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EFFICIENT WASTE MANAGEMENT SECTOR

Summary of the Doctoral Thesis

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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF ENGINEERING SCIENCES

To be granted the scientific degree of Doctor of Engineering Sciences, the present Doctoral Thesis has been submitted for the defence at the open meeting of RTU Promotion Council on _______________, 2019 at the Faculty of Faculty of Power and Electrical Engineering of Riga Technical University, 12/1 Āzenes Street , Room _______.

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DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Engineering Sciences is my own. I confirm that this Doctoral Thesis had not been submitted to any other university for the promotion to a scientific degree.

Kaspars Kļavenieks ……………………………. (signature)
Date: ………………………

The Doctoral Thesis has been written in Latvian. It consists of Introduction; 3 chapters; Conclusions; 27 figures; 6 tables; the total number of pages is 123. The Bibliography contains 65 titles.

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1. INTRODUCTION

The aim of the waste management system is to reduce the impact of waste and waste management process by reducing the amount of waste generated, by treating and recovering waste in environmentaly sound way or by recycling it [1]. The use of waste as a resource has been significantly updated in recent years. This is in line with both the European Union (EU) waste hierarchy established in 2008 [1] and the 2015 EU Action Plan for the Transition to the Circular Economy [2]. Waste becomes a resource when it reaches its end status or is appropriately prepared for recovery. End-of-waste status is achieved when a substance or object can be used for a specific purpose, there is a market or demand for such a substance or object, the substance or object meets the technical requirements for that purpose and its use will not adversely affect the environment or human health [1].

In contrast to past waste management practices, which aimed primarily to minimize environmental damage caused by waste, the current purpose of a waste management system concerning waste already generated is to ensure that waste is returned to the economy as a resource. Such a paradigm shift is leading to the expansion of the waste management sector in other sectors of the economy to a greater extent than before. Thus, the range of factors influencing and relating to waste management encompasses a number of economic aspects that go beyond the results of the cost-benefit analysis of waste management. This in turn points to the need for new methodologies to ensure efficient and modern management of the waste management sector. In addition, when studying a waste management system, it is necessary to consider not only environmental and economical aspects but also social aspects, which will allow the most accurate assessment of the current situation, the identification of problematic issues and the development of solutions to improve the waste management system.

1.1. Topicality of the Doctoral Thesis

A circular economy package was approved by the European Parliament in May 2018, incl. Amendments to the main EU directives related to waste management setting the objectives to be achieved in the waste management sector. These amendments set much higher targets for recycling rates, expand the range of types of waste to be collected separately, and significantly limit the use of landfill as a waste recovery method. In addition, the timeframe for reaching the targets is an additional challenge – the first threshold for increasing recycling rates is already expected in 2025, which means that decisions need to be taken immediately. The second challenge is more tight limits for landfilling. Not all types of waste can be recycled in an economically sound way and without creating additional environmental pressures, so it is necessary to provide the best available alternatives for the treatment of those categories of waste. Achieving the goals set and putting the principles of the circular economy into practice requires a timely and effective decision-making process based on systematic research, analysis and impact assessment of the implementation of alternative scenarios in the waste management sector.

1.2. Aim and Tasks of the Doctoral Thesis

The aim of the Doctoral Thesis is to develop methodologies for efficient management of the waste sector, which would facilitate the decision-making process, thus promoting the implementation of the principles of the circular economy in the waste management sector. The analysis of the current situation shows that often the objectives set are not achieved or are partially achieved due to the delayed or unsuccessful decision-making process. The identified reasons that hinder decision-making are the lack of data characterizing the current situation, the limited use of data processing methods and the lack of knowledge in the evaluation of alternative development scenarios, which all together can generally be described as a limited and fragmented flow of information. In order to facilitate the solution of these problems, the following main tasks were carried out in order to reach the goal.

1. Identification of data sources characterizing the waste management sector and evaluation of their quality, analysis of the current situation, empirical studies for obtaining characteristics of municipal waste.
2. Selection of policy instruments and technological solutions suitable for solving the identified problems, assessment of their capability, and analysis of application experience.
3. Assessment of alternative solutions for the development of the waste management system, assessment of the impact of implementation of alternative scenarios and their contribution to the objectives.

1.3. Hypothesis of the Doctoral Thesis

The hypothesis put forward for the study assumes that the management of the waste sector can be improved by promoting its efficiency by moving towards the goals of the circular economy. This can be done by using statistical data and experimentally derived data characterizing the waste management sector, as well as by improving data processing methodologies and empirical models.

1.4. Structure and Description of the Doctoral Thesis

The Doctoral Thesis is based on 5 thematically related scientific publications, published in internationally indexed scientific journals and available in scientific publications databases. The purpose of the publications is to approbate the methods developed and the results obtained during the research. Both the developed methodologies and the conclusions drawn from the analysis can be used in the decision-making process, thus contributing to effiecient development of the waste management sector.

The Doctoral Thesis is written in Latvian. It contains an introduction and three chapters.

1. Effective management of the waste sector.
2. Methods used in the research.
3. Results and evaluation of the results obtained.

The introductory part of the Doctoral Thesis defines the purpose of the research and defines the tasks to be accomplished and the topicality of theme, describes the research methods, as well as summarizes the research results approbation at scientific conferences and lists the author's publications. Chapter 1 of the Doctoral Thesis gives an overview of the research topics, identifies the main problems and outlines possible solutions. Chapter 2 describes the methods used in the study to obtain and process data for an analysis of alternatives. Chapter 3 of the Doctoral Thesis presents the results of the research and presents the main conclusions.

1.5. Scientific Significance of the Doctoral Thesis

According to the aim of the study – to support decision-making process, thus promoting implementation of circular economy principles – the stages of waste management system, which are directly related to the increase of waste recovery and recycling and factors influencing the decision-making process, are analyzed. The study concludes that research methods, data acquisition, processing and analysis are generally considered and defined as a flow of information the purpose of which is to link individual functional elements of a waste management system. In keeping with this concept of information flow, the study develops methodologies for situational analysis and decision support, from data acquisition, processing and analysis, to impact assessment of alternative scenarios.

1.6. Practical Significance of the Doctoral Thesis

The methodologies developed for the management of the waste sector in the framework of the Doctoral Thesis provide an opportunity for the stakeholders to implement evidence-based decision-making, thus contributing to efficient operation of the waste management system. The developed methodologies include a complex approach offering solutions for the assessment of the current situation, development of alternative scenarios and evaluation of the implementation of the scenarios. The proposed set of solutions allows to analyze and design system performance as a whole, the methodology is applicable both at regional and national level. Certain elements of the methodology have been implemented in practice – the method for determining the composition of unsorted municipal waste developed within the framework of study has been used as a basis for the preparation of legislation requirements for regular monitoring of municipal waste composition in municipal waste landfills. The proposal on the inclusion of household packaging waste in the quantification of municipal waste is used to prepare the annual statistical overview of the National Statistical Report "No.3-Waste Report".

1.7. Approbation of the Research Results

Presentation of results at scientific conferences

1. Klavenieks, K., Kubule, A., Vesere, R., Blumberga, D. Towards efficient waste management in Latvia: an empirical assessment of waste composition // International Scientific Conference Environmental and Climate Technologies, CONECT 2019, May 2019, Riga, Latvia.

2. Kavals, E., Klavenieks, K., Gusca, J., Blumberga, D. Indicator analysis of integrated municipal waste management system. Case study of Latvia // International Scientific Conference of Environmental and Climate Technologies – CONECT 2018, May 2018, Riga, Latvia.

3. Klavenieks, K., Dzene, K. P., Blumberga, D. Optimal strategies for Municipal solid waste treatment –environmental and socio-economic criteria assessment // International Scientific Conference of Environmental and Climate Technologies – CONECT 2017, May 2017, Riga, Latvia.

4. Klavenieks, K., Blumberga, D. Common and Distinctive in Municipal Solid Waste Management in Baltic States // International Scientific Conference of Environmental and Climate Technologies – CONECT 2016, October 2016, Riga, Latvia.

5. Klavenieks, K., Blumberga, D. Forecast of Waste Generation Dynamics in Latvia // International Scientific Conference Environmental and Climate technologies – CONECT 2015, October, 2015, Riga, Latvia.

6. Klavenieks, K., Feofilovs, M., Blumberga, D. Solar energy use in landfill // International Scientific Conference of Environmental and Climate Technologies – CONECT 2014, October 2014, Riga, Latvia.

7. Timma, L., Vilgerts, J., Vanaga, R., Kļavenieks, K., Blumberga, D. Decomposition analysis based on IPAT and Kaya identity for assessment of hazardous waste flow within enterprise // 27th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy systems, June 2014, Turku, Finland.

Scientific publications

1. Klavenieks, K., Kubule, A., Vesere, R., Blumberga, D. Towards efficient waste management in Latvia: an empirical assessment of waste composition // Energy Procedia (ISSN: In Press)

2. Kavals, E., Kļavenieks, K., Gušča, J., Blumberga, D. Indicator Analysis of Integrated Municipal Waste Management System. Case Study of Latvia. Energy Procedia, 2018, Vol.147, pp. 227–234. ISSN 1876-6102. Available from: doi:10.1016/j.egypro.2018.07.086

3. Kļavenieks, K., Dzene, K., Blumberga, D. Optimal Strategies for Municipal Solid Waste Treatment – Environmental and Socio-Economic Criteria Assessment. Energy Procedia, 2017, Vol. 128, pp. 512–519. ISSN 1876-6102. Available from: doi:10.1016/j.egypro.2017.09.071

4. Kļavenieks, K., Blumberga, D. Common and Distinctive in Municipal Solid Waste Management in Baltic States. *Energy Procedia*, 2017, Vol. 113, pp. 319–326. ISSN 1876-6102. Available from: doi:10.1016/j.egypro.2017.04.072

5. Kļavenieks, K., Blumberga, D. Forecast of Waste Generation Dynamics in Latvia. Energy Procedia, 2016, Vol. 95, pp. 200–207. ISSN 1876-6102. Available from: doi:10.1016/j.egypro.2016.09.049

6. Timma, L, Vilgerts, J., Vanaga, R., Kļavenieks, K., Blumberga, D. Decomposition analysis based on IPAT and Kaya identity for assessment of hazardous waste flow within enterprise // 27th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, ECOS 2014. DOI: 10.13140/RG.2.1.4450.0888

Papers in conference proceedings

1. Āriņa, D., Kļavenieks, K., Burlakovs, J. The Cost-estimation of Mechanical Pre-treatment Lines of Municipal Solid Waste in Latvia // Proc.Latv.Univ.Agr.,2014,32(327) DOI: 10.2478/plua-2014-0009

2. Kļavenieks, K., Feofilovs, M., Blumberga, D. Solar Energy Use in Landfill. In: Abstracts of 55th International Scientific Conference: Subsection: Environmental and Climate Technologies, Latvia, Rīga, 14-15 October, 2014. Riga: RTU Press, 2014, pp. 42–43. ISBN 978-9934-10-612-5.

2. EFFICIENT MANAGEMENT OF THE WASTE SECTOR

Waste reuse, recycling and recovery targets are set out in the EU directive on "Waste and repealing certain Directives" (2008/98/EK) [1], restrictions on the disposal of biodegradable waste are set out in the EU Landfill Directive (1999/31/EK) [3]. These directives have been in force for more than 10 years, however, in achieving the goals set therein, Latvia is behind the result to be achieved. The development of the waste management system so far in Latvia and the results achieved are presented schematically in the Fig. 2.1. From 2010 until 2017, recycling volumes have increased from ~10 % to 23 % [4]. It should be noted that, in the last three years, there has even been a decrease in recycling, according to statistics.

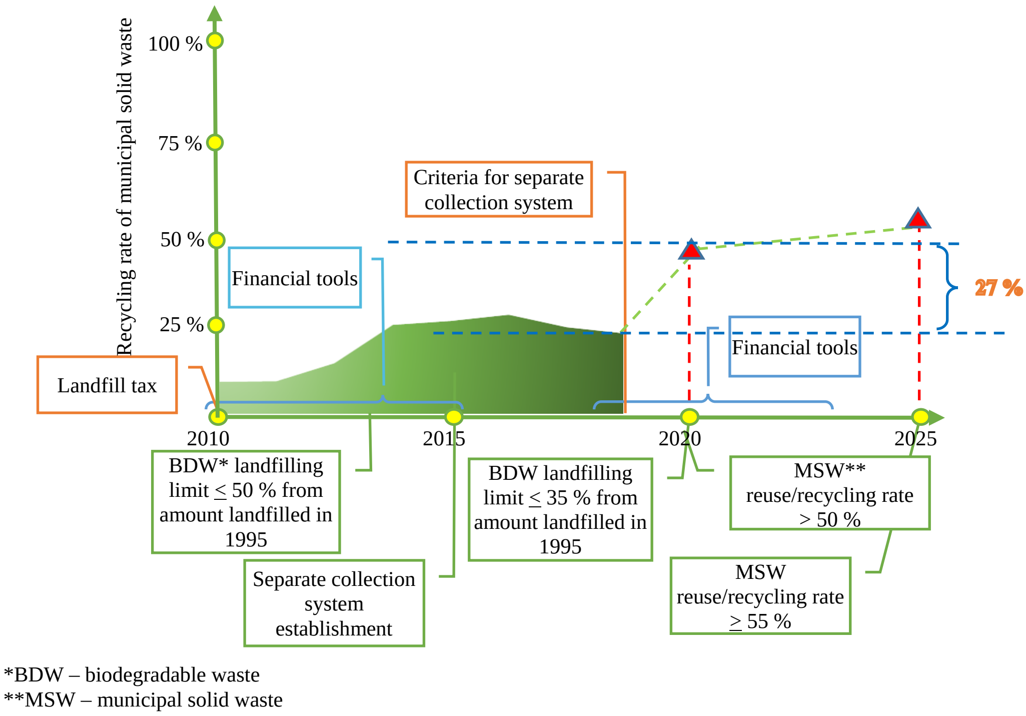

Fig. 2.1. The development of the waste management system in Latvia, 2010–2017.

An analysis of measures applied to increase waste recycling and reduce waste disposal shows that administrative tools and financial support mechanisms have been used, but the results achieved are unsatisfactory, indicating that the management implemented is ineffective. A more detailed analysis of the implemented management reveals a number of issues – firstly, delays in the required actions have been identified – for example, financial instruments, or European Union funds supporting the development of infrastructure have been available 2 to 3 years later than it would be necessary for the timely development of infrastructure. Secondly, there is no up to date definition of requirements – for example, regarding the establishment of a separate waste collection infrastructure, the minimum criteria to be met when implementing a system are set only 2 years after the requirement for a mandatory separate waste collection system were in force. An analysis of measures taken to reduce the disposal of biodegradable waste shows that no criteria have yet been set for the end-of-waste status of biodegradable waste. Thirdly, in some cases, the implementation of the policy has limitations that are contrary to generally accepted practices, e.g., financial support to develop infrastructure co-financed from the EU Cohesion Fund 2007–2013 during the 2007–2013 financial programming period was only available for biodegradable waste treatment projects that did not produce biogas. This has limited the development of widely used recycling technologies such as anaerobic fermentation and has not contributed to the reduction of biodegradable waste disposal.

When analyzing the possible reasons that have resulted in the current situation, it is assumed that the cause of the problem is limited information flow, lack of knowledge and lack of long-term vision. It may be plausible that decision-making is weakened due to lack of recommendations and conclusions drawn from detailed analysis, thus limiting decision makers to make justified, evidence-based decisions.

The process of waste management system optimization involves a number of sequent steps, from analyzing the current situation to putting the decision-making process into practice. The purpose of this Thesis is to develop methodologies for efficient management of the waste sector in order to develop the implementation of principles of the circular economy in the waste management sector. Accordingly, the task is to demonstrate step by step the necessary actions the result of which is the endorsement of approbated recommendations. Planning the future development of the system requires an assessment of the current situation with respect to the amount and composition of the waste generated, the existing technologies and the policy instruments used. System evaluation includes data collection, data processing and indicator calculations. The next step is the preparation and assessment of future development scenarios, which include both the preparation of forecasts of potentially manageable waste streams and the development of alternative scenarios for the application of technological solutions and their impact on the achievement of the set objectives. The functional stages of the system and their interaction are presented in Fig. 2.2.

An important element in ensuring effective management is the flow of information between the functional phases of the system. Adequate solutions are needed to ensure the proper functioning of the waste management system and to achieve the stated objectives. On the other hand, in order to offer the most appropriate solutions, information is needed that characterizes the current situation, as well as an analysis of the advantages and disadvantages of the existing system. The flow of information should ensure that decision-making and system management are evidence-based, thus contributing to its effectiveness. It should be noted that a waste management system is a complex set of measures of area-specific and time-specific characteristics, such as quantities of waste generated and managed, both in quantitative and qualitative terms, proportion of waste materials in waste streams, quantities and types of waste generated in territorial division, etc. Also, the system's functioning and future development path are affected by the resources available for the implementation of the functions, as well as external factors, incl. economic and social aspects. These considerations support the assumption that a set of case-specific solutions is needed to achieve the intended results, since universal solutions may not include all the specific factors that determine the set of measures to achieve the set goals. According to Mohammadi et al. [5], a waste management system is a complex system involving many waste streams, collection schemes and treatment processes; all these steps must be taken into account in order to implement an integrated waste management system. In turn, Cobo et al. [6] emphasizes the need for an initial analysis of alternatives before developing a waste management system.

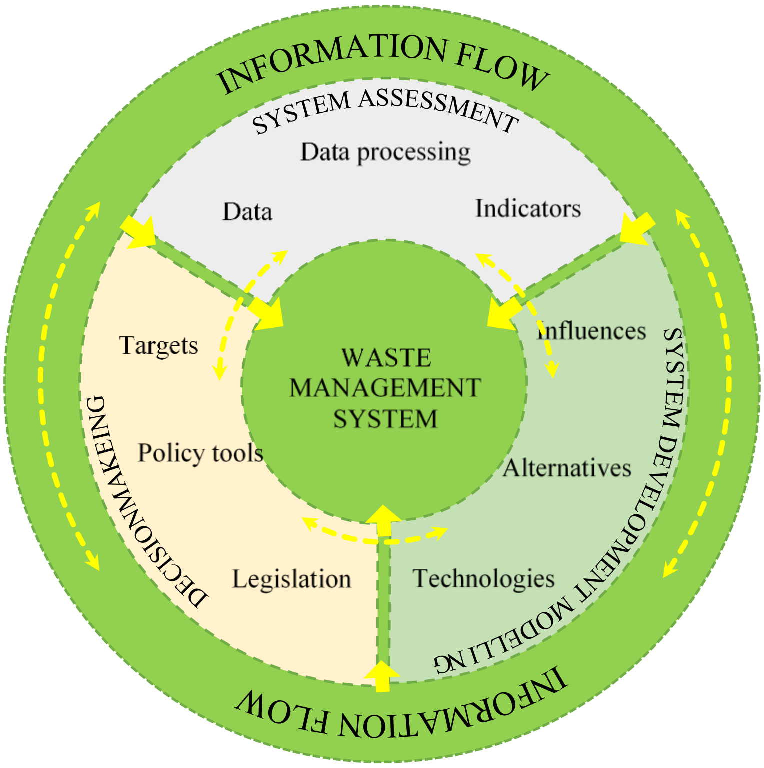

Fig. 2.2. Functional phases of the waste management system and their interconnection.

The main stages of the development of the Doctoral Thesis, their interconnections and the main research methods used are shown schematically in Fig. 2.3. The research process was structured in line with the aim of the Thesis – to develop methodologies for efficient management of the waste sector, and included sequential, mutually complementary stages. The initial step in the development of the dissertation was to evaluate the current situation regarding the efficiency of the system. This phase of the study is needed to assess the current situation and identify constraints on achieving the stated goals. During the research phase, available data sources were identified and data processing methods were used, incl. indicator calculations for complex system performance evaluation. In parallel, as data describing unsorted municipal waste composition was not available, a waste composition evaluation study was performed, thus providing the necessary information for the evaluation of technological solutions and capacities required for system development.

In addition to the assessment of the current situation, the experience of other countries in waste management was analyzed, thus identifying those factors, incl. applied policy tools and technological solutions, that contribute to the successful move of the waste management sector towards the implementation of the principles of the circular economy. As a result of the analysis, potentially applicable solutions for the improvement of waste management system were selected.

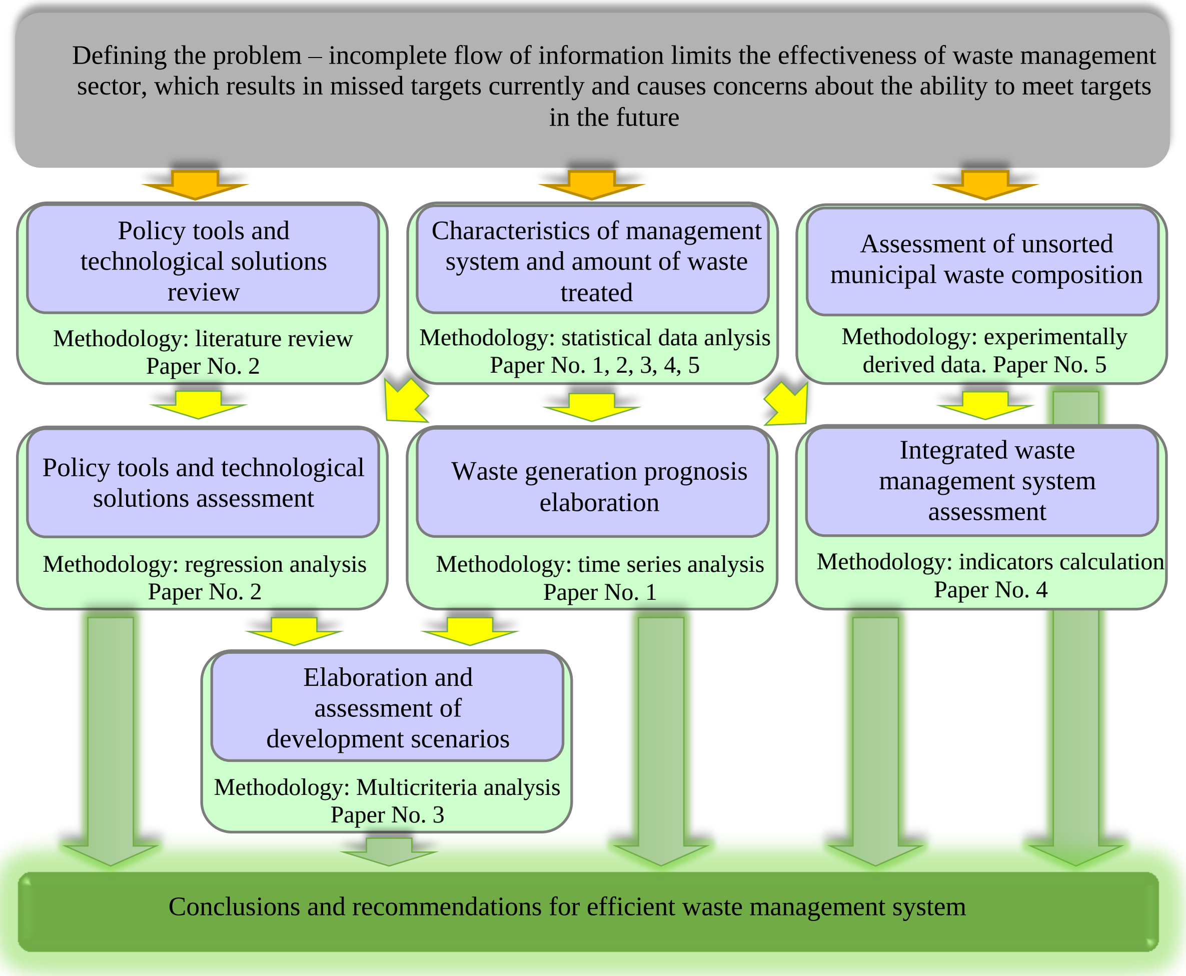

Fig. 2.3. Stages of the Doctoral Thesis development and their content relation.

An important factor in the system development planning is the assessment of the amount of waste to be managed. In order to calculate the future volumes of waste to be managed and to assess the capacity of the waste management infrastructure needed, a methodology for forecasting waste production was developed.

The final step to develop methodologies is the elaboration of future scenarios and the selection of the optimal scenario for reaching the objectives set. This phase was carried out on the basis of the results of the current situation analysis, the objectives set out in the legislation and the potentially applicable technological solutions. The selected solutions were combined in different scenarios, each scenario was assessed for technical, environmental, economic and social factors. The closest to the ideal scenario was determined using a multicriteria analysis method.

The preparation of each of the stages of the Doctoral Thesis resulted in conclusions that can be used to improve the management of the waste sector, as well as a methodological framework for solving similar problems in the future. A list of the main publications to which references are made in the Doctoral Thesis is given in Table 2.1.

Table 2.1

Papers Published During the Development of the Doctoral Thesis

#	Title of the paper
No. 1	Kļavenieks, K., Blumberga, D. Forecast of Waste Generation Dynamics in Latvia. Energy Procedia, 2016, Vol. 95, pp. 200–207. ISSN 1876-6102. Available from: doi:10.1016/j.egypro.2016.09.049
No. 2	Kļavenieks, K., Blumberga, D. Common and Distinctive in Municipal Solid Waste Management in Baltic States. Energy Procedia, 2017, Vol. 113, pp. 319–326. ISSN 1876-6102. Available from: doi:10.1016/j.egypro.2017.04.072
No. 3	Kļavenieks, K., Dzene, K., Blumberga, D. Optimal Strategies for Municipal Solid Waste Treatment – Environmental and Socio-Economic Criteria Assessment. Energy Procedia, 2017, Vol. 128, pp. 512–519. ISSN 1876-6102. Available from: doi:10.1016/j.egypro.2017.09.071
No. 4	Kavals, E., Kļavenieks, K., Gušča, J., Blumberga, D. Indicator Analysis of Integrated Municipal Waste Management System. Case Study of Latvia. Energy Procedia, 2018, Vol. 147, pp. 227–234. ISSN 1876-6102. Available from: doi:10.1016/j.egypro.2018.07.086
No. 5	Klavenieks, K., Kubule, A., Vesere, R., Blumberga, D. Towards efficient waste management in Latvia: an empirical assessment of waste composition // Energy Procedia 2019 (ISSN: In Press)

3. RESEARCH METHODS

3.1. Data Acquisition

3.1.1. Statistical Data Sources

In order to obtain data on the amount of waste treated in Latvia, the data base maintained by the State Ltd Company “Latvian Center for Environment, Geology and Meteorology” the State Statistical Report “3-Waste” was used [7]. The data available in the National Statistical Report have been used for the preparation of publications Nos. 1, 2, 3, 4 and 5. The information in the database is available on an annual basis, with the level of detail corresponding to the waste classification used in the EU (*list of waste*) [9]. Separately recorded waste management activities are the quantities of waste generated, collected, recycled, disposed of, exported and imported. The recycling and disposal activities are classified according to their type in accordance to the classification of the Waste Framework Directive [1] .

EUROSTAT databases [4] were used to obtain EU-wide statistics on waste management. In Publication No. 2, corresponding data bases to the Latvian national statistical survey “3-Waste” in Lithuania and Estonia [10], [11] were used to obtain additional information on the operation of waste management systems in these countries. In order to obtain general demographic and socio-economic data in Latvia, databases of the Central Statistical Bureau of Latvia were used [12].

3.1.2. Empirical Data on Unsorted Municipal Waste Composition in Latvia

An experimental study on the composition of unsorted municipal waste in Latvian cities was carried out. 32 Latvian cities in different regions of Latvia were included in the study. The methodology of the study was mainly based on the “*NT ENVIR 001*” [13] waste determination method developed by “Nordtest”. The aim of the study was to determine the composition of unsorted municipal waste. The breakdown of the sorted waste fraction was mainly determined taking into account standard LVS EN 15440: 2011 “Production of fuels from solid waste. Methods for determination of biomass content”. This approach has been used as the standard is widely used and the division of waste fractions is well known and understood. In order to obtain a more detailed results and identify specific waste groups, several separate waste fractions were added to the basic division. Firstly, for each type of materials that are used in the production of packaging (plastic, paper, metal, etc.), a separate fraction was defined which characterizes the proportion of certain type of packaging in unsorted municipal waste flow. In addition, separate accounts were kept for beverage carton packaging and other composite packaging (coffee, chip packs, etc.). Concerning plastic waste, plastic bags were identified as a separate category. In total, 27 separate waste fractions were analyzed.

3.2. Evaluation of Policy Instruments, Technological Solutions, Calculations of Indicators

3.2.1. Evaluation of Policy Instruments and Technological Solutions

The research phase included the following tasks: selection of policy instruments and technological solutions under consideration, selection of data characterizing the waste management system, evaluation of the efficiency of the use of policy instruments based on the historical performance of the system, comparison of results of individual countries – Latvia, Estonia and Lithuania. The algorithm of the research process is shown in Fig. 3.1.

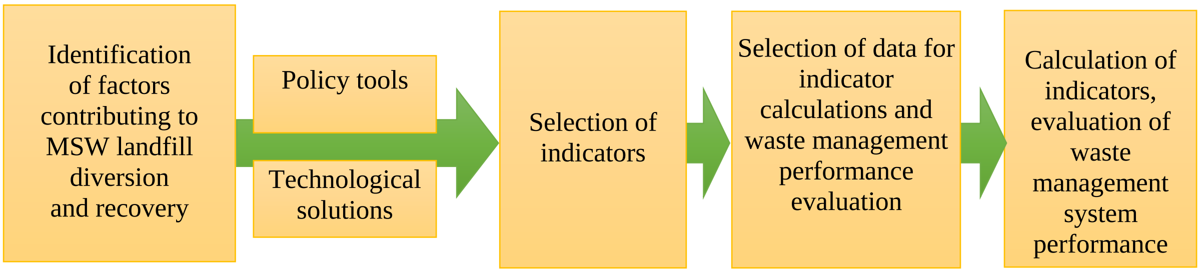

Fig. 3.1. Algorithm of research process.

The selection of policy instruments under consideration is based on the results of literature analysis. Information on the policy instruments used in each of the three Baltic States is obtained from a study carried out for the European Commission [14], [15], [16].

Alongside the policy instruments, the technological options of the waste management system, or alternatives to waste disposal as a method of waste utilization – waste incineration and waste recycling – were evaluated.

3.2.2. Assessment of Waste Management System Using the Integrated Indicator Calculation Methodology

In order to evaluate the efficiency of the waste management system, a methodology developed by Rigamonti et al. [8] was adopted for the situation in Latvia, which includes the calculation of an integrated indicator. The methodology includes two interconnected modules: a module for analyzing the recovery of waste materials, and a cost estimation model according to Rigamonti et al. proposed methodology [8]. The baseline scenario includes an analysis of the current situation in Latvia, including a compilation of statistical data and data quality analysis based on an estimate of about 500 data sets. Indicator analysis includes material recycling, energy recovery and cost estimates for 10 waste management regions in Latvia and the City of Riga, using a total of 1354 datasets. Indicator analysis includes three indicators – material recovery indicator, energy recovery indicator, and cost indicator.

The material recovery indicator measures the amount of waste recycled in relation to the total amount of municipal waste produced. The energy recovery indicator describes how much municipal waste is used for energy recovery. A cost indicator is needed to compare the cost per tonne of waste management and to estimate the volume of waste recovery in relation to the cost level.

By combining material and energy recovery parameters in a single indicator, it is possible to evaluate the overall efficiency of the waste management system in terms of the use of waste as a resource.

3.3. Analysis of Alternatives

3.3.1. Development of Waste Forecasting Methodology

There are no common guidelines or standards for the generation of waste forecasts, but in most cases estimates of expected waste production dynamics are based on GDP values as well as indicators of resource and/or commodity consumption [17], such as purchasing power [18].

The algorithm of the methodology development process is shown in Fig. 3.2. The initial task of developing a methodology is to select influencing factors that illustrate historical changes in waste generation and their relation to changes in welfare levels. Indicators – the amount of municipal waste collected and the amount of packaging waste collected – were selected to characterize the historical volume of waste generated. GDP at constant prices is selected as an indicator of changes in the level of welfare.

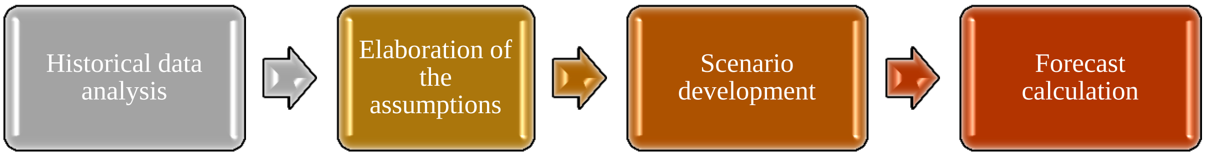

Fig. 3.2. Algorithm to develop a methodology for preparation of waste production.

The next step in the application of the methodology is the historical analysis of the selected characteristics and indicators leading to the development of assumptions regarding the types of waste to be included in the municipal waste stream forecast and the fluctuations between the amount of waste generated and economic development indicators. In the next step, the results of historical value fluctuation analysis are used to produce waste generation forecasts.

3.3.2. Developing Alternative Scenarios and Assessing the Potential Outcomes of Their Implementation

The development of alternative scenarios and the evaluation of the potential outcomes of their implementation involved four main steps from a methodological point of view. The methodology algorithm is shown in Fig. 3.3. The first step was an assessment of the current situation with regard to the characterization of the waste generated, the available waste treatment technologies, the capacity of the technological equipment, and the results achieved by treatment. The second step was to select alternative solutions and combine them in different potential development scenarios. The third step involved selecting criteria for evaluating and comparing alternative scenarios. The final step involved evaluating the scenarios and selecting the optimal scenario.

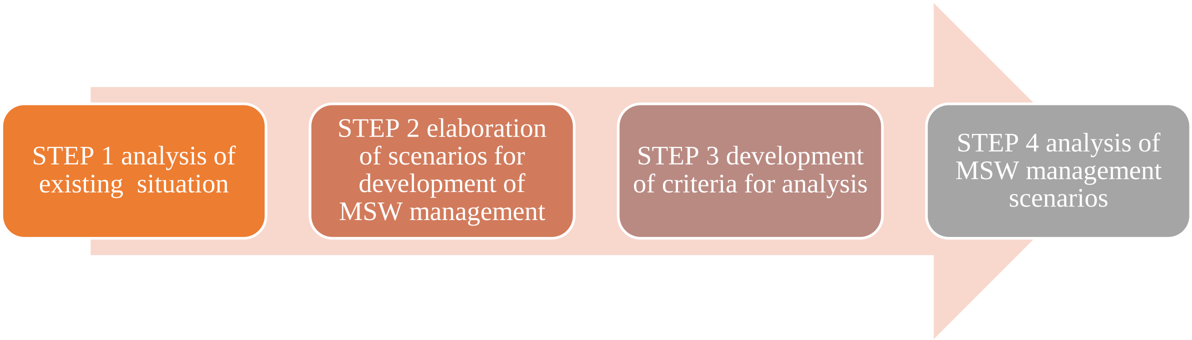

Fig. 3.3. Methodology algorithm for development of alternative scenario and evaluation process.

Scenario evaluation and cross-comparisons were performed using the multi-criteria analysis method. The multicriteria analysis method was chosen as the most appropriate for the given task because it allows to evaluate different, difficult to compare factors, which cannot be correctly evaluated, for example, using the cost-benefit analysis method. A set of criteria for scenario analysis was developed taking into account aspects that are essential for successful scenario implementation, such as the feasibility of technology or financial implementation and environmental aspects. The values and significance of the evaluation criteria were determined on the basis of consultation with waste management experts, technology providers and literature analysis.

4. RESULTS AND DISCUSSION

4.1. Determination of Waste Composition

Within the study there were collected and sorted 160 unsorted municipal waste samples – five samples for each of the 32 cities included in the study. The results characterize the composition of unsorted municipal waste collected in the existing waste management system prior to pretreatment and thus allow to evaluate the efficiency of the existing waste management system in terms of separating recyclable materials from the overall waste stream. In interpreting the results, it should be taken into account that the mass of waste is determined for naturally wet waste, accordingly the moisture absorption capacity of the various waste fractions influences the results, and the results obtained should not be interpreted as the proportion of materials of dry mass.

4.1.1. Results of the Waste Composition Assessment

Overall, the results indicate a rather significant dispersion of the measurement results for the waste composition. This can be explained by the non-homogeneous composition of unsorted municipal waste as well as differences in consumer habits across regions. When estimating the average value of each city, calculated from five individual measurements, the dispersion of the minimum and maximum values is balanced (see Table 4.1).

In addition to the experimentally determined waste composition, statistical data on the total amount of waste generated in Latvian cities and population of these cities were collected. The specific amount of waste in tonnes per capita was calculated using the data collected. The data was further analyzed using the *Spearman's correlation test*. Based on the conclusion that there is a close relationship between the amount of waste produced and the number of population, an additional indicator – specific amount of waste (municipal waste, t per inhabitant) – was created.

For the purposes of this assessment, individual waste fractions are grouped on the basis of their management options or the specific requirements for their management. The obtained distribution allows to estimate the volume of different waste streams and to compare the proportion of waste types in different groups of cities. The following groups were used in the analysis:

1) biodegradable waste – including biodegradable fraction and half of the fine fraction;
2) paper – including paper and cardboard and their packaging;
3) plastic – all plastic fractions, including packaging, bags, soft and dense plastic;
4) glass – including glass and glass packaging;
5) metal – including ferrous and non-ferrous metals and their packaging;
6) packaging – including all packaging fractions, including composite materials, beverage packaging, wood packaging;
7) inert waste – inert materials, ceramics, soil, stones, sand, etc.;
8) fines – fine fraction, particle size <40 mm;

9) hazardous waste – including all three groups of hazardous waste;
10) others – including residual fractions, incl. wood, hygiene waste, textiles, leather, rubber, carpets.

Table 4.1

Proportion of Waste Fractions in Unsorted Waste Flow in Latvian Cities

Waste fraction	Average	Mean	Standard deviation	Coeff. of var.	Median	Min	Max	Stnd. skewness
Biodegradable waste	29.22	5.39	18.43 %	28.96	14.14	37.47	–1.48	0.29
Paper, cardboard	4.65	1.47	31.63 %	4.72	1.99	7.87	0.43	–0.17
Paper, cardboard (packaging)	3.44	1.17	33.90 %	3.38	1.88	6.32	2.58	1.42
Beverage packaging	1.37	0.52	38.23 %	1.26	0.76	2.97	3.52	2.74
Wood	0.56	0.45	78.30 %	0.46	0	1.74	3.15	1.60
Wood (packaging)	0.16	0.22	142.66 %	0.08	0	1.01	5.29	7.16
Hygienic wastes	6.30	2.46	39.05 %	5.94	2.27	14.65	3.24	3.71
Textiles	5.04	1.37	27.18 %	4.71	2.50	8.96	2.37	1.93
Leather, rubber	0.76	0.62	81.78 %	0.62	0	1.82	1.06	–1.42
Glass	1.14	0.63	55.43 %	1.03	0.31	3.05	2.75	1.73
Glass (packaging)	8.00	2.11	26.32 %	8.26	2.37	11.41	–1.10	0.01
Inert wastes	2.08	2.01	96.52 %	1.28	0.30	10.11	5.25	8.23
Soft plastics	1.41	0.72	51.00 %	1.26	0.24	3.84	2.81	3.16
Soft plastics (packaging)	1.58	0.56	35.52 %	1.55	0.72	2.75	0.68	–1.01
Soft plastics (bags)	3.73	1.47	39.26 %	3.82	1.50	6.87	0.81	–0.63
Dense plastics	0.82	0.37	44.47 %	0.75	0.33	1.98	2.89	2.20
Dense plastics (packaging)	4.48	3.20	71.44 %	3.16	1.65	12.93	3.96	1.70
Carpets	0.48	0.37	76.03 %	0.53	0	1.24	0.65	–1.08
Ferrous metal	0.62	0.39	63.20 %	0.53	0.15	1.70	3.36	2.25
Ferrous metal (packaging)	1.39	0.58	41.94 %	1.23	0.72	3.10	3.25	2.23
Non-ferrous metal	0.21	0.29	139.00 %	0.10	0	1.14	4.30	3.40
Non-ferrous metal (Packaging)	0.76	0.30	39.50 %	0.66	0.29	1.34	1.12	–1.12
Composite material packaging	0.64	0.41	63.72 %	0.49	0.19	1.95	3.91	3.41
Fine matter	19.23	3.30	17.18 %	19.51	12.70	25.81	0.13	–0.75
DHW (batteries, accumulators)	0.23	0.22	95.37 %	0.17	0.01	0.93	4.03	3.99
DHW (WEEE)	0.54	0.45	84.30 %	0.37	0.08	2.08	4.16	4.06
DHW (chemicals, etc.)	1.16	0.52	44.83 %	0.97	0.59	2.70	3.26	1.77

Table 4.2

Spearman Correlations for Different Waste Fractions

	Biodegradable waste	Paper	Plastics	Glass	Metal	Packaging	Inert	Hazardous	Others	Fines	WAP	EAW	Unsorted waste amount	Inhabitants
Paper	0.23													
Plastics	–0.68**	–0.51**												
Glass	–0.45*	–0.02	0.24											
Metal	–0.50**	–0.10	0.28	0.32										
Packaging	–0.24	0.36*	–0.18	0.10	0.19									
Inert	–0.55**	–0.18	0.60**	0.15	0.29	–0.32								
Hazardous	–0.56**	–0.40*	0.35*	0.06	0.55**	–0.00	0.28							
Others	–0.69**	–0.64**	0.52**	0.21	0.54**	–0.09	0.30	0.72**						
Fines	0.36*	0.35	–0.36*	–0.36*	–0.60**	0.19	–0.24	–0.42*	–0.67**					
WAP	0.09	0.22	–0.35	–0.12	–0.02	0.34	–0.52**	–0.01	–0.09	0.09				
EAW	0.07	0.11	0.05	–0.20	–0.24	0.12	–0.01	–0.36*	–0.17	0.12	0.01			
Unsorted MSW	0.17	0.33	–0.33	–0.13	–0.16	0.37*	–0.26	–0.14	–0.34	0.30	0.19	0.34		
Inhabitants	0.20	0.33	–0.34	–0.19	–0.21	0.33	–0.26	–0.19	–0.38*	0.34	0.16	0.35*	0.99**	
SWA	0.10	0.16	–0.24	0.01	–0.07	0.32	–0.26	–0.04	–0.21	0.13	0.26	0.26	0.86**	0.81**

** High significance probability between 0.001 and 0.01.
* Medium significance probability between 0.01 and 0.05.
WAP – Share of working age population, %.
EAW – Employee average wages, EUR.
SWA – Specific waste amount, t per inhabitant.

The correlation test results (see Table 4.2.) indicate that there are some underlying relationships between the waste fraction variables. Especially strong and specifically significant correlations are identified between biodegradable wastes and plastics, between other wastes and hazardous wastes, paper, fines and biodegradable wastes. Weaker negative, but significant correlations are identified between the share of working age population and the fraction of inert wastes, and between hazardous waste fraction share and average wage variable. Interestingly only packaging waste fraction correlated significantly with unsorted waste amount; however, no significant correlations are identified between SWA and the particular waste fractions, which could be due to the reason that SWA value is based on statistical data and was not measured. Thus, this means that as determined before, the amount of unsorted waste generation is strongly related to the number of inhabitants, however waste composition is affected by other factors than specific waste generation amount.

4.1.2. Results of the Waste Composition Assessment by Group of Cities

In order to further analyze the obtained data and to find possible correlations characterizing the existing waste management system, a waste composition analysis by groups of cities was performed. Figure 4.1 a shows the results of the survey on unsorted municipal waste per capita in five urban groups classified by population. The results show that cities with a larger population have higher specific waste production rate, whereas in smaller cities the specific amount of waste is only about half of the average.

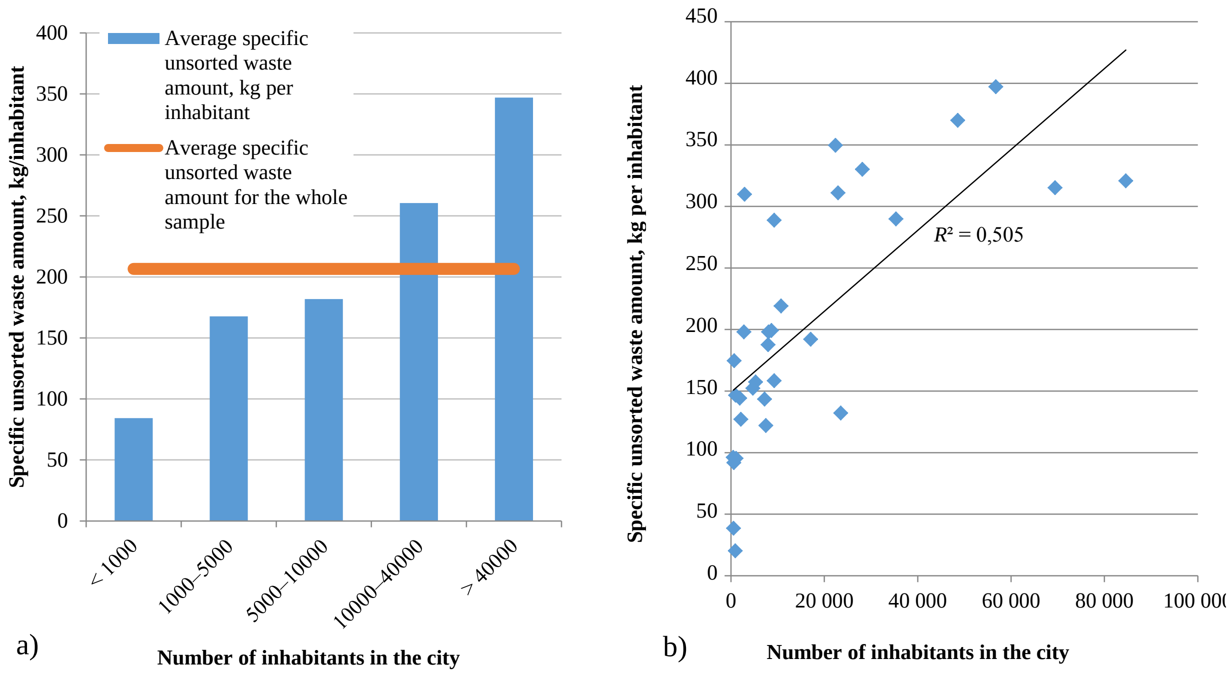

Fig. 4.1. Specific amount of unsorted municipal waste in the analyzed cities.

In Fig. 4.1 b, the trend is described using linear regression, r^2 is 0.505, which indicates a moderate correlation and confirms that there is some correlation between the size of the city and the habits of waste producers (Riga is excluded due to a significantly larger population).

The results of the determination of unsorted municipal waste by groups of cities are presented in Fig. 4.2.

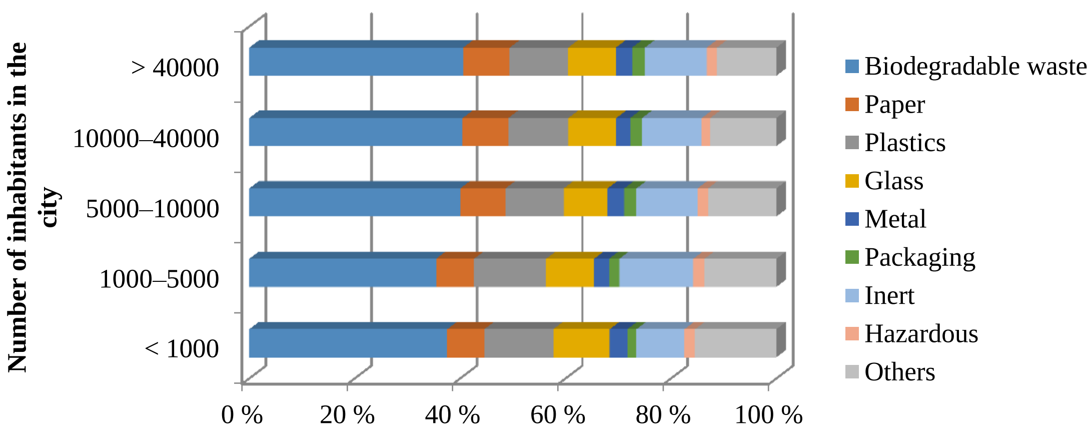

Fig. 4.2. Results of waste composition determination by groups of cities.

The biodegradable waste group makes the majority of all waste fractions in the sample of all cities. The highest proportion of biodegradable waste is in cities with population of 10–40 thousand, while the lowest – in cities with population of 1–5 thousand inhabitants. The difference between the minimum and maximum percentage of paper waste in the respective groups of cities is 1.8 %, with the larger percentage of paper waste being typical of larger cities. Similar to paper waste, plastic waste results show that there is a more significant relation to the size of cities, only in this case, a larger proportion is found in smaller cities.

4.2. Indicators for Assessing the Efficiency of a Waste Management System

Within research, the material recovery indicator (MRI), energy recovery indicator (ERI), integrated indicator (II) and cost indicator (CI) were calculated for each waste management region.

In 2016, Latvia's average MRI, taking into account all waste management regions and the city of Riga, was 0.154. Results of MRI calculations for some regions show that the highest level of material recovery was in Ziemeļvidzeme waste management – 0.26 (or 26 % of the total amount of municipal waste collected) for the region, 0.24 for the Ventspils waste management region and 0.23 for the Zemgale waste management region. For other waste management regions the MRI is less than 0.2 (see Fig. 4.3).

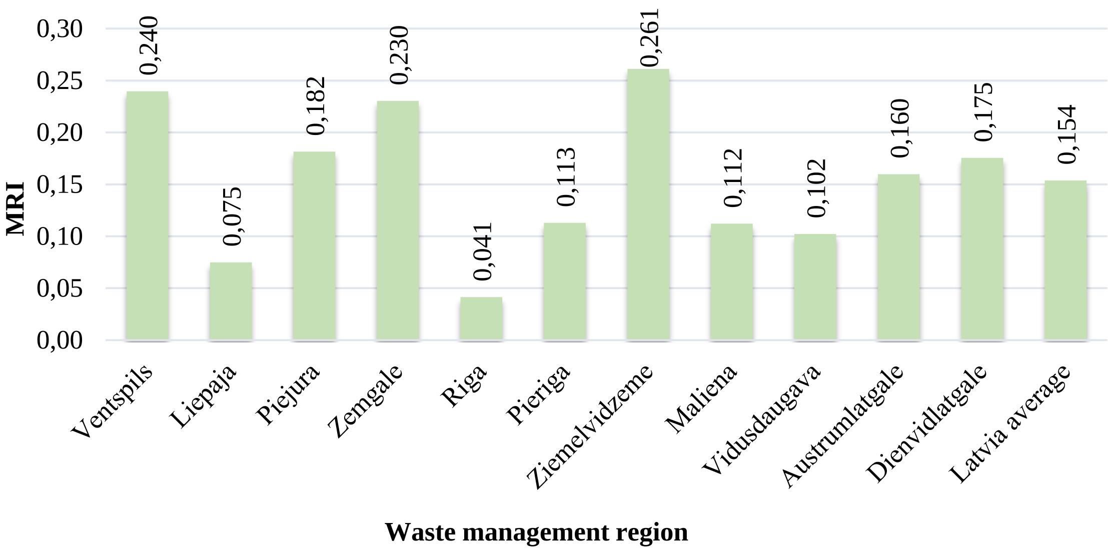

Fig. 4.3. Results of MRI calculations for 2016.

The results of the ERI calculations are presented in Fig. 4.4. Landfill sites of Ventspils, Piejūra, Maliena, Vidusdaugava, Austrumlatgale and Dienvidlatgale waste managemenet regions do not produce energy from landfill gas, therefore the ERI value is 0 for these regions. The highest ERI is in Liepaja waste management region, where the ERI value is 0.065 or 6.5 %, followed by the Ziemeļvidzeme waste management region, where the ERI value is 0.048 or 4.8 %. In Latvia, the average ERI value was calculated as the average ERI value for all waste management regions, in 2016 it was 0.016 or 1.6 %.

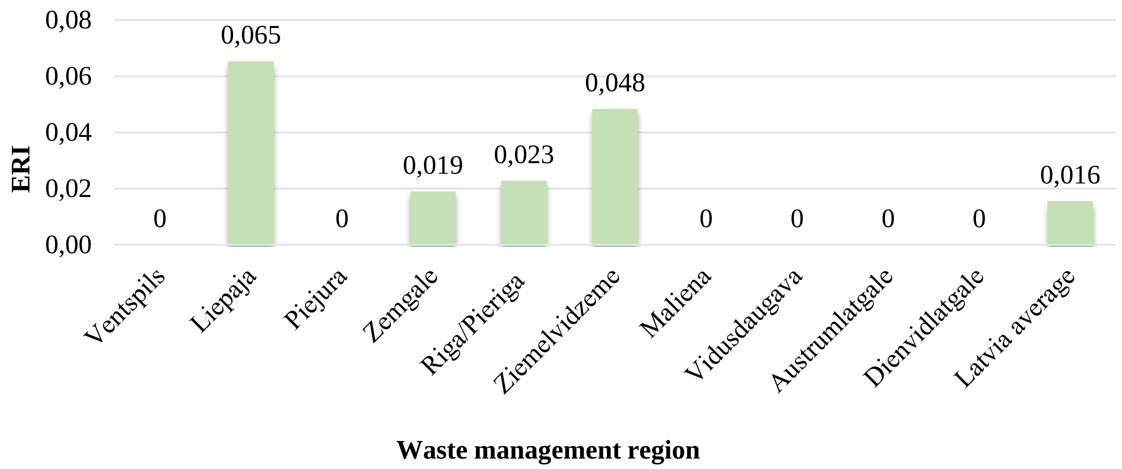

Fig. 4.4. Results of ERI calculations for 2016.

Results of MRI and cost indicator (CI) are shown in Fig. 4.5.

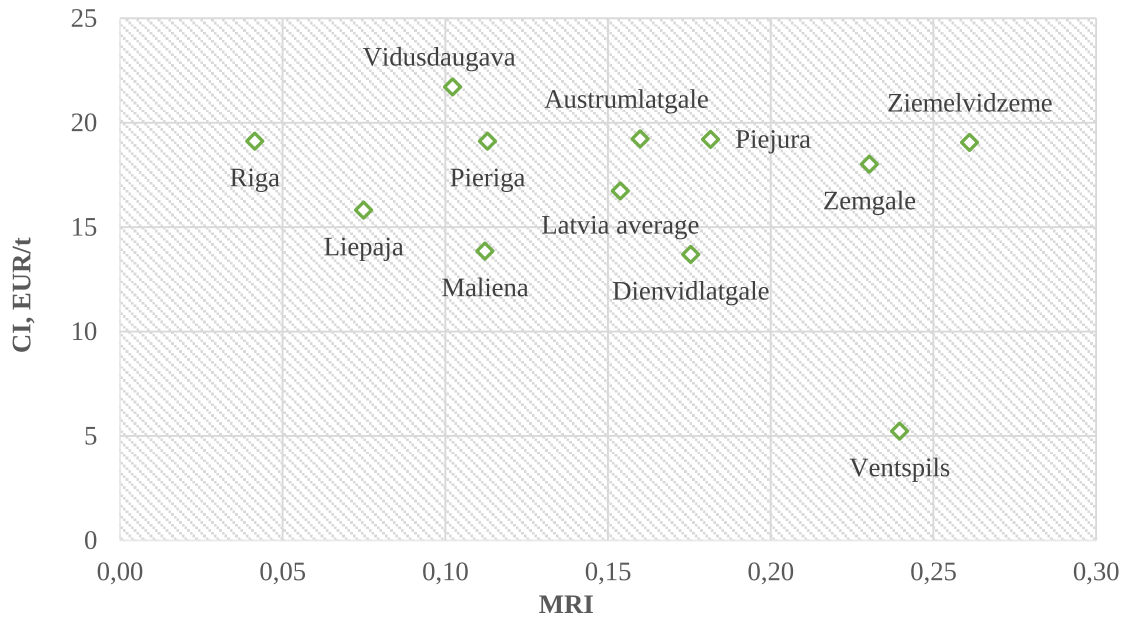

Fig. 4.5. CI versus MRI.

The analysis shows that the value of MRI increases with the increase of the value of CI. This is a logical result, since increasing the investment in the development of the system (by improving the waste management system, e.g. by newer, more efficient sorting and recycling technologies) also increases the environmental benefits, which in this case means an increase in material recycling and recovery.

4.3. Supporting Tools for Decision-Making

4.3.1. Forecast of the Waste Generation Dynamics

In accordance with the developed methodological approach, the data characterizing historical waste production were analyzed using the time series analysis method and identifying related indicators. In order to assess the possible relation between changes in welfare and the amount of waste produced, a comparison of characteristics was performed over a 10-year period. The historical values of the indicators are shown in Fig. 4.6.

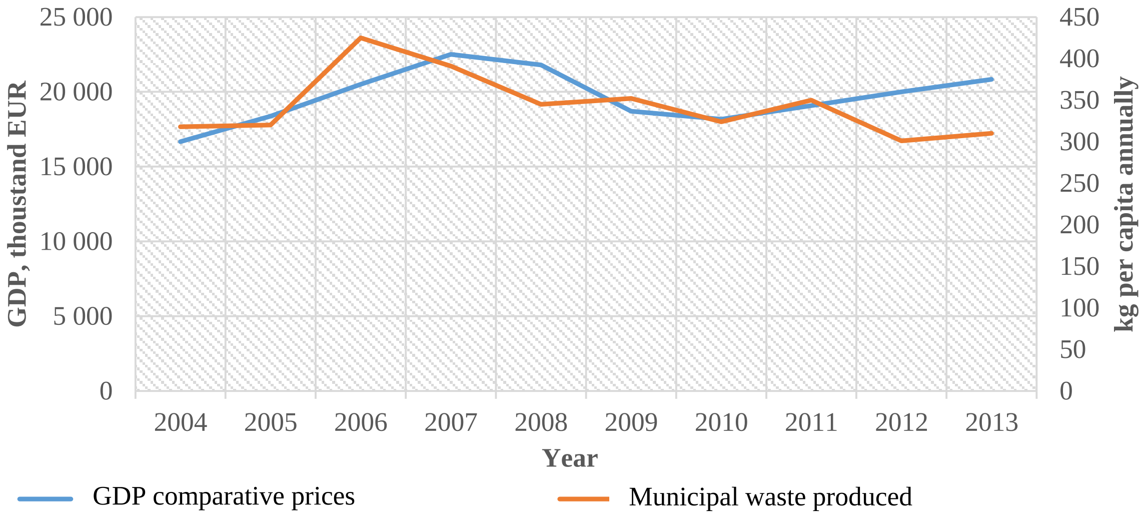

Fig. 4.6. Dynamics of generated waste and GDP in 2004–2013.

An additional aspect of the historical production rate of waste is related to the types of waste included in the calculation of the municipal waste stream. The basic approach involves the assumption that, although the potion of packaging waste is generated by households, the amount of packaging waste is not included in the municipal waste. In order to identify the possible relation between the amount of municipal waste collected, the packaging waste collected and the dynamics of GDP, a comparison of the calculation method "with" and "without" household packaging waste inclusion in totals is made. The results are shown in Fig. 4.7.

Fig. 4.7. Comparison of household and household packaging waste with GDP in 2006–2013.

Comparing the "with" and "without" packaging waste scenarios, the scenario "with" packaging waste tends to approach the fluctuations in GDP values over the period considered, suggesting that such an approach would more accurately reflect actual household waste production. As regards the relation between the GDP dynamics and the volume of waste produced, it should be noted that this relation is not directly proportional. When comparing changes in waste volumes with changes in GDP, it can be concluded that changes in waste volumes are about 1/3 of the change in GDP.

Taking into account the impact of waste reduction measures on potential waste volumes, the assumption was made that the amount of waste generated as a result of preventive activities will decrease with an increasing trend of approximately 0.1 % in 2015 and 1.0 % in 2020.

Based on the conclusions of the analysis carried out, a forecast model for municipal waste generation for Latvia in 2015–2021 has been prepared, which is presented in Fig. 4.8.

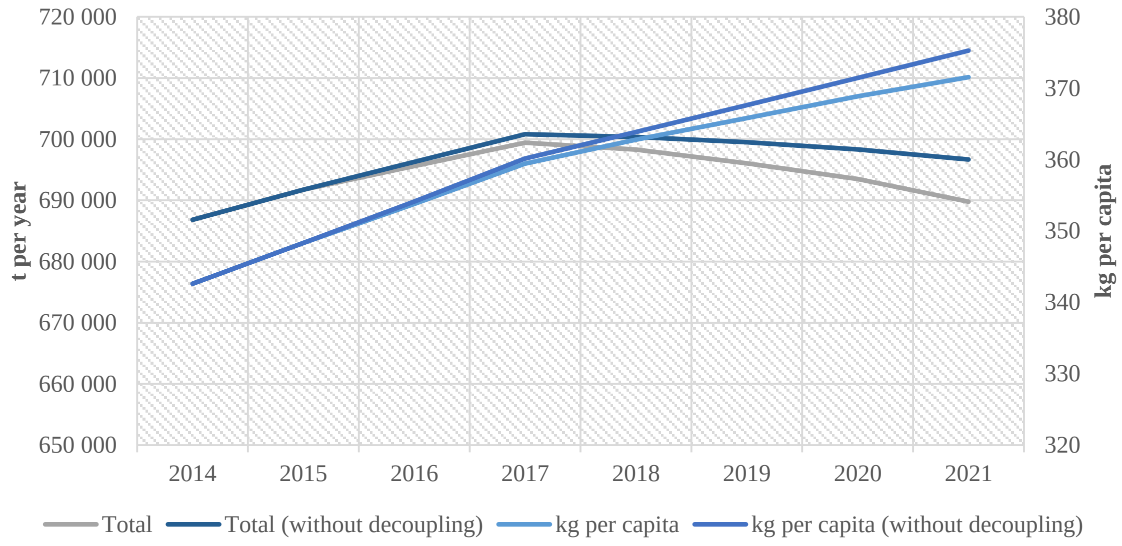

Fig. 4.8. Municipal waste production forecast for Latvia 2014–2021

The forecast foresees a steady increase in waste generation per capita over the period under review and is supported by positive GDP figures. In terms of total waste generation, growth is projected for the period up to 2017, and after 2017; a decline in the ratio of demographics to GDP is projected – the population decline outweighs the increase in waste generated by GDP.

4.3.2. Impact of the use of technological solutions and policy instruments

The impact assessment of the use of technological solutions and policy instruments is based on an assessment of the use of tools over time in the context of changes in waste management activities. The analysis compares the waste management systems of Latvia, Lithuania and Estonia in the period from 2004 to 2014.

4.3.2.1. Effectiveness of the Landfill Tax

The impact of the landfill tax on waste disposal in Latvia and Estonia has been analyzed by comparing the tax rate with the amount of waste disposed of. No such analysis has been carried out in Lithuania as no landfill tax was introduced in Lithuania during the reporting period. The rate of the landfill tax in Latvia has increased from EUR 0.70 to EUR 12.00 per tonne of waste disposed of in 2004–2014 [20]. In Estonia, this tax rate has increased from EUR 0.30 to EUR 24.90 per tonne of waste disposed of during the period under review [21], [22], so in 2014 the tax rate in Estonia was more than twice as high as in Latvia. The ratio of the landfill tax to the amount of municipal waste disposed of [4], [11] at a fixed tax rate in Latvia and Estonia is shown in Fig. 4.9.

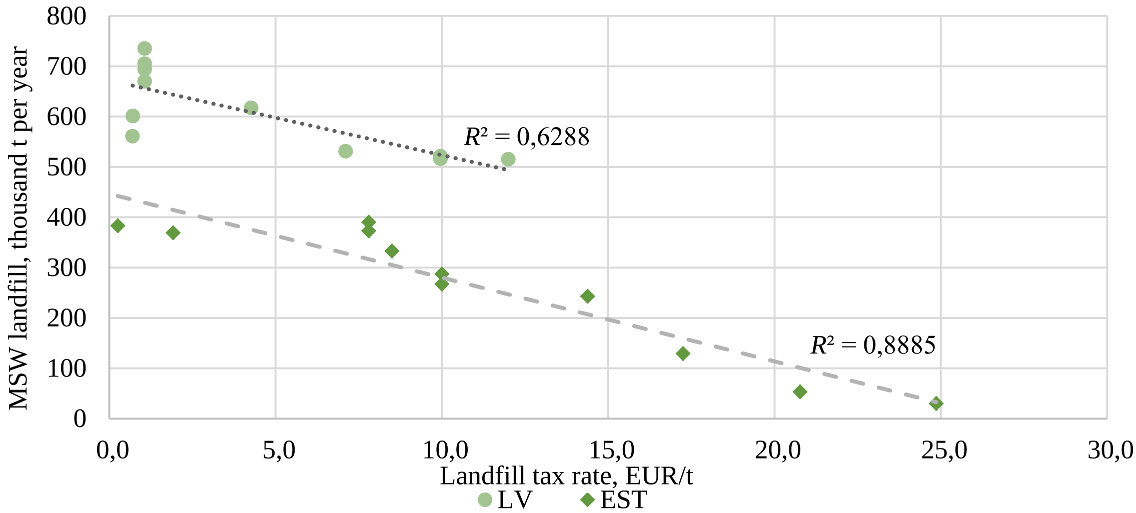

Fig. 4.9. Ratio of the landfill tax rate to the amount of waste disposed of.

The results of the analysis show a high correlation between the increase of the landfill tax rate and the decrease of the amount of waste disposed of, which suggests that this instrument also has a positive effect in achieving the waste management objectives in the case of Latvia and Estonia.

4.3.2.2. Ratio of Recycling of Biodegradable Waste to Separate Collection of Quantities

Separate collection of waste is emphasized as a key prerequisite for successful recycling, since separately collected waste is a higher quality material (less impurities of other material types) with more recycling possibilities than mechanically sorted waste. In order to evaluate the relation between separately collected and recycled waste in the Baltic States, the volumes of biodegradable waste streams and biodegradable waste recycling using biological treatment have been analyzed. The amount of recycled waste in relation to the amount of separately collected biodegradable waste in Latvia, Estonia and Lithuania is presented in Fig. 4.10.

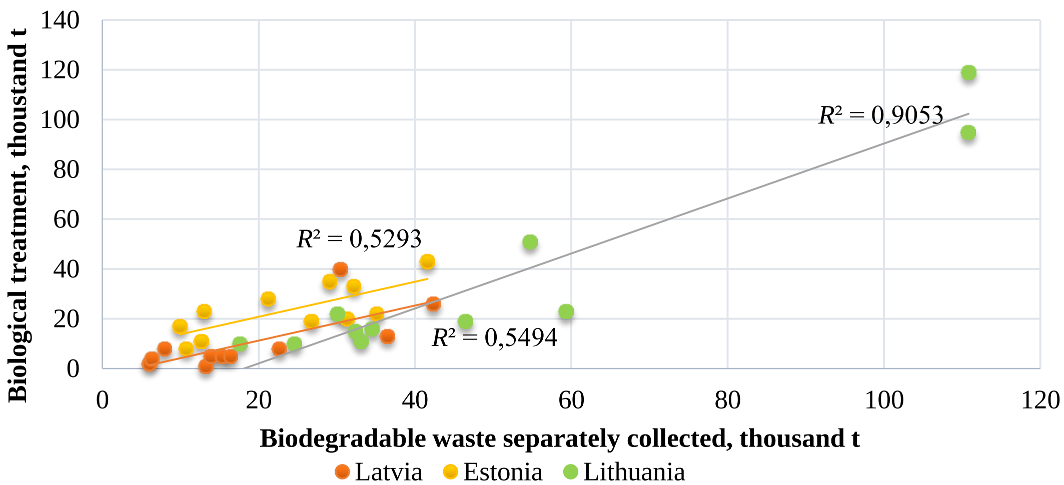

Fig. 4.10. Volume of separately collected biodegradable waste in relation to recycling volumes.

The analysis shows that there is a strong correlation between separately collected biodegradable waste and recycled biodegradable waste in Lithuania, while in Latvia and Estonia the link is weaker.

4.3.2.3. Household Waste Recovery Alternatives

The operation of waste management systems in Latvia, Estonia and Lithuania can be compared using the volume of waste recovery by different types of recovery, incl. biological treatment, material recycling, and incineration. Volumes of municipal waste recovery by types of recovery in Latvia, Estonia and Lithuania in 2004–2014 are presented in Fig. 4.11.

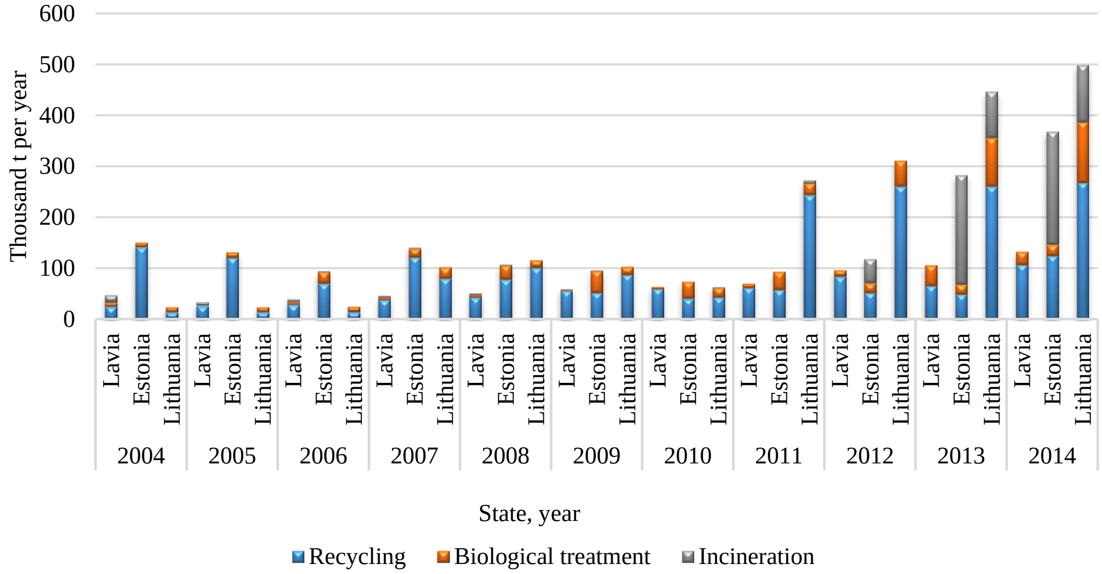

Fig. 4.11. Volumes of recycled/recovered waste 2004–2014.

The collected data describing the situation in Latvia indicate a steadily increasing trend of total municipal waste recovery starting from 2005. In 2014, the maximum recovery volume is reached, which is 21 % of the generated municipal waste.

In the case of Estonia, during 2004–2012 the total recovery volume in different years vary between 17 % and 25 % of the total amount of municipal waste generated. A significant increase in the recovery started from 2013, when the recovery volume reached 73 %. It can be concluded that in 2013 and 2014 waste incineration gives a significant increase – 55 % and 47 % of the generated municipal waste.

The analysis of the Lithuanian example shows a very low recovery volume during 2004–2010. Total recovery volumes vary from 2 % to 9 % of total municipal waste generated in different years. In 2011 a significant increase is observed in the recycling of materials – up to 20 % of the total amount of municipal waste generated. An additional contribution to increasing the recovery volume is provided by incineration – 9 % in 2014, thus achieving a total recovery volume of 39 % of the generated municipal waste.

4.3.3. Development and Analysis of Alternative Scenarios

The development of alternative scenarios involves the selection of suitable solutions to the problems identified in the analysis of the current situation and the combination of these solutions in the alternative scenarios (see Fig. 4.12).

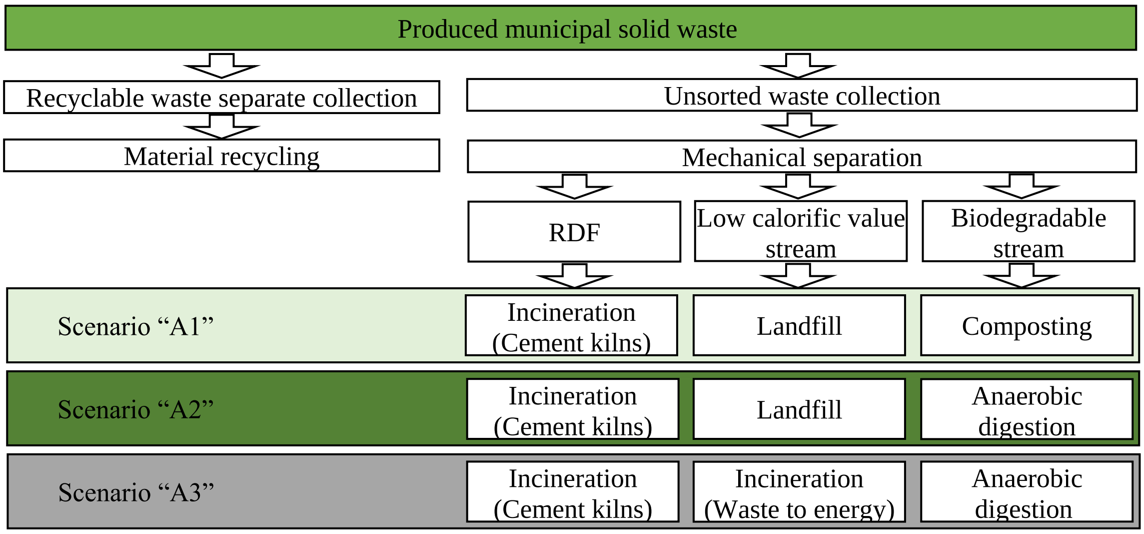

Fig. 4.12. Waste management system development scenarios.

Scenario "A1" is a baseline or business-as-usual scenario that allows to evaluate the potential of an existing system to achieve its goals, the other two development scenarios involve different technological solutions. The scenarios were evaluated from technical, economic, environmental and social aspects. The assessment of the technical aspects evaluates the level of approbation of the technology and the suitability of the quantities of waste to be treated in regards to the optimal capacity of the technological equipment. The economic factor assessment includes a comparison of investment costs, operating and maintenance costs, waste producers' ability to pay for services, and technology energy balance. In the context of environmental factors, the environmental impact of the implementation of the scenarios, the ability of the scenarios to ensure the achievement of the waste management sector goals and the opportunities for use of end products acquired from waste recycling and recovery were assessed. In the context of social factors, the importance of public involvement and support in implementing the scenarios was assessed.

The feasibility of the scenarios and the choice of the optimal scenario are based on the results of the multi-criteria analysis. Criteria evaluated, criteria weights and values are listed in Table 4.3.

The results of the multicriteria analysis (see Fig. 4.13) indicate that the "A3" scenario outperforms the other scenarios, with the "A3" scenario being driven mainly by the good environmental and economic performance. The "A1" scenario does not manage to achieve the waste recovery targets and there are no economic advantages in this scenario as the low investment costs are not sufficient to offset the significantly higher cost of the landfill tax due to the low waste recovery volumes. Although "A2" has a lower score than "A3", "A2" is more appropriate than “A1”. In the case of significant barriers to the implementation of “A3”, “A2” is a viable alternative to implementation.

Table 4.3

Criteria Weight and Values

Criteria	Weight	Scenario “A1”	Scenario “A2”	Scenario “A3”
Engineering factors	0.3	3	5	4
Economic factors	0.4	2	3	4
Environmental factors	0.2	2	3	5
Social factors	0.1	5	3	2

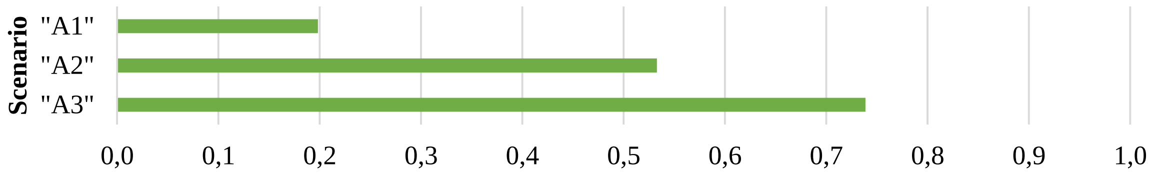

Fig. 4.13. Results of multicriteria analysis.

The results of the analysis show that the practice of biodegradable waste recycling by anaerobic digestion and incineration with energy recovery of non-recyclable materials achieves the required results in the recovery of waste. It also shows that simple waste treatment technologies such as biodegradable waste composting and disposal of non-recyclable waste streams in landfill are not optimal.

The limiting factors impeding the implementation of an energy recovery from waste strategy are, in most cases, related to concerns about the level of investment costs and the potential negative environmental impact. The results of the analysis show that the significant investments are offset by the revenues from the sale of the produced heat and energy. The energy balance assessment shows that the “A3” scenario provides the best energy production / consumption ratio, which is also a positive aspect from an economic point of view.

Possible limiting factors for the implementation of the “A3” scenario are ensuring sale of the produced energy and, to a certain extent, compliance with future waste policy priority objectives. With regard to “A3”, it is important to note that the ability to sell heat is a critical factor in its implementation, as the economic performance of this scenario depends on the revenue from the supply of heat to the district heating system or to industrial purposes. In addition, from an environmental point of view, only efficient use of the energy produced offers advantages over other scenarios.

With regard to the waste management hierarchy, it should be noted that waste incineration is only one step higher than waste disposal and the implementation of this scenario does not address issues such as waste prevention and re-use. In fact, there may be some concerns that the availability of waste incineration facilities may have an undesirable effect on waste recycling, as the availability of incineration may reduce the incentive to develop recycling opportunities. To avoid such consequences, policymakers should monitor the operation of the waste management system and use policy tools to achieve the preferred results.

CONCLUSIONS

1. The aim of the Doctoral Thesis is to develop methodologies for efficient management of the waste sector, which would facilitate the decision-making process, thus promoting the implementation of principles of circular economy in the waste management sector. This target was based on the results of the current situation analysis, which shows that the results of the recycling and recovery of municipal waste, despite the policy instruments used and the financial support to the waste management sector, are unsatisfactory.
2. The hypothesis put forward for this study involves the assumption that moving towards the goals of circular economy the management of the waste sector can be improved by promoting its efficiency. This can be done by using statistical data and experimentally derived data characterizing the waste management sector, as well as by improving data processing methodologies and empirical models. The results of the study support the hypothesis proven by the research that the available data, empirical research data and appropriate data processing methods, as well as appropriate tools for modelling and evaluating future scenarios, allow to advance decision-making and improvement in the waste management sector.
3. Evidence-based management of the waste sector requires data describing the composition and volume of municipal waste generated. Such data allows to evaluate the efficiency of the existing system and to plan the development of the system. Experimental data on the composition of municipal waste in Latvia during the development of the Doctoral Thesis show that up to 32.9 % of unsorted municipal waste streams are made from recyclable materials and 29.2 % from biodegradable waste. This means that at least 60 % of unsorted municipal waste is potentially recyclable if appropriate management systems are in place.
4. Indicators such as "total municipal waste disposal", "total municipal waste recycled" are used to describe the efficiency of the waste management system. Within the framework of the Doctoral Thesis, the waste management system in Latvia has been evaluated using the integrated indicator methodology. During the research it was found that the methodology can be successfully adapted to the situation in Latvia and the calculations of the indicator can be performed using publicly available data. The advantage of using an integrated indicator is the ability to use a single indicator to describe the total outcome of a waste management system, that is, both the volumes of waste recycling and waste recovery. Such an approach is particularly needed in situations to evaluate and compare waste management systems that share the same objective of reducing the amount of disposed waste, but to achieve this goal, different strategies are used, i.e., recycling strategy or recovery strategy.
5. Forecast of waste streams generated in the future plays an important role in the decision-making process, as the amount and type of waste to be managed determines what solutions will be needed. The results of the study show that the amount of waste produced is related to the level of welfare and that the increase of the level of welfare

contributes to the increase of the amount of waste generated. At the same time, when preparing forecasts for generated waste according to the proposed methodology, it should be taken into account that its accuracy is directly determined by the reliability of demographic and macroeconomic forecasts. A factor that is difficult to assess for the amount of waste generated is the effectiveness of waste reduction measures, as the dynamics of waste generation in the common market is influenced not only by national policy instruments but also by cross-border flows of goods.

6. The analysis of factors contributing to the reduction of waste disposal shows that the policy instruments, the "landfill tax", and the "landfill ban" have a direct relation to the reduction of the amount of waste disposed in landfill. At the same time, a "landfill tax" will be effective only at sufficiently high tax rates; a ban on disposal will only be effective if precise criteria for a ban on disposal are defined. From the point of view of the technology used, incineration with energy recovery contributes to the reduction of landfilling. At the same time, the results of the analysis do not exclude the possibility that the implementation of incineration technology could reduce the amount of waste recycled, so that decision-makers should introduce preventive measures when introducing waste incineration to prevent recyclable waste from arriving incineration facilities.
7. Preparation and evaluation of waste management sector development scenarios has been carried out within the framework of the Doctoral Thesis. The implementation of scenarios is influenced by technical, economic, environmental and social factors, it means, when selecting the optimal scenario, it is necessary to use a methodology that allows to evaluate all the above factors. Such an approach provides significant support to decision-makers and facilitates decision-making in situations where multiple stakeholders are representing their interests. Within study, assessment of the prepared scenarios by the method of multicriteria analysis was carried out. It was found that despite the limiting economic factors the scenario with the highest costs and the application of new waste recycling and recovery technology – anaerobic digestion for biodegradable waste and energy recovery from waste by incineration – most likely will provide the highest benefits.

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