Natālija Cudečka-Puriņa

Ensuring municipal waste management sustainability by administration of landfill management companies

DOCTORAL THESIS

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CONFIRMATION

I hereby confirm that I worked out this Doctoral thesis that has been submitted for review to RISEBA for the promotion to the degree of Doctor for Business Administration. This Doctoral thesis has not been submitted to any other University in order to receive any scientific degree..

Natālija Cudečka-Puriņa _____ __, 2018

The Doctoral thesis is written in English, and consists of an introduction, 3 parts, conclusions and proposals, reference list, 8 appendices; the total page count is 166. The Bibliography contains 295 sources of references.

The Doctoral thesis and Summary are available at the library of RISEBA and online *www.riseba.lv*. To submit reviews please contact the secretary of the RISEBA Promotion Council, RISEBA, Meža Street 3, Riga, LV-1048, Latvia. E-mail: anna.strazda@riseba.lv; Fax + 371 67500252, Tel. + 371 67807963.

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ABSTRACT

Doctoral thesis by Natālija Cudečka-Puriņa "Ensuring municipal waste management sustainability by administration of landfill management companies", developed to obtain degree of Doctor of Business Administration.

In the 21st century, the sustainable management of municipal waste will become necessary precondition for any stage of economic development. Waste disposal in the landfills is one of the six functional waste management options. Significant decrease of disposed waste in the landfills up to 10% in 2035 is an important challenge for management of landfill management companies and their economic efficiency. There are scientific works regarding diverting waste from landfill, although a research gap has been identified – lack of business management studies concerning sustainable management of LMCs in the situation of a crucial change of waste management hierarchy, leaving waste disposal as least favourable option. The objective of the thesis is to develop a solution for sustainable management of landfills within decrease of incoming waste volumes. As a result of the thesis, industrial symbiosis model as well as decision-making matrix have been developed, which allow assessing company current situation and may be used as decision-making support tool, when choosing further company's development directions.

The *first chapter* of the thesis is devoted to the review and analysis of scientific literature in the field of waste management and circular economy, leading to research limitations - waste management at landfill stage. The chapter covers theories of resource availability and resource dependency, including multi-criteria decision making and circular economy business models. The topicality of the research is grounded, highlighting the lack of previous researches and the necessity to undertake research on the industrial symbiosis with the landfill as its starting point. The *second chapter* is devoted to the evaluation of Latvian waste management industry, case studies, as well as analyses the theoretical perspective on problems and their potential solutions through the results of the surveys. The analysis also concludes that it is necessary to develop a management model for landfill management companies in order to ensure their transition to circular economy. The *third chapter* is devoted to practical research, developing the industrial symbiosis model, determining its replicability preconditions and the decision-making matrix, as well as approbating them with a specific waste stream. The thesis is written in English, it consists of 166 pages. The thesis includes 39 figures and 42 tables. The reference list includes 295 titles. The paper contains 8 appendices. ***Keywords****: business management, circular economy, industrial symbiosis, waste management. JEL classification: M1, M21, Q57.*

Definitions

Circular economy	a type of the economy, where the value of products and materials is maintained for as long as possible, waste generation and the use of primary resources is reduced, and when the product reaches the end of its life cycle, resources remain in the economy where they are re-used to create added value.
Waste management	the collection, storage, transport, recovery and disposal of waste (including incineration in municipal waste incineration facilities), the supervision of such activities, the after-care of disposal sites after their closure, as well as trade with waste and mediation in waste management.
Industrial symbiosis	a connection between two or more facilities in which the waste or by-products of one can become as raw materials for another.
Industrial symbiosis complex	physical place, where industrial symbiosis between a range of entities takes place.
Industrial symbiosis model	a model for landfill management companies that takes into account landfill internal resource flow and offers industrial symbiosis modules for effective management of resources.
Landfill management companies	an inter-municipality company, operating in one of 10 Latvian waste management regions and providing a municipal waste disposal service (public utility). The public service provider must ensure that users are able to receive uninterrupted public service in compliance with safety requirements and quality of the relevant public service. The Public Utilities Commission in the municipal waste management sector only regulates the provision of municipal waste disposal service in municipal waste landfills.
Municipal waste	waste generated in a household, trade, in the process of provision of services or waste generated in other places which, because of its properties, is similar to domestic waste.
Municipal waste landfill	a physical waste disposal site, selected on the basis of a feasibility study. Long-term engineering and technical facility for 25-30 years usually one per waste management region.
Resources, generated during waste disposal	resources that arise during daily operation of landfill and that can be used for industrial symbiosis purposes.
Waste management	the collection, storage, transport, recovery and disposal of waste (including incineration in municipal waste incineration facilities), the supervision of such activities, the after-care of disposal sites after their closure, as well as trade with waste and mediation in waste management.

INTRODUCTION

Theoretical and practical relevance

With the end of the 20th century, waste management has become a significant field of the economy, closely linked to society and the environment. Environment and entrepreneurship are in a constant conflict situation, which means there is continual search for compromise in order to ensure fulfilment of environmental requirements alongside with provision of company competitiveness and sustainable development. After re-gaining its independence, Latvia started the preparatory stage for accession to the European Union and already in 1995 a country waste management inventory was performed. The inventory identified 558 operating dumpsites and approximately 160 closed dumpsites, which did not meet sanitary requirements and possessed air, water and general environmental pollution as well as had negative impact on the health of the local population. The first stage was development of a national programme "500- Development of national municipal waste management system in Latvia". This was followed by development of the Environmental protection policy in 1998 and the Sustainable development strategy of Latvia in 2002. State level programmes, as well as state and regional waste management plans were based on an increase in the population, stable GDP increase of 6% annually and a 3% annual increase of waste generation volumes. The trend on the basis of which all calculations were laid was an increase in waste generation volume. Latvia was at the stage of accession to the European Union (hereinafter – EU) and one of the EU requirements was to close and recultivate all illegal dumpsites and to construct sanitary landfills, which would correspond to the EU Directives as well as to secure that further waste collection and disposal would be performed in an environmentally friendly manner. Waste landfills are long-term infrastructure elements and are designed to operate for a longer time period – for 20-30 years. Development of waste management regions and construction of the infrastructure required considerable time and was undertaken in the time period from 2000 to 2012. In 2012 Latvia was divided into 10 waste management regions, each of which had its own waste management infrastructure via a sanitary landfill for municipal waste, sorted waste collection points and areas, sorting stations, re-loading stations, etc., which were managed by an inter-municipal landfill management company (LMC). In order to secure further sustainable development of the company, it is necessary to choose the appropriate further development direction and define priority goals for the company's development.

During the time period when waste management infrastructure was under its development stage in Latvia, EU decision-makers were quite active through advancing legislative improvements in the waste sector. For instance, during 2005-2007 the European

Commission performed a feasibility check of the Directive on waste and certain linked Directives and issued a new 2008/98/EC on waste (Waste Framework Directive). The amendments assumed a significant shift in policy, changing emphasis in the waste management hierarchy accents, focusing on recycling, reuse and recovery and developing a range of landfilling bans. This stage had a significant impact on functioning of LMCs. Thus, unwittingly sustainable development of landfills was endangered on the EU level, especially for the member states, where a significant volume of waste was still being landfilled. When applying these legislative changes in LMCs in Latvia, it has to be noted that waste landfills are complicated elements of infrastructure, the management of which cannot adapt instantly to such changes. In Latvia's case, it meant that a decision on significant changes in the current waste landfill sustainable development was required in a fairly immediate timeframe. In the nearest future there are no plans in Latvia to implement any revolutionary waste treatment technology in Latvia and the target to decrease disposed waste from 71% in 2014 to 10% in 2035 is a significant challenge both for the existence and the economic stability of landfill management companies in Latvia. Basically the decrease of waste volumes reaching a landfill is the result of increasing legislative pressure. Only a limited number of scientific researches have been conducted in the field of waste management in Latvia, mostly focusing on hazardous waste, some particular waste management activities or analysing waste management field from an economic point of view. There has not, however, been any research carried out in the field of management processes at the waste landfilling stage. When turning to international research, a range of scientific papers and researches can be found concerning diversion of waste from landfills. The environmental targets are ambitious thus no significant research has been identified that would solve further development issues of landfills as long-term infrastructural objects on the business administration level within change of the emphasis on the waste hierarchy when waste disposal is left as the most disadvantaged method of waste management.

Increase of a tariff for waste disposal (hereinafter – tariff) could improve the economic situation of LMC's only partly and to a certain extent, although it will definitely trigger a social objective. Although, it has to be considered that an increase in tariff can be justified only in case there are price-competitive treatment options in place (ECOTEC, 2001). It is of vital importance for LMCs in Latvia to develop a smart and sustainable decision-making system that will allow LMCs not only to be able to fulfil their financial obligations but as legal entities, to generate a positive cash flow and choose further development options. Analysis of the current situation within LMCs in Latvia has revealed a negative trend that some of the companies have problems with keeping together managerial, entrepreneurial and

environmental decisions – companies dealing only with landfilling are interested in the increase of landfilled waste volumes, but this is in direct conflict with current waste management trends, which indicate that countries are to focus on decrease in landfilled waste as much as possible. Moreover, since the EU currently provides financial support for recovery and recycling activities, the respective infrastructure will continue to develop and, alongside with on-going education programmes for society and waste prevention programmes, these activities will have an impact on the final waste volume to reach a landfill. The aforementioned leads to the conclusion that, in order for a LMC to become economically effective, a new management approach has to be considered in order to secure the economic efficiency of the LMC in the future. Present research is aimed at performing an in-depth analysis of waste management concepts, latest trends and developments, decision-making techniques, applied in waste management on the European level, then focusing on Latvian landfill management companies and identifying their critical problems. This research is applicable not only to Latvian waste management companies, but to all EU and non-EU countries, which still rely significantly on landfilling.

Currently resource efficiency issues are assessed and range of researches are developed, linked to circular economy issues. In this context the author also examines the EU Circular economy action plan, which notes development trends and mostly highlights the necessity to limit waste landfilling. The trends of 2016 show that the limitations of waste allowed for landfilling could reach 10% or even 5% from generated volumes in 2030. Taking into consideration the above mentioned, it may be concluded that an important Latvian waste management issue is closely linked with the economic efficiency of landfills, as landfills need to secure a strategy in their development, which would foresee return of valuable resources into the economic turnover rather than looking for increases in the waste landfilling tariff which would have a direct impact on the waste management rate of the population. The outcome of the research and the hypothesis of the research is adaptable from institutional and managerial aspects and applicable not only for Latvian waste management companies, but may also be applied to newer EU Member States (since 2004) and non-EU countries, which still rely significantly on landfilling and have similar waste management model.

The object, the subject and hypothesis of the research

The **object** of the research is landfill management company.

The subject of the research is management of landfill with a precondition of decreasing incoming waste flow.

The **hypothesis** of the research: the industrial symbiosis built on the basis of a landfill ensures further development of landfill management companies within decreasing waste volumes and limited increase of waste disposal tariff tendencies.

The research aim and main tasks

The main **goal** of the research is to develop a solution for sustainable management of landfills within decrease of incoming waste volumes.

Main **tasks** of the research are:

1. Critical analysis of the latest trends in waste management and further evaluation of the current waste management system in Latvia, identification of preconditions for sustainable development of landfills.
2. Development of two surveys to verify theoretical framework based vision on current waste management sector problems and possible solutions.
3. Development of a methodologically justified industrial symbiosis model and decision-making matrix for a landfill management company.
4. Development of industrial symbiosis business model application scenarios for landfill management companies.
5. Practical approbation of the results on the basis of particular material flow and identification of its potential in industrial symbiosis framework.
6. Development of practical recommendations that would facilitate further development of landfill management companies.

Theses presented for defence

1. Development and implementation of landfill management company development model ensures sustainable development of such companies within decreasing waste volumes and limited increase of waste disposal rate tendencies.
2. Implementation of industrial symbiosis on waste landfills, within decrease of waste generation volumes, allows landfill management companies to ensure their economic sustainability.
3. Implementation and development of industrial symbiosis, transforms waste landfill into scientifically technological park and under certain preconditions it may contribute to economic development of a particular region.
4. Resource flow evaluation along with application of LMC decision-making matrix, allows LMCs to identify available resources and to choose most suitable development strategy for company’s further development.

5. Industrial symbiosis model on a landfill basis can be replicated on other landfills abroad with certain similar output data.

Research methods

The research was developed using qualitative methods (case studies, system dynamics, logical causal-loop diagrams) and quantitative methods - surveys, analysis of waste management system data (primary and secondary data), benchmarking, mathematical modeling, interpretation and data analysis. The theoretical framework has been developed using the monographic, critical analysis and synthesis methods. Data for the empirical part of the study were obtained through two surveys. The surveys have been developed based on *Sekaran, Bougie, (2009)* methodology. The surveys were developed in order to prove the author's theoretical framework-based vision of possible LMC development, with two main focus groups – Landfill group (covering 10 LMC) and Expert group (30 waste management field experts), representing Latvian and foreign experts. The respondents in the Landfill group were mainly top managers or members of the board of LMCs and in the Expert group – representatives of foreign LMCs, Ministries of Environment, waste management associations, universities and consultants. All the experts covered by the survey have an impact on policy planning and development in particular country. For the empirical study, *Excel (MonteCarlo modelling), SPSS, Vensim* and *STAN* software were used. In addition to surveys, the data was obtained from statistical databases available through Eurostat, the World Bank, Confederation of European Waste-to-Energy Plants and Organization for Economic Co-operation and Development (OECD).

Limitations of the research

Waste management in terms of company management is a very complex system, comprising of various sub-systems and management options. Within the EU, waste management is highly regulated on the waste treatment side and a variety of goals have been set to achieve by Member States for minimisation of each type of waste stream. The business administration part of the sector is unregulated, offering Member States free choice to establish public, private or public-private partnership (PPP) companies. The landfill management companies analysed within the present research are **public companies (inter-municipality limited liability companies)** and the research does not evaluate forms of ownership for such companies that do not exist in Latvia.

The present research is focused only on **municipal waste management,** which includes household waste and production waste (similar to household by composition) and does not include hazardous waste. Municipal waste in Latvia constitutes 30-40% of the total

waste stream and, due to its mixed composition, requires a particularly complex and high-quality waste collection and treatment system. The present research focuses on analysis of **waste management at the stage of landfilling**, not covering the waste collection system, sorted waste collection, transportation and pre-treatment. Currently in Latvia over 70% of municipal waste is being landfilled. During this process, a range of resources that are either not used, or being used in an inefficient manner are generated i.e. electricity, heat, technical water, secondary resources, refuse derived fuel, etc. Overall, the waste management sector is comprised of a range of market players and stakeholders – from municipalities to waste collection, treatment, recycling companies, NGOs and landfill management companies, which total over 70 entities. The research covers **all landfill management companies**, who undertake municipal waste disposal activities. **Landfills in Latvia form an integral part of the municipal waste management infrastructure, being stationary and long-term (up to 30 years) facility**. Despite the fact their number is way lower than the number of municipalities, a major part of municipalities (except Pieriga region), are owners of the landfills situated in their waste management regions thereby bearing also certain financial liabilities.

Period of conducting the study

As with the second half of the 20th century, significant attention was paid to ecological issues, the research period of the theoretical framework covers the second half of the 20th century and the beginning of the 21st century until present. The framework reviews environmental policy, development of waste management and its rethinking – a shift from waste to resource management. Analysis, undertaken by the author within the practical part of the research covers the time period from 1995 until January 2017. The practical part of the research took place from the end of 2011 until 2017. The survey of the landfill management companies and experts in the waste management field took place from July to October 2016.

Theoretical and methodological basis of the research

In order to develop a convincing theoretical framework, the author has undertaken research covering published scientific work of scientists from Latvia and other countries and studies that are available in electronic data bases, special environmental management and management literature, materials from scientific seminars and conferences, European Union and Latvian legislation, statistics data, studies and methodological materials of EU institutions, Eurostat, OECD, Central Statistical Bureau of Latvia, the Ministry of Environmental Protection and Regional Development in Latvia (MEPRD) and other

international and Latvian organizations. The theoretical and methodological basis has been developed based on developed theories and models of the following researches:

- In strategic management and decision-making in waste management field (resource-based theory; multi-criteria decision-making model; decision making tree) – *Ansoff (2007), Boulding (1966), Ciumasu (2013), Cutaia (2015), DeFeo (2005), Finnveden (2013), Mintzberg (2013), Porter (1998; 2008), Powell (2000)*;
- In sustainable business model field (circular economy business models) – *Eriksson and Penker (2000), Lüdeke-Freund (2010), Richardson (2008);*
- In circular economy, industrial symbiosis and management of companies in waste management field (resource dependency theory) – *Baccini and Brunner (2012), Blumberga (2011), Brunner (2007), Chertow (2008; 2012), Dyson (2005), Gibbs (2008), Goorhuis (2012), Heck (2006), Jacobsen (2006), Lombardi (2012), Patala (2014), Rehan (2017);*
- In sustainable development field (PESTLE) – *Azapagic and Perdan (2000), Dalal-Clayton (2002), Garmendia (2010), McDougall (2001; 2003), Munasinghe (1993), Nilsen (2010).*

Scientific novelty of the research

The scientific novelty of this research as well as its main achievements can be formulated as follows:

1. Based on the business administration theoretical framework a model for management of landfill management companies, has been developed – industrial symbiosis on the basis of a landfill.
2. The thesis provides a contribution to Latvian scientific research concerning management processes in waste disposal. 4 resource balance equations have been developed, which are used as a tool for effective management of resources that enter the landfill.
3. The thesis offers three new definitions - "industrial symbiosis", "industrial symbiosis model" and "resources, generated on a landfill" within Latvia's waste management framework.
4. New decision-making matrix combines four LMC development directions: internal industrial symbiosis; more sophisticated waste sorting; waste recycling facilities and external industrial symbiosis.
5. For the first time in Latvia an integrated assessment of waste management system at the stage of waste landfills has been carried out. Developed industrial symbiosis model and

decision-making matrix are replicable and can be applied in similar LMCs within the EU and beyond.

Research materials can be used as a basis for decision-making at inter-municipal waste management companies, educational materials (lectures, seminars, etc.).

Practical significance of the research

The industrial symbiosis model, together with LMC decision-making matrix, developed within the boundaries of the research, allows assessing the current situation in landfill management companies and can be used as a decision-making support tool to choose further directions in development. The research covers a range of resources that are ineffectively used at present, which can be assessed using the author's developed methodology, in order to evaluate a company's potential for improving resource efficiency.

The obtained results of the research can be used for policy making in waste management, identifying the economic sectors, which could potentially be involved in industrial symbiosis and developing an action plan, which would provide special support for motivating the sectors to engage in this initiative.

The developed model, as well as the decision-making matrix can be applied to the landfill management companies of any other country, with the precondition of certain landfilling volumes. This solution is of special interest to the countries, which are at the primary stages of the waste management hierarchy and mainly rely on landfilling.

The results of the research may serve as a basis upon which further Latvian or foreign scientific research can be conducted– further in-depth development of the model and decision-making matrix or the resolution of particular landfill management company problems. The results of the research also have practical significance in terms of the education of society, as they provide explanations on how waste management can be transformed into resource management and attract other industries, involving them in the circular economy.

Approbation of the research results

During thesis development, a total number of 18 scientific articles have been published, including articles published in international scientific and academic journals, books and review collection of scientific articles. 24 reports in international scientific conferences have been delivered regarding the main conclusions and general findings of the thesis. Conclusions obtained within the research have been submitted for review to the Latvian Association of Waste Management Companies.

Scientific publications and research papers by the author

International reviewed scientific journals (covered by international indexing services):

1. Cudecka-Purina N., Atstaja D. (2018) "Implementation of circular economy based business model for landfill management companies" – pieņemts publicēšanai *Journal of Business Management*, ***EBSCO.***
2. Cudecka-Purina, N. (2017) „Increase of Technogenic Safety of a Waste Management Company". *Safety of Technogenic Environment*, 8, 37–41, ISSN 2255-8702, doi: 10.1515/ste-2017-0006.
3. Cudecka-Purina, N. Cudeckis, V. (2017) „Assessment of Latvian waste management system and its direction towards 2020 targets". *Proceedings of the Sixth International Environmental Congress (Eighth International Scientific-Technical Conference) "Ecology and Life Protection of Industrial-Transport Complexes"* ELPIT 2017, 20–24 September 2017, SamaraTogliatti, Russia: Edition ELPIT. Printed in Publishing House of Samara Scientific Centre, pp. 35–44.
4. Cudecka-Purina N., Atstaja D. (2017) "Landfill-based industrial symbiosis as a tool for regional development enhancement". Proceedings of Reports of International scientific conference "New Challenges of Economic and Business Development", pp. 450–459, ISBN 978-9934-18-242-6. ***Web of Science, Thomson Reuters.***
5. Cudecka-Purina, N., Cudeckis V. (2017) "Economic aspects of waste management in the Baltic countries". Sustainable Development, Year VII, Vol. 1, pp. 37–46, ISSN 1314-4138.
6. Cudecka-Purina N., Atstaja D. (2017) "Assessment of business performance in waste landfills and shifting towards circular economy". Proceedings of the 2017 International Conference "Economic science for rural development" No. 45 Jelgava, LLU ESAF, 27–28 April 2017, pp. 30–39, ISSN 1691-3078. ***ISI Web of Science, AGRIS, CAB Abstracts, EBSCOHost Academic Search Complete databases, Google Scholar***.
7. Cudecka-Purina N., Cudeckis V. (2014) "Decrease of household waste incineration risks in waste collection, transportation and landfilling". Riga Technical University Scientific Journal of Riga Technical University. Technogenic environment Safety, Vol. 6, ISBN 978-9934-8275-2-5, pp. 10–14, **doi: 10.7250/ste.2014.008**.
8. Cudecka-Purina N., Atstaja D., Cudeckis V. (2013) "Assessment and mitigations of household waste collection transportation risks". Journal of Business Management, No. 7, ISSN 1691-5348, pp. 118–129. ***EBSCO.***
9. Atstaja D., Cudecka-Purina N., Cudeckis V. (2013) "New European Union member states towards sustainable waste management, involvement of individuals into the system". Proceedings of the 2013 International Conference "Economic Science for Rural Development" Jelgava, LLU EF, Latvia. ISSN 1691-3078, pp. 98–103. ***EBSCO, AGRIS, Web of Science, Thomson Reuters.***
10. Cudecka-Purina N., Cudeckis V., Mavropoulos Al., Mavropoulos A., Mavropoulos N. (2013) "Comparative analysis of municipal waste management in selected European capitals". International Solid Waste Association world congress, Conference proceedings, Vienna, Austria (Online and on USB).
11. Cudecka-Purina N., Cudeckis V. (2013) "Integrated approach to waste management problems on Latvia North-Vidzeme region example". International Solid Waste Association (ISWA) Specialised Conference MSW: management systems and technical solutions. Moscow, Russia. International Solid Waste Association (ISWA) Specialised

Conference. MSW: management systems and technical solutions, ISWA conference collection of papers, ISBN 978-5-904941.

12. Atstaja D., Cudecka-Purina N., Cudeckis V. (2012) "Green Economics: New EU Member Countries towards Sustainable Waste Management, Involvement of Individuals". Green economy: Reform and Renaissance of economics and it's methodology – Green Economics – the solutions for the 21st century Green Economy: Rethinking Growth: RIO +20: Proceedings of the Green Economics Institute. Edited by Miriam Kennet, proceedings Series Edited by Volker Heineman, Green Economics Institute; 2012 July 19–21, Oxford, United Kingdom. Green Economics Institute, ISBN 978-1-907543-30-2.
13. Cudecka-Purina N., Cudeckis V. (2012) "Solution methods for irrational waste landfilling in terms of environmental protection". Riga Technical University Scientific Journal of Riga Technical University. Safety of Technogenic environment, Vol. 3, ISSN 2255-6923, pp. 10–14.
14. Cudecka-Purina N., Atstaja D. (2012) "Climate change and sustainable development – as experience in the study courses". European Integration Studies. Research and Topicalities, No. 6, ISSN 1822-8402, pp. 7–14. ***EBSCO, DOI: http://dx.doi.org/10.5755/j01.eis.0.6.1488***
15. Cudecka-Purina N. (2011) "Evaluation of financial investment effectiveness in Latvian waste management Regions". Riga Technical University Scientific Journal of Riga Technical University. Safety of Technogenic environment, Vol. 1, 2255-6923, pp. 14–20.
16. Cudecka N. (2011) "Retrospective feasibility analysis of Latvian waste management system". Third International Environmental congress "Ecology and life protection of industrial-transport complexes". Proceedings of young scientists, ELPIT – 2011, Togliatti, Russia.
17. Cudecka-Purina N., Cudeckis V. (2009) "Development of waste management on regional basis". Between Europe and Russia Problems of Development and Transborder Co-operation in North-Eastern Borderland of the European Unon. 2009, Scientific Publshing House of Nicolaus Copernicus University. Wydawnietwo Naukowe UMK, ISBN 978-83-231-2348-4, 285 p.
18. Cudecka N. (2007) "Solid waste management on the Regional basis in Latvia". First International Environmental congress "Ecology and life protection of industrial-transport complexes". Proceedings of young scientists, ELPIT – 2007, Togliatti, Russia.

The results of the research were also discussed during international summer schools and seminars in Austria, Germany and Latvia:

1. Circular PP. Tendencies of future products and services: Circular economy and public circular procurements (Latvia, April 2018).
2. Circular PP. Promoting of circular economy through innovative procurements and capacity building. (Latvia, March 2018).
3. Practical Approach for Teaching Circular Economy. Nordplus Higher Education 2017, Valmiera (Latvia, September 2017).
4. RECO BALTIC summer school „BUP summer course 2013 on Sustainability and Waste Management in the Baltic "Making Waste Work"" Hamburg, (Germany; September 2013).

5. International solid waste association organized summer school for doctoral students and field professionals *"1st ISWA-TU Summer School on Solid Waste Management (iTOOL)"* Vienna (Austria; September 2012).

Participation in international conferences by the author

The most relevant results of the research were presented and discussed at 24 international scientific conferences in Latvia and abroad.

International scientific conferences:

1. "The Baltic countries towards the goals of waste framework directive" International scientific-practical conference „Sustainable development 2018" (Bulgaria; June 2018).
2. "Sustainability of municipal waste landfill within circular economy" International Round Table Conference "Circular economy for global sustainability" From Aspiration to implementation. (India; April 2018).
3. "Integration of circular economy into study courses" 11th Annual scientific Baltic business management conference. Trends of business and funding models in contemporary world. (Latvia; March 2018).
4. "Economic aspects of waste management in the Baltic countries" International scientific-practical conference „Sustainable development -summer- 2017" (Bulgaria; June 2017).
5. "Landfill-based industrial symbiosis as a tool for regional development enhancement" 9th international scientific conference "New Challenges of Economic and Business Development – 2017: digital economy**"**. (Latvia; May 2017).
6. "Assessment of business performance in waste landfills and shifting towards circular economy" 18th International Scientific Conference "Economic Science for Rural Development' 2017" (Latvia; April 2017).
7. "Decision-making in Latvian transition from waste to resource management" Riga Technical University 57th International Scientific Conference "Scientific Conference on Economics and Entrepreneurship (SCEE'2016)" (Latvia; September 2016).
8. "Increase of technogenic safety of a waste management company". Riga Technical University 56th International Scientific Conference "Scientific Conference on Economics and Entrepreneurship (SCEE'2015)" (Latvia; October 2015).
9. "Decrease of household waste incineration risks in waste collection, transportation and landfilling". Riga Technical University 55th International Scientific Conference "Scientific Conference on Economics and Entrepreneurship (SCEE'2014)" (Latvia; October 2014).
10. "Regional decision-making based on economic assessment of waste management options". 7th International Scientific Conference "Business and Uncertainty: Challenges for Emerging Markets" (Latvia; April 2014).
11. "Assessment and mitigations of household waste collection transportation risks" 6th International Scientific Conference "New business Solutions for Emerging Future", Latvia; April 2013).
12. "Economic Assessment of Household Waste Collection Transportation Risks" 4th LEA international scientific conference "A path to well-being – economic globalization and economic localization" (Latvia; April 2013).

13. "New European Union member countries towards sustainable waste management, involvement of individuals into the system" 14th International Scientific Conference "Economic Science for Rural Development' 2013" (Latvia; April 2013).
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Structure of the research

The thesis consists of: introduction, 3 chapters, conclusions and recommendations, the list of references and annexes. The content of the research is explained in 166 pages it has been illustrated by 64 figures and 32 table. The cited literature list consists of 295 references. 8 annexes have been included in the thesis.

The thesis has the following structure:

List of abbreviations used

Introduction

1. Ensuring waste landfill sustainability

1.1. Sustanability and its characteristics for a landfill management company

1.2. Necessity of ensuring sustainable company management

1.3. Particularities of company sustainability assurance in waste management

1.4. Necessity for industrial park establishment within waste management

1.5. Research model and design

2. Assessment of business performance of Latvia's landfill management companies and identification of improvement necessity
2.1. Development of Latvia's waste management sector
2.2. Regional approach to waste management in Latvia, as a decision making process
2.3. Specifics of Latvia's landfill management companies
2.4. Assessment of Latvia's full-cycle landfill management company
2.5. Necessity of managerial improvement of Latvia's landfill management companies
3. Development of managerial improvement for landfill management companies
3.1. Closing the loop in the waste management system
3.2. Industrial symbiosis model
3.3. Landfil as a basis for industrial symbiosis cluster
3.4. Example of LMC matrix application
Conclusions and recommendations
References
Annexes

KEY SCIENTIFIC TENETS

1. Theoretical aspects of waste landfill sustainability

(Chapter 1 consists of 49 pages, 5 tables and 22 figures)

In order to comprehend the complexity and broad scope of the waste management sector, this chapter devoted to development of the theoretical framework and literature review, covers the definition of such terms as "waste management" and "sustainable development", which are core concepts necessary for the research (McDougall, 2001; McDougall *et al.,* 2003; Scharff *et al.*, 2007; UN, 1987; Westlake, 1997). In addition it will tackle the importance of sustainable development for landfill management companies, going beyond the topic and expanding the understanding of landfill sustainability, integrated waste management and recycling. The chapter also covers sustainable development indicators, decision-making techniques applied in waste management, economic aspects of waste management, such as circular economy and decoupling economic growth from waste generation ratios (*Khajuria et. al., 2011; Kuznets 1955; Mazzanti, Zoboli, 2008*).

Circular economy is seen as economy's development direction expected to lead to a more sustainable development and a harmonious society. It covers at least five different business models, one of which is resource recovery, tackling in particular benefits of industrial symbiosis (*Geng and Doberstein*, 2008; *Ness*, 2008; *Mathews and Tan*, 2011; *Europesworld*, 2014; *Lett*, 2014).

Salemdeeb *et. al.* (2016) notes that in order to achieve a circular economy, there must be a greater understanding of the links between economic activity and waste generation. A consensus exists on the vital role of waste and resource management in achieving transition from a linear model to a circular one where the value of materials and resources are maintained in the supply chain. Waste systematically emerges throughout the supply chain as a result of economic activities and trade (*Kurz*, 2006; *Parfitt et al*., 2010).

Systemic and transformative change is also reflected in the growing number of case studies analysing innovative solutions based on new systemic thinking like "cradle to cradle" (*McDonough* and *Braungart*, 2002) and "industrial symbiosis" (*Gibbs*, 2008). The industrial symbiosis approach allows achieving environmental, economic, and social advantages (Mirata, 2004). As stated by OECD (2012), the core of industrial symbiosis is a shared utilisation of resources and by-products among industrial actors on a commercial basis through inter-firm recycling linkages. In industrial symbiosis traditionally separated industries engage in an exchange of materials and energy through shared facilities.

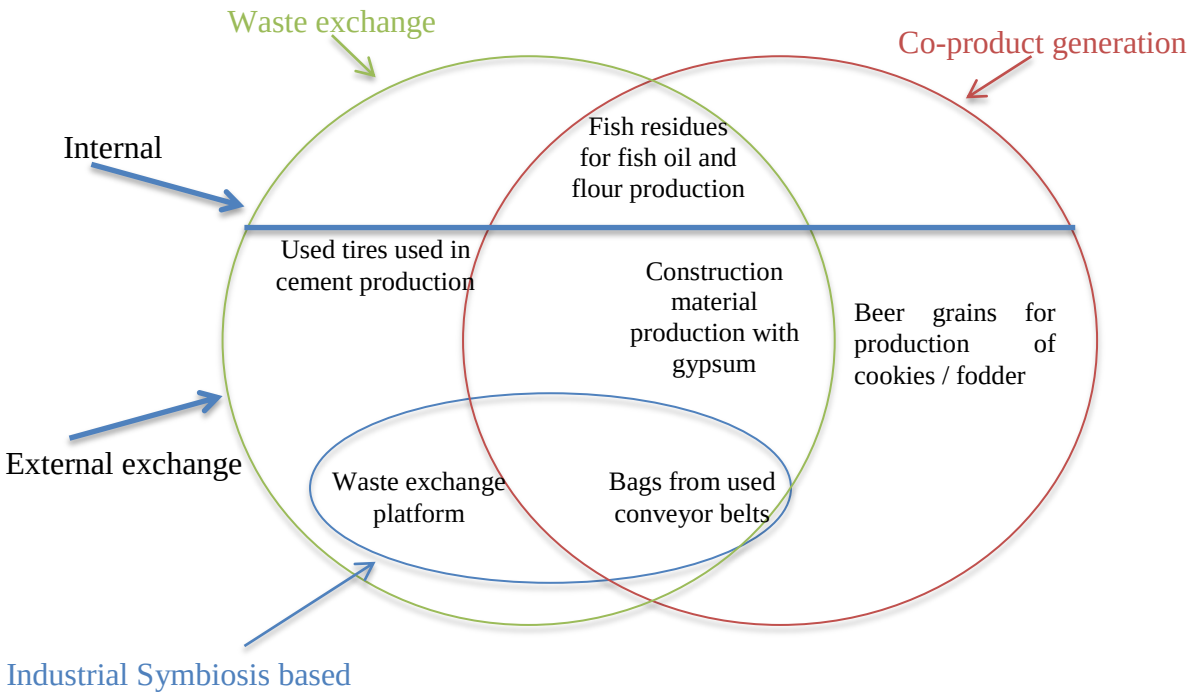

Fig.1.1 Classification of business models oriented to the industrial symbiosis approach

Source: by author, based on ZeroWIN (2014), Albino, Fracassia (2015)

According to *van Berkel* (2006) "symbiosis/by-products exchanges" generate the highest environmental, social and economic benefits as well as business opportunities, but comprehend at the same time the highest business risks followed by "utility sharing" and "planning and management".

From a technical point of view, three interesting opportunities can be discerned with respect to physical flows inside the complex: collective use of available utilities; collective processing of waste streams; mutual exchange of materials and energy.

Apart from these, two more options are present that are related to external exchange: applying residual products from remote companies; delivering residual products to remote companies (*Lambert, Boons*, 2002; *Posch*, 2010).

As noted by *Chertow*, 2006, policies prescribed to encourage the uncovering of symbioses include (1) forming reconnaissance teams to identify industrial areas likely to have a baseline of exchanges and mapping their flows accordingly, (2) offering technical or financial assistance to increase the number of interactions, inspired by managers with a symbiotic mind-set, and (3) pursuing locations where common symbiotic precursors already exist, such as co-generation, landfill gas mining, and waste water reuse, often as one-off activities, to determine whether they may be likely candidates for technical or financial assistance as bridges to more extensive symbiosis.

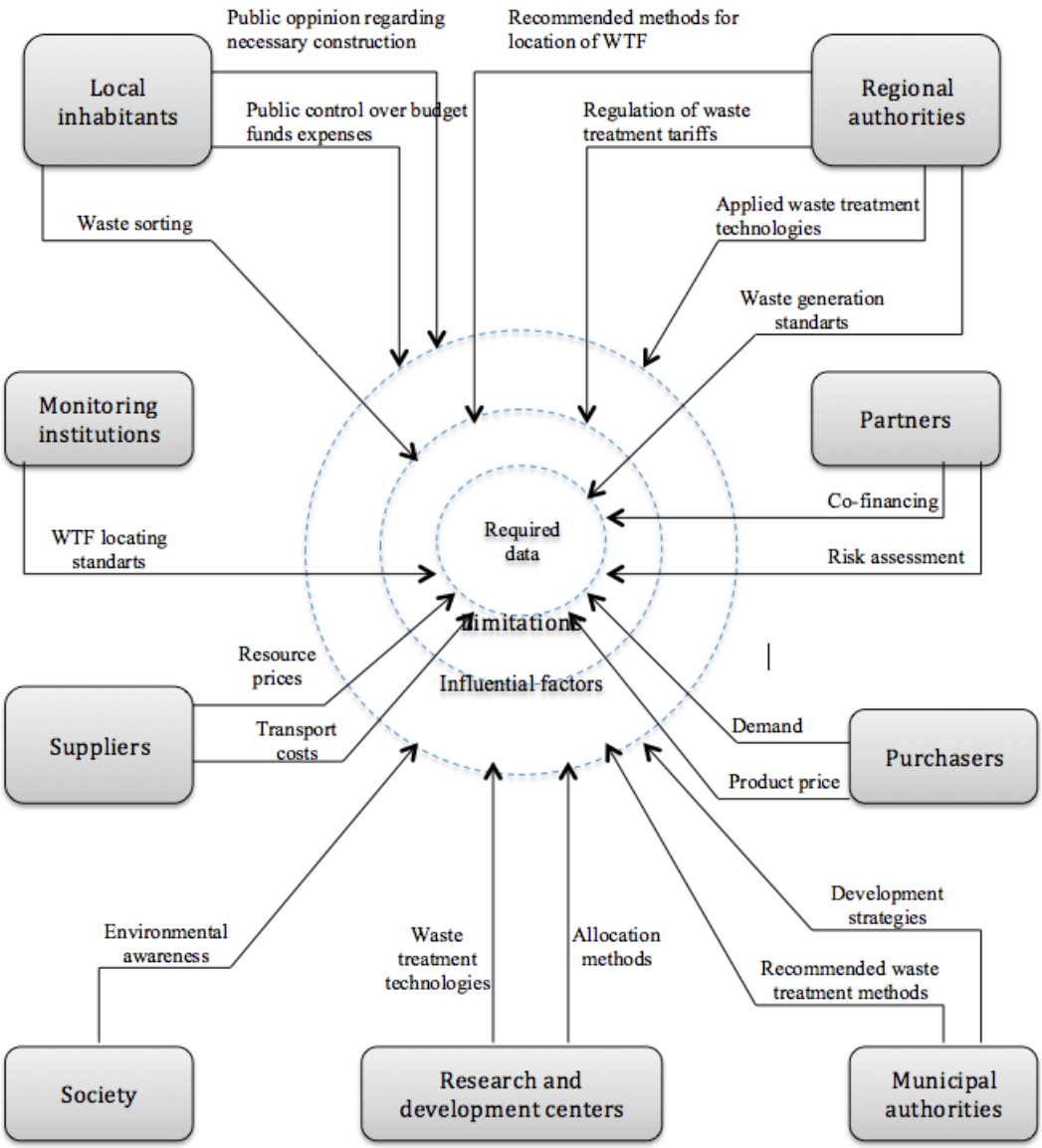

Fig. 1.2 Information flow for decision-making process for locating a waste management infrastructure element

Source: by author, based on Velikanova (2014)

Most popular and viable waste management models developed to support decision-making and selection of an optimal waste management strategy can be classified as:

- Models based on the *cost benefit analysis* of the studied waste management system;
- Models that consider environmental, energetic and material aspects of the waste management strategy – *life cycle assessment*;
- *Multi-criteria decision making* models for selection of the optimal waste management strategy (*Morrissey and Browne*, 2004).

Multi-criteria decision making can guide decision makers in evaluating existing or potential alternatives by simultaneously applying multiple conflicting criteria (*Kou et al.*, 2011; *Zhou et al.*, 2010). Because of their ability to handle several criteria, multi-criteria

decision making methods are considered to be some of the most effective and thorough decision support frameworks for decision-making in solid waste management (*Soltani et al*., 2015). The decision making process is implemented in the steps highlighted in Figure 1.3.

Fig. 1.3 Multi criteria decision making model

Source: by author, based on Jovanovic et.al. (2016)

The first step involves defining the scope and primary objectives that comprise the decision context. These objectives must be specific, realistic and measureable. The second stage involves identification of all possible alternatives to achieve the projected goals. In the third step, the decision makers define criteria for assessment of the performances that reflect the level to which the objectives have been realized. This stage involves assigning weighting coefficients and defining criteria priorities, if any. The last stage of the multi criteria decision making procedure includes assessment and ranking of the options in order to reach an optimal choice. The most frequently used criteria include economic, environmental and energetic parameters. Recently, however, numerous analyses have also included various sociological and legal criteria (*Ehrgott et al*., 2010; *Mourits*, *Lansink*, 2006).

According to *Coelho* (2016) multi-criteria decision making approaches are normally classified in two main streams: multi-attribute decision-making and multi-objective decision-making. Multi-attribute decision-making comprises of selection or ranking problems, while multi-objective decision-making encompasses optimisation problems (Hung *et al.*, 2007; Haastrup *et al*., 1998; Tran *et al*., 2002). In other words, multi-attribute decision making methods aim to compare or rank any set of alternatives based on the criteria adopted, whereas multi-objective decision making techniques are focused on determining the set of optimal alternatives according to the criteria considered.

Back in the twentieth century *Alfred Marshall* (1920) has started describing the advantages of agglomeration of economic activities. His concepts are still widely discussed and developed further (Okubo, 2004; Pfluger, Tabuchi, 2016). Marshall proved that, due to concentration in close geographical proximity within "industrial districts", companies get the benefit of large-scale industrial production and of technical and organizational innovations. Michael Porter has developed and popularized the cluster concept. According to *Porter's* (2008) definition "clusters are geographic concentrations of interconnected companies, specialized suppliers, service providers, firms in related industries and associated institutions

(e.g. universities, standards agencies and trade associations) in a particular field that compete but also cooperate".

There is a strong association between industrial symbiosis and improved competitiveness in the industrial symbiosis literature (*Geng ,Cote* 2002; *Lowe, Evans* 1995), often attributed to improved natural resource productivity (*Esty, Porter* 1998). In the experience of *Lombardi, Laybourn* (2012), opportunities to improve competitiveness through industrial symbiosis are much broader than improved resource efficiency. They include reducing cost through innovative product or process changes, increasing revenue, diversifying business, and managing risk (*Laybourn and Morrisey,* 2009).

Business models implementing the industrial symbiosis practice have been recognized as sustainable business models, classified under the archetype "create value from waste" (Bocken *et al.,* 2014). According to OECD (2012), by replacing old business practices, innovative business models also allow firms to restructure their value chain and generate new types of producer-consumer relationships, and alter the consumption culture and use practices. The sustainability of business models oriented to the industrial symbiosis approach stem from the economic value created for firms simultaneously with the environmental benefits generated for the society as a whole. In particular, the economic benefits are in the form of lower production costs or higher revenues. As a result, the competitiveness of the firm can be increased by implementing such an approach (Esty and Porter, 1998). Business model innovation is about the creation or reinvention of a business itself. Whereas innovation is typically seen in the form of offering a new product or service, a business model innovation is more about introducing different business strategies offering not only new value propositions, but aligning its profit formula, resources, processes and partners to enhance that value proposition and capture new market segments (OECD, 2012). According to Fraccascia *et.al.* (2016), when talking of industrial symbiosis, value proposition is based on resource saving and higher efficiency, key activities are linked with research and development, it requires a reconfigured network of partners and new expertise as key resources. With respect to customer aspects, both customer relations and channels require the establishment of new relationships.

Within the present research the author develops an industrial symbiosis model, using an approach distinctive from those historically developed –using currently existing waste management infrastructure elements - municipal waste landfills, which already offer a range of resources (electricity, heat, waste water treatment plants, technical water, infrastructure, etc.) as a basis of industrial symbiosis system.

Research model and research design

The dependent variable within the research has been formulated as **"*Industrial symbiosis, developed using internal landfill resources/by-products*".** The variables as well as their sub-factors have been identified as most significant within present research, although other factors of influence cannot be neglected. The structured theoretical framework can be observed in the Figure 1.4.

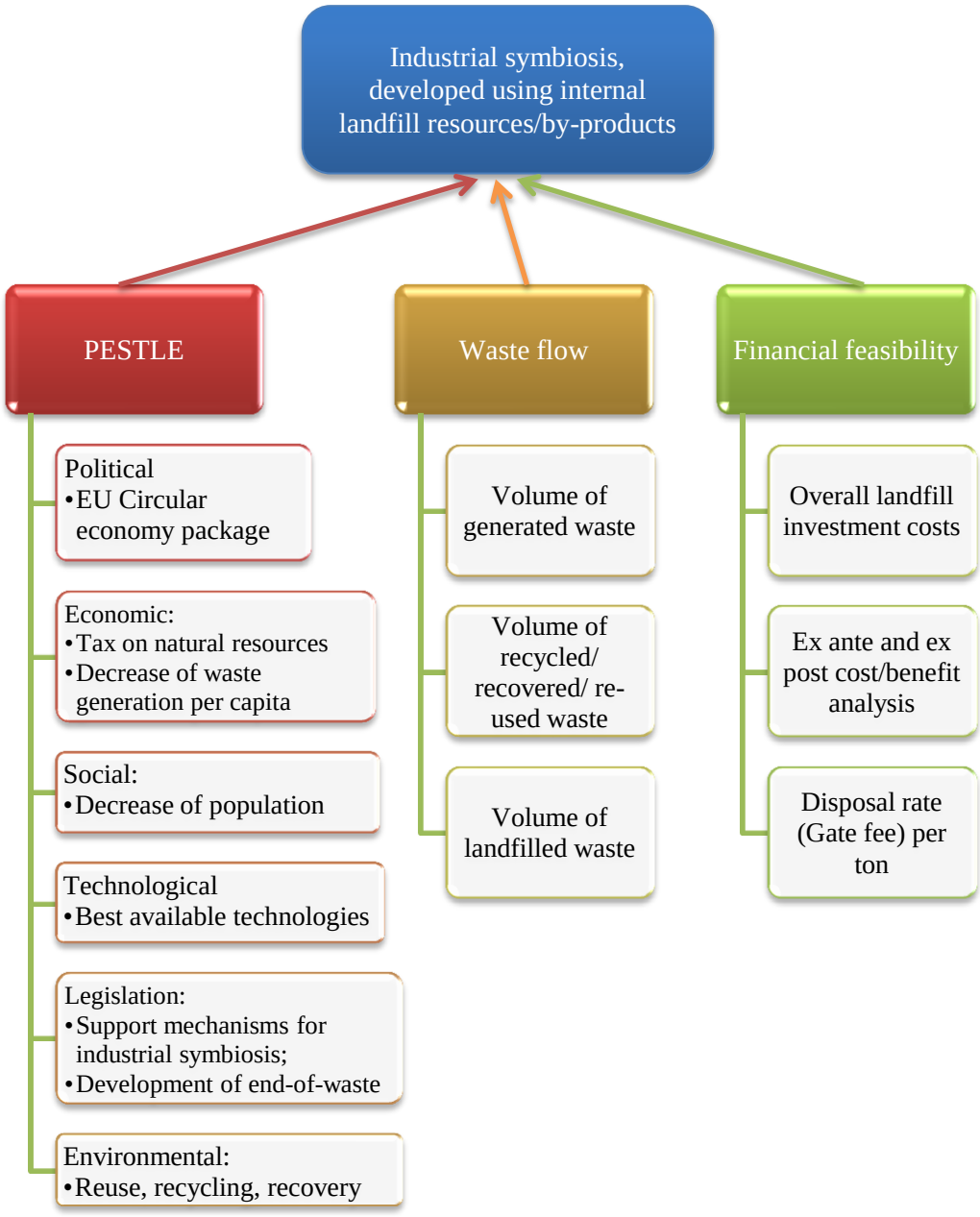

Fig. 1.4 Theoretical Framework *Source: developed by the Author*

Figure 1.5 shows the relationships and interdependence of the independent variables.

Relationship: PESTLE – Waste flow. This relationship shows, that changes in economy, have direct impact on waste generation and it's flow, changes in taxation system influence the volume of waste landfilled, changes in legislation influence the waste treatment options (implementation of EU Directive, development of waste sorting, re-use, etc.).

Relationship: Waste flow – Financial feasibility. This is a direct and strong relationship, it stands for – change of waste generated/treated or landfilled leading to a momentary effect on the financial feasibility of the landfill management company.

Relationship: PESTLE – Financial feasibility. Changes in PESTLE have an impact on financial feasibility and it`s ratios, stated in the Figure 1.5, for example, increase in taxation, gate fees and collection rates may lead to illegal dumpsite and this will affect the overall feasibility, while the ratios calculated, from the landfill data will be a) lower, than expected; b) not according to the real situation, as part of waste will not reach the landfills.

The moderating variable *Landfill as a basis for industrial symbiosis* has been identified - which is influenced by all the independent variables and directly influences the dependent variable. The IS module$_1$ … IS module$_n$ are directly dependent on the flow and volume of the resources of each particular landfill. In addition, each IS module can use different resources and share different resources with the other IS modules.

Table 1.1

Research design *Source: developed by author*

Elements of the design	**Type of research undertaken**
Purpose of the Study	descriptive
Type of Investigation	correlational
Extent of Researcher Interference	minimum interference
Study Settings	noncontrived
The Unit of Analysis	Landfill management company (10 in total)
Time Horizon	Longitudinal (2011 - 2017)
Data Collection Method	Primary and secondary data

A research design is developed, covering main elements of the design, which sets the framework for the research conducted and presented in the Chapter 2 and 3. First stage of the research was aimed on the overall evaluation of Latvian waste management system, followed by development of two surveys, choice of experts for Landfill and Expert group, survey and analysis of the results, assessment of landfill internal resource flow, development of resource equations, development of industrial symbiosis model and decision-making matrix and approbation of the model and matrix on a particular waste flow.

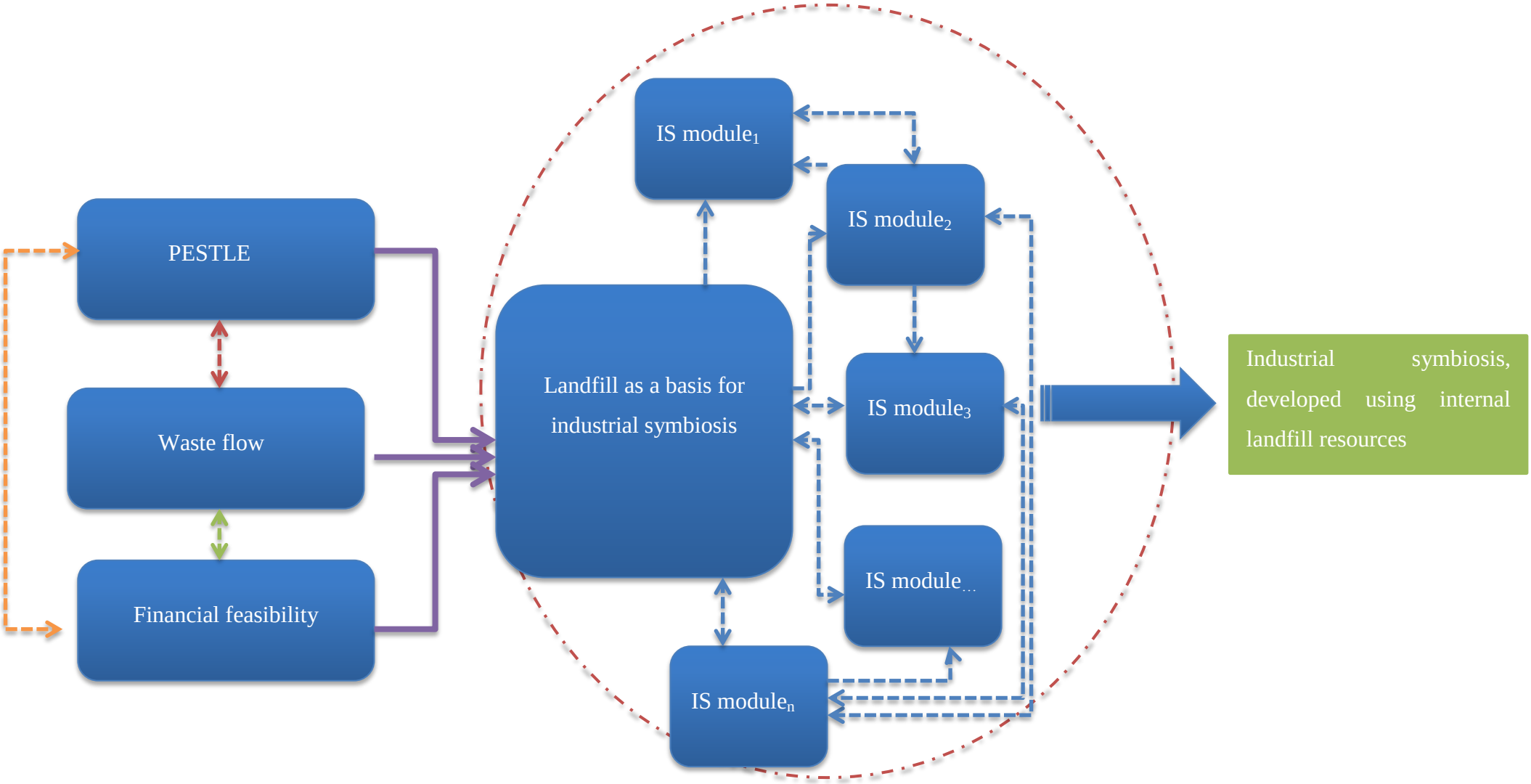

Fig. 1.5 Interdependence of the independent variables and industrial symbiosis research design *Source: developed by author*

2. Research on the business performance of Latvia's landfill management companies

(Chapter 2 consists of 46 pages, 12 tables and 21 figures)

The harmonisation of legislation in Latvian with European Union legislation has led to the fact that Latvia, being a EU member state has to achieve certain percentage in the decrease of waste landfilling and increase of waste sorting, preparation for re-use and recovery.

A common legislation framework regarding waste management has been developed within the European Union, although it is becoming more and more obvious that there is not a "one size fits all" solution but rather many different mixtures of technologies, institutional frameworks and policies applied across the European Union. The coexistence of different waste management systems that must achieve the same results in terms of recycling targets, diversion of biodegradable waste from landfills and waste prevention is a strong driver towards the development of benchmarking techniques that will allow a deeper comparison of different systems (*Cudecka-Purina et. al., 2013*).

Table 2.1 shows different approaches to waste management systems in leading EU countries and in the Baltic States. It has to be emphasized that landfills will always be present in the waste management system, as a final point of waste treatment (even after incineration, anaerobic digestion or any other activity, there will still be leftovers that will require landfilling). The European Union has set control figures, which have to be reached in a certain timeframe and which aim at a maximum decrease of landfilled waste. The manner in which each of the member states will modify or adapt landfills for their sustainable development, however, stays in the competency of each member state.

Under the circumstance when leading waste management countries are approaching 1-5% waste landfilling rates and recycle over 37% of waste generated, newer member states, which joined the European Union after 2004, are only on the first stages of waste management system development. Up to now many of member states have meager development of waste composting and incineration. Historically Latvia's waste management was focused on landfilling. Country-wide inventory in the field of waste management revealed 558 operating dumpsites and approximately 160 closed dumpsites, which did not correspond to sanitary requirements and caused air and water pollution. In order to implement the European Waste Management Directive, Latvia had to develop an integrated approach to municipal waste management. The sustainable waste management system in Latvia had three main stages: 1) involvement of 100% of urban and at least 75% of rural inhabitants; 2) implementation and development of sorted

waste collection from 5% in 1995 to 50% in 2025; 3) development of new infrastructure - waste disposal and dumpsite recultivation.

Table 2.1

Different waste treatment methods in 2011 and 2014

Source: by author, based on Cudecka-Purina et. al. (2013)

	Municipal waste generated, kg/ capita	Waste treatment 2011, %					Waste treatment 2014, %			
		Landfilling (D1-D7, D12)	Incineration(incl. energy recovery)	Material recovery	Composting	Waste generated, kg/ capita	Landfilling (D1-D7, D12)	Incineration(incl. energy recovery)	Material recovery	Composting
Estonia	311	77	-	14	9	357	6	47	27	5
Lithuania	381	94	0	4	2	433	59	9	23	9
Latvia	304	91	-	9	1	364	71	0	21	4
EU 27*	499	34	24	26	14	477	25	27	27	17
Germany	626	0	37	46	17	625	0	31	48	18
Belgium	456	1	41	34	20	418	1	43	31	19
Sweden	449	1	52	33	14	447	1	51	32	16
Netherlands	568	2	49	24	25	523	1	47	23	27
Austria	573	5	35	24	33	560	3	38	25	31

As a result of the activities undertaken, Latvia has been divided into 10 waste management regions and by 2016 all of the identified dumpsites were recultivated and 11 landfills for municipal waste, 1 for hazardous waste and 1 for asbestos waste (see Figure 2.3) have been constructed. The regions have been determined in order to be able to ensure positive development of waste management system in Latvia, developing infrastructure for waste disposal that is in accordance with environmental requirements. Simultaneously, the regions varied significantly (by territory – from 6.3% up to 17% from Latvia's area; by number of inhabitants – from 3.5% up to 43.1% of total population; by density – from 15.6 inhab/km^2 to 161.7 inhab/km^2). As well, significant differences have been identified in the volumes of investments for development of waste management infrastructure – from 5.8 million Euro to 23.7 million Euro. All this has led to a situation whereby waste management regions and corresponding waste landfills have come into different economic situations. At the moment when all the landfills have been constructed, and dumpsites have been closed and recultivated, the emphasis in waste management has shifted to important issues such as waste prevention, re-use of packaging, sorted collection of certain recyclable waste streams, recycling and re-use. A range of landfill bans have been introduced, including for some waste, which contributed to up to 30% of the waste stream.

These limitations alongside with economic downturn and decrease of population in the country have developed preconditions for the situation where landfill management companies face a complicated economic situation. Moreover, the inefficiency has also been proven by the fact that from the 11 waste management companies, one company receives 58% of the total waste for landfilling in the country, with others receiving from 1% to 8% of the waste dedicated to landfilling.

Approximately 700 000 tons of municipal waste are generated in the country annually, 500 000 tons of which are being landfilled, meaning that approximately 71% of the municipal waste generated in the country delivered to landfills. Although, if initial priority was development of basic waste management system and to initiate sorted waste collection, then already in 2008 a system perspective has changed significantly on the European level and it was foreseen that up to 2020 a significant focus on preparation for re-use recycling or recovery of waste has been set (setting the target to 50% from the generated waste). Due to the necessity of decreasing landfilled waste volumes, efficiency and sustainable development of landfill management companies is becoming an important issue. Economic mechanisms-applied through the regulation of waste landfilling include waste landfilling tariff and the natural resources tax on waste landfilling. An increase of the waste disposal tariff compensates a decrease in landfilled waste volume although it has to be mentioned that this tariff is the main revenue source for landfill management companies. On the other hand, an increase in the natural resources tax on waste landfilling creates a stimulus for waste management companies to seek alternative waste treatment options to waste landfilling – i.e. to improve waste sorting and to decrease the volume of waste for landfilling. Although, it has to be understood that increase in both the tariff and tax cannot be infinite and tariff increase is not sufficient for the sustainable development of a company. The present waste landfilling tariffs also vary significantly across the waste management regions – from 19.38 Eur/t in *Ventspils labiekartosanas kombinats (Landfill management company in Ventspils region)* up to 32.16 Eur/t in *Vidusdaugavas SPAAO (Landfill management company in Vidusdaugava region)*, or in percentage the difference reaches 60%. The analysis performed by the author (Cudecka, 2011b) already in 2011 (see Table 2.2) leads to an important discussion on region efficiency and the author raised doubt regarding the appropriate development approach chosen.

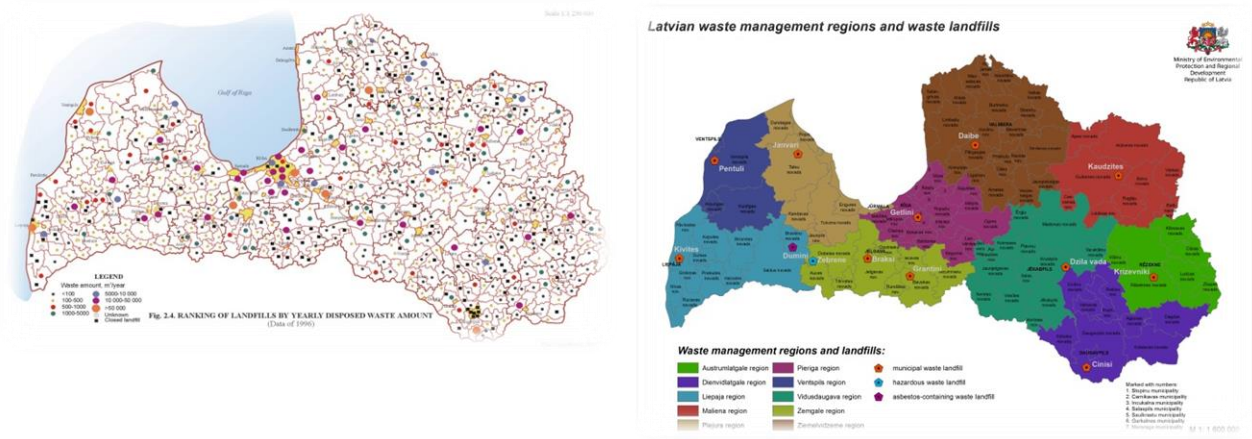

Fig. 2.1. Waste dumpsites and landfills in Latvia in 1996 and 2016

Source: GeoConsultants (1997) and VARAM (2016)

In order to avoid this negative result, one of the conclusions was in support of the necessity of unification of the waste management regions in order to shift from an ineffective to economically effective and practically efficient system.

Table 2.2

Results of the Cost/Benefit analysis

Source: Cudecka 2011a

	Austrumlatgale	**Dienvidlatgale**	**Maliena**	**Ventspils**	**Liepaja**	**Riga**	**Piejura**	**Zemgale**	**Ziemelvidzeme**	**Vidusdaugava**
Net present value	650675	336196	-5333371	811691	8291935	1812871	-12436954	-4820129	3468664	-8345850
Internal rate of return	6,44%	5,5%	-3,35%	6,39%	12,65%	5,44%	-1,20%	-1,31%	9,17%	-0,42%
Cost/ Benefit	1,21	1,12	0,83	1,28	1,48	1,17	0,91	0,95	1,29	0,97

Latvia's municipalities are responsible for organizing waste management within their territories. When analysing waste management companies operating in Latvia, the following distinctions can be made: municipal waste collection companies that operate across Latvia, in accordance with the procedures laid down in the laws and regulations governing public procurement or public-private partnership in a particular municipality; construction & demolition waste collection companies that operate across Latvia, in accordance with the procedures laid down in the laws and regulations governing public procurement or public-private partnership in a

particular municipality; hazardous waste collection companies that operate across Latvia and which do not require specific contracts with municipalities; waste management intermediaries that operate across Latvia and which do not require specific contracts with municipalities; waste recycling companies that operate across Latvia and which do not require specific contracts with municipalities; landfill management companies, that operate only in a particular waste management region. The main activities of a landfill management company include but are not limited to: weighting and registration of incoming waste flow; waste sorting, preparation for recycling, reuse or recovery; waste temporary storage; landfilling (including all management aspects of a landfill cell); composting of biodegradable waste; management of leachate; management of biogas; production of electricity and heat; environmental state monitoring; management of landfill infrastructure objects and educational activities (see Figure 2.7).

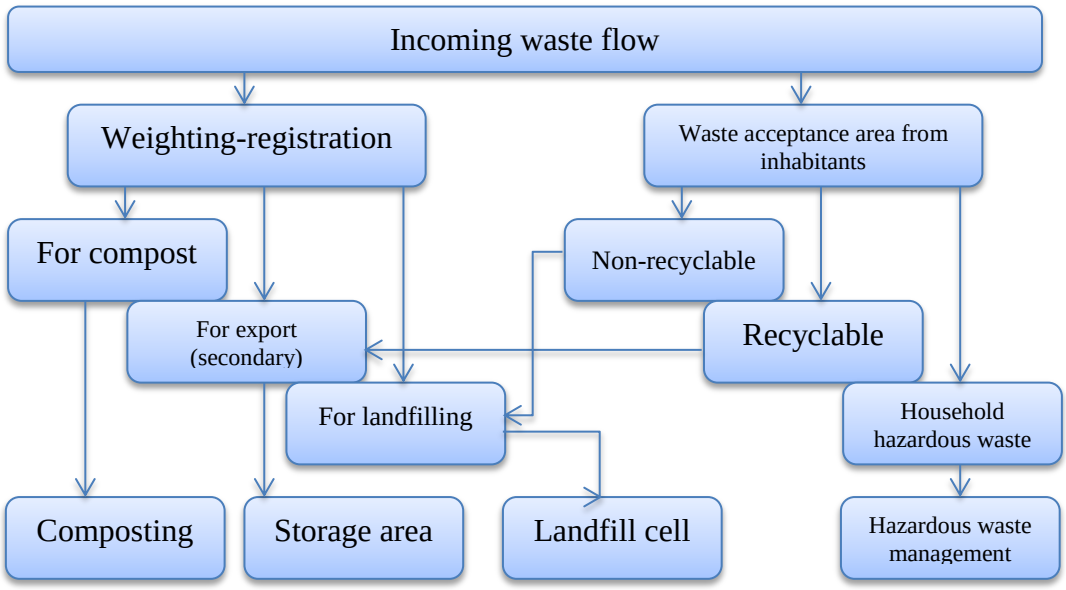

Fig. 2.7. Schematic waste flow within landfill management company, *Source: by author*

In the second chapter of the Thesis the author has analysed waste management regions, landfill management companies and waste disposal tariffs. A range of differences has been identified, but nevertheless all the entities have to secure sustainable development for reaching a unified target – decrease of landfilled waste. During analysis of landfill management companies, an important contradiction has been identified: the current target of the waste management system is - by 2020, preparing for re-use and the recycling of waste materials such as at least paper, metal, plastic and glass from households and possibly from other origins as far as these waste streams are similar to waste from households, shall be increased to a minimum of overall 50 % by weight with further decrease of landfilled waste up to 10% or even 5% from waste

generated. While goal of landfill management companies is to survive within these preconditions, without shifting the burden to inhabitants by escalating waste landfilling tariff. In order to solve this task, the author stresses the necessity to develop efficient internal use of resources and by-products that arise during landfill daily operation or to offer the resources to other industries. An idea of development of technological parks on the landfill basis arises. A technological park or industrial symbiosis entities would be interconnected by resource and infrastructure.

The author develops the idea of horizontal and vertical integration into a industrial symbiosis model. This is mostly explained by the fact that eventually less waste will be reaching the landfills and the activities such as sorting and even pre-treatment might be kept to a minimum. As methane has a very continuous life-cycle (even after no additional waste is being disposed at the landfill) and especially taking into account that Latvian landfills still have a significant proportion of biodegradable waste being disposed there, methane collection followed by production of heat and electricity will bring long-term opportunities for landfills.

In order to verify theoretical framework based vision on current waste management sector problems and possible solutions the author has developed a survey, which is oriented to two focus groups – landfill management companies, as an interested party and independent experts – consulting companies, field experts, scientists and researchers. The polled waste landfill management companies represent 100% waste management region coverage. Landfill management companies have influence on waste management policy development in Latvia, as they are members of the association of Latvian waste management companies and their interests are represented also in the MEPRD Working group developed on improvement of waste management legislation. In terms of responsibilities, the companies fulfil municipality-delegated functions within a particular waste management region. In the second group the author included 30 experts from Estonia, Latvia, Lithuania, Russia, Malaysia and Spain. Key factors for choice of experts were: at least 5 years of scientific or professional expertise, type and level of education (Phd or Mg. in environmental science, business administration, and economics), activity in international scientific or practical waste management conferences and publications in this field. The geographical spread of the expert group is explained by the fact that it is important to compare the views and visions of the neighbouring countries, as well as to have examples of southern EU member states and a couple of countries outside the EU – in order to attain a broader picture of the waste management issues, problem-solving approaches and potential development direction. The survey consists of 19 open and closed-type questions and it is divided into three

sub-sections. The first sub-section covers landfill management companies, their functions, output of landfill daily operation activities, potential resources for industrial symbiosis and disposal rates. The following sub-section covers waste management trends in Latvia, it is aimed to disclose a landfill management company's vision on further development. The last sub-section tackles decision-making practices in waste management companies. Overall the survey results show that the author's proposed development path was supported by landfill management companies and by field experts – as an optimal solution to secure sustainable development and the increased efficiency of landfill management companies. Analysis of the survey shows, that both target groups consider it logical for the municipalities to delegate all waste related functions to landfill management companies and to turn them into regional waste management centers.

The landfills are quite similar in the types of by-products arising from their daily operations, although they currently do not feel confident about sharing these resources with other industries. Both focus groups consider it as an important precondition for further development to have end of waste criteria, establish local recycling facilities, as well as to have a country-level circular economy or industrial symbiosis support programs and better education of society on waste-related issues, the groups are also quite consistent in highlighting part of the abovementioned topics to be implemented into current legislation. The majority of the expert group stress the necessity of implementing differentiated targets for waste management regions, depending on their social, economic and demographic peculiarities. When analyzing the obtained results from the Landfill group in terms of company managerial aspects, it can be summarized that the companies do pay a lot of attention to personnel training and education (60%-80%), follow the leading tendencies and innovations (50%). Involvement in the scientific research and assessment of problems from the scientific perspective (20%), is not on the company's priority list, although the Expert group consider these activities of high importance. In terms of decision-making, the companies tend to rely on consultations (60%), evaluation of economic efficiency (60%) and benchmarking (50%). The author considers that these questions show a positive trend, that the Landfill group is represented by open and flexible management, which does consider different development options, not limited to the top-bottom approach.

3. Industrial symbiosis model and decision-making matrix

(Chapter 3 consists of 48 pages, 15 tables and 21 figures)

Latvia's waste management system was not designed using the "one fits all" approach, but it allowed municipalities to choose their desired management and operation, a landfill management company would undertake.

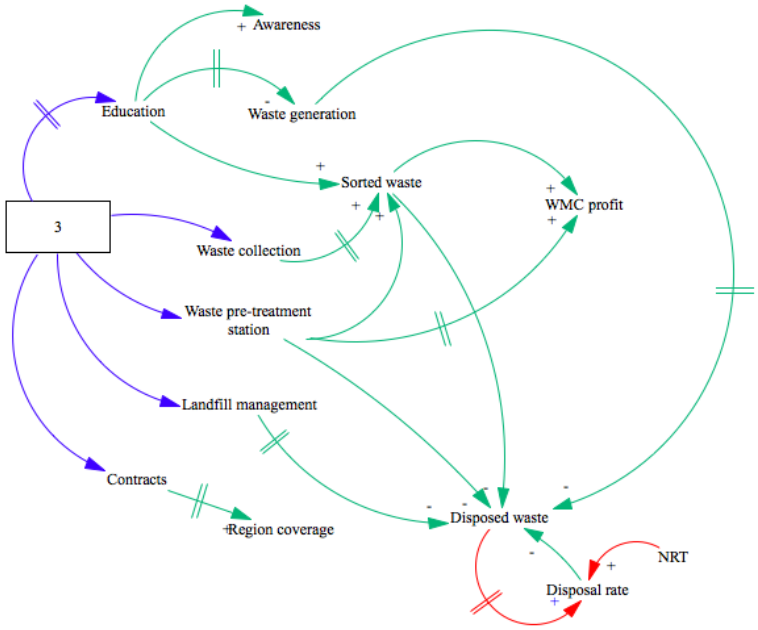

Fig. 3.1 Causal loop diagram of full cycle LMC, *Source: by author*

The author has analysed all the operations, undertaken by the LMC and developed the following schemes.

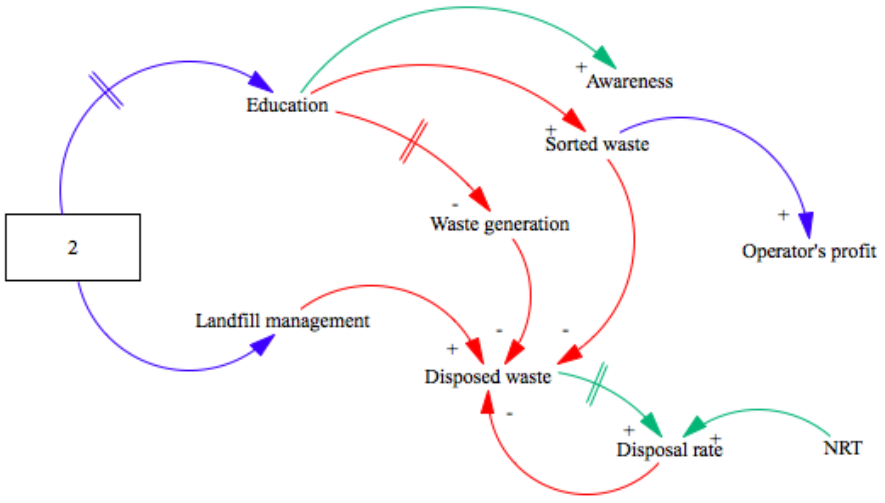

Fig. 3.2 Causal loop diagram of LMCs performing waste landfilling & inhabitant education activities, *Source: by author*

The author has identified a range of problems that are currently faced by landfill management companies and do not allow them to engage directly in industrial symbiosis. This means that the first obligatory stage in order to promote involvement in industrial symbiosis is the necessity to revise and change or amend legislation in order to stimulate promotion of such activities.

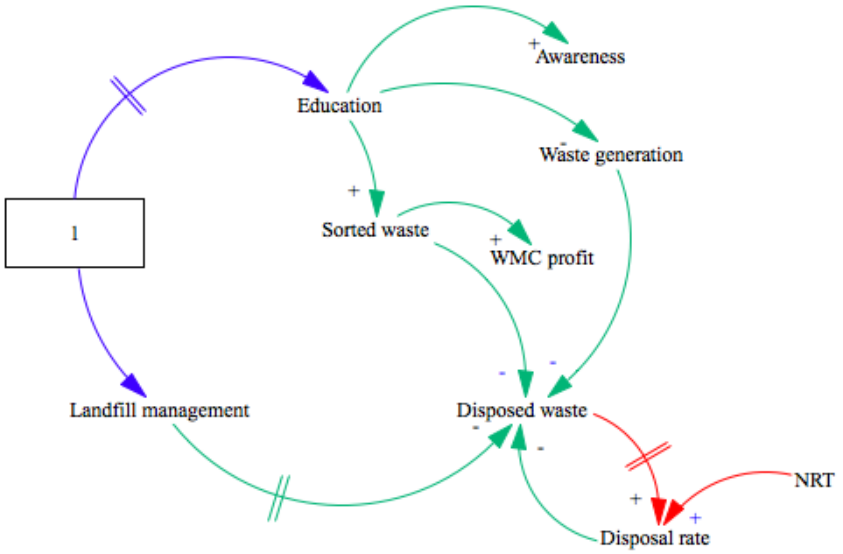

Fig. 3.3 Causal loop diagram of LMCs performing landfilling, sorted waste collection & inhabitant educational activities, *Source: by author*

With implementation of industrial symbiosis, landfill management companies will be able to offer their resources to other industries, which could be located by the landfill. In this case it could lead to a win-win situation for both entities, as both effective resource management will be secured and cost savings on primary resource consumption will emerge.

The author has undertaken assessment of currently available resources within a landfill and has grouped them into four categories: waste, electric, thermal, wastewater resources. Figure 3.2 depicts resource flow within industrial symbiosis. Further four balance functions are presented, that will allow landfill management companies to evaluate resources that can be used for industrial symbiosis and, depending on their volume, will be able to develop a decision making tree for an optimal development strategy.

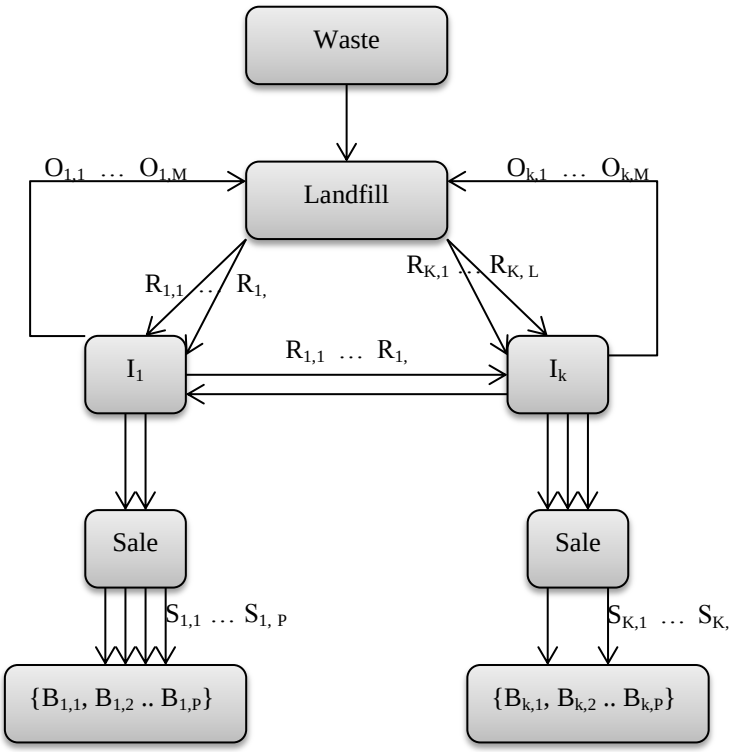

Fig.3.4 Flow of the resources within industrial symbiosis*; Source: by author*

Four balance functions are provided below, which allow landfill management companies to assess the resources which could be used for industrial symbiosis, and, depending on their volume, landfill management companies can make a decision, using the author's developed LMC matrix in order to choose the optimal development strategy.

1. Waste balance

$$Q = \sum_{i=1}^{K} Q_i = Q_{rw} + Q_{fi} + Q_{sl} \tag{3.9}$$

$$Q \leq R$$

where:

rw – return waste

fi – for industries

sl – second level

$$Q_{rw} + Q_{fi} + Q_{sl} \leq R \tag{3.10}$$

2. Electric balance

$$\sum_{j=1}^{K} E_{1,j}^{first} + \sum_{i=1}^{T} E_{2,i}^{second} \leq E \tag{3.11}$$

3. Thermal balance

$$\sum_{j=1}^{K} TE_{1,j}^{first} + \sum_{i=1}^{T} TE_{2,i}^{second} \leq B \quad (3.12)$$

4. Technical water balance

$$\sum_{j=1}^{K} W_{1,j}^{first} + \sum_{i=1}^{T} W_{2,i}^{second} \leq W \quad (3.13)$$

With significant financial support from the European Union, new member states have harmonised their legislation, waste management regions have been developed, all sub-standard landfills have been closed and remediated, sanitary landfills for solid waste disposal have been constructed alongside with the basic infrastructure elements (depending on each country's and in particular waste management region's financial possibilities), extensive work on sorted waste collection has been launched. Currently a new stage of development of waste management in these countries has been initiated and this is the time when the countries can introduce circular economy elements into their waste management system. Latvia's state waste management plan 2013 – 2020 foresees financial support only for sorted waste collection and recycling, thus the author considers that the next logical stage should be development of industrial symbiosis, following latest trends from the EU in resource efficiency and closed-loop approach. One of the solutions to avoid contradiction between decreasing disposed waste volumes and increasing disposal tariff and Natural Resources Tax (NRT) rate that both from certain point will have a negative impact on LMCs that are engaged only in waste disposal activities, offered by the author – assessment and management of the waste/resources that are being generated in the landfill during waste disposal process in an economically effective way. Current and further in-depth research will allow developing specific tailor-made recommendations for each particular region and this know-how can be applied in the future to other member states struggling with economic efficiency of LMC.

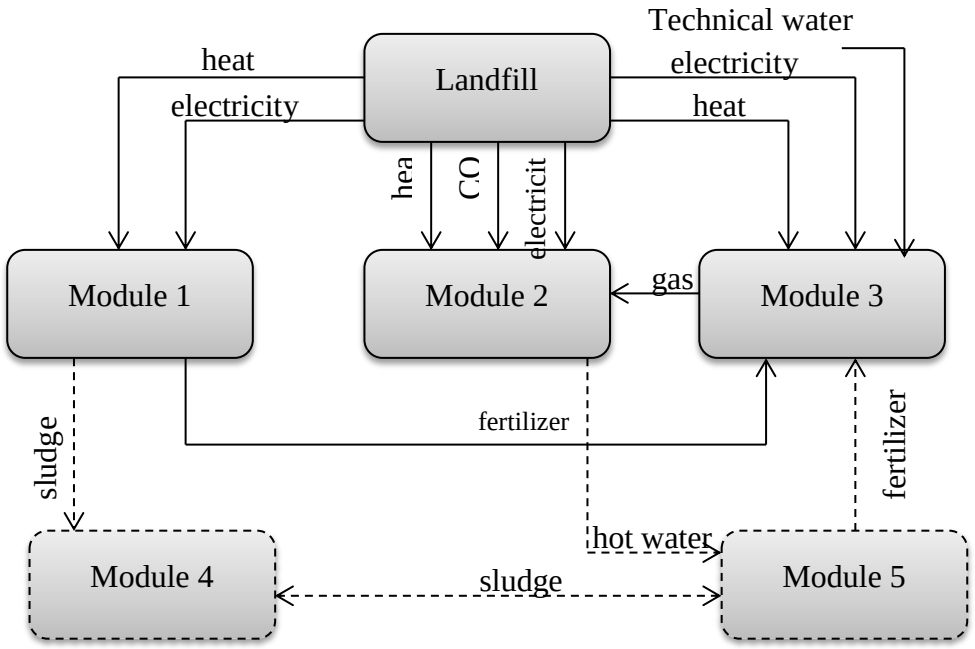

Fig. 3.5 Industrial symbiosis model. *Source: by author*

As a result of the research, including mathematical modelling and development of resource balances, the author was able to develop an industrial symbiosis model that can be applicable for a landfill management company. Future development paths, according to the author's concerns have to include primary resource consumption, assessment of critical resources for the country and highlight possible solutions, ensuring resource efficiency, development possibilities as industrial symbiosis.

Figure 3.5 depicts a possible industrial symbiosis model, offering cooperation between the modules. Based on this model, the landfill management company is able to choose the best suitable modules, which can then be constructed by it or a cooperation model with the desired industry can be offered. Further on, developing the industrial symbiosis, other industries can join the symbiosis, not necessarily interacting directly with landfill, but sharing resources with other modules. Thus waste landfill becomes a starting point for industrial symbiosis.

In order to prove the hypothesis, defined within present research, the author provides certain calculations. Figure 3.6 clearly depicts the difference of landfill development with and without industrial symbiosis. The $\Delta\downarrow$ of disposal tariff shows the possibility to maintain a company's positive performance without an increase in waste disposal tariff, thus avoiding social resistance. This is compensated by direct implementation of resource use, which, even with the significant decrease of waste disposal volumes, brings positive Δ.

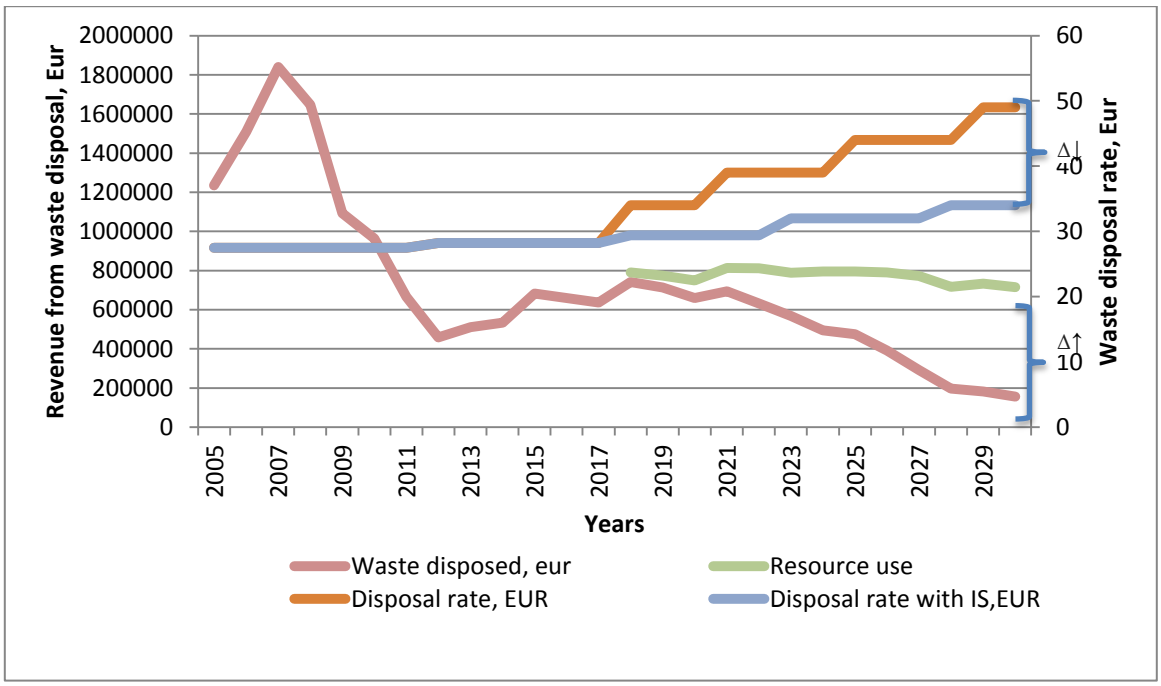

Fig. 3.6 Development of a landfill with industrial symbiosis (IS) and impact on waste disposal tariff; *Source: by author*

A summary of different business model application scenarios for landfill management companies is provided in Table 3.1. The analysis took into consideration following assumptions – the LMCs were initially financed by municipalities and Cohesion fund; European Investment Bank recommendation is for IRR to be at 5% level (although, for private investors (for industrial symbiosis scenarios), it is advised to have IRR at 12% level); real discount rate is assumed to be 5% and the reference period is calculated to be 25 years.

In Table 3.1 Scenario 1 is updated from Cudecka (2011a). The main reason for such decrease in the ratios is the fact that in 2030 a dramatic decrease of permitted waste disposal volume is expected and even increase of disposal tariff will not be able to compensate this. Although, it has to be noted, that Scenario 1, due to extremely high waste disposal tariff, is not a realistic scenario, as such increase of the costs for inhabitants are beyond breakeven point and will not be acceptable and bearable to the population. This scenario would definitely lead to littering and environmental pollution. Scenario 2 is considered to be a pessimistic development of industrial symbiosis, using only 10% of resources available for a landfill management company. Scenario 3 is considered to be the most realistic, with a significant percentage of resources used for industrial symbiosis – 60%. Scenario 4 is considered to be very optimistic, in case industrial symbiosis gets major support through Government support and entrepreneurship opportunities.

Table 3.3

Summary of landfill management scenarios

Source: by author

	Ratios	Austrumlatgale	Dienvidlatgale	Maliena	Ventspils	Ziemelvidzeme	Vidusdusdaugava	Riga	Zemgale	Piejura	Liepaja
Scenario 1	NPV	-2116380	-10214138	-8655869	-5119762	-1994882	-16990079	-7598282	-8780395	-19083403	-2843428
	IRR	-1%	-6%	-12%	-13%	2%	-11%	3%	-6%	-6%	2%
	C/B	0.841	0.787	0.348	0.613	1.076	0.445	1.082	0.778	0.607	1.060
Scenario 2	NPV	909526	-2889932	-7425400	-4705460	1068959	-13764336	32330788	-1590764	-14007391	511780
	IRR	7%	3%	-7%	-7%	6%	-7%	10%	4%	-1%	5%
	C/B	0.835	0.715	0.311	0.603	1.042	0.416	1.052	0.756	0.566	0.988
Scenario 3	NPV	7383493	14405535	-4562836	-3779216	8041946	-6510571	117806054	13323738	-2498956	9142617
	IRR	13%	11%	0%	-2%	11%	1%	16%	11%	4%	10%
	C/B	0.835	0.715	0.311	0.603	1.042	0.416	1.052	0.756	0.566	0.988
Scenario 4	NPV	11429723	25215201	-2773733	-3200313	12400063	-1976969	171228095	22645302	4693815	14536891
	IRR	15%	14%	3%	0%	13%	4%	18%	14%	6%	12%
	C/B	0.835	0.715	0.311	0.603	1.042	0.416	1.052	0.756	0.566	0.988

The research also included risk analysis for Scenarios 3 and 4. Within the analysis following risks have been assessed: resource, financial, demand and operational. The risk analysis for the Scenarios 3 and 4 convincingly shows that the residual risks for the IS project are mostly kept at Low level, as a result of the measures already implemented to prevent their occurrence. All in all, the overall level of the residual risk is deemed to be fully acceptable, it can be concluded that the probability of project failing to attain its targeted objective at a reasonable cost is with low probability.

In order to make precise calculations for a yearly benefit of a landfill management company's engagement into industrial symbiosis, the author provides real figures of a landfill's available resources. In 2015 one of Latvia's landfills ensured constant collection of landfill gas for production of electricity and heat. In total 851 276 Nm^3 of biogas was collected and 1047.46 MWh of electricity and 1200 MWh of heat was produced. Collected and utilized landfill biogas volume provided a decrease of greenhouse gas emissions equivalent to 6256.9 t/CO_2. With the electricity produced it would be possible to provide approximately 500 households with average electricity consumption. Table 3.1 provides a summary of resources generated by the landfill in 2016 and their market price for the reference year.

Table 3.2

Landfill resources for 2015; *Source: by author*

Resources	**Volume**	**Market price**
Heat	1200 MWh	53,56 Eur/MWh
Leachate	24215 m^3	1,10 m3 /2,37m3
Electricity	1047,46 MWh	0,01185 Kwh
Premises	200 m^2	2 Eur/m^2
Territory with infrastructure (access roads, asphalted areas, etc.)	1 ha	1 Eur/m^2

Further the author has elaborated potential revenue from the resources available, by landfill engagement into industrial symbiosis.

Table 3.3

Landfill benefit from engagement into industrial symbiosis; *Source: by author*

Resources	Revenue from efficient resource use, Eur/year
Heat	64 300
Leachate	57 400
Electricity	12 400
Premises	4 800
Territory	120 000
Total:	**258 900**

As Table 3.3 shows, total revenue for a particular landfill from engagement in industrial symbiosis may reach 260 000 Eur per annum. For the same year the revenue from waste disposal of the landfill are equal to 660 000 Eur, meaning that industrial symbiosis may add up or compensate up to 40% of revenue. This leads to the conclusion that a landfill management company can benefit from such a development direction and, moreover, it can significantly limit increase of waste disposal tariff (see Figure 3.6.), which would have a positive social impact.

In order to be able to apply the developed resource balances to a particular landfill and thus to chose the best possible solution taking into consideration all the nuances and particularities of the landfill's operation, the author has developed a decision-making matrix. This matrix will allow landfill management companies to take into account the main variables as well as the company's desired development direction.

Figure 3.7 offers a landfill management company decision making matrix. It consists of four quadrants:

- First quadrant with preconditions of low volume of resources and low profit foresees development in the form of modular internal industrial symbiosis. This means that the landfill management company has to perform a balance of the available resources and can chose one or a combination of modules.
- Second quadrant has the precondition of high volume of resources and low profit. This situation is considered to be a good starting point in order to develop more sophisticated waste sorting – focusing on smaller fractions with higher value (i.e. development of sorting of Low-density Polyethylene (LDPE) and High-density Polyethylene (HDPE) and preparing this material in flakes/ regrinds or pellets).
- Third quadrant foresees that a landfill management company has both high volume of resources as well as high profit. In this case it may consider focusing on fractions, which can be imported for recycling from abroad and/or other waste management regions in Latvia. These could be sophisticated tyre recycling facilities or specific material recycling facilities, which currently are not available in Latvia or nearby countries.
- Fourth quadrant with low volume of resources and high profit is suitable for a landfill management company that wishes to focus on sale of resources and development of infrastructure. In this case the company will be able to attract other industries and develop industrial symbiosis centre.

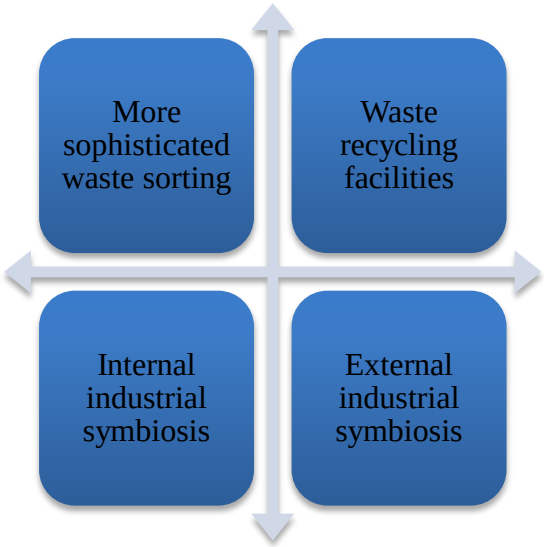

Fig. 3.7 LMC matrix

Source: by author

Application of the LCM matrix will allow a landfill management company to identify its current position and its prospects for future development. Together with industrial symbiosis model, developed within present research (Figure 3.5), landfill management companies can apply the matrix and use these tools for decision-making and shifting towards the circular economy.

It has to be mentioned that the developed model and decision-making matrix are not limited for use by landfill management companies in Latvia, and can be applied for the analysis of the resources of a similar foreign company and can be used as a basis for decision-making regarding further development direction. The main precondition for landfill management companies is landfilled waste volumes and their further trends, which secure generation of the required resources. This solution is of special interest to countries, which are at primary stages of waste management hierarchy and mainly rely on landfilling

In order to provide some empirical data, the author has chosen one type of waste – plastics and has undertaken an in-depth research regarding volumes of separately collected material, divided into 3 sub-categories: 1) PET; 2) PP, PS, PVC and 3) LDPE, HDPE. Although, it has to be mentioned, that the prices for plastics resources within European Union are divided into 6 groups by type of plastics and 3 groups by type of prepared materials: 1) in flakes; 2) in pellets and 3) in bales. The author has used for their analysis the data available regarding volumes of separately collected plastics, divided into 3 sub-categories: 1) PET; 2) PP, PS, PVC and 3) LDPE, HDPE. This division is based on the data available on the volumes of each type of material. Figure 3.8 depicts frequency of volumes of each particular material.

The undertaken modelling on the example of only one waste stream out of the extensive municipal waste stream shows how complicated municipal waste composition is and what a variety of different materials exist in one particular waste stream.

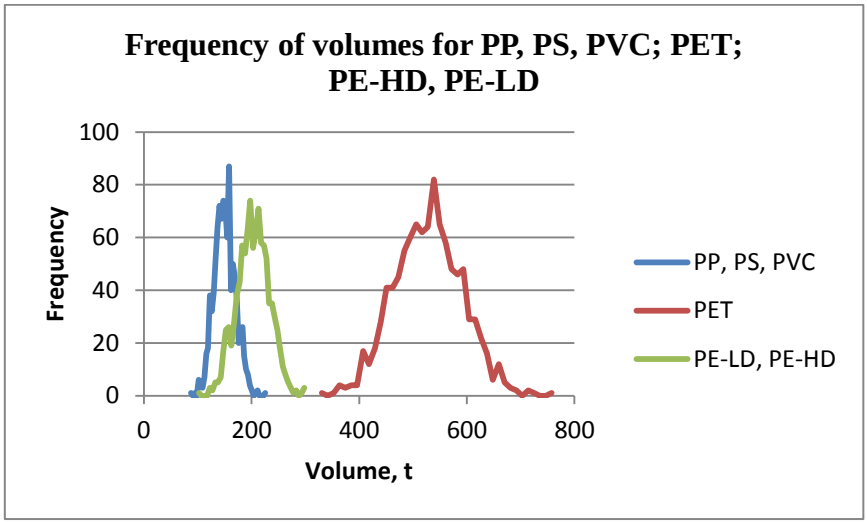

Fig. 3.8 Volumes of PP, PS, PVC, PET, HDPE, LDPE, *Source: by author*

When modelling prices for each material type in the purchased preparation types, the author also develops corresponding equations. Below are examples of equations for PP, PS, PVC materials:

in flakes:

$$\mathbf{y = -3{,}75x + 548{,}64}$$

$$\mathbf{R^2 = 0{,}771}$$

in pellets:

$$\mathbf{y = -3{,}38\ x + 905{,}16}$$

$$\mathbf{R^2 = 0{,}1945}$$

in bales:

$$\mathbf{y = -0{,}31\ x + 244{,}05}$$

$$\mathbf{R^2 = 0{,}0013}$$

Where, $\boldsymbol{x_{i,\,model} = a*t_i + b + e}$

$\boldsymbol{i = 1, \ldots, n\ (n=18)}$

$\{e = x_{i,\,real} - x_{i,\,model}\}$

$\{e_{i,real}\}$ *is average* $\{e\}$*, equalling to* μ

σ *– standard deviation.*

and $e = N(\mu;\sigma)$ *– normal distribution.*

As a result of the modelling provided in this part of the research, it can be seen that, in order to generate more profit from separate waste collection and return more valuable materials into an economic cycle, a more sophisticated waste sorting has to be undertaken, trying to separate from the waste stream different types of plastics. In addition, it can be seen that the economic assessment of the most valuable type of material preparation has to be assessed, either to prepare material in flakes, bales or pellets. Pellets or bales have considerably small preparation costs, compared to flakes. Moreover, the company has to assess the incoming potential volumes of each of the waste streams and identify the most valuable ones. For example, the modelling has identified that PET occupies biggest volume (average volume 523 t) of material in the total flow when HDPE, LDPE is approximately 201,53 t and PP, PS, PVC accounts for 148,45 t. Although the most valuable material is PP, PS, PVC prepared in pellets (average price 873,06 Eur/t), followed by: HDPE, LDPE in pellets (average price 847,78 Eur/t); HDPE, LDPE in flakes (average price 616,67 Eur/t); PP, PS, PVC in flakes (average price 513,06 Eur/t); PET in flakes (average price 389,44 Eur/t); HDPE, LDPE in bales (average price 243,89 Eur/t); PP, PS, PVC in bales (average price 241,11 Eur/t); PET in bales (average price 193,33 Eur/t).

Current practise shows, that the most commonly sorted and traded material from landfill management companies is PET in bales, which, according to the modelling, results to be the most numerous but simultaneously the most cheap material. The author advises landfill management companies to evaluate the possibility of focusing on sorting of HDPE, LDPE and PP, PS, PVC and their preparation in pellets. Preparation of all of the materials in flakes has to be economically evaluated, as this method requires significant capital investments. It has to be taken into account, that analysed types of plastic materials are stock materials and have certain supply and demand. With the change of market environment, a change of price proportions may also be affected. The expenditures for material preparation should always be considered prior to a decision on focusing on a certain material and its preparation type.

When applying results of the modelling to LMC matrix developed in Chapter 3.3 of the present research, the company, possessing significant volumes of sorted materials, can be advised to choose II quadrant development direction. In a similar approach, the company has to assess all other material flows in its possession and afterwards a decision of both further company's further development and engagement into industrial symbiosis has to be made by the management.

CONCLUSIONS

After undertaking an extensive and broad research on the topic of the thesis, the author has come up with following summarisation of the results.

Regarding methodology and theory of the research:

1. Waste management is a complex field, involving such aspects as society, economy and environment. Environment and entrepreneurship are in a constant conflict situation, which means a constant need for compromise in order to ensure fulfilment of environmental requirements alongside with provision of company competitiveness and sustainable development.
2. Each Member State of the European Union has the right to determine the set of economic instruments that are applied in the country with a view to ensuring a sustainable waste management system, taking into account national social, economic and historical differences, in spite of the common goals set by the current legislation. In part, this also serves as the reason why it is not possible to apply a one-size-fits-all solution in the field of waste management.

Regarding studies of industry trends:

3. When assessing Latvia's waste management system, the main contradiction has been identified – from one side current trends are focusing on sustainable use of resources and necessity of decrease of landfilled waste volumes, thus from the other side landfill management companies are interested in large as possible volume of waste incoming to a landfill, thereby securing them with income.
4. Within the present research it was determined that by applying industrial symbiosis, a decrease in incoming waste volumes would not be the main factor for significant increase of waste disposal tariff and as the consequence of the fee for waste management borne by the inhabitants.
5. The present legislation in Latvia does not foster engagement of landfill management companies in industrial symbiosis. In order to promote transition to a circular economy and the possibility of implementing industrial symbiosis, a range of legislative acts have to be revised, thus developing a beneficial environment for this type of development.

Regarding the developed industrial symbiosis model:

6. With implementation of industrial symbiosis on a landfill basis a landfill management company will have a possibility to undertake risk diversification, consequently decreasing their current direct dependence on incoming waste volume.
7. Management of by-products arising from landfill daily operations allows saving primary resources and enhances inter-sectoral development. Thus landfill management companies are able to save primary resources, influence waste prevention and sustain resources for a longer time within the economic cycle.
8. Within this research, an industrial symbiosis model is developed, which is aimed at effective use of a landfill's available resources. With the development of scientific technological parks, regional development would encourage improvement of infrastructure and development of new jobs, which altogether will have a positive effect on improvement of a country's economic ratios.
9. The hypothesis, formulated within the research, has been accepted - the industrial symbiosis built on the basis of a landfill, ensures further development of landfill management companies within decreasing waste volumes and limited increase of waste disposal rate tendencies.
10. The research provides landfill management companies with a LMC matrix, which facilitates decision-making in terms of choosing a company development direction and initiates inter-sectoral cooperation. Landfill management scenarios confirm that industrial symbiosis is a solution for 7 landfill management companies and for 3 companies it can be used as a partial solution, in combination with other development options.

RECOMMENDATIONS

The author of the research has developed a range of recommendations, in order to implement the results of the research into practice.

Recommendations for landfill management companies:

1. To develop a special type of scientific technological park on the basis of the landfills, in order to ensure effective management of the resources arising from the daily operations of landfills.
2. To undertake resource flow mapping and to identify primary resources required by potential IS facility, and its waste/by-products, so LMC or another industry company would have an opportunity to engage effectively in industrial symbiosis.
3. To ensure that landfills as costly infrastructural elements are self-sufficient. The developed model, which includes elements of circular economy is a potential solution to the problem, in order to be able to turn to other waste treatment options at a national level, moving through the waste management hierarchy.

Recommendations for national - level institutions:

4. To conduct a revision and improvement of present legislation (especially in the municipal waste disposal rate evaluation methodology, waste management law, law on public person divestment, etc.), which would expand landfill management company's rights to manage secondary resources and infrastructure in an effective manner, in order to develop a industrial symbiosis model on a landfill *(Ministry of Environmental Protection and Regional Development, Ministry of Economics, Ministry of Finance).*
5. To develop an action plan with special financial support in order to motivate industries to take part in the establishment and development of industrial symbiosis *(Ministry of Environmental Protection and Regional Development, Ministry of Economics, Ministry of Finance, Ministry of Welfare, Ministry of Agriculture).*
6. To amend Waste Management Law with three new definitions: 1) "industrial symbiosis – a connection between two or more facilities in which the waste or by-products of one can become as raw materials for another"; 2) "industrial symbiosis model - a model for landfill management companies that takes into account landfill internal resource flow and offers industrial symbiosis modules for effective management of resources" and 3) "resources, generated on a landfill – resources that arise during daily operation of landfill and that can be

used for industrial symbiosis purposes" *(Ministry of Environmental Protection and Regional Development).*

Recommendations for future research:

1. To determine optimal industrial symbiosis modules for a particular landfill, evaluating its geographic location, distance to public utilities, market conditions, economic feasibility, consumer behaviour and other independent variables.
2. To determine the linkage between industrial symbiosis and commitment of the public to waste sorting.
3. To assess economic, managerial and environmental benefits in case municipalities form a regional waste management company within a waste management region.

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