Agronomy Research **12**(2), 575–588, 2014

Cleaner production in biowaste management

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Abstract. The article provides a study concerning possible future developments in biowaste management in Latvia. In the article, planning, impact assessment, implementation and improvement phases, as well as the required improvements in these phases of biowaste management, are analysed. Furthermore, the problems faced by the energy sector with resource scarcity and energy dependency from one side, and waste management and EU targets for the minimization of the deposited amount of biodegradable waste, from the other side, are presented. The possibility to reach targets concerning the share of renewable energy sources through the use of biowaste resources and possible impacts are presented. During the research, principles of cleaner production in waste management were created and analyzed. The paper presents new assessment methods based on a combination of different methods for the impact assessment of the waste sector, and the implementation of cleaner production in biowaste management.

Key words: cleaner production, impact assessment, biowaste treatment, anaerobic digestion, evaluation methodology.

INTRODUCTION

Currently, global attention, including in Latvia, is being paid to two aspects of the energy crisis – energy dependency and climate change. The global experience has proven that with an increase in the consumption of energy, a deficiency of energy resources occurs. In this situation, public officials have increased the import of energy resources, rather than encourage a reduction of consumption. Consequently, the state becomes more dependent on imported energy resources. At the same time, scientists are researching alternative energy resources, and the development of new technology. Latvia is a country with limited resources. The development of the national economy is unthinkable without an increase in the manufacturing sector. In turn, the development of the manufacturing sector is connected with the intensification of manufacturing capacity, and the resulting consequences to the environment.

Resource scarcity is thus the 1st dimension of the problem. The 2nd dimension of the problem faced in the power industry is energy dependency. The power industry in Latvia has acquired a stable position in the national economy. It is necessary to elaborate on the common approach of EIA power projects. During the process of impact assessment, principles of 'from-cradle-to-grave' should be implemented. This would enhance the quality and efficiency of the impact assessment. The use of these principles in the process of the impact assessment will allow for the assessment of the designed activities and environmental impact of proposed alternatives to have greater objectivity.

The move from a fossil fuel economy to an economy of renewable energy sources (RES) is a complicated process which requires a long-term development strategy and a concerted effort to ensure its implementation. The use of biowaste as a resource allows Latvia to move closer to the EU's common objectives by reducing the amount of waste disposed in landfills. There are possibilities to utilize biowaste for energy production in Latvia. If biowaste is used to produce biogas, then biogas upgrading to biomethane quality and the distribution of biomethane through the natural gas network is an opportunity to efficiently use renewable energy in more populated (urban) areas, as well as increase the energy independence of the country. Thus, the 3rd dimension of the problem that Latvia is facing is the undeveloped biowaste management system. The 4th dimension of the problem is the lack of a harmonized methodology for impact assessment and cleaner production in waste management.

The primary motivation for this research came from the above mentioned four dimensions of the problem.

The Latvian energy supply is characterized by a strong dependence on energy imports, and the highest share of renewable energy in the whole European Union. Latvia has the highest share of renewable energy in gross electrical consumption among the most recent EU member states (Patlitzianas and Karagounis, 2011) and the highest share of renewable energy in the final consumption of energy (Roos et.al., 2012). The latter consists of approximately one third of the total energy consumed. Imported energy sources account for roughly two thirds of Latvia's total energy consumption. Except for peat, which can be found in approximately 10% of its soil, Latvia has no fossil resources for energy production worth mentioning. Natural gas, oil products, and coal are mainly imported from Russia. However, renewable energy sources are substantial. Forests cover approximately 55% of Latvia's territory, making biomass the largest domestic resource currently used in heat generation. Wind power gained importance in recent years and has good potential as wind is abundant. This is particularly the case along the coast where, in addition, the transmission network is particularly well-developed.

The target for renewable energy as a share of final consumption is 40% by 2020 according to the EU-Directive 2009/28/EC on the promotion of the use of energy from renewable sources. At the same time, in many European countries the main practice for waste management is landfilling. Only in the most developed countries as Germany, England, Sweden, Denmark, Austria, France (Monson et.al., 2007; Niklass et.al., 2012) do biogas plants use organic waste for biogas production (Zhang et.al., 2012; Tampio et.al., 2014). Anaerobic digestion (Kastner et.al., 2012), incineration with energy recovery, mechanical biological treatment (MBT) with anaerobic digestion (Siddiqui et.al.; 2013), and gasification are possibilities both to manage biowaste and a waste-to-energy option (Walker et.al., 2009; Križan, 2011). European countries have to comply with the Landfill Directive 1999/31/EC, and with the Waste Framework Directive 2008/98/EC to considerably reduce the landfilling of the biodegradable part of municipal solid waste (MSW). Unfortunately, the implementation of the European targets is still lagging behind. The use of biowaste as a resource will help to reach the above mentioned targets regarding the use of renewable energy and the reduction of landfilling as a part of the biodegradable part of the MSW.

To summarize, the objectives for this research work were:

1. The problems faced by the energy sector with resource scarcity and energy dependency;
2. EU targets for the minimization of the deposited amount of biodegradable waste and RES must be achieved;
3. Principles for cleaner production in waste management should be implemented;
4. A new assessment method based on the combination of different methods for impact assessment of the waste sector and the implementation of cleaner production in biowaste management should be developed.

METHODOLOGY

To achieve the goal of this study, a combination of multi-criteria analysis (MCA) and System Dynamics (SD) modelling, as well as a correlation-regression analysis (CRA) was developed. The developed methodologies for the assessment of biowaste management scenarios, and the implementation of cleaner production principles in biowaste management, were investigated by simulating different biowaste treatment scenarios (see Fig. 1).

It is crucial to offer an evaluation tool that reflects the criteria of applicability, consistency, reliability and affectivity from a practical point of view.

Within the framework of this work, a quantitative and qualitative analysis of existing waste management, environmental impact assessment, and energy projects practice was performed. The work identifies qualitative and quantitative indicators of the materiality of effect. The inventory phase includes a selection of criteria for the assessment of principles of cleaner production in biowaste management. The second phase of the methodology is based on the use of MCA for the evaluation of biowaste management scenarios. To find and evaluate the optimal treatment scenario, TOPSIS (the Technique for Order of Preference by Similarity to Ideal Solution) was applied.

The empirical model was processed by using two statistical data processing methods: correlation and regression analysis. The statistical analysis of data, and the multi-factor empirical model, were developed using the computer program STATGRAPHICS.

The last step of the proposed methodological framework was based on the use of System Dynamics modelling. Integrating MCA and SD methods can help to structure complex problems, respond to the interests of multiple stakeholders, avoid the weaknesses of each individual modelling approach, and perform an overall assessment of complex problems.

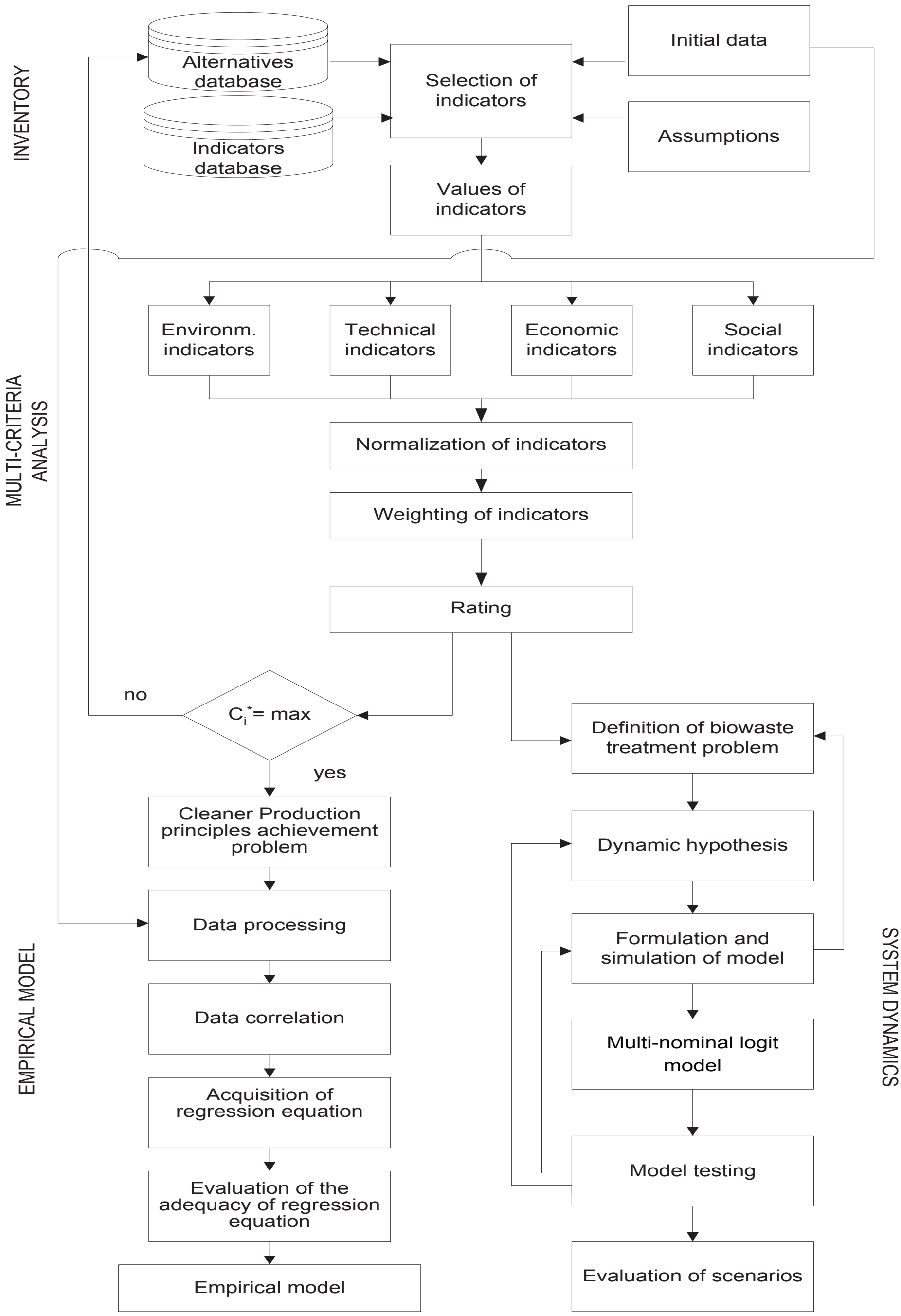

Figure 1. Methodological algorithm.

In the study, planning, impact assessment, implementation, and improvement phases in biowaste management were described (see Fig. 2).

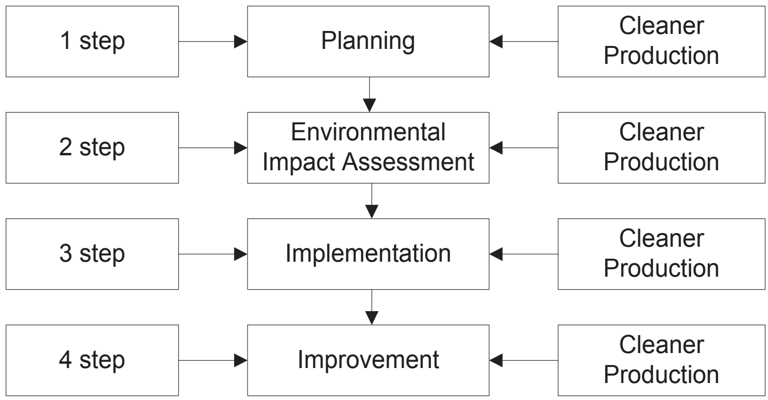

Figure 2. Biowaste management scheme.

Planning and Environmental Impact Assessment

The previous research (Pubule et al., 2012) regarding environmental impact assessment, analyzing the planning stage of energy projects in Latvia, showed that for the achievement of renewable energy sources energy efficiency of used energy resources must be ensured, and energy sources must be constructed where fossil fuels are replaced by renewable ones. As the only legislative tool in the planning phase of energy and waste projects, Environmental Impact Assessments should include a common approach which allows for the enhancement of the quality and efficiency of the EIA. Therefore, cleaner production principles should be analyzed and implemented in the first step of the project implementation – EIA, or the preliminary screening procedure.

The aim of the screening phase is to determine if the project is subject to an EIA. During the screening, it is decided whether the EIA process for the project or activity is necessary or not. Without this verification, some actions can be evaluated very precisely while others can be forgotten or even ignored. While carrying out an effective assessment, a list with the activities planned, accompanied by the values and criteria for determining whether an action should be evaluated, must be formulated (Toro et al., 2010). The criteria of the significance of the impact include the description of the threshold value for identification. The threshold values in Latvia are environmental quality standards, emission limit values, and other limits and restrictions set in various pieces of legislation. Since the various restrictions and environmental quality standards vary in different areas, and for various types of activities, then in most cases the significance of impacts are assessed individually in each case. Often the significance of the impact is not only dependent on the type, amount, and hazard of the planned action, but also the characteristics of the selected place have an important role. In some cases, the impacts of small objects which do not exceed the allowable thresholds are potentially dangerous if they are planned in a sensitive or congested area. Therefore, these projects apply to the EIA procedure. But at the same time, the relatively large objects with possible impact parameters similar to EIA application volumes may not require the application of the EIA procedure, because of the optimal choice of location, and the projected technology to be used which allows for the impacts to be reduced to an insignificant amount.

So we can say that the screening stage is one of the most important and responsible steps in the process of the EIA. A faulty decision could lead to substantial financial losses for the future performance of the project, if an unreasonable decision is made to apply the full environmental impact assessment procedure, which requires substantial financial investment and time, to the project.

Of no less importance, and perhaps even greater losses are possible, if technical regulations are not fully prepared because the possible impact is not fully assessed for the proposed action. Furthermore, if the implementation of the project has already started, while not realizing the potential problem situations and risk factors resulting in damage to the environment, it is known that in most cases, the consequences of the negative effects requires more resources and time than measures that could have prevented or reduced the possibility of the caused damage.

Implementation and Improvement

Nowadays, different methods for municipal solid waste treatment are used:

1. Mechanical Biological Waste Treatment (MBT);
2. Mechanical Biological Stabilisation (MBS);
3. Mechanical Physical Stabilisation.

Furthermore, energetic utilization of wastes has started to become more popular in Europe. Numerous waste incinerators (WIP), facilities for waste and refuse derived fuels (RDF), were built and often controversially discussed. Since the price of primary energy carriers has increased in the last years, waste as an energy resource has become more and more attractive. Therefore, the energetic utilization of high calorific fraction from municipal solid waste (MSW) and commercial waste is processed in power stations for refuse derived fuels.

On top of this, high calorific solid recovery fuels (SBS) are used with high energy efficiency as quality assured co-firing material in power plants and in cement kilns.

The situation in Europe is very different with waste treatment technology, for example, the biowaste sector is not developed in Latvia, but in Germany the plant operators are ready to import waste for treatment from other European Countries due to overcapacities.

Previous research (Pubule et al, 2013) has shown that the existing biowaste management system in the Baltic States is ineffective; therefore, other solutions regarding organic waste should be sought. In Latvia and Lithuania, the percentage of biowaste treatment is very low since the vast majority of biowaste is landfilled.

The concept of cleaner production is well known in industrial environmental management. The key principles of cleaner production are:

1. The Precautionary Principle;
2. The Preventive Principle;
3. The Public Participation Principle;
4. The Holistic Principle (Nilsson et al., 2007; Dubrovin and Melnychuk, 2010).

In biowaste management, these principles are related with the use of more sustainable technologies for biowaste treatment.

Clean production is an integrated approach to production, constantly asking what happens throughout the life cycle of the product or process (Dovi et al., 2009). It is necessary to think in terms of integrated systems, which is how the living world functions (see Fig. 3).

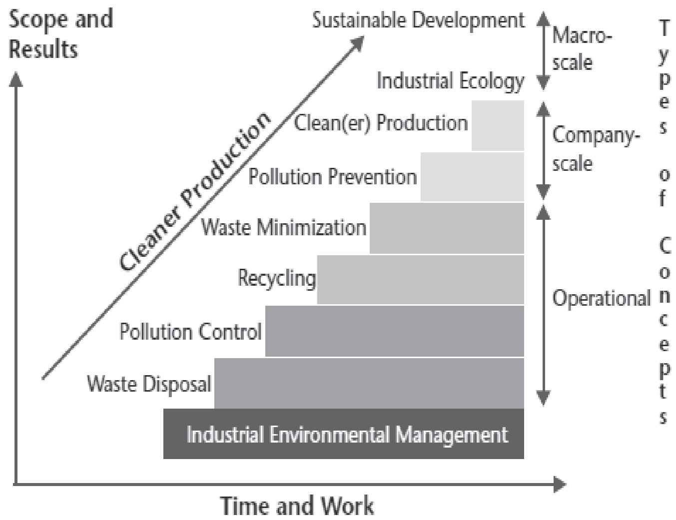

Figure 3. Cleaner production scheme (Nilsson et al., 2007).

Identification and analysis of cleaner production indicators

During the study, different possible options for biowaste management were analysed. Based on the economic situation, climatic conditions, infrastructure, amount, and composition of biowaste, seven more suitable scenarios were found to be more appropriate:

1. Anaerobic digestion of separately collected biowaste (A1).
2. Composting of separately collected biowaste (A2);
3. MBT with anaerobic digestion (A3);
4. MBT with composting (A4);
5. Waste incineration with energy recovery (A5);
6. Waste incineration without energy recovery (A6);
7. Landfilling of biowaste (existing practise) (A7).

Anaerobic digestion of separately collected biowaste is an option with a lot of advantages thanks to the high energetic output (Murphy & Power, 2007); closed energetic cycle (Rutz et al., 2012), lower emissions (Bozano Gandolfi et al., 2012), as well as the positive impact on the social environment and employment.

In the case of this scenario, a separate biowaste collection system must be introduced. For the treatment of biowaste, some existing biogas stations can be used, and there is a necessity for new plants close to urban areas to be constructed. Anaerobic digestion plants should be constructed close to the main organic waste producers to optimize feedstock transportation. As well, plants can be located in the territory of existing MSW treatment facilities. The location of the biogas plants close to urban areas might be economically feasible in the case of source separated organic waste being collected and delivered to the biogas plant near the city. This would allow for savings on transportation costs compared to the scenario if the biogas plant is located in landfills.

During these years, equipment for mechanical waste preparation and separation (Department for Environment Food & Rural Affairs, 2005; Department for Environment Food & Rural Affairs, 2013) will be installed in Latvian landfills. Waste preparation and separation equipment will be installed for the production of RDF and the minimization of the amount of the landfilled biodegradable part of MSW. Questions concerning the biological treatment of the prepared and separated MSW are still unresolved. There are 3 options which are the most suitable for biological treatment in Europe (Muller, 2009; Di Maria et al., 2013):

1. Aerobic – Bio-drying/ Biostabilisation: partial composting of the whole waste;
2. Aerobic – In-Vessel Composting: may be used to either biostabilise the waste or process a segregated organic rich fraction;
3. Anaerobic Digestion: used to process a segregated organic rich fraction (see Fig. 4).

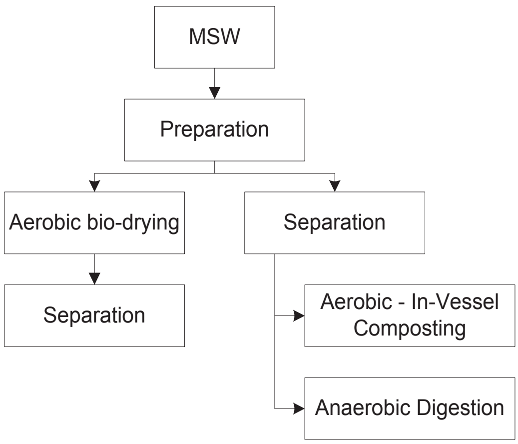

Figure 4. Biological treatment of MSW.

The first MSW plants with MBT in Latvia use aerobic treatment, since the amount of waste is small and composting can be done in existing composting facilities in landfills. In landfills with bigger amounts of biodegradable waste, anaerobic digestion should be introduced for the treatment of waste after the mechanical treatment. In the case of MBT, only dry fermentation technologies can be used, since waste contains impurities. In the case of MBT, the energetic output will be lower.

MBT scenarios can be applied for collected MSW. At the same time, the separate collection of biowaste should be supported and promoted.

In accordance to an EC report on the assessment of the options to improve the management of biowaste in the European Union (European Commission, 2010), the best method for biowaste treatment is composting. Composting is the only method mentioned in Latvian legislation for minimizing the amount of biowaste and biowaste treatment. During the development process of the waste management system, several solid waste disposal landfills in Latvia established composting facilities. The aim of the composting facilities was to minimize the amount of biowaste to be deposited in the country; however, practical experience shows that these composting areas are not being used to their full potential (Pubule et al., 2013a).

Waste incineration, with or without energy recovery, is a well-known technique in Europe. There are no incineration plants in Latvia, and a small amount of RDF is co-combusted in cement kilns. The construction of incineration plants was accompanied with substantial investments and public protests. Therefore, the realistic option is waste export to incineration plants in neighbouring countries coupled with existing incineration plants.

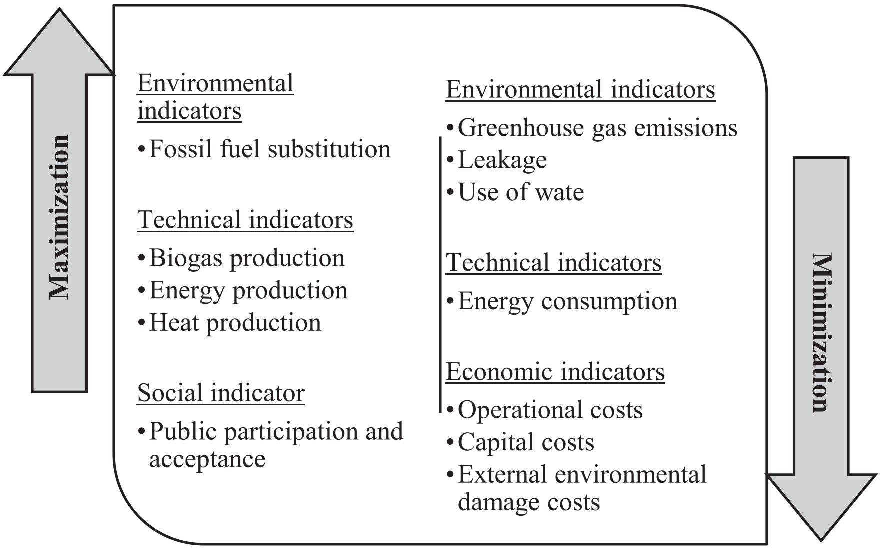

Figure 5. Cleaner production indicators in biowaste management.

Landfilling is the current practice in Latvia. Landfilling is the cheapest option and no investments are needed for this scenario. Waste landfill operators are still making loan payments. Since the income of landfills depends on the amount of landfilled waste, and the amount of landfill gas produced, landfill operators are uncertain about the introduction of biowaste treatment scenarios. At the same time, landfilling has the biggest impact on the environment (Cherubini et al., 2009, Boldrin et al., 2011), the energetic output is low (Assamoi& Lawryshyn, 2012), and the EU targets regarding landfilling cannot be achieved.

During the study, the 12 biowaste management indicators with the highest significance were selected. These indicators must be analysed during all project development stages, starting with Planning and Environmental Impact Assessment until the Implementation and Improvement of the project. An analysis of the set indicators should be done continuously. The proposed indicators can be used in the Environmental

Impact Assessment process of biowaste management projects, especially during the screening phase of the procedure. These indicators help to identify basic conditions for the introduction of principles of cleaner production in biowaste management (see Fig. 5).

Methodology for integration of cleaner production into biowaste management

MCA

Based on the results described above, a multi-criteria analysis for the definition of cleaner production principles was completed. The input data for a TOPSIS biowaste treatment alternative analysis are shown in Table 1.

Table 1. Input data for a TOPSIS biowaste treatment alternative analysis

Criterion / Altern.	Environmental dimension				Technical dimension			
	GHG emissions	Leakage	Fossil fuel substitution	Water usage	Biogas production	Energy consumption	Energy production	Heat production
A_1	0.49	0	0.63	0.14	110	20	250	250
A_2	0.49	0	0	0	0	52.5	0	0
A_3	0.7	0	0.355	0.05	75	40	145	140
A_4	0.7	0	0	0	0	20	0	0
A_5	0.36	0	1.44	0	0	142	450	1,000
A_6	0.36	0	0	0	0	142	0	0
A_7	1.47	0.145	0.22	0.052	20	2.8	23	20

Criterion / Altern.	Economical dimension			Social dimension
	Operational costs	Capital costs	External environ. damage costs	Social participation and acceptance
A_1	28.00	376	22.24	5
A_2	8.00	124.5	8.66	6
A_3	28.00	372	22.24	2
A_4	14.00	176	8.66	3
A_5	20.00	651	12.63	4
A_6	22.00	631	19.95	7
A_7	5.00	119	62.09	1

An evaluation of the biowaste management scenarios using TOPSIS was performed. The results showed that pertaining to the Latvian conditions, there are three options: separate collection and anaerobic digestion, incineration with energy recovery, and separate collection with composting (see Fig. 6).

These all share the highest rating. Therefore, selection between these options can be made based on different local factors, such as, the decision-makers preference or the amount of skills necessary for the introduction of a specific biowaste treatment practice. Landfilling is the least feasible option.

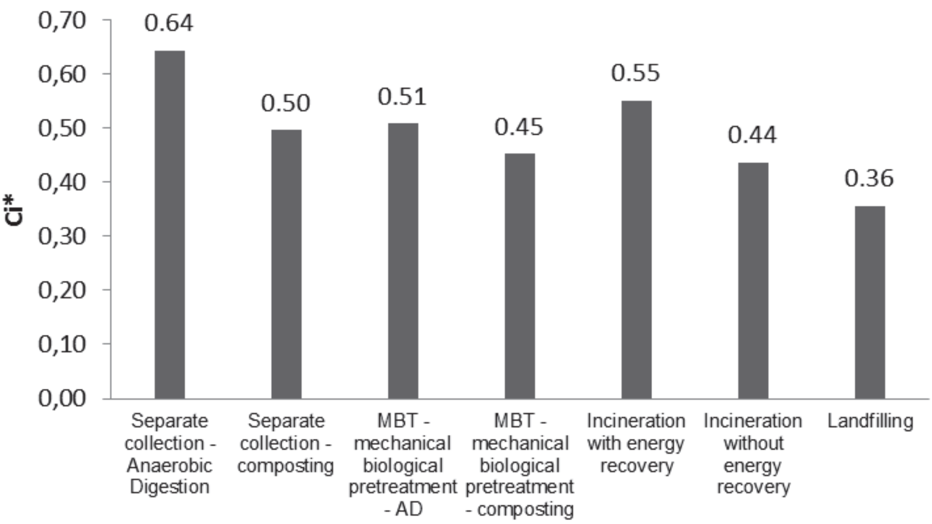

Figure 6. MCA results.

Empiric Model

During the research, the cleaner production principles achievement problem was analysed, and a multifactor empirical model was created. The main aim of the created multi-factorial empirical model was a determination of the regression equation which could then determine the reduction of GHG emissions.

A database based on the existing biowaste treatment plants was created and analysed. During the research, the above mentioned cleaner production indicators and parameters of the existing plants was processed.

During the research, data correlation, acquisition of the regression equation, and an evaluation of the adequacy of the regression equation was completed.

The completed analysis shows that the reduction of GHG emissions is determined by three statistically significant parameters:

- energy consumption;
- energy production;
- heat production.

System Dynamics

During the research SD model was created: biowaste treatment problem, hypothesis were defined, formulation and simulation of model using Powersim program was done. Model was tested on Latvian conditions.

DISCUSSIONS AND CONCLUSIONS

The problems faced by the energy sector concerning resource scarcity and energy dependency can be partly solved if biowaste is used as a resource for energy production.

EU targets for the minimization of the deposited amount of biodegradable waste and RES can be achieved if anaerobic digestion of separately collected biowaste or mechanical biological treatment of unsorted biowaste with future anaerobic digestion is introduced into waste management in Latvia. Another possibility is to export waste and the incineration of biowaste with energy recovery to Lithuania, Estonia, or Germany. The principle of cleaner production in waste management must be implemented starting from the planning and impact assessment of each biowaste management project.

Today, one of the central EU waste management issues is biowaste management. Carbon dioxide emissions causing global warming are a seemingly inevitable by-product of biowaste disposal. Threats to groundwater, as well as general environmental damage, are a result of pollution from landfilled biowaste. In this light, policy- and decision-makers are constantly facing the complex nature of this multidimensional management on which economic, technical, environmental, and social perspectives always have prominent and interconnecting roles. As a response to these challenges, different technological and legal strategies are discussed by the parties involved.

This study proposes an integrated methodological approach by having a combination of MCA, SD and CRA modelling. This approach has been applied within a case study, specifically for Latvia, proposing an effective analytical framework that allows policy- and decision-makers to compare various alternatives in order to strengthen the most promising waste management technology.

The proposed method basically acts in three main phases: the first is addressed to the identification of the optimal solution for a biowaste management strategy with the identification of selected indicators to be used within the MCA approach by using the TOPSIS method, the second based on creation of multi-factorial empirical model, the third implements a complex system analysis through SD modelling. As reported from other literature findings (Forester, 1980; Blumberga et.al., 2010) the goal of a general system dynamics study is the identification of the fundamental reason, that is the key issue, generating a specific problematic behaviour. This is a crucial point in order to find the most sensitive aspect within the system that is effectively the problematic behaviour in itself. In other words, through the second step, it would be possible to not only find the optimization of the system, which is fixed in a specific time frame, but to give the opportunity to create an optimization based on a time scale reference. The identification of leverage points is thus essential for the further definition of action (in terms of 'policies') that can improve the situation, or reveal the proper way to reach a fixed target. In the proposed case study, this is represented by the EU directive 1991/31/EC sorting target.

The proposed methodological approach applied for the case study provides a real insight into the behaviour of the biodegradable waste market in Latvia.

The proposed methodology was used to evaluate seven competing solutions for the biowaste management systems of Latvia.

The proposed approach, integrating the three methodologies, can be applied to the waste sector.

ACKNOWLEDGEMENTS. This work has been supported by the European Social Fund project 'Involvement of Human Resources for Development of Integrated Renewable Energy Resources Energy Production System' (project No. 2013/0014/1DP/1.1.1.2.0/13/APIA/VIAA/026).

EIROPAS SOCIĀLAIS FONDS

EIROPAS SAVIENĪBA

IEGULDĪJUMS TAVĀ NĀKOTNĒ

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