou and Panagiotakopoulos, 2006b).
- Input material: treated mixed municipal waste from the MBT plants, the residues from manual sorting and composting (waste, containing hazardous components and WEEE are not disposed at landfills)
- The landfill must guarantee free leachate discharge and must be equipped with systems of collection and treatment of leachate.
- The landfill gas collection system is not needed, since pre-processed and stabilised MBT waste emits significantly less gas than untreated waste (less than 50% of the original gas production potential), and therefore its collection is not necessary (Binner, 2017).
- Total Organic Carbon Content (TOC) ≤ 18 mass-% (Scharenberg, 2017).

6. Indicator Assessment

The next chapter describes main outcomes of the indicator evaluation and is broken down into four subchapters. The evaluation and comparison of the scenarios utilized six economic (chapter 3.4), six environmental (chapter 3.6), two social (chapter 3.5) and four technical (chapter 3.7) indicators. Material flow analysis is conducted for each scenario to identify capacities of waste treatment and disposal facilities.

6.1.1 Economic Assessment

This section presents the economic assessment of developed waste management scenarios for Mogilev.

6.1.1.1 Total Annual Discounted Costs of Waste Management System

The total cost of waste management system is a major analysis parameter of scenario economic feasibility. This indicator covers three subsystems:

- bins & container system
- trucks & collection
- treatment & disposal.

Total Annual Discounted Costs of Subsystem Bins & Container system

Following costs of subsystem bins and container are required for the calculation:

- Equivalent Annual Discounted Total Purchase cost,
- Equivalent Annual Discounted Total Location Costs of bins
- Annual Maintenance Cost of bins.

Based on the information provided by Belarusian partners the 'Equivalent Annual Discounted Total Location Costs of bins (EADTLCbins i(j)) are taken as EUR 70 for construction of one container (Skryhan, 2017b).

The 'Equivalent Annual Discounted Total Purchase Cost of bins (EADTPC bins i(j)) is calculated as multiplication of number of bins for waste stream I in sector j, and purchase price of bins.

The city Mogilev has already containers available for collection of residual waste, plastic, glass and paper. Thus, only additional required containers have been taken into account for future scenarios. Table 24 lists density of containers as well as frequency of waste collection that are taken into account for the calculation of bins number.

Table 24: Density of containers and frequency of waste collection

Input material	Bin capacity (m^3)	Density (kg/m^3)	Frequency
Residual waste	1.1	125	daily
Plastic	1.1	25	1 time per 7 days
Glass	1.5	250	1 time per 14 days
Paper	1.1	90	1 time per 7 days
Metal	1.1	70	1 time per 14 days

Organics	240 l.	250	daily
Dry waste (pl, me, gl, pa)	1.5	60	1 time per 7 days

Number of bins, as shown in Table 26, is calculated based on the Ukrainian guidelines for collection organization, transportation, processing and disposal (MRD, 2010b)[10]. Additionally, Table 25 provides purchase prices for bins that are investigated on local level by project partners at BRU.

Table 25: Assumed purchasing prices for bins

Type of container and its volume	Purchase Price (€ per bin)
Container for residual waste (1.1 m^3)	100
Container for plastic (1.1 m^3)	100
Container for glass (1.5 m^3)	100
Container for paper (1.1 m^3)	100
Container for metal (1.1 m^3)	100
Container for organics (240 l)	100
Container for dry recycl. of dry-wet bin (1.5 m^3)	200

Table 26: Additional number of bins required for waste stream j in Mogilev.

	Scenario				
Input Material	**0**	**1**	**2**	**3**	**4**
Residual waste	3,305	2,832	1,933	1,933	2,408
Plastic	760	0	2,313	2,313	0
Glass	0	0	317	317	0
Paper	745	0	2,032	2,032	0
Metal	0	0	1,292	1,292	0
Organics	0	0	3,202	3,202	3,202
Dry waste (pl, me, gl, pa)	0	1,470	0	0	955

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[10] National guidlines for Belarus were not avaible in the course of this thesis.

Table 27: Total annual costs for bins for future scenarios

	Scenario				
Input Material	**0**	**1**	**2**	**3**	**4**
Equivalent Annual Total Purchase Cost of bins (€/year)	24,053	28,861	55,444	55,444	37,598
Equivalent Annual Total Location Cost of bins (€/year)	16,837	15,057	38,811	38,811	22,977
Annual Maintenance Cost of bins (€/year)	481	577	1,109	1,109	752
Total Annual Investment costs of bins (€/year)	40,891	43,918	94,255	94,255	60,575
Total annual cost for bins (€/year)	**41,372**	**44,495**	**95,364**	**95,364**	**61,327**

*Annualization factor – 20 years

Total Annual Discounted Costs of Subsystem Trucks & Collection

Following information is required for the calculation of the 'Total Annual Costs of Subsystem Trucks and Collection':

- Equivalent Annual Discounted Total Purchase Cost of CVs,
- Annual Operating Costs of CVs,
- Annual Maintenance Cost of CVs
- Annual Total Personnel Costs of CVs

The indicator 'Equivalent Annual Discounted Total Purchase Costs of Collection Vehicles' (EADTPCCV i (j)) is calculated by multiplying the number of collection trucks for a specific scenario and the purchase price for a collection truck.

In the Baseline Scenario collection trucks are available, but they are to a large extent outdated and have low efficiency (e.g. low compression rate). Since municipality plans gradual upgrade of the collection fleet, it was decided to assume replacement of all trucks for new for handling future waste amounts.

The Ukrainian methodological recommendations regarding organization of collection, transportation, processing and disposal of waste were used for the calculation of number of collection vehicles for the transportation of MSW (MRD, 2010).

Table 28: Number of collection trucks in each scenario and corresponding purchasing prices for collection trucks

	Scenario				
	0	**1**	**2**	**3**	**4**
Total number of CV per scenario	49	52	59	59	50

Purchase Price (€)	70,000	70,000	70,000	70,000	70,000

Table 28 shows for each scenario a certain number of CVs that was calculated according to the amount of collected recyclables and number of waste fractions (see material flow diagrams for each scenario).

The purchase price for a collection vehicle is assumed as EUR 70,000 for each scenario and was investigated on the local level (Skryhan, 2017b).

The 'Annual Total Personnel Costs of CVs' ($ATPC_{CV\ i\ (j)}$) for the subsystem trucks and collection sum-up the annual costs, including salaries and overheads, for all drivers of collection vehicles and collectors, as well annual costs for all reserve personnel. According to the data provided on local level, three number of workers per CV entered the calculation. Detailed information is referred in Chapter 3.4.1.

Table 29: Total Annual Discounted Costs of Subsystem Trucks & Collection

	Scenario				
Input Material	**0**	**1**	**2**	**3**	**4**
Equivalent Annual Discounted Total Purchase Cost of CVs (€/year)	171,774	181,956	206,195	206,195	173,765
Annual Operating Cost of CVs (€/year)	2,893,632	2,972,085	3,531,236	3,531,236	3,018,537
Annual Maintenance Cost of CVs (€/year)	412,258	436,695	494,868	494,868	417,036
Annual Operating costs (€/year)	3,305,890	3,408,781	4,026,104	4,026,104	3,435,573
Total Annual Discounted Costs of Subsystem Trucks & Collection (€/year)	**3,477,665**	**3,590,737**	**4,232,299**	**4,232,299**	**3,609,338**

*Personnel costs are included in annual operating costs

*Annualization factor 20 years

Total Annual Discounted Costs of Subsystem Treatment & Disposal

The indicator 'Total Annual Costs of Subsystem Treatment and Disposal' is a sum of the 'Total Annual Discounted Cost' for the MBT plant, incineration plant, anaerobic plant, sanitary landfill and composting facility. For the calculation of Total Annual Discounted Costs of Subsystem Treatment & Disposal capacities of treatment plants are required that are attached in Annex 2.

Annual investment and operating costs of treatment facilities shown in Table 30.

Table 30: Annual investment and operating costs of treatment facilities

	Annual investment costs [€/year]				
	Scenario				
Type of treatment facility	**0**	**1**	**2**	**3**	**4**
MBT	1,313,609	1,223,125	1,223,125	-	-
Incineration	-	-	-	3,489,240	3,802,574
Composting	12,734,820	12,410,203	12,964,673	15,329,858	15,174,748
Anaerobic Plant	-	-	-	-	563,883
Landfill	508,149	501,564	265,254	208,084	213,375
	Annual operating costs [€/year]				
	Scenario				
Type of treatment facility	**0**	**1**	**2**	**3**	**4**
MBT	5,279,226	5,004,076	4,452,560	-	-
Incineration	0	0	0	2,508,454	2,704,485
Composting	0	0	483,088	483,088	0
Anaerobic Plant	0	0	0	0	997,563
Landfill	360,015	355,349	219,340	181,259	170,156

The calculated results for indicator Total Annual Discounted Costs of Waste Management System are shown in Table 31.

Table 31: Results of economic indicator Total Cost of MSWM system

	Economic indicator				
	Scenario				
Indicator	**0**	**1**	**2**	**3**	**4**
Investment costs [€]	34,369,229	33,028,745	34,308,141	73,740,086	80,397,116
Annual operating costs [€/year]	8,945,613	8,768,783	9,182,201	7,200,013	6,310,966
Tot. ann. disc. costs [€/year]	12,734,820	12,410,203	12,964,673	15,329,858	15,174,748

Figure 17 illustrates the investment costs (blue bar) and the total annual operation costs (orange bar) in a graph presented below.

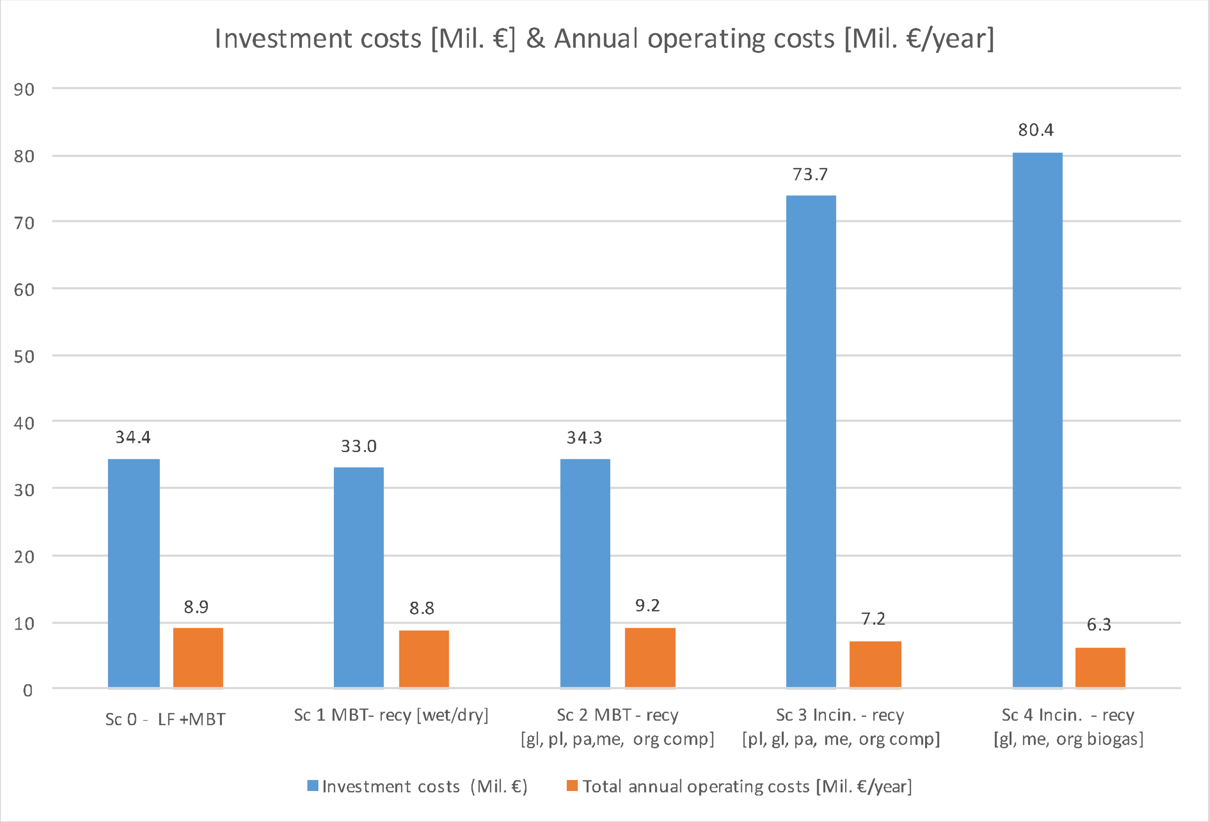

Figure 17: Total Costs of Waste Management System Scenarios

Table 31 lists the investment cost for each scenario that range from € 33 million (Scenario 1) to € 80.4 million (Scenario 4). The investment costs for each scenario vary depending on the suggested treatment and disposal facilities. Different waste quantities and types enters treatment and disposal facilities in each scenario. Depending on the waste amount and chosen treatment facilities, different number of collection vehicles and containers are chosen. For Scenario 3 and 4 anaerobic digestion and incineration plants are chosen as treatment technologies. Thus the investment costs are especially high in these two scenarios.

The investment costs of scenarios 3 and 4 are nearly 2.4 times higher as the costs for Scenario 1 and 2. In comparison to this variation of the investment costs the 'Total annual operation costs' range from € 6.6 million (Scenario 4) per year to € 8.9 million per year (Scenario 0). Although, the investment costs vary substantially the annual operating costs are closer to each other and have a negative correlation to the investment costs.

A decision on the basis of economic data requires more than a look on the investment and operating costs. All associated costs have to be viewed together with the 'Equivalent Annual Discounted Total Costs'. As listed in Table 31 the 'Equivalent Annual Discounted Total Costs' range from € 12.4 million per year (Scenario 1) to € 15.3 million per year (Scenario 3).

The 'Equivalent Annual Discounted Total Costs' demonstrate total costs of waste management system (investment + operation costs) throughout the WM system lifetime (assumed 20 years). The differences in 'Equivalent Annual Discounted Total Costs' depend on following factors:

- Amount of waste entering the treatment and disposal facilities;
- Operational costs of treatment and disposal facilities, that are subject fuel costs per collection vehicle, stuff costs.

As described above in chapter 3.4.1 (Materials and Methodology), the costs for subsystems ‘Bins and Container’, ‘Trucks and Collection’ and ‘Manual Sorting’ were available on local level. While the operational costs for MBT-plant, Incineration, anaerobic plant, sanitary landfill and composting facilities were calculated by application of costs curves based on European price level at 2003. To enable a better comparison of the operation costs a yearly inflation rate of 1.6 % was applied in the cost curves to get the purchase prices in the year 2025. However, the fact of lower price level in Belarus (e.g. lower salaries, lower costs of construction works), is not reflected in the available costs curves for Western Europe. This factor might influence the final results of scenario calculations.

6.1.1.2 Total Annual Discounted Costs of WM per ton of Formally Collected Waste

The total annual costs of a MSWM system per ton of formally collected waste were calculated based on results of previous indicators.

The ‘Total Annual Costs of the MSWM System’ range from 62.3 € / ton (Scenario 0) and 67.6 € / ton (Scenario 3). The difference in total costs is a result of the costs of each subsystem. Table 32 lists the total annual costs of each subsystem for better understanding of financial interrelations.

Table 32 compares all three subsystems respectively percentage allocation of their costs in the ‘Equivalent annual discounted total costs’. The costs for the subsystem bins and containers are low, that can be explained that bin system already exists in the Baseline Scenario and solely additional bins are required for future scenarios.

Table 32: Results of total annual costs per subsystem

	Scenario [€/t formally collected]				
Indicator	**0**	**1**	**2**	**3**	**4**
Subsystem bins & container system	0.3	0.3	0.6	0.6	0.4
Subsystem collection & transport	20	21	25	25	21
Subsystem treatment & disposal	43	41	41	42	43
TOTAL:	**63.3**	**62.3**	**66.6**	**67.6**	**64.4**

As shown in Table 32 Scenario 0 is not the most feasible scenario from the ‘Total Annual Costs per Subsystem’ perspective, as it would appear at a first glance. A main part of the total waste amount is channelled to MBT plant and landfill. Thus great capacities of facilities and landfill are required in Scenario 0 that result in high costs for subsystem treatment and disposal.

Scenario 1 has the lowest costs per ton of formally collected waste and at the same the subsystem treatment and disposal in this scenario has the lowest costs as well. In this scenario, the total amount of waste first goes into the MBT-plant and afterwards it is landfilled. The amount waste going to the MBT plant is lower due to increase of separate collection rate. Thus, the size of the MBT plant is smaller than in Scenario 0 and consequently the costs of the subsystem treatment and disposal are smaller as well.

Scenario 3 has the highest costs per ton of formally collected waste, due to separate collection of five different fractions and expensive incineration technology. The costs for the subsystem collection and transport increase with the number of separately collected fractions. Scenario 3 similar to Scenario 2 collects separately the most possible number of fractions.

The subsystem bins and containers have the least impact on overall costs, because this subsystem already exist in the current waste management system. Only costs for additional containers are calculated. However, a comparison of scenarios shows that the cost per ton of formally collected waste in subsystem bin and container system are double in the Scenario 2 and 3 as in other scenarios, due to collection of most possible number of fractions.

Table 33 shows a comparison of the ‘Total Costs per Formally Collected Waste’ among different European cities. As shown, costs range from 39 to 94 Euros per ton in Poland and Lithuania. Relatively, the minimal costs in Mogilev are around 63 Euros per ton that is within the middle range of its neighbour countries. But, in comparison to other European cities in Spain or Slovakia with cost range from 95 to 121 Euros per ton, the costs of the most expensive scenario of 67.6 Euros per ton in Mogilev are substantially lower. One of the reasons are the operation and staff costs in Belarus that are lower than in other European countries

In the course of the WaTra-project results of scenarios in Mogilev and Derhachivsky Rayon in the Ukraine were compared. The minimal costs of 127 Euros per ton in Ukraine are twice as high as in Belarus. Notwithstanding the neighbouring country with similar economic situation the primary reason is the fact that low waste quantities are treated in each scenario in Derhachivsky Rayon in Ukraine. This fact is confirmed by the statement that it is economically unfavourable to build a waste treatment facility for a small amount of waste, and economies of scale are very important.

Table 33: Costs in € per ton of collected waste in different European cities and Ukraine (den Boer et al., 2005; Dobreva, 2018)

City	Costs [€/ton]
Kaunas (Lithuania)	56 – 94
Nitra (Slovakia)	99 – 119
Reus (Spain)	95 – 121
Wroclaw (Poland)	39 – 71
Xanthi (Greece)	52-140
Derhachivsky Rayon (Ukraine)	127-194

6.1.1.3 Annual Revenue from the Recovery of Material and Energy

Financial revenues have to be reviewed additionally for a full financial assessment of scenarios beside costs of a MSWM system. For this assessment revenues from recovery of materials (plastic, glass, metal, paper, compost from source separation and MBT outputs: glass / metal), revenues from energy recovery (electricity/heat) and revenues from sales of RDF (MBT output RDF) have to be evaluated. The market fluctuations make the evaluation of the revenues from recovered material more complicated. Hence, revenues are calculated at current average prices or assumed values without taking possible price changes for recyclables into account.

The calculated results demonstrate that scenarios equipped with technologies incineration and anaerobic digestion earn higher revenues in comparison to other scenarios without energy production. Table 34 demonstrates that high investment costs into incineration plant and biogas facility are to some degree compensated by high revenues from heat and electricity sale.

In all scenarios the revenues from recovered materials and energy range between 1.7 Mio €/year to 9.1 Mio €/year. Top revenues are generated in Scenario 4, with second Scenario 3. Revenues from RDF sale are only considered in Scenario 0, 1 and 2. When comparing these three scenarios, the highest revenues are earned in Scenario 1. This Scenario processes the maximum input of waste in MBT plant that makes most RDF material available for sale.

The proceeds from the sale of RDF fuel are significantly dependent on the cost of coal at the stock exchange. According to the concept of the creation of capacities on production of alternative fuel from solid waste and its use (Ministry of Republic Belarus, 2016), it is advisable to set the purchase price of one ton of RDF not more than 25% of the value of coal at the stock exchange. Given that presently the market price for coal is 40 euros per ton, the purchase price RDF fuel may not be more than 10 euros per ton respectively (Ministry of Republic Belarus, 2016).

Table 34: Annual revenues from recovery of material and energy

	Scenario				
Revenue	**0**	**1**	**2**	**3**	**4**
Recyclables [m€/year]	1.19	2.41	2.39	2.39	1.45
Total Revenue Energy recovery [m€/year]	0	0	0	5.3	7.6
RDF selling [€/year]	518,390	455,940	416,410	0	0
Total [m€/year]	1.7	2.9	2.8	7.7	9.1

The complexity of the evaluation of the cost-to-revenue ratio is due to the unavailability or uncertainty of data. The data which was possible to receive with the aid of the project partners and the information on expected prices for some products refers to nowadays. It is impossible to determine future level of real prices with the help of theoretical modelling of the situation. The amount of waste arriving to the treatment plants, the quality of each fraction and the market conditions (like price fluctuations, product demand) – that is not a complete list of circumstances, affecting the price; so modelled values can be hardly considered as absolute. So, the result can be understood as approaching the real one and is used only for rough estimation.

6.1.1.4 Self-financing Rate

Self-financing rate represents cost recovery of a scenario that are summarized in Figure 18. Green bar shown in the graph represents the financed part of the system by means of revenues. The red bar of the graph represents the non-financed part. The blue bar represents the income from the fees. The self-financing rate that indicates the diversion between financed and non-financed part of each scenario in percent is highlighted in Figure 18 with a green box.

Benefits for each waste management system are revenues from sold recyclables, energy or fuel recovery and fees paid by the public. Additional budget financing or subsidies were not taken into account. The non-financed part of the costs is a deduction of generated revenues from the ‘Total Annual Discounted costs of the WM system’ (related to the number of Mogiliev city inhabitants).

Waste tariff is a fee paid by citizens and legal entities to a municipality. An estimation of the income from fees in the year 2025 was calculated based on the assumption of increasing waste generation by 11.6 %, while the level of fee remains the same as in the year 2015. The results of this estimation is an average local tariff of 11.41 €/person and year.

National waste management strategy for Belarus provides that, if landfill taxes are introduced, then actual tariff for MSW treatment for the population must be increased and can reach 40-42 euros per ton, on the provision of its indexing to the inflation rate (The Council of Ministers of the Republic of Belarus, 2017).

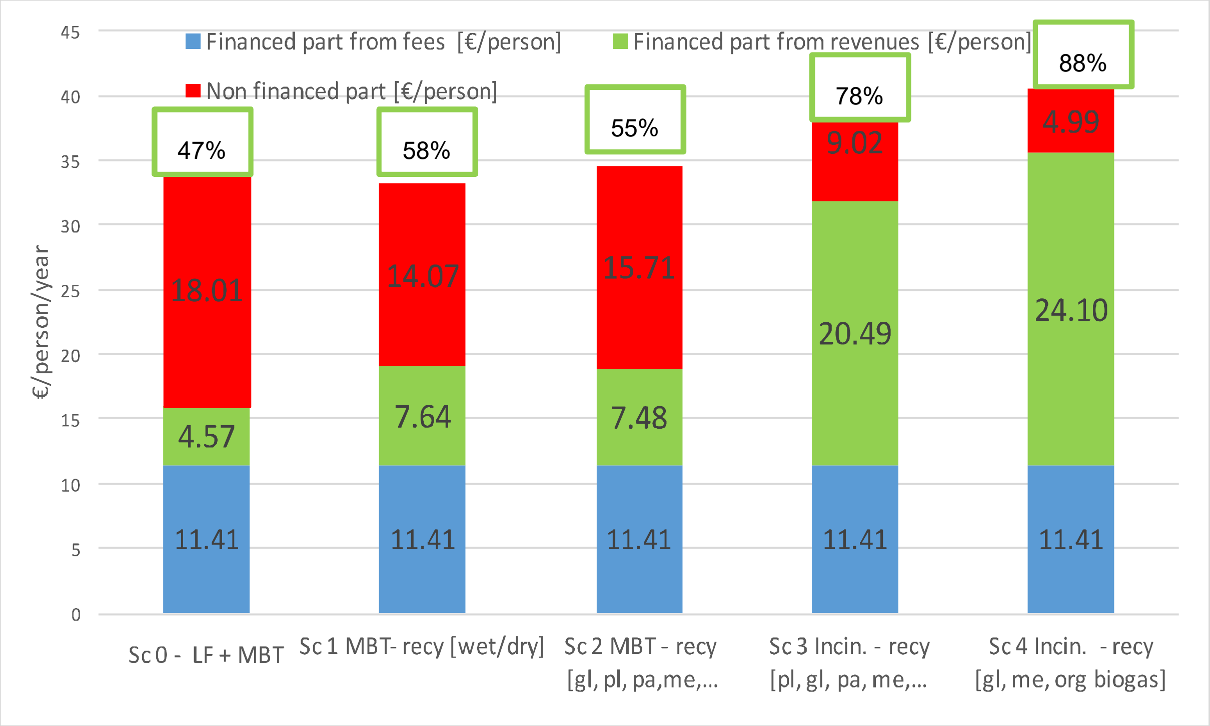

Figure 18: Self-financing rate of future WM-scenarios in Mogilev

As shown in Figure 18 Scenario 0 has the lowest self-financing rate, whereas Scenario 4 has the highest self-financing rate. Due to different technologies implemented, Scenario 0, 1 and 2 should be compared directly, as these scenarios produce RDF. Scenario 3 and 4 should be compared as a separate block, as these scenarios implement incineration as main treatment.

Scenario 0 does not have a high separate collection rate of recyclables with the consequence of the lowest revenues from RDF sale among the other scenarios. Scenario 1 has better cost-revenues ratio with a highest financed part among Scenarios 0 and 2 with MBT technologies. In Scenario 1 58% of the total annualized costs are financed by public fees, as well by commercial selling of recyclables and RDF.

High revenues from selling heat and electricity produced by incineration and anaerobic digestion allow to compensate high total annual discounted costs of Scenario 3 and 4. Current tariffs (Ministry of Energy Republic of Belarus, 2017) were taken into account to calculate the revenues from electricity and heat.

The comparison between Scenario 3 and Scenario 4 is in favour of Scenario 4. The main reason for better performance of Scenario 4 is the maximum production of energy and heat from the incineration and anaerobic plant. Separate collection of inert materials (glass and metal) and collection of paper and plastic together with residual waste increases the calorific value of incinerated waste. Furthermore, Scenario 4 generates additional heat and electricity from biowaste that is processed for energy recovery in the anaerobic digestion plant.

In Scenario 0, 1 and 2 the self-financing rate does not cover the operation of the waste management system. On the one hand, an increase of the consumer tariffs, on the other hand, an establishment of an extended producer responsibility scheme (ERP) could provide better results. An ERP scheme request from industrial producers to create an infrastructure for collection and management of their products and its packaging material (The Council of Ministers of the Republic of Belarus, 2017). Beside additional contribution to self-financing rate, this measure will encourage producers to reduce packaging material and to consider the product life cycle.

The City Mogilev has following potential financing sources to fund municipal waste infrastructure: national budget, loans from international financial institutions, public private partnerships, or ERP scheme (The Council of Ministers of the Republic of Belarus, 2017).

6.1.1.5 Total Annual Discounted Costs as % of City Budget Expenditures

The creation of a modern waste management system and its maintenance very often requires substantial investment. Municipalities of different cities spend from 3 to 15% of their budget on solid waste management (UN-Habitat, 2010). Analysing the contents of Table 35 it can be seen that the total annual discounted costs as a percentage of the Mogilev city budget range from 10 to 11.9 percent, lying within the range of typical annual costs.

Table 35: Total Annual Discounted Costs as % of City Budget Expenditures in 2015

	Scenario [%]				
	0	**1**	**2**	**3**	**4**
Costs as % of city budget expenditures	10	9.7	10.2	12.0	11.9

From the Table 35 is seen that the city's expenditures in Scenario 3 and 4 are higher than in the other ones. These two scenarios are high-tech ones (technology of anaerobic digestion and incineration) and involve the purchase of expensive equipment. Information about the budget of the city of Mogilev was taken from the documents of the Executive Committee of the city (Mogilev city executive committee, 2017).

6.1.1.6 Total Annual Costs as % of Nominal Average Salary

A modern waste management system typically includes a well-designed and functioning system of tariffs, where the compensating costs are incurred. Current rates in Mogilev do not cover current costs. Thus, to finance a new waste management system the local authorities will have to raise consumer rates. In the case of specified scenarios, the current cost per person would be a minimum of 0.36% (Scenario 0) and 0.80% (Scenario 4) of the Nominal Average Salary as shown in Table 36.

Table 36: Total annual costs as % of Nominal Average Salary

	Scenario [%]				
	0	**1**	**2**	**3**	**4**
Costs as % of Nominal Average Salary	0.36	0.43	0.43	0.72	0.80

In other words, in order to support the waste management system in full scope in addition to the self-financing part of WM system, 0.36% to 0.80% of local nominal average salary have to be paid by taxpayers for removal and processing of waste in each scenario.

The national statistics for Belarus shows that 0.19% of the average wage was spent to finance the waste management expenditures in 2016. In comparison this figure is 0.6% for Germany. In conformity with the waste management strategy for Belarus (The Council of Ministers of the Republic of Belarus, 2017) this ratio goes up to 0.24%, which does not affect significantly the wellbeing of the population.

However, the increase in the current rates still has its reserves because of the international recommendations that estimate as 1% of household income (= 2 people) as the fee for waste processing (Wilson et al., 2013). Tariffs, therefore, can be raised gradually, to avoid disproportion and to avoid the extra undue pressure for the population.

It is obvious that such an increase could have a negative impact on the low-income people, but such an unpopular measure will have to be done due to the high social significance of this project. As a possible option to mitigate the social discontent the subsidizing may be offered to citizens with low incomes or the implementation of PAYT (pay as you throw) approach.

PAYT system bills the households depending on the amount of waste, weight/volume of waste, a frequency of collection, or the degree of segregation. While encouraging the reduction of waste, the system controls the change of habits and behavioural patterns of the population by means of economic incentives. The tax system is replaced by a system of services, where users pay depending on the services used. Since PAYT intends to finance the separate collection of recyclable materials at the expense of higher fees for mixed waste, its efficiency is much higher for the waste from household than anywhere else. PAYT tools are a good way to reduce the general amount of waste and to increase the recovery of recyclable materials from the residual waste. It should be kept in mind that they can cause waste export when the exported waste will either be moved to a neighbouring community or illegally dumped.

To encourage homeowners and to affect their behaviour in waste processing and interaction with separate collection systems, PAYT should be reasonably diversified: the highest rates must be for unsorted waste and the lowest - for fine sorted waste. However, it is clear that too high tariffs may lead to illegal dumping (European Commission, 2012).

6.1.2 Environmental assessment

The impact on environment has been calculated for all future scenarios. The following chapter shows the results of six assessed indicators.

6.1.2.1 Source-separated Collection Rate

Although MSW is only a small part of the overall generated waste (including waste from demolitions, industrial sources, etc.) its collection still remains one of the most difficult problems around the world (Martin et al., 2006). There are some obstacles on the way to the successful solution of this problem, like peoples habits, lack of space, high cost, specific requirements to the collection of different types of waste, a design of logistics and many others (Letcher and Vallero, 2011; Tchobanoglous and Kreith, 2002).

The idea in the project was to calculate the maximum potential of waste segregation and compare the possibilities of different collection systems. Therefore, it was decided to set ambitious "high" collection targets (based on highest level of collection rates achieved currently in EU cities, see the Table 10), and additionally, to compare two different collection systems (separate bins for all recyclables or dry bin system). The results of waste separate collection performance depending on the number of collected fractions and collection system are presented in Figure 19.

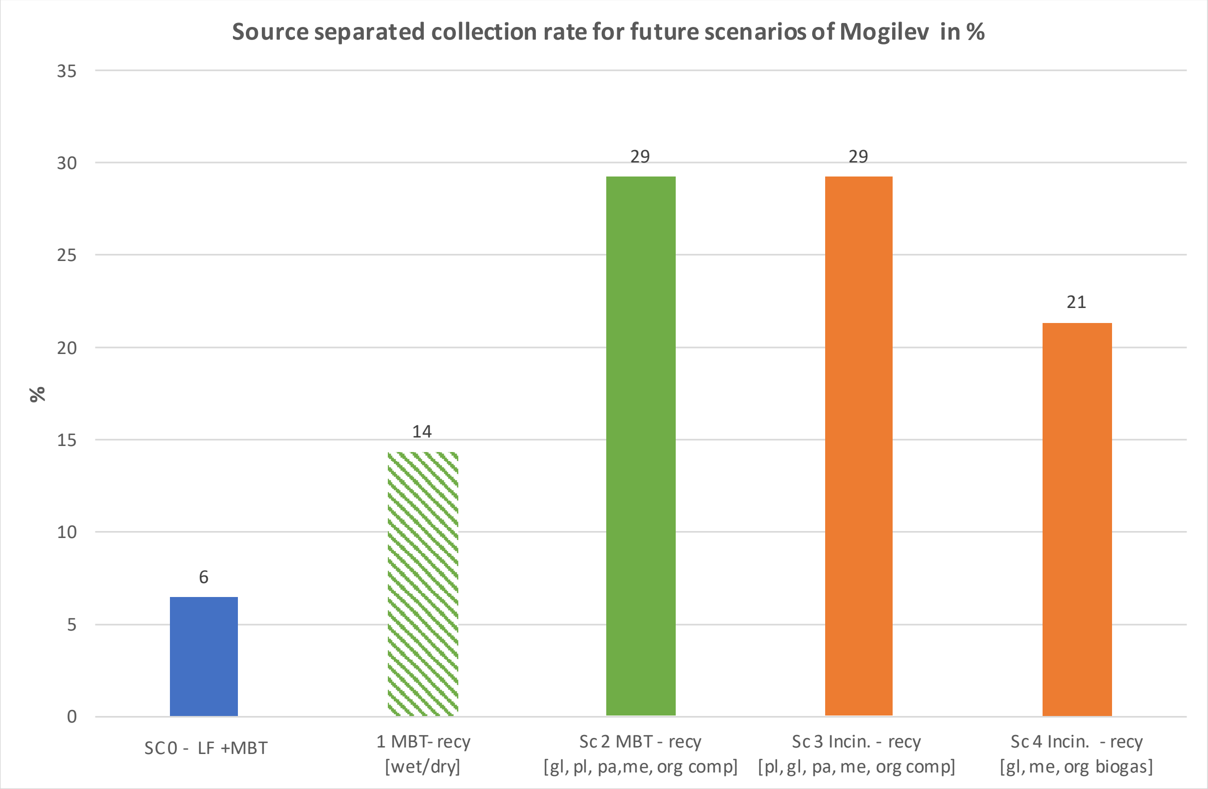

Figure 19: Source-separated collection rate for future WM scenarios in Mogilev

As is shown in Figure 19, Scenario 2 and 3 aimed to maximise the separate waste collection were more efficient in comparison with dry-wet bin target in Scenario 1. The reason for the 15 % difference in source-separated collection rate between Scenario 1 and Scenario 2, 3 is the separate collection of organic waste in Scenario 2 and 3. By comparison between these scenarios regarding recyclables only (excluding separate collection rate of organic waste) the source-separate collection rate in scenario 1 with dry-wet target is 0.5 % higher than in Scenario 2 and 3.

Scenario 0 shows current separate collection rate, which is quite low. Scenario 2 and 3 are most preferred because they demonstrate the possibility of high-level waste separate collection and separate collection of five different fractions.

A new National Waste Management Strategy for Belarus provides no targets for collection of waste for each waste fraction, which makes the direct comparison of calculated results with the Strategy guidelines impossible. The Strategy had just laid the requirement to increase the collection of recycling material and the separation of the raw materials (plastic, paper, metal, glass) through the involvement of the population in segregation of home waste (The Council of Ministers of the Republic of Belarus, 2017).

Among the targets of the National Waste Management Strategy for Belarus is the modernisation of transport fleet and container management, logistics, collection infrastructure (including sites for outdoor containers). So, for example, closing down of garbage chutes that are very often incorporated in each floor in multi-storied buildings, and switch to the container system, allows increasing degree of segregation of waste in general.

Scenarios 2, 3 and 4 have more advanced requirements compared to the Strategy's text about the separate collection of organic matter. Strategy sets no quantified goals and only proposes to develop a system of separate collection of organic waste in the sector of private houses and green waste collection in urban areas. It is also proposed to complement mechanical treatment with biological step within the MBT facility, although, perhaps in the future it could make sense to involve an advanced technology of anaerobic digestion of organic waste (as in Scenario 4).

The collected materials of separately collected waste stream are passed on for manual sorting, and only after that sent for recycling. The material recovery rates resulting from these processes will be discussed in the next chapter.

6.1.2.2 Material Recovery Rate

The degree of recycling of MSW in the Republic of Belarus amounts nowadays as low as 15.6%. New Waste Management Strategy of Belarus sets the target of increasing the amount and improving the composition of secondary raw materials extracted from the MSW (The Council of Ministers of the Republic of Belarus, 2017).

Material recovery rate is not to be described separately for each fraction of waste in this study, yet, to be aggregated for the different processes (see Chapter 3.6.2). Figure 20 presents a comparison of the share of separately collected waste (excl. WEEE & hazardous waste), output recyclables after sorting, MBT- recyclables (gl, me) after recycling, output recyclables after recycling and output organics after composting process. Material recovery rate does not include the composted material.

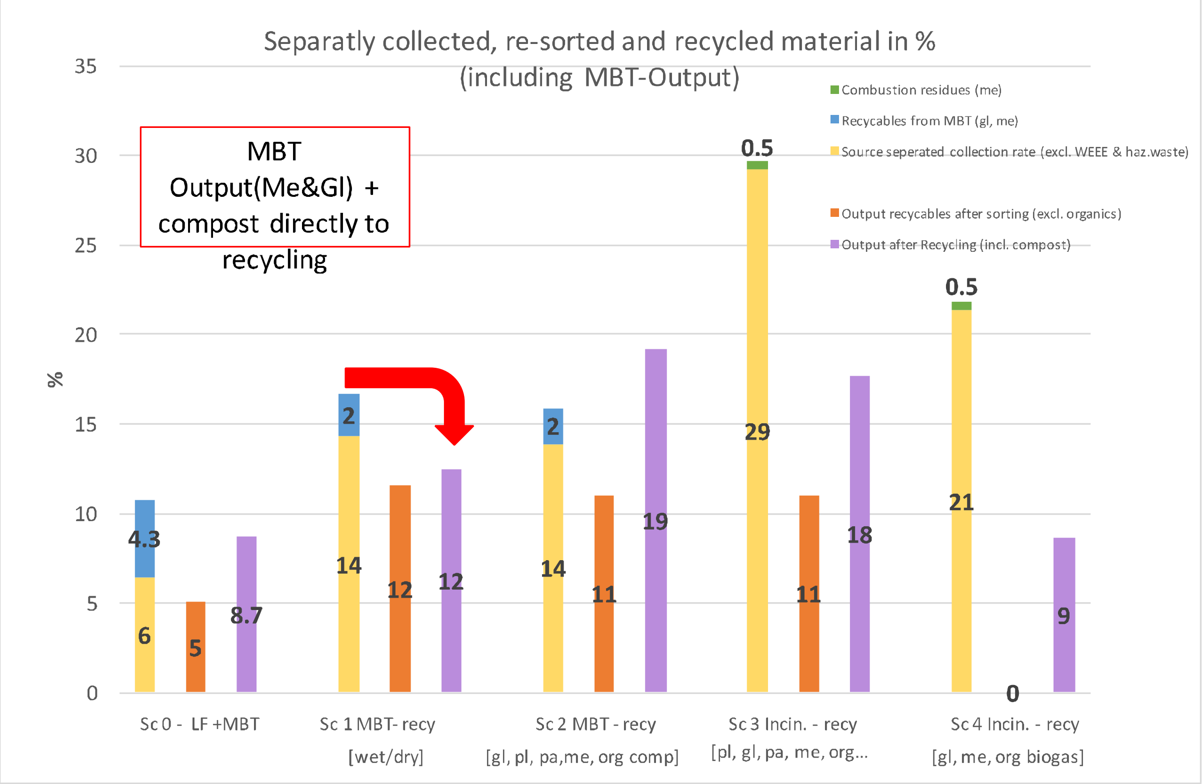

Figure 20: Source separated, re-sorted and recycled material in future WM scenarios

Graph shows the amount of residual material resulting from various procedures and treatment technologies.

The blue bar shows the MBT recyclables (glass and metal) after recycling. The orange bar shows the volume of recyclables sent to manual sorting line. The green bar shows the amount of metal after the combustion. The purple bar shows the resulting total material recovery rate which characterises the level of recovery of the material after recycling. Additionally to collection and sorting rates it takes into account the technical material recycling rate of the recycling processes and composting rate the separately collected organic substances. The source-separated collection rate (yellow bar) was discussed in the previous Chapter.

The MBT outputs are not included in the orange bar because they are not subject to manual sorting since all valuables been extracted directly at MBT plant. Table 10 and Table 11 show the reference values used in the calculation of source-separated collection rate, an efficiency of sorting, composting efficiency and technical recycling rates.

The scenarios with an initially low level of separate collection (Sc. 0, 1, 4) have lower material recovery rates than the ones with its initially high level (Sc. 2, 3). The total recovery rate of the material is composed of several components, namely outputs of re-sorted recyclables after recycling process, MBT recyclables after recycling and the amount of compost obtained through open windrow-composting.

Analysing the results of the material recovery rates it is important to amend the agenda with the examination of the impact of the informal sector on waste collection and the benefits of home-composting of organic material in private sector. On this issue we faced the problem of lacking/incomplete data, therefore, two assumptions, based on expert opinions, literature and “best qualified guess” estimates were made for all scenarios, namely: 2,977 t/yr of recyclable materials fall out of MSW system due to informal activities for its collection; 22,473 t/yr composted annually by the private households (Ramusch, 2016a; Skryhan et al., 2016).

6.1.2.3 Energy Recovery Rate

The recovery of energy from waste allows reduction of the share of primary energy carriers consumption, which in turn, allows to conserve natural resources (Margallo et al., 2014). The indicator is calculated as the ratio between MJel, MJth, MJindirect, and Mjavailable, showing the amount of recovered exergy out of total available exergy in the input (collected) waste amount. This method of measuring the rate of energy recovery provides an objective tool for monitoring the performance of each scenario of solid waste management and allows to compare their efficiency (Rigamonti et al., 2016b). More details about electrical and thermal efficiencies of the used technologies are presented in chapters 5.1.4 and 5.1.5. Obtained values for MJ_{el}, MJ_{th}, $MJ_{available}$, $MJ_{indirect}$ and own energy consumption are presented in Table 37.

Table 37: Energy-related key parameters for future scenarios

	Scenarios				
	0	**1**	**2**	**3**	**4**
$MJ_{indirekt}$ [MJ][11]	556,369,342	470,865,808	470,865,808	0	0
MJel [MJ]	0	0	0	84,117,600	130,244,400
MJth [MJ]	0	0	0	294,415,200	378,576,000
Net calorific value of RDF [MJ/kg]	15	13	11	12	12
$MJ_{available}$ [MJ]	1,253,779,293				
Energy Consumption [MWh]	56,041,200	51,256,800	42,192,000	21,027,600	35,100,000

The results of the calculations are presented in chart form in Figure 21.

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[11] $MJ_{indirekt}$ [MJ] - 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).

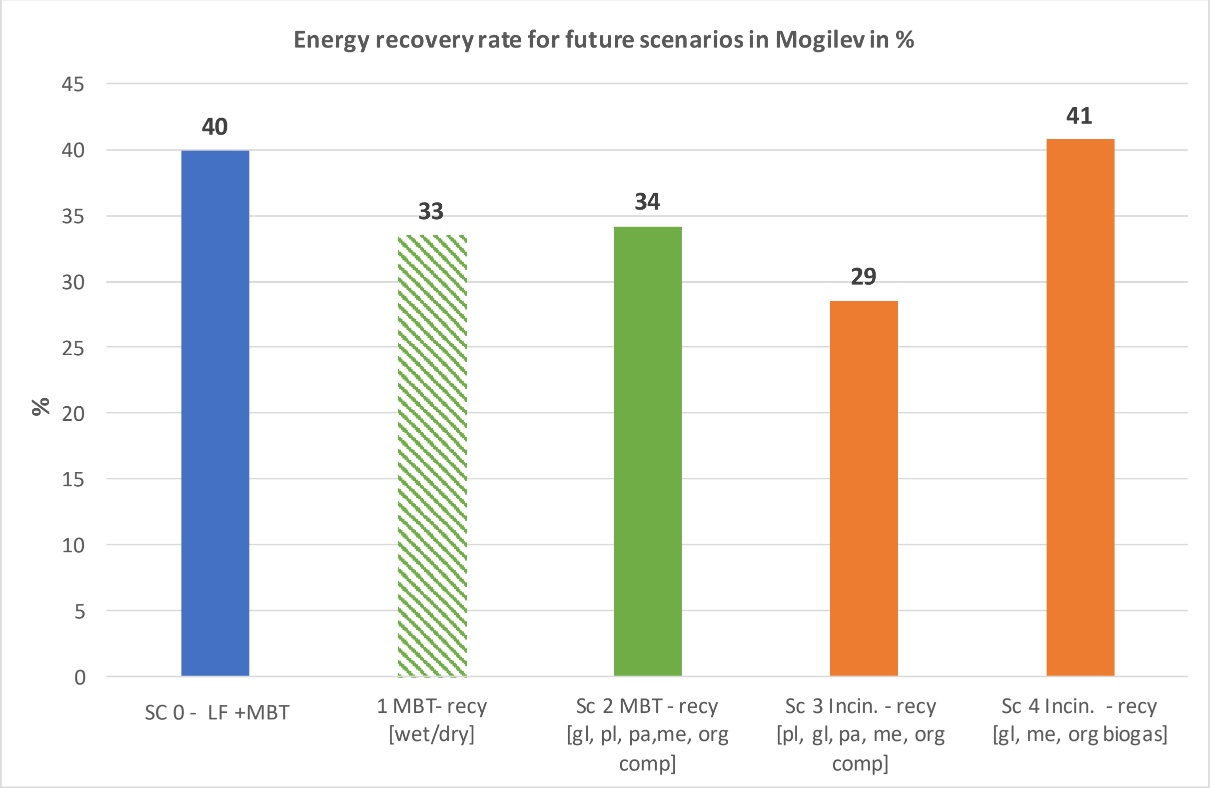

Figure 21: Energy recovery rate for future WM scenarios

As it can be seen from the chart, Scenario 4 performs the best due to the high level of energy recovery from incineration and anaerobic digestion. Due to the huge volume of waste circulated at the MBT plant, Scenario 0 has the second place after Scenario 4 benefitting from high RDF production. In the absence of a high ratio of separate collection of waste more quantities of plastic, paper and other valuable materials remain for RDF production, which increases the energy recovery rate.

Scenarios 1, 2 and 3 exhibit similar results and almost the same ERR. However, the indicators in these scenarios are very dependent on the calorific values of the material obtained RDF and the amount of waste entering the MBT facility.

The calorific values in scenarios 1, 2, 3 differ: Scenario 1 shows the lowest calorific value (10 MJ/kg); the highest calorific value is achieved in Scenario 2 (11 MJ/kg), calorific values in the other European cities are ranging from 11 to 20 MJ/kg (European Commission, 2003; McDougall et al., 2003; Ministry of Republic Belarus, 2016). The calorific value of the scenarios under analysis is not as high as in European cities, this can be explained, for instance, by relatively high organic content and low content of high-calorific fractions (paper, plastic) in the input waste composition compared to European countries. However, it has to be kept in mind that all above-presented results are based on preliminary rough estimates only. To obtain the reliable realistic result, one must carry out full-spectrum waste composition examination.

In the recent years, the use of RDF fuel in Belarus has become particularly important and this was reflected in the “Concept of the creation of capacities on production of alternative fuel from solid utility waste and its use” (Ministry of Republic Belarus, 2016).

For the period up to 2035 the National waste management strategy along with the development of the production of RDF fuel highlights importance of the construction of waste incineration plants as the source of electrical and thermal energy. This development corresponds to Scenarios 3 and 4. Maximum energy recovery rate is achieved in Scenario 4 due to the processing of mixed waste in incineration plants and biological waste in the anaerobic facility, both technologies involving production of heat and electricity.

6.1.2.4 Waste Landfilling Rate

In accordance with the new Strategy of waste management all old landfills or dumpsites that do not meet the requirements of the EU Landfill Directive, 1999/31/EC must be closed, on the one hand, a network of facilities that meet the requirements of this Directive are to be built. All possible future scenarios take into account this requirement, offering to close all existing dumpsites and to build modern sanitary landfills.

The changes in source separate collection targets of the materials and different options for the treatment of organic waste has led to differences in the calculated landfilling rates, presented in Figure 22. This means a direct relationship between the overall increase in recycling or composting and the reduction of the percentage of disposal of solid waste.

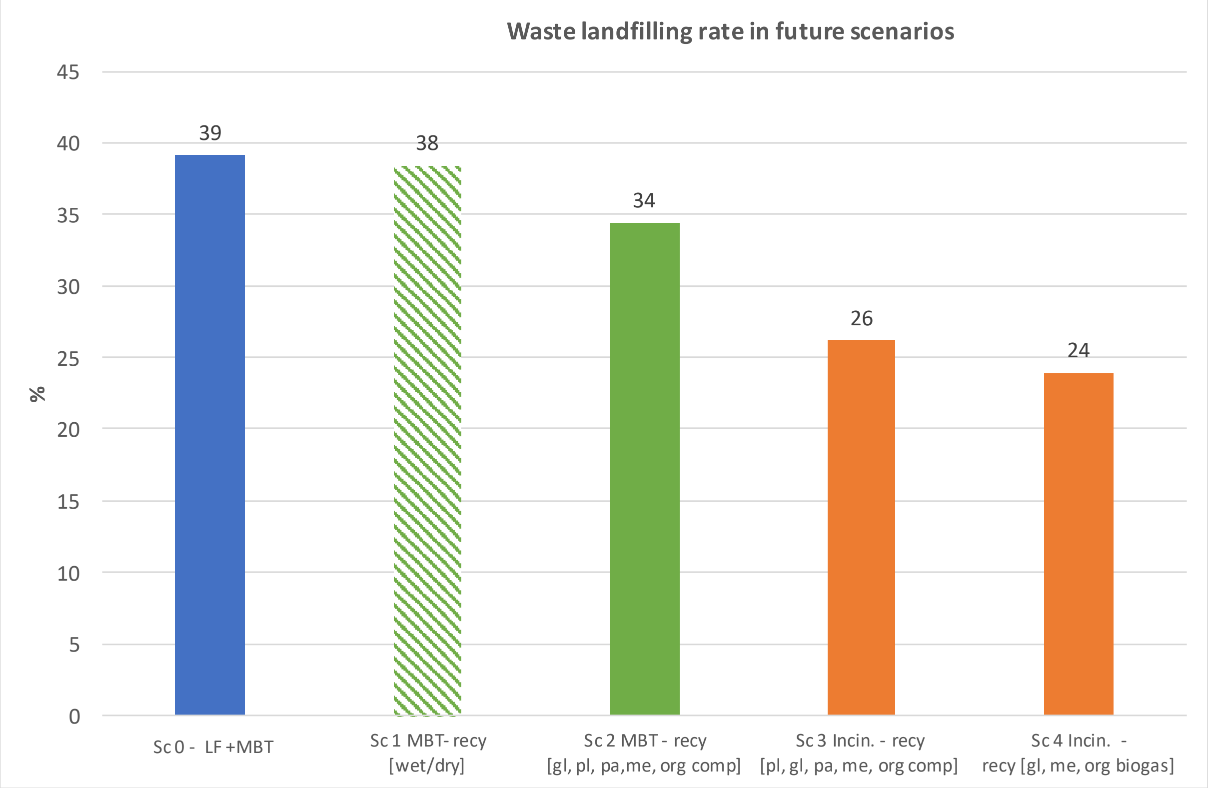

Figure 22: Municipal waste landfilling rates for future WM scenarios

In Scenario 0 the idea of separate collection is present, but collection rate is low; the landfill rate is, therefore, higher than in all other scenarios. In scenarios with a higher degree of source-separated collection, the amount of landfilling rate is much lower.

If we look at the statistics of waste treatment in Belarus for 2015, one may see that 84.4% of the waste were buried in landfills, and only 15.6% were recycled. In the period up to 2035, it is planned to build at least 6 new regional landfills in the country each year (The Council of Ministers of the Republic of Belarus, 2017). But at the same time, the construction of a waste incineration plants is planned, that will reduce the landfilling of waste by 10-15% at the national level.

To reduce the amount of landfilling of the residual waste streams, one needs to extract all valuable material and send it for further processing. It requires, as suggested by Scenario 2, 3, and 4, to implement separate collection, processing of organic matter and treatment of residual waste at incineration plant.

To minimize the volume of the disposed waste is still one of the environmental problems in Belarus along with the above-mentioned challenges that affect the level of waste disposal. In 2013 the European Environment Agency conducted the study comparing the strategy of waste management in 32 European countries. It showed that the taxation of waste disposal affects the amount of waste, sent to the landfill, directly: the higher is the cost of waste disposal, the more waste is been treated alternatively (European Environment Agency, 2013).

6.1.2.5 Reduction of Biodegradable Waste Landfilling

Landfilling in the waste hierarchy possesses the last place, yet it still has the leading role in waste management in Belarus. It is well known, that biodegradable fraction of MSW produces methane at landfill. The emitted gases contribute significantly to global warming, to acidification of the atmosphere and have other negative impacts. The biodegradable fraction, moreover, allocates a significant amount of nitrogen and phosphorus compounds. From here, the objective to remove biodegradable waste from landfill and significantly reduce the negative impact on the environment originates (Christensen et al., 2011). The Landfill Directive 1999/31/EC demands to reduce global warming through the reduction of the landfilling of biodegradable waste by the member countries of the European Union. By 2006, the use of landfills for waste disposal meant to be reduced by 25% from the level of 1995, by 2009 - to 50% and by 2016 supposed to be only 35% from the level of 1995 (EC, 1999). Because of the lack of legal reduction targets on disposal of biodegradable waste in the Republic of Belarus, the National strategy on this issue is being developed now based on the EU Landfill Directive (The Council of Ministers of the Republic of Belarus, 2017).

Once again, the problem of lacking/insufficient data forced the project members to calculate the assumptions based on available data. Year 2015 was set as baseline reference year (instead of 1995 in EU). For each scenario it was investigated how much biodegradable waste is able to be diverted from landfill based on the waste composition and collection / treatment options in each scenario.

Three-step scheme of calculations looks as follows:

1. The calculation of the amount of landfilled bio-waste for each scenario separately. It required to summarise the entire volume of waste: output of the MBT material sent to landfill, the residues of sorting and compost, multiplied with their biologically degradable share.
2. The volume of each fraction of waste disposed in 2015, multiplied by its biologically degradable share gave the amount of biodegradable waste formally collected in 2015.
3. Finally, the difference between p.2 and p.1 (diversion rate) is calculated.

Figure 23 shows the results of reduction of biodegradable waste diversion for each future scenario in %.

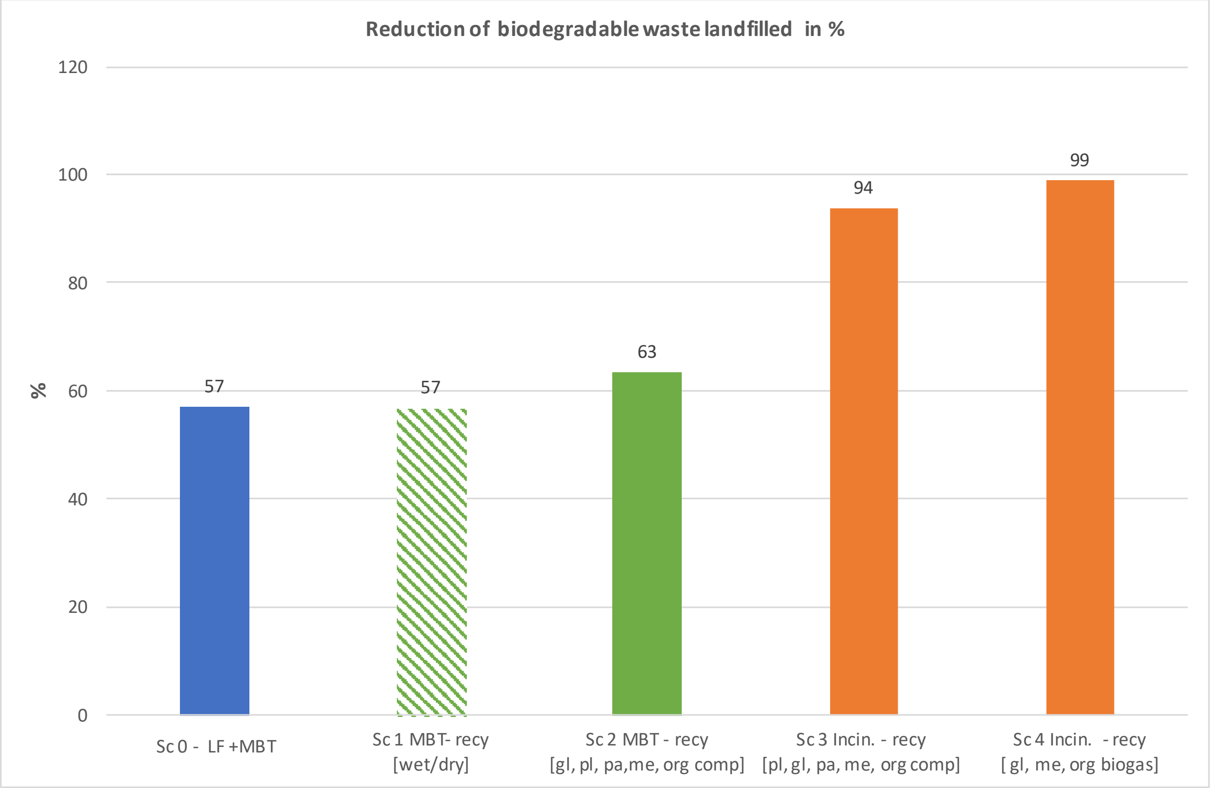

Figure 23: Reduction of biodegradable waste landfilling of future WM scenarios

Of all of the scenarios, Scenario 0 and Scenario 1 have the lowest biodegradable waste diversion rate as they can process the least amount of biodegradable waste. According to the calculations 57% of the total amount of biowaste collected in 2015, was subjected to processing, the remaining 43% was disposed in a landfill.

In this study the potential of different scenarios in terms of processing large volumes of biodegradable wastes instead of its disposal is assessed positively. Preference can be given to Scenarios 3 and 4 due to the presence of technologies of thermal processing (incineration) of the major part of waste. In accordance with the European Targets for 2016, both of these scenarios reached the level of the estimated amount of reduction of disposal of 35% from the amount accumulated in the reference year 2015.

Referring to the experience of European countries the new National Waste Management Strategy in Belarus plans the imposition of high tax rates for the disposal of waste as one of the ways to increase the management efficiency of the disposal of unprocessed residual waste to landfills. The Strategy states, that thereby stimulation of the development of other methods of waste management takes place, such as energy generation, production of compost material from organic waste, recycling (The Council of Ministers of the Republic of Belarus, 2017). All of these priorities and alternatives are reflected in the Scenarios 2, 3, 4, tailored to promote efficient and safe waste treatment in Mogilev, thus being in line with the National Strategy.

6.1.2.6 Greenhouse Gas Emissions

From 3% to 4% of anthropogenic GHG emissions are global emissions of GHGs resulting from the activities of waste management (IPCC, 2006). In 2012, the GHG emissions in the waste sector amounted to 7% of the total national emissions

(Ministry of natural resources and environmental protection of the Republic of Belarus, 2015).

As a result of the disposal and treatment, GHG are generated that contribute to global warming. Approximately 18% of the world production of methane formed as a result of waste processing and disposal. Landfills are recognized as one of the largest sources of anthropogenic emissions of greenhouse gases in the world. Waste treatment can reduce GHG emission. For instance, recycling reduces GHG emission through substitution of raw materials and avoiding GHG emission released at their production. Waste-to-energy treatment reduces greenhouse gas emissions in two principal ways. First, the absence of MSW in landfills – by diverting MSW to a WTE facility - prevents the emission of methane from landfills. Second, the generation of electricity and/or district heating (cooling) from the MSW replaces a certain amount of fossil fuels, required for the production of an equivalent amount of energy/heat (Netherlands Environmental Assessment Agency, 2005).

The government of the Republic of Belarus has adopted a number of programs aimed at the wider use of renewable energy sources to reduce greenhouse gas emissions and more sustainable development of the waste management industry. In particular, the Program envisages the introduction of facilities for collection and utilisation of landfill gas, planned increase of waste recycling and incineration would also contribute to reduction of GHG emissions (Ministry of natural resources and environmental protection of the Republic of Belarus, 2015).

Assessment of the level of greenhouse gas emissions for the Baseline Scenario and five future scenarios were implemented in this study, using unpublished emission calculation tool of TU-Dresden (Wünsch, 2013). The quantification of GHG emission in the tool includes gases carbon dioxide (CO_2), methane (CH_4), nitrogen dioxide (N_2O), that are considered most relevant for the WM system.

The tool takes into account GHG emission savings due to substitution of raw materials by recycled materials and substitution of fossil energy by produced energy or RDF fuel. One should pay attention to the fact that due to the necessary assumptions and limitations in the Tool to calculate emissions from the TU-Dresden, the results should be considered as preliminary. Table 38 shows which WM subsystems are included into the calculation by the tool.

Table 38: The reporting subsystem in the calculation of GHG emissions

Facilities/Subsystems	Considered in calculation
MBT	✓
Landfill	✓
Cement Killn	✓
Treatment of Recyclables	✓

Anaerobic Digestion	✓
Incineration Plant	✓
Composting	assumed climate neutral
Collection & Transport	✗

The results presented in Table 39, indicate the amount of greenhouse gas emissions in the Baseline Scenario and the five other scenarios. In this table, the positive values indicate the gases released into the environment, while avoided GHG emissions are shown by negative values. The last column presents the balance of released and avoided GHG emissions.

Table 39: 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]**
baseline	110,049	-4,558	105,491
Sc 0 - LF +MBT	89,203	-71,427	17,777
Sc 1 MBT- recy [wet/dry]	84,180	-69,362	14,819
Sc 2 MBT - recy [gl, pl, pa,me, org comp]	68,385	-65,471	2,915
Sc 3 Incin. - recy [pl, gl, pa, me, org comp]	23,238	-55,064	-31,826
Sc 4 Incin. - recy [gl, me, org biogas]	32,838	-54,848	-22,009

Highest GHG emissions (110,049 t CO2 eq.) caused by high emissions of methane from landfilling of untreated waste are shown in the Baseline Scenario. Total greenhouse gas emissions is shown in Figure 24.

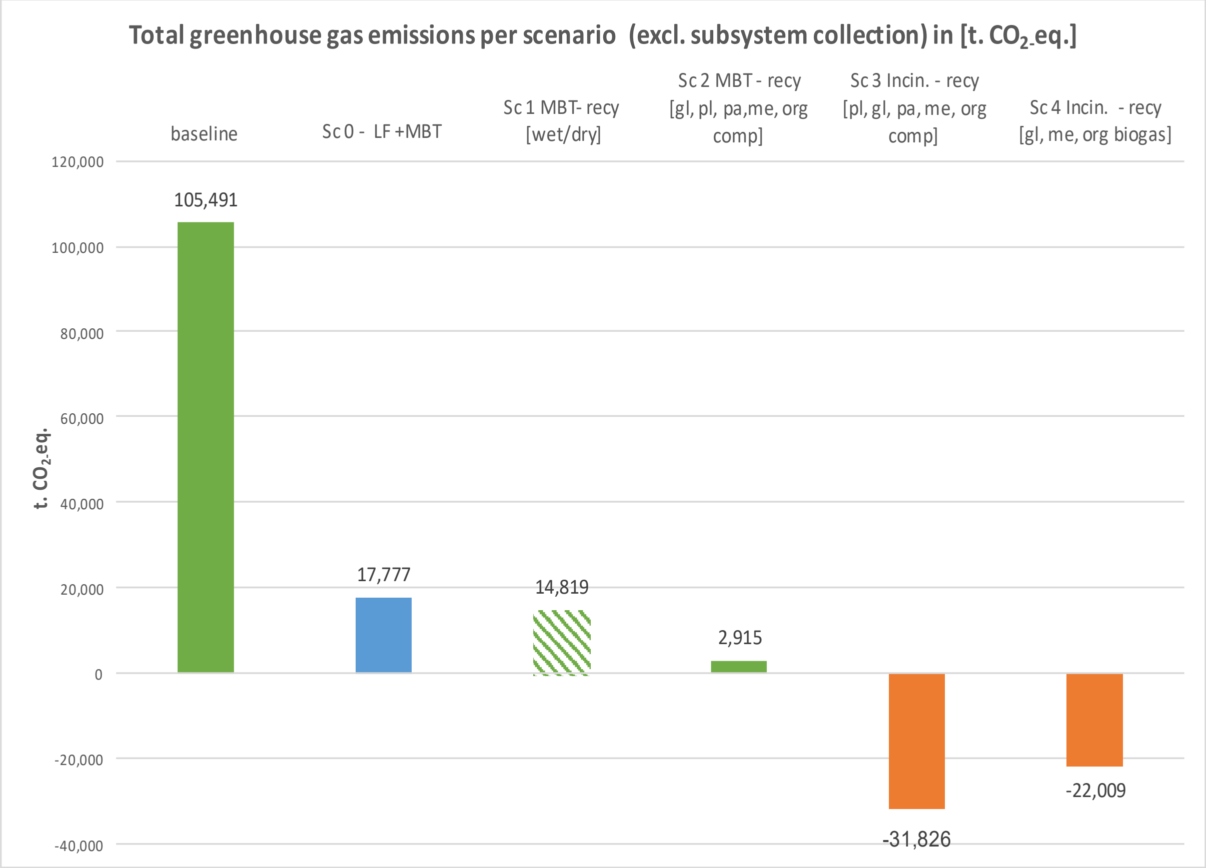

Figure 24: GHG emissions in the WM scenarios

Scenarios 3 and 4 release lowest amounts of GHG: respectively, 23,238 t CO2 eq. and 32,838 t CO2 eq. Moreover, these scenarios have best results in GHG net emissions, achieving GHG emission avoidance of -31,826 and -22,009 t CO2 eq, respectively. Scenarios 1 and 2 avoid most of GHG-emissions due to the highest material recovery rates compared to all other scenarios. But these scenarios show higher (positive) GHG net emission in comparison to Scenarios 3 and 4.

Hence, any scenario with a high proportion of recycled materials contributes to the avoidance of greenhouse gas emissions. The generation of electrical and thermal energy from incinerating waste prevents emissions of greenhouse gases from conventional energy generation (Mohareb et al., 2008).The incineration facility requires heat and electricity for their own industrial cycle. It can use the produced energy for its own needs or take electricity from the grid (Teichmann and Schempp, 2013).

Scenario 4 produces heat and electricity from incineration and also from biogas. The electricity and heat produced from biogas in internal combustion engine is used on-site in the operation of the plant. The surplus of electricity and heat is served in the power net and district heating network and displaces the electricity/heat generated from conventional sources.

As shown by calculations, the most harmful process from the GHG emissions viewpoint is the disposal of untreated waste in landfills. Technical solution for the reduction of landfill methane emissions could be landfill gas collection, however, in the future scenarios waste undergoes biological pre-treatment in the MBT plant and only insignificant amount of methane will be produced during landfilling of stabilized MBT material, which can be- for example - turned into CO2 by microbial methane oxidation in biocovers.

To sum up the results of Figure 24:

- The GHG results varies due to differences in quantities treated in different facilities and due to differences in quantities of material and energy recovery.
- The amount of greenhouse gas emissions is affected by the input volume on the MBT and the input to the landfill (Scharenberg, 2017)
- The smaller the organic fraction is in the composition of the waste, the fewer greenhouse gases will be allocated (Scharenberg, 2017)
- During the composting process the production of harmful gases also induces, but they are not included in the calculation tool, since their influence can be balanced by the benefits obtained from the use of compost as fertiliser and for land reclamation (replacement of other fertilizers compost). Therefore, net emissions in scenarios 2 and 3, in fact, may have different indicators (Linzer and Mostbauer, 2005).
- To a greater extent of emissions may be avoided by recycling of the extracted waste and by waste-to-energy technology.

The more detailed GHG balance for each scenario is given in Annex 3. A detailed calculation of greenhouse gase emissions for both case study regions in Belarus and Ukraine was made in the Master`s Thesis of Laura Scharenberg, TU-Dresden (Scharenberg, 2017).

6.1.3 Social assessment

Social sustainability of a municipal solid waste management system mainly means social acceptance and equal distribution of benefits and disadvantages between citizens, as well as performance of social function in respect of safe waste handling (den Boer et al., 2005). Two indicators "social acceptability" and "job creation" were applied in order to measure social sustainability of the five future scenarios. The following chapter discusses the results of both indicators in each scenario.

6.1.3.1 Social Acceptance

Qualitative indicators, in contrast to the quantitative, are difficult to measure. The chosen qualitative indicators in this thesis are based on four interviews with experts from ABF-BOKU and TU-Dresden.

In Table 40 the estimates of the level of social acceptance of each evaluated sub-criteria in different future scenarios of the future are summarised. The scores of experts were summed up to simplify the analysis. At first, the arithmetic average of all stages of waste management within each subcategory was calculated. The second step was the calculation of the arithmetic mean of all scores for all sub-categories given by all experts.

Thus, the ranking of all five scenarios was estimated. The ranking ranges on a scale from 1 to 5, where 1 indicates the most positive projected social impact and 5 indicates the worst effect.

Table 40: Assessment of the level of social acceptance

	Scenario				
Indicator	**0**	**1**	**2**	**3**	**4**
Social acceptance [ranking]	1	3	2	4	5

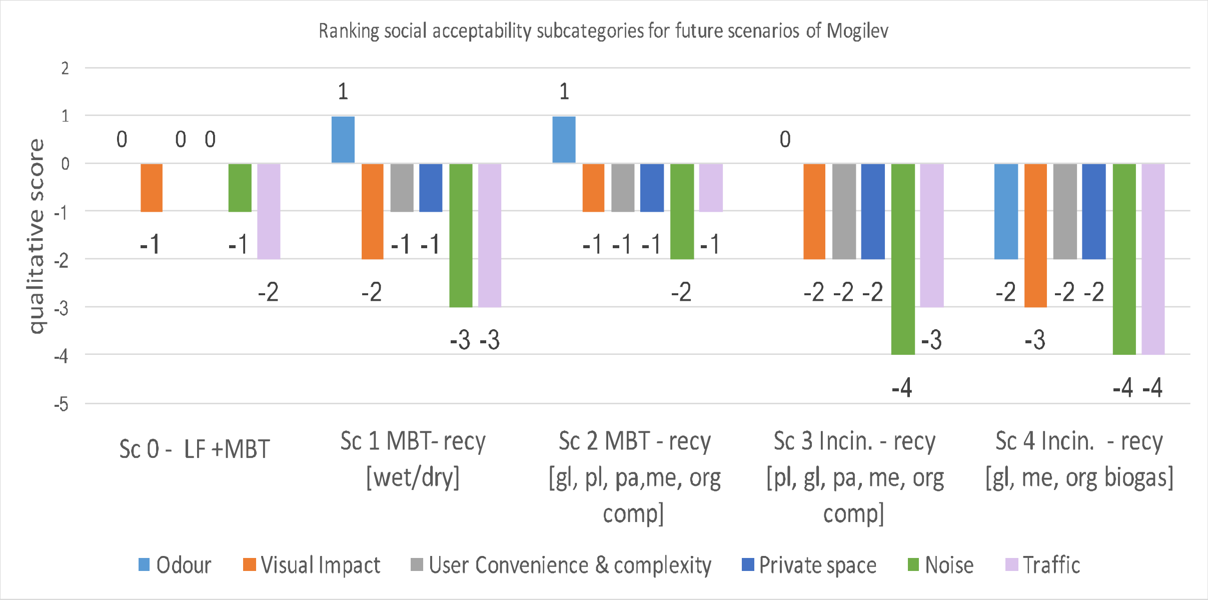

Figure 25: The ranking results for social acceptance of future scenarios of WM

As one may see from the data, almost all subcategories demonstrate the decrease of the level of social acceptance. The main reason for this state of affairs is the unwillingness of the population to change its habits: compared to the status quo when waste is not sorted by factions within households, status quo brings the best results in terms of social acceptance ranking, but will not improve the system waste processing, and thus environmental security. The need to change its behaviour to include in the routine the set of actions, sorting of waste, is perceived negatively.

According to Figure 25 Scenario 0 - LF + MBT has the best score, then in descending order are Scenario 2 - MBT - recy [gl, pl, pa, me, org comp], Scenario 1 - MBT-recy [wet / dry]. Scenario 3 - Incin. - recy [pl, gl, pa, me, org comp] and Scenario 4 - Incin. - recy [gl, me, org biogas] in inverse proportion to the parameter of improving the whole waste management system. Categories: noise, traffic and visual impact are ranked very low.

According to expert opinions, the increasing noise in relation to the boost of the number of empty containers may be negatively perceived by the population, the increase in traffic due to the ascension of the frequency of collection and raising the number of containers and facilities for the treatment (incineration and biogas plants). To reduce the negative perception it is very important to carry on the explanatory work among the population about changes of the existing system (Tulokhonova and Ulanova, 2013).

In general, some results are not easy to understand at first view. The score given by experts strongly differentiates for the same question. The reason for this different evaluation might be due to unclear survey, which might require personal explanation rather than to send this survey via E-Mail. After the survey has been completed, we understood that the assessment results are a subjective evaluation of the experts, and are in some cases not logical. For future replication of qualitative assessment it has to be taken into account that a survey may require more detailed questions and better explanation of the evaluation procedure.

The qualitative assessment can be changed if more experts are involved. Thus, the pool of experts affects the results of the study. In this case, only experts with a scientific degree were asked in the survey. Involvement of other stakeholder groups such as NGOs, politicians, local citizens would have changed the final results since the perception of odour, visual impact, noise, and traffic is subjective and difficult to measure.

6.1.3.2 Job Creation Potential

This indicator defines how many jobs can be created under certain scenario. Methods of assessing potential job creation are based on the stages of the system of solid waste management and are taken from the literature (BMLFUW, 2015; European Commission, 2001; Maletz, 2017; Murray, 1999; Sedman, 2002). So, jobs can be created anywhere: within as well as outside of the three subsystems: bin & container system, collection, transportation, processing and disposal, in recycling company, or industry that uses recycled materials. That is why the number of jobs presented in Figure 26, also includes jobs outside the city of Mogilev.

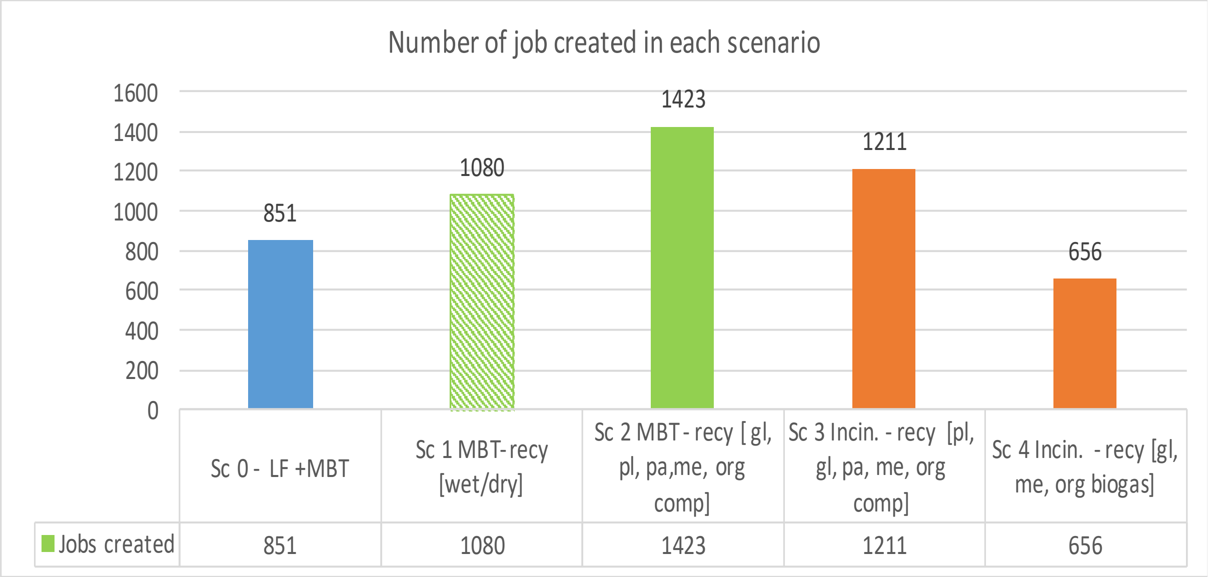

Figure 26: Results of number of jobs created from future WM scenarios

First, to calculate the potential and the arithmetic average of jobs created based on literature data the whole cycle WM was divided into subsystems processing and certain stages. Subsequently, the number of jobs was compared to the amount of waste processed at a certain stage or at the subsystem of WM. The creation of jobs is based on the calculation of the annual amount of 10 000 tons. For instance, based on the above mentioned literature on job creation, additional 10,000 tons in landfill create three new jobs in this facility. According to Scenario 1 66,192 tons of waste per year enter into landfill. Thus, 20 new job are created in landfill in Scenario 1 (3 * 66,192 / 10,000 = 19,85).

From the Figure 26 above it becomes clear, that for the more labour-intensive activities (separate collection and recycling of waste, for example) the level of employment is higher than in automated facilities (such as disposal in landfills, composting or incineration and anaerobic digestion). Therefore, Scenario 4 - Incin.-recy [gl, me, org biogas] project creates less number of jobs. In scenarios involving separate collection, sorting and separate treatment of recyclables, the number of the projected jobs is much higher. These results should not be viewed as objectives but as reasonable conservative scientific estimates. They are forecasted on the basis of literature data and may differ from the practical results on jobs creation. However, this indicator gives an idea about the potential of job creation in the framework or the given scenario.

6.1.4 Technical Assessment

The technical assessment was conducted in four aspects: technical reliability, the need for technical staff and maintenance, sensitivity to the amount of material and sensitivity to the quality of the material for treatment or disposal. The results for each scenario were based on expert opinions, aggregated within each indicator and shaped the cumulative rating for all four indicators, without separating them from each other. The two-step procedure of aggregation forms the total score in all four indicators, and the calculation of the average score for all experts.

Figure 27 shows the results of aggregating the four indicators of the technical assessment: the worst performance is achieved in Scenario 0 and the highest value achieved in Scenario 1.

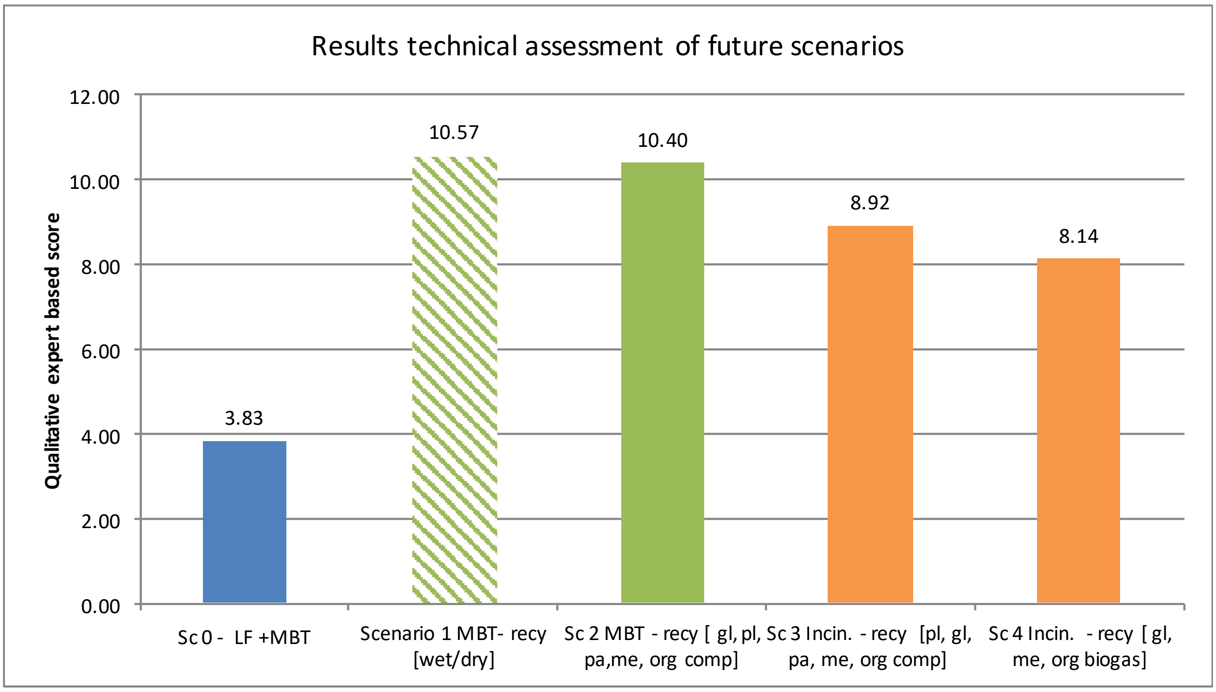

Figure 27: Results of technical assessment for future WM scenarios

Scenarios 1 and 2, respectively 3 and 4 have fairly similar results. Scenarios 3 and 4 receive lower score in the basement due to additional high technologies, like incineration facility and biogas plant. Scenario 0 is evaluated with the highest score that was not expected because Scenario 0 does not have a variety of technologies.

The reason for this assessment lies in the uncertainties of expert reviews since the final score reflects the subjective opinion of the involved experts and is not necessarily actual. In further consideration of the indicator, it became clear that the results for each indicator differ significantly among different experts, although the calculation of the arithmetic mean offsets these differences. Thus, the inability to measure and to understand the components of the final technical evaluation demonstrates that its value is not comparable with other indicators. It is recommended to refer to technical assessment with caution since it is impossible to conclude what factors are decisive for the end results and are subject to change if other experts are asked.

7. Conclusions

Worldwide experts agree that it is quite challenging to organise an effective waste management and recycling system in growing cities, and particularly in regions or countries with transit economy. Effective waste management system has to be created for the future, while, abandoning the obsolete and decaying practice of today. For example, the countries of the former Soviet Union are affected by these issues. Within this master`s thesis five possible scenarios were developed, calculated and evaluated using quantitative and qualitative indicators to ensure the sustainable development of the MSWM system of a region in the Republic of Belarus.

One major problem people usually have to face when developing waste management plans and systems in such countries, is the availability of reliable statistical waste management data. High quality data is essential to develop realistic scenarios and to forecast the future development. In the investigated region, for instance, it was hardly possible to get reliable quantities and compositions of the total waste generation, since data of home composting, the informal collection of recyclables, disposal of unprocessed mixed MSW and disposal of wastes in open dumps were missing, respectively all this data was scanty and unsystematic. Thus, it was necessary to make rational assumptions, mainly based on comparable literature data and country reports, national calculation norms or information individually provided by diverse national stakeholders and experts. To maximise the reliability of the research, all data was cross-checked with information from diverse other sources. However, there is still a possibility of inconsistency and discrepancy of the data.

The study developed a methodology to assess the efficiency of the waste management system. To do this, in the beginning, 62 parameters were selected (15 economic, 25 environmental, 16 social and technical). In the process of the research, the list of parameters was varying quantitatively and qualitatively while the final version consisted only of 17 indicative parameters. To enhance research on the topic of waste management in these regions data collection and data availability have to be improved, as mentioned above. Due to these limitations on data different methods and indicative parameters that can be implemented in assessments of WMS in western European countries are not fully applicable on countries in transition.

In this thesis, the possible options for waste management for Mogilev were identified. So, 100% collection coverage of MSW (the exception was made for home composting and the IRS), disposal only after pre-treatment of municipal waste (e.g. in MBT facilities), the construction of a sanitary landfill in accordance with environmental safety standards, collection of WEEE and hazardous waste - that was the set of minimum requirements for all development scenarios. Thus, according to all the requirements five scenarios were developed. Scenarios focus on different targets for source separate collected waste, on the production of RDF material from MBT plant, and on energy recovery from incineration and biogas plant. Modelling technology scenarios are also described in this paper. So, together with the project partners from TU Dresden the rational technical configuration for each treatment facility was developed. The project involved state of the art technologies of waste processing, which are widely used throughout Europe.

A strategy for a MSWMS derives from the desired objectives. Before developing a strategy a region has to define goals to be achieved. For instance, one may focus on the environmental protection or on the energy recovery potential. According to the new waste management strategy for Belarus only one nationalwide incineration plant is planed to be build in Minsk. Thus, the implementation of the waste incineration plant in Mogilev might not be applied. Hence, the optimal technologies in accordance with the national waste management strategy are MBT and anaerobic treatment plant.

Five scenarios, discussed above, were evaluated in four areas: economy, ecology, society, and technology, on the basis of the results of material flow analysis and on basis of capacities of different waste treatment and disposal facilities. The results and overview of the evaluation are presented in Table 41.

Table 41: Summary results of Economical, Ecological, Social and Technical Assessment

	Economical Assessment				
	Scenario				
Indicator	**0**	**1**	**2**	**3**	**4**
Investment costs [10^6€]	34.4	33	34.3	73.7	80.4
Ann. operating costs [10^6€/year]	8.9	8.8	9.2	7.2	6.3
Tot. ann. disc. costs [10^6€/year]	10.9	10.7	11.4	11.6	11.1
Costs per ton [€/year]	63.3	62.3	66.6	67.6	64.4
Revenues [10^6€/year]	1.7	2.9	2.8	7.7	9.0
Self-financing rate [%]		15	26	20	16
Costs as % of city budget expenditures	10	9.7	10.2	12	11.9
Costs as % of Nominal Average Salary	0.36	0.43	0.43	0.72	0.80
Environmental Assessment					
	Scenario				
Indicator	**0**	**1**	**2**	**3**	**4**
Separate collection rate [%]	6	14	29	29	21
Material recovery rate [%]	9	12	19	18	9
Energy recovery rate [%]	40	33	34	29	41
Landfilling rate [%]	39	38	34	26	24
Red. biod. waste landfilling [%]	57	57	63	94	99
GHG Net-Emissions [t $CO_{2eq\,/\,year}$]	17,777	14,819	2,915	-31,826	-22,009

Social Assessment					
	Scenario				
Indicator	0	1	2	3	4
Social acceptance [ranking]	1	3	2	4	5
Job creation [nr.]	851	1,080	1,420	1,210	660
Technical Assessment					
	Scenario				
Indicator	0	1	2	3	4
Technical assessment [ranking]	5	1	2	3	4

The economic assessement of scenarios shows that most of the suggested treatment technologies are expensive and are difficult to be financed by the city budget. Based on the economic assessment it is suggested to choose the instrument of PAYT (pay as you throw). Thus, current consumer tariffs should be increased gradualy over time to allow financing of a modernized waste management system. As mentioned, raising of tariffs has to be done steadily to avoid disproportionate financial pressure on population. To avoid excessive pressure on economically vulnerable citizens a subsidy support could be introduced or a PAYT (pay as you throw)-scheme could be implemented.

The environmental assessment of scenarios shows the importance of citizens' behaviour regarding waste generation, and the impact of waste composition on separate collection efficiency, material and energy recovery rate. Informal collection of recyclables affects the process of planning of a new waste management system. Furthermore, the results underline the significance of different waste pre-treatment options prior to landfilling and the diversion of biodegradable waste from landfills. The best results have been forecasted in scenarios where more sorting fractions and higher recycling goals were set. Additionaly, in comparison with the current situation all scenarios enhance greenhouse gas reduction, whereby full energy recovery achieves the best results.

The methodology used for the technical assessment recorded the potential of high uncertainties for the evaluation of qualitative indicators. The assessment results are strongly impacted by the individual opinions of the participating experts. Thus, the results of the technical assessment have to be treated with caution. The outcome may change, due to the involvement of additional number of experts or by inclusion of other experts.

The conclusion based on the social assessment indicates that all of the proposed scenarios may face less social acceptability. As expected, the complex scenarios including a high diversity of separate fractions are less favourable regarding the point of social acceptance, as these scenarios need the change of peoples' habits. Furthermore, technologies like incineration or anaerobic digestion may be also hardly accepted by the community, due to a lack of information or technological know-how.

To reverse the situation in the future an educational program for the people involved would be crucial, to make aware of the benefits provided by the new waste management system, and to engage them, to facilitate the change of behavioural patterns. Thus, the efficient development and implementation of a new waste management system is determined largely by the awareness and acceptance of the community members. Evaluation of the social indicators showed for example, that more jobs can be created in labour-intensive scenarios, such as separate collection and recycling of waste, and limited jobs in less effort-consuming activities such as disposal and composting. It can be concluded that the development of MSWS infrastructure in general will create new jobs in Mogilev. Moreover, it is recommended to keep the manual sorting at the sorting plant ZUBR to secure the employment.

Public acceptance and support, which is crucial for a successful regional recycling system, is highly dependent on the level of public awareness. On the one hand, population is the main consumer of utilities and waste generator, and on the other hand, peole are often not familiar with the process of separate waste collection and waste disposal and the range of services provided by the municipality. In this regard, population’s knowledge is often limited regarding the risks of poor waste management and the impact on health, safety, and the environment; and vice versa, about the benefits of recycling and preservation of natural resources.Thus, awareness raising and public education is an important aspect in modern waste management systems. In this respect the main goals and objectives of public education are to change people's habits, to increase the understanding for waste avoidance and separate collection of waste fractions, and to encourage the willingness of people to pay for effective waste management services.

To improve the current system some further challeges remain that are applicable for the most economies in transition in general:

- Improvement of the accessibility and increase the reliability of statistical data.
- Determination of control functions between various institutions of waste management.
- Enhancement of the effectiveness of procedures for monitoring and evaluation.
- Adaptation of the existing legislation in line with international and European legislation on this issue.
- Development of awareness-raising campaigns on the management of urban and regional MSW.
- Implementation of extended producer responsibility.
- Approval of new tariffs and the establishment of an adequate system of financing.
- Reviewal and reorganisation of all available waste management subsystems (container, collection, processing, deleting).
- Integration of informal sector into MSWM.

To assess the effectiveness of the waste management system it requires time and effort of all stakeholders. It is obvious that a large number of actors involved, makes it difficult to find one suitable strategy. The development of such a strategy can be both a long and costly procedure and -on a first glance - a burden for the region and its economy. The assessment results can be used by local authorities, stakeholders and decision makers for the development of a modern and sustainable waste management system that is responsive to local needs and priorities. However, beside assessement process and strategy development, the implementation of a waste management system requires time and experience. Despite available financial resources and strong institutional framework the implementation of a high level waste management system in Austria for example required more than 20 years. Hence, waste manamegement modernisation in transition economies has to be considered as a longterm process, but which has to be addressed and started immediately.

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9. Annex

Annex 1: State-of-the art waste collection services and waste treatment & disposal

Photo 1: Container site for MSW collection and temporary storage at multi-story housing area (Skryhan et al., 2016)

Photo 2: Container for collelction of glas (© ABF-BOKU)

Photo 3: Container for collelction of plastic (© ABF-BOKU)

Photo 4: "Yard detour" approach to waste collection in rural area (Skryhan et al., 2016)

Photo 5: Waste collection vehicles in Mogilev in 2016 (© ABF-BOKU)

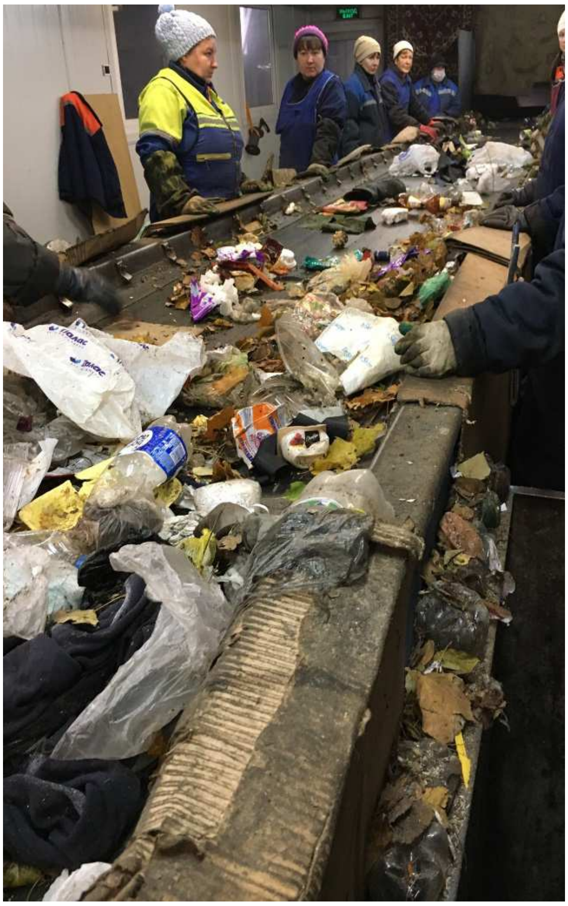

Photo 6: Process of waste sorting at ZUBR (© ABF-BOKU)

Photo 7: Reception point for mix waste at ZUBR (Skryhan et al., 2016)

Photo 8 :Sorting line at ZUBR (Skryhan et al., 2016)

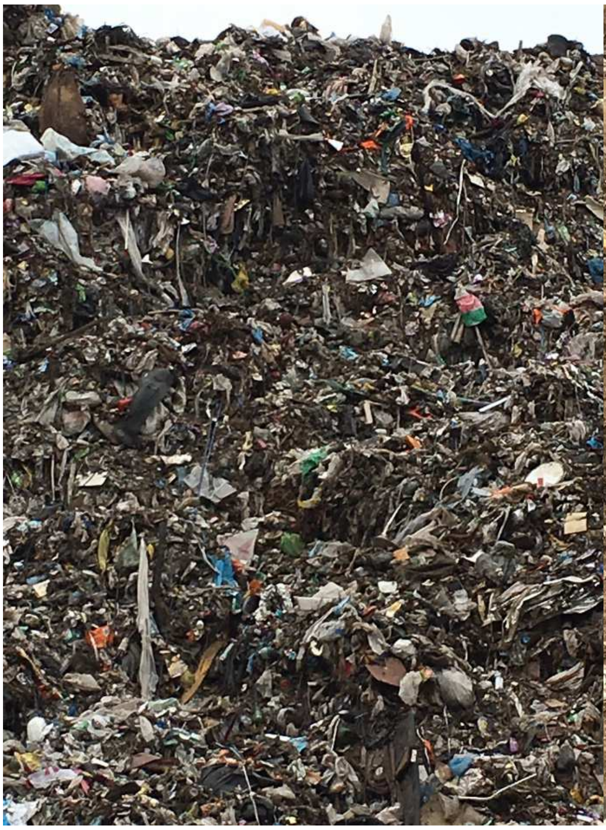

Photo 9: Landfill (© ABF-BOKU)

Photo 10: Landfill (© ABF-BOKU)

Annex 2: Overview waste amounts in future scenarios, Belarus

Input Material in tons/year	Baseline	Sc 0 - LF +MBT	Sc 1 MBT- recy [wet/dry]	Sc 2 MBT - recy [gl, pl, pa,me, org comp]	Sc 3 Incin. - recy [pl, gl, pa, me, org comp]	Sc 4 Incin. - recy [gl, me, org biogas]
Total Generated waste	170,748	197,870	197,870	197,870	197,870	197,870
Formally collected waste	87,601	172,400	172,400	172,400	172,400	172,400
Separate collected waste:						
plastic	689[12]	1,800	3.620	3,362	3,362	-
paper		4,900	11,723	10,206	10,206	-
glass		4,400	7,241	8,327	8,327	8,327
metals		-	2,069	2,069	2,069	2,069
organics		-	-	26,377	26,377	26,377
Total recyclables (without organic)[13]	10,599	11,100	24,653	23,964	23,964	10,396
Treated material in WM-facilities:						

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[12] 689 t/y of recyclables are collected at separate containers from the population. Remaining amount of 9,910 t/y are received from yard detour (7,484 t/y), from collecting points (4,507 t/y) and from other legal entities (2,771 t/y).

[13] Excluding WEEE & hazardous waste

Sorting line	87,601	11,100	24,653	23,964	23,964	-
MBT treatment	-	158,800	145,247	119,559	-	-
Composting	550 (input)	-	-	39,566	39,566[14]	-
Anaerobic digestion	-	-	-	-	-	26,377
Incineration	-	-	-	-	119,559	133,127
Landfilling	107,152	67,437	66,192	59,296	45,148	41,248
Output of treated material:						
Residues after sorting		2,385	4,741	4,936	4,936	-
RDF		51,839	45,594	41,641	-	-
Compost		-	-	13,057	13,057	4,088
Output recycables after sort. process		8,715	19,912	19,028	19,028	10,396 (direct. to recy)
Output MBT (gl)	-	4,764	2,896	2,245	-	-
Output MBT (me)	-	2,731	1,186	1,186	-	-

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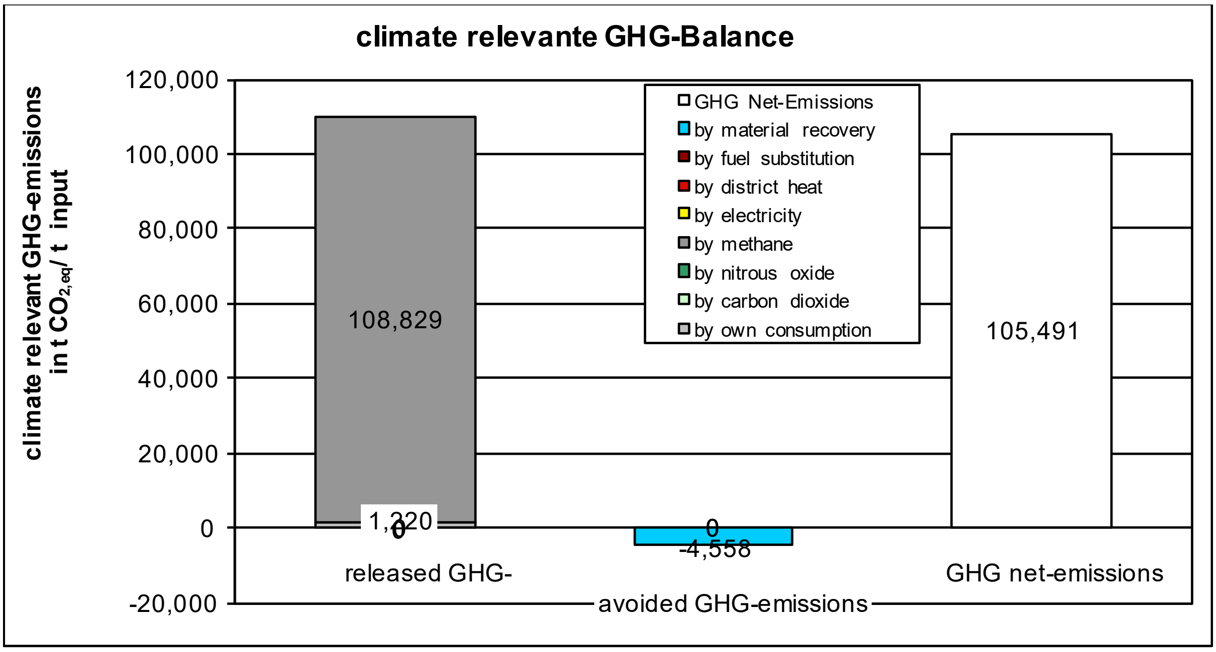
[14] Amount includes separate collected organics + structure material for composting process (26,377+ 50%*26,377=39,565 t/y)

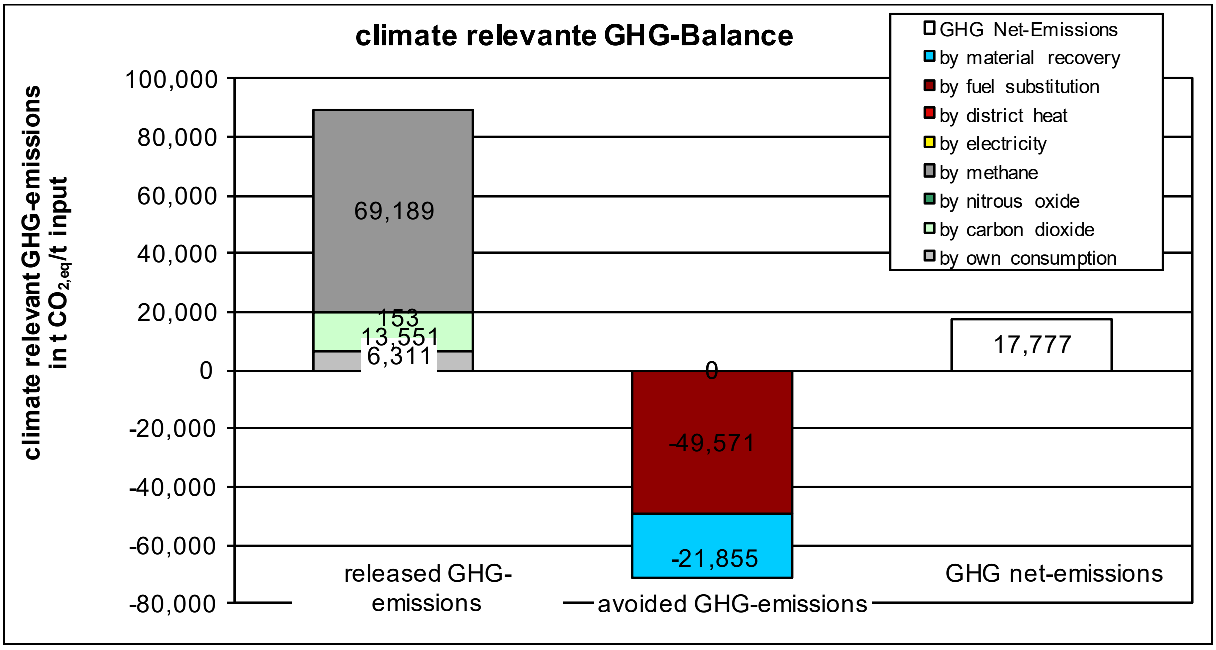
Total recyclables		16,210	23,994	35,516	32,085	14,484
From Incineration:						
Electricity (MWh)	-	-	-	-	23,366	29,380
Heat (MJ)	-	-	-	-	294,415,200	370,184,400
From biogas plant:	-	-	-	-	-	2,420,522 (m^3 CH4)
Electricity (MWh)						8,391,600
Heat (MJ)						6,799

Annex 3: Climate relevant GHG balance of all future scenarios

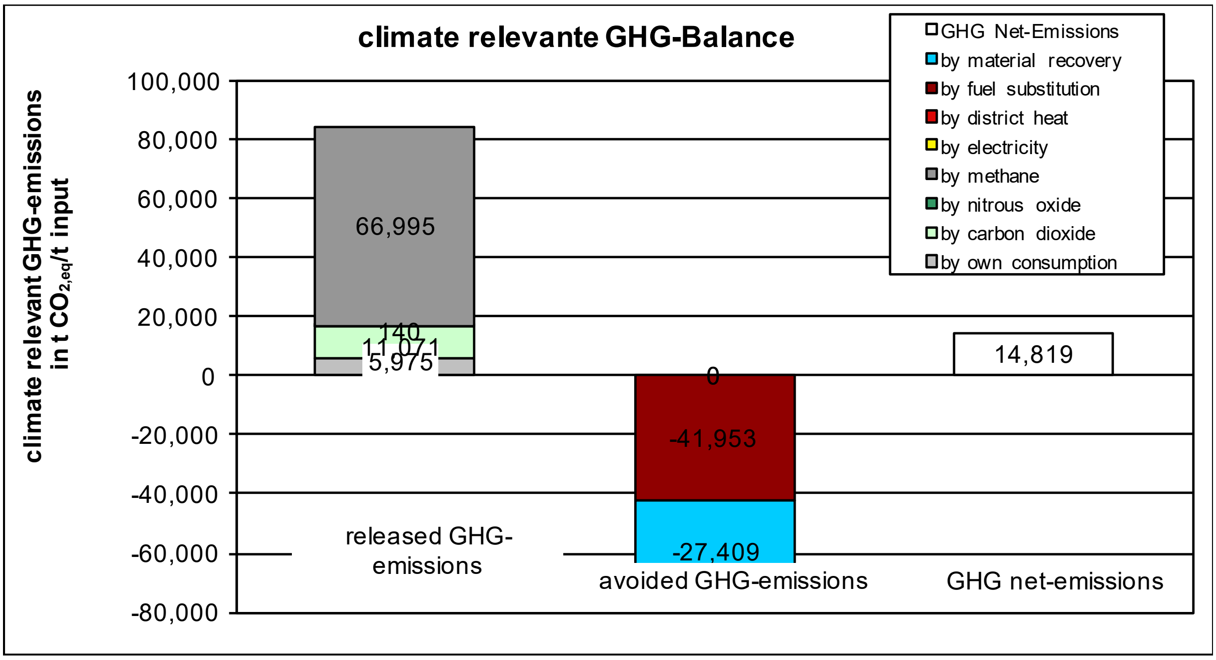
Baseline Scenario



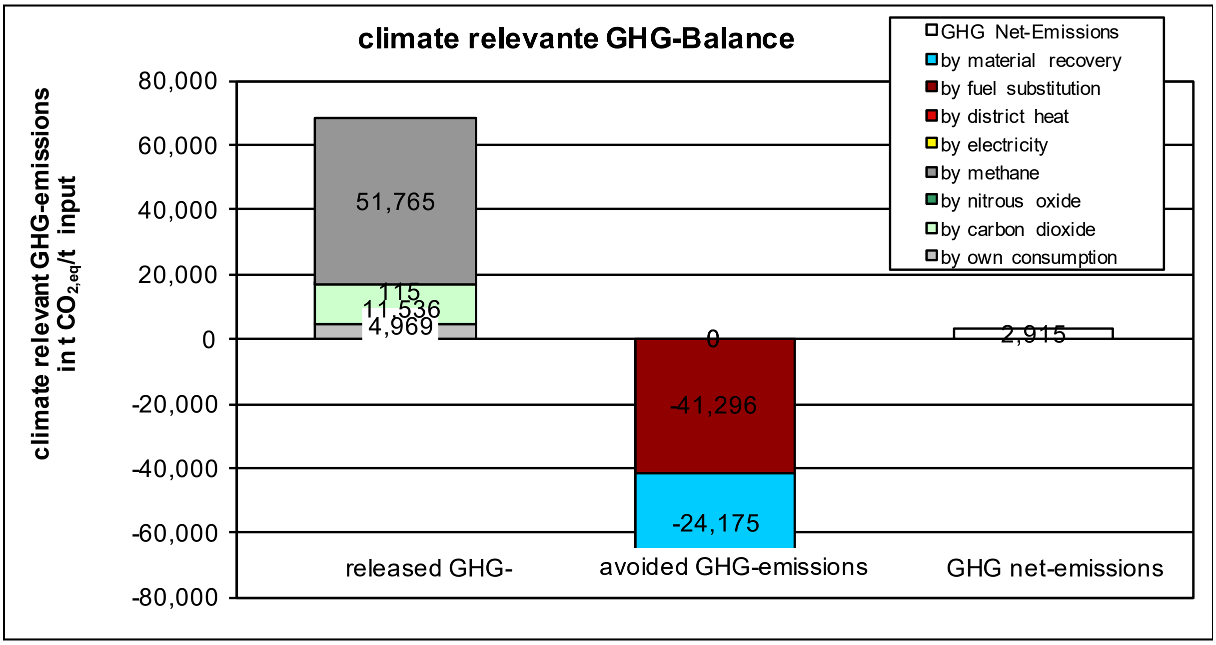
Sc 0 - LF +MBT



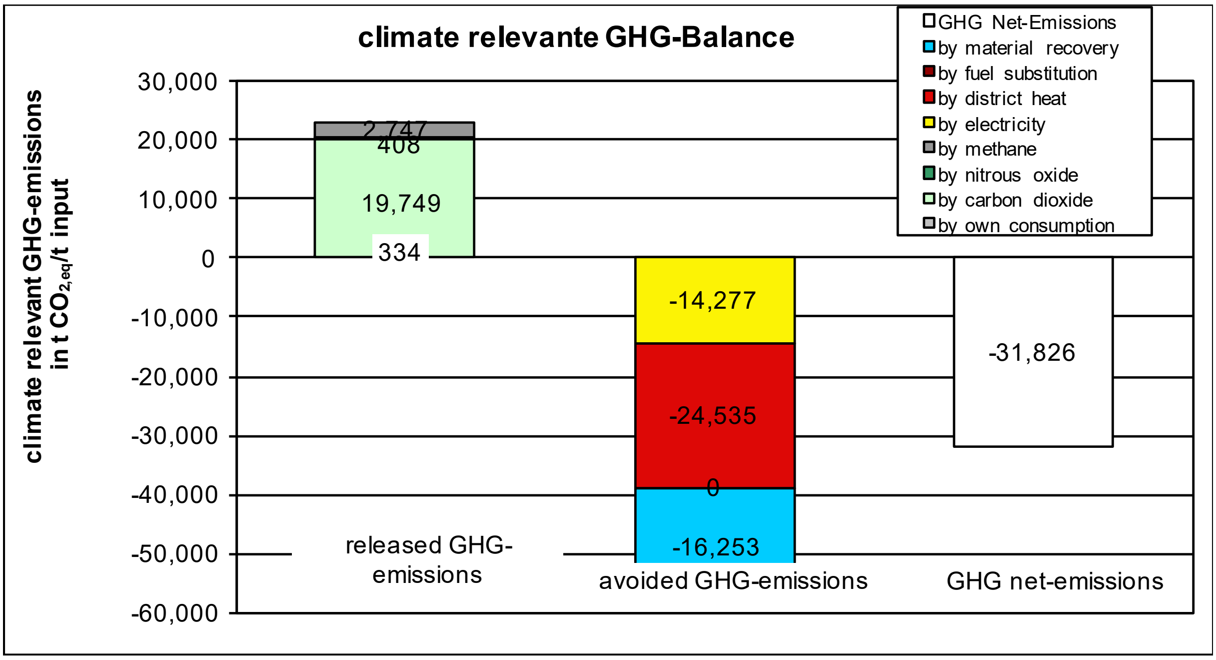
Sc 1 MBT- recy [wet/dry]



Sc 2 MBT - recy [gl, pl, pa,me, org comp]



Sc 3 Incin. - recy [pl, gl, pa, me, org comp]



Sc 4 Incin. - recy [gl, me, org biogas]