DOI: 10.2478/lpts-2013-0039

LATVIAN WASTE MANAGEMENT MODELLING IN VIEW OF ENVIRONMENTAL IMPACT REDUCTION

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In the work, the life-cycle assessment approach is applied to the planning of waste management development in a seaside region (Piejūra) using the Waste Management Planning System (WAMPS) program. In Latvia, the measures to be taken for the climate change mitigation are of utmost importance – especially as related to the WM performance, since a disposal of biodegradable waste presents the primary source of GHG emissions. To reduce the amount of such waste is therefore one of the most significant goals in the State WM plan for 2013-2020, whose adoption is the greatest challenge for municipalities. The authors analyse seven models which involve widely employed biomass processing methods, are based on experimental data and intended for minimising the direct disposal of organic mass at the solid waste landfills. The numerical results obtained evidence that the thermal or biotechnological treatment of organic waste substantially reduces the negative environmental impact of WM practices – by up to 6% as compared with the currently existing.

Keywords: waste management, life cycle assessment, environmental impact, Piejūra region.

1. INTRODUCTION

To elaborate the National Waste Management (WM) system for the first WM planning stage (2006-2012), the Latvian territory was divided into ten WM planning regions, in each of them one landfill for solid waste being organised in compliance with the sanitary requirements. This allowed more than 550 waste dumps to be closed. However, according to the investigation of European Commission on the implementation of requirements set for 27 member states by the EU directives [1], the Latvian WM system occupies only the 21st position – leaving behind such countries as Cyprus, Romania, Lithuania, Malta, Bulgaria, and Greece. As one of the main problems indicated is that of strong dependence of the Latvian WM system on the solid waste landfills, which, in turn, entails a number of other problems: a large amount of the disposed waste; not fulfilled targets as to decreasing the disposal of biodegradable waste; as yet a high proportion of the recycled household waste.

The non-optimal organisation and performance of the waste management system has given rise to unjustifiably large amounts of GHG emissions, and, consequently, to global environmental impact. In Latvia, the volume of emissions due to the activities of the waste management branch was in 2010 5.23% (632.6 CO_2 eq.) of the total GHG emissions produced in the national economy (12 097 Gg CO_2 eq., except the land use, land-use change and forestry (LULUCF)). For comparison, in the 27 EU member states in 2009 this quantity was only 3.2% on average [2, 3]. Meantime, in compliance with the indicators elaborated by the European Commission the volume of WM-related emissions is to approach 2.5% of the total GHG emissions in a country [4].

The National inventory of the GHG emissions [2] evidences that in 2010 the most negative impact was precisely from the solid waste disposal on land – at dumps as well as at solid household waste landfills created in the last decade – total 436.2 Gg CO₂ eq. This is mainly explained by the emergence of CH₄ and CO₂ at decomposition of natural waste organic mass in a large and consolidated disposed waste under anaerobic conditions. A separate group of GHG emission sources in the WM sector – the waste water handling – gave 192.77 Gg CO₂ eq., although this group was not included into the scope of research. In turn, such waste treatment as composting made up only 3.28 Gg CO₂ eq., and quite an insignificant impact was due to waste incineration – 0.35 Gg CO₂ eq.

The GHG emissions reduction is of high priority in the formation and development of WM policy. Therefore, the mathematical modelling methods for GHG emission calculations in various waste treatment and disposal models are applied to ever increasing extent in WM planning as supporting tools in decision making [5]. The lifecycle analysis/assessment allows our decision-makers in the WM area to comprehend easier the environmental impact (both with its positive and negative effects) caused by the use of different waste treatment methods.

In our work, several WM models are analysed which are designed with the purpose to abandon the direct disposal of natural waste organic mass at the solid waste landfills. In the State WM plan for the years of 2013-2020, high enough targets are set for the collection, treatment, and disposal of organic waste. The models have been elaborated taking into account the requirements dictated by the EU Directive 2008/98/EC on the waste management: for example, already in 2020 it is mandatory to process 50% of such household waste as paper, glass, metal, and plastics, while on landfills it will be allowed to dispose only 35% of the biodegradable waste as compared with its amount in 1995 [6].

2. METHODS AND MATERIALS

To estimate the environmental impact due to the WM performance, in the research a special waste management planning system (WAMPS) program was employed, which is based on the waste lifecycle analysis [7]. The program made possible calculations of the WM-related emissions into the air, water, and on the land, as well as the energy and material flows. The WAMPS is a multi-step program into which the data are sequentially entered that characterise (in the framework of a case study) the waste management in the Piejūra region. The steps are: 1) introduction of the input data (amount of collected waste, its composition and parameters); 2) selection of the waste sorting/grading conditions; 3) selection

of the waste processing and disposal technologies; 4) data on the collection of waste and its transportation in small volumes and to short distances; 5) waste transportation in large volumes and to long distances.

In the research, different waste processing and disposal scenarios have been analysed; however, the last two steps are not included in its scope. Although in the WAMPS program the treatment of sorted waste is not modelled separately, the final calculation results are presented for each waste sort and related emissions (including emissions due to energy consumption and emissions into air and water due to waste treatment processes). Besides, not modelled is the treatment of hazardous waste, electronic and electric devices; the relevant emissions are however presented in the final inventories of the environmental hazard.

The WM-related emissions (given in the work in relevant equivalent units) are characterised by specific processes of environmental changes. In the program, as the most negative environmental processes the following are included: climate changes, eutrophication, acidification and photo-chemical oxidation. The most significant compounds influential for climate changes are such emitted greenhouse gases as CO_2 , CH_4 , and N_2O . In the program, the corresponding potentials are characterised by the equivalents: CO_2 for climate changes, O_2 for eutrophication, SO_2 for acidification, and C_2H_4 for photo-chemical oxidation [8, 9].

2.1. Characteristic features of the Piejūra WM region

As mentioned above, for the case study the Piejūra waste management region (one of the ten Latvian WM regions) was taken. The region includes Jūrmala (a major seaside resort) and eight sub-regions. The total territory of the region is 5 285 km², or 8.2% of the Latvia's total. The population is 153 899 (as of 2011), and the density of population in the municipalities – from 6.97 to 560 inhabitants per km².

The regional WM infra-structure comprises the Janvāri landfill for solid waste and four sorting stations. For composting the green garden waste, two areas are fitted with the use of the Janvāri landfill envisaged for this purpose. In the Piejūra region 366 points for decomposed waste are functioning, where collection of such waste as paper, cartoon, tetra-packages, PET bottles and glass is provided. Other kinds of sorted waste are received by the bring system at sorting stations.

2.2. Household waste estimation

The quality of computer-aided estimation made for WM environmental impact depends to a large extent on the quality of input data. Since in the Piejūra region in the last years no measurements of waste composition were performed, to estimate the amount, composition, etc., of the waste produced in the region, in our research we employed the empirical results obtained in 2007 in the framework of INTERREG III program RECO project.

In 2007, in the Tukums-city 19 535 residents were registered, and the amount of waste produced in its territory was 13 068 t/year, 31% of which being household waste, 33% – waste produced by service suppliers and institutions, and 36% – waste of industrial enterprises [10]. The total Tukums waste amount and composition by source is illustrated in Fig. 1.



Fig 1. Household waste composition and amount in the Tukums city in 2007 (tonnes).

According to the data of the environment, geology and meteorology centre of Latvia, in 2010 in the Piejūra WM region 62 476 t of household waste (the 20th group) were collected, of which 12% were sewage sludge and 21% – metals. The mentioned waste fractions are not typical of household-produced; therefore, we can consider the value of 42 314 t. Of this amount 1% was paper, plastics, and glass; 3% bio-degradable waste – 3%, inert waste – 2%, other sorts (hazardous waste included) – 1%; the rest (93%) was unsorted household waste [11].

2.3. Waste composition and specific features determined due to mechanical pre-treatment line operation

To reduce the amount of unsorted disposed waste, at several Latvian waste landfills it is planned to implement the pre-treatment mechanical sorting lines (some of them already functioning). The main purpose of this method is to obtain the RDF (a combustible material derived from waste whose regeneration is planned in Latvia for the cement industry) as well as to separate from the total waste the biodegradable organic fraction. As shown in [12], when the amount of such waste as paper, plastics, glass, metallic packages and bio-waste separated already at the source reaches 12%, at a landfill equipped with such a sorting line it is possible to derive from the total unsorted household waste mass four fractions, i.e.:

- ~35% fine fraction mainly composed of organic waste;
- ~40% medium fraction of diversified waste;
- ~22% coarse fraction (RDF) containing waste of high calorific value (plastics, paper, textile, rubber);
- ~3% iron-containing waste.

This percentage was used in calculations at creation of mathematical WM models. In detail, the fraction composition is shown in Table 1.

Waste type	Coarse fraction,%	Medium fraction, %	Fine fraction, %	
Paper/cardboard	39.5	23.9	2.4	
Plastic	38.7	24.5	2.1	
Putrescible green waste	0.7	6.6	12.3	
Small particles (<10mm)	3.2	6.3	43.7	
Hygiene (diapers, pads)	5.1	7.1	0.7	
Textile	5.5	4.0	0.1	
Rubber/ leather	4.1	3.4	0.1	
Wood	1.1	3.6	0.5	
Metal	1.5	3.5	0.5	
Glass	0.2	9.1	32.1	
Inert minerals, ceramics	0.4	8.1	5.5	

 Table 1

 Average composition of mechanically sorted municipal solid waste fractions (%, for dry waste)

3. PLANNING OF HOUSEHOLD WASTE MANAGEMENT

In the WM planning for the Piejūra region, several scenarios of waste processing and disposal technologies with the initially equal specific weight of waste sorted at the source were elaborated in compliance with the requirements of the State WM plan for 2013-2020. As the basic scenario the situation in the Piejūra region in 2010 was chosen, with 93% of unsorted waste disposal on the Janvāri landfill without gas collection and re-generation systems. With each subsequent model, the basic scenario is complemented with a new waste treatment or disposal technology which promotes the treatment of organic waste and allows abandonment of direct disposal on a landfill.

3.1. Waste sorting conditions

Modelling of waste management development in the case of waste sorting at its source was selected in compliance with the targets set by the Latvian State WM plan for 2013-2020, namely, to reach by 2020 for each sort of waste: paper & cartoon -50%, plastics -50%, glass -50%, metal -50% of its total amount [6]. Since it could be expected that the management of bio-waste in Latvia would present a most serious problem, to reach the planned 65% waste treatment only 30% of bio-waste will be sorted at its source (as estimated by mathematical models), whereas the rest of organic waste mass will be sorted at a landfill using mechanical sorting line.

Taking into account the types of waste in the fractions sorted on such lines (see Table 1), in the modelling it is assumed that the coarse fraction (~22% of the total volume) will be used for production of alternative fuel, the medium fraction (~40% of the total) – disposed on landfill or incinerated, while the fine fraction (~35% of the total) – stabilised by composting, processing in a bio-cell or a closed reactor in anaerobic environment. The bio-technologically obtained material will be used for covering the waste heaps on a landfill, and the separated metal (~3% of the total) – for obtaining scrap.

3.2. Waste management models

In order to minimise the direct disposal of biodegradable organic mass on landfills we have analysed seven WM models (scenarios) which involve different technologies of waste treatment, regeneration and disposal (for details see sub-sections 3.2.1-3.2.4):

- 1. Intensive disposal of unsorted household waste without gaining energy (Scenario 1).
- 2. Intensive disposal of unsorted household waste with gaining energy (Scenario 2).
- 3. Intensive sorting at the source of waste, composting of the separated organic mass by open-field technologies and in a reactor, stabilisation of the fine fractions in a bio-cell with biogas production; disposal of the remaining waste mass (Scenario 3).
- 4. Intensive sorting at the source, composting of the separated organic mass by open-field technologies and in a reactor, composting of the fine fractions; disposal of the remaining waste mass (Scenario 4).
- 5. Intensive sorting at the source, processing of the separated organic mass by open-field technologies and in a closed reactor under anaerobic conditions; processing of the fine fractions in a closed reactor under anaerobic conditions; disposal of the remaining waste mass (Scenario 5).
- 6. Intensive sorting at the source, composting of the organic mass by open-field technologies and in a reactor; stabilising the fine fractions in a bio-cell; incineration of the RDF part; disposal of the remaining waste mass (Scenario 6).
- 7. Intensive sorting at the source, composting of the organic mass by open-field technologies and in a reactor; stabilising the fine fractions in a bio-cell; incineration of the RDF part; elimination of the medium fraction by its incineration (Scenario 7).

3.2.1. Basic model: intensive disposal of non-sorted waste without energy gain (Scenario 1)

The basic scenario describes the situation with waste management in the Piejūra region in 2010; according to the state statistics (LEGMC) data [11] in that year 93% of unsorted household waste was disposed on the Janvāri landfill without collection and regeneration of gases produced there.

Treatment of the sorted biodegradable waste was performed at households (3%) and using the open-field technologies (3%), with account in this stage of the energy consumption for operation of transport and equipment, of the emissions into air and water as well as of the saved summary emissions caused by the use of nitrogen and phosphate fertilizers. It is estimated that the obtained compost amount was 60% of the original organic waste mass [13]. In the model estimation it was assumed that the approximate amount of waste composted at households does not exceed 3% of the total organic waste produced there. For estimation of the biowaste collected in a centralized way the LEGMC data were employed [11]; the

specific weight of the green garden and park waste compostable by open-field technology is taken to be 3% of the total biomass collected.

3.2.2. Intensive disposal of non-sorted waste on landfill with energy gain (Scenario 2)

The output data of this model are identical to those of the basic model with a system added for collection and regeneration of landfill gases (to be introduced on all Latvian landfills in the nearest future).

The efficiency of collection of a landfill's gases was 10-50%, and that of regeneration – only 25% [14]. We have obtained similar results by calculating mathematically the potential of methane emissions in compliance with 2006 IPCC guidelines of the National GHG inventory at four Latvian landfills. The calculated efficiency of landfill regeneration is 26-34% [15, 16] (in our research 30% are assumed).

The estimation of disposal technologies includes: the energy turnover; the intensity of gas production and the efficiency of its regeneration; and the emissions into air and water. It is assumed that the collected biogases can give 40% of electric energy and 50% of thermal energy. The calculations were performed for the chosen energy fuel to be replaced (in our research it is natural gas).

3.2.3. Intensive waste sorting at the source; stabilisation of the fine fractions (Scenarios 3-5)

In these models, at the source of waste from such its type as paper and cartoon, glass, plastics, and metal, 50% predefined by the state plan were sorted. In turn, at the source of garden and kitchen waste only 30% was segregated. In the calculations it is assumed that from the total separated volume of biodegradable waste 5% of its composted amount was obtained at households, 10% of garden and park waste were composted by open-field technology, while composting of the major part (85%) of the kitchen and the like waste was realised in a closed reactor (Scenario 3). As alternative to the 85% treatment of natural organic mass in Scenario 4, its treatment in a closed anaerobic reactor is offered, whose output will be biogas and liquid (the digestant to be used in farming).

The remaining organic mass that reaches landfills in the total mix is sorted on a pre-treatment mechanical sorting line. The quality of fine fraction stabilisation is estimated for three technologies: disposal in a bio-cell (Scenario 3), composting (Scenario 4), and digestion in the aerobic environment (Scenario 5). Since the derived material contains many admixtures (glass, minerals, plastics, etc.), after stabilisation it is used for covering the waste on landfills.

The disposal on landfills using bio-cells is similar to the traditional disposal in a cell but with everyday's bio-coverage of waste, which accelerates the processes of organic waste decomposition and makes the gas collection more effective than in a traditional cell – from 50 to 70% [14] (in the present research 50% is taken).

To facilitate comparison of the results on environmental impact at the use of different technologies for processing the fine fractions it is assumed that the remaining waste (medium and coarse fractions) in all the models are disposed with production of gases while the metallic fraction is to be processed.

The calculations were performed for emissions arising at the waste incineration, in the WM processes in air (water), and at the consumption of diesel fuel for waste transportation in the landfill territory. Besides, the digestant related emissions are included as well as the savings of summary emissions due to the use of nitrogen and phosphate fertilizers. Currently, it is assumed that in Latvia the biogases obtained will be employed for electricity production; however, these can be used for other purposes – e.g. to produce biogas fuel for transport.

3.2.4. Intensive waste sorting at the source; stabilisation of the fine fractions and waste incineration (Scenarios 6, 7)

Scenarios 6 and 7 are complemented with the waste incineration as treatment method. In practice, these models involve the final treatment and disposal methods. As the basic, Scenario 3 was chosen (see sub-section 3.2.2: the intensive sorting at the source, with 50% sorted glass, plastics, paper, and metals, and 30% sorted natural organic waste), and organic mass composting performed using the open-field technology (15%) and a closed reactor (85%). Stabilisation of the fine fraction obtained from a sorting line proceeds in a bio-cell, and at the waste disposal place the assessment of thermal treatment technologies is made.

The environmental impact of incineration processes is estimated by two methods: the coarse fraction disposal at the incineration plant (Scenario 6) and the coarse fraction incineration in the cement kiln (Scenario 7). The derived energy is used for electricity and heat production, and the type of replaced energy is determined – in this research natural gas (similar to gas production and/or gas regeneration on landfill).

The incineration proceeds in specially built incinerators and gives additional energy, with the emissions into air and water also taken into account. Apart from that, calculated is the impact caused by ashes and slag (to be disposed on landfills). Such incineration process complies with the requirements set by EU directives 2000/76/EK.

In turn, the incineration in a cement kiln also requires energy and produces emissions; however, the use of refuse-derived fuel (RDF) in this method implies reduced amount of fossil fuel; gypsum is not required for clinker production; also, the output of iron oxides (metallurgical slag) is smaller.

4. RESULTS

The assessment of environmental impact for the seven modelled scenarios of WM development in the Piejūra region is presented in Table 2. The results obtained characterise such consequences of the WM performance as climate changes, acidification, eutrophication, and formation of chemical photo-oxidants. As compared with the climate change impact, other processes are less influential; however, their contribution could be decisive – in a particular degradation process or a particular territory taking into account other anthropogenic impacts.

Since the climate change mitigation is one of the main priorities in the Latvian sustainable development strategy – especially as concerns the waste economy – the estimation of the research results will only be related to the $\rm CO_2$ emissions.

Table 2

Category	Unit	Scenario						
		1	2	3	4	5	6	7
Acidification	Tonnes SO ₂ -eq.	315	319	118	96	115	87	1
Eutrophication	Tonnes O ₂ -eq.	3004	3236	1339	1003	1341	1102	631
Global warming	Tonnes CO_2 -eq.	103 923	68 256	37 843	24 788	32 487	25 077	6 392
Photo oxidant formation	Tonnes C_2H_4 -eq.	67	47	27	16	25	21	11

Environmental WM impact by type of waste treatment in the Piejūra region (Scenarios 1-7)

Based on analysis of the emissions arising in the WM processes (expressed in equivalents, see Table 2) it is found that CO_2 emissions are mostly due to waste incineration, its industrial treatment and disposal on landfills. Comparatively smaller amount of carbon dioxide arises in the composting process as well as from CO_4 emitted on landfills at oxidation of the waste upper layer and in the gas regeneration process.

In turn, the N_2O emissions are mostly formed in the waste incineration hightemperature processes during the waste treatment. Apart from those, depending on the S, Cl, and F concentration in the waste-produced fuel also SO₂, HCl, HF compounds as well as heavy-metal (Zn, Pb or Cu) impurities are formed in air and sewage which further could pollute (under)ground waters. Poor-quality incineration can result in accumulation of toxic substances in the living organisms and affect the ecosystems.

The major sources of CH_4 emissions are waste landfills and dumps, where under anaerobic conditions the organic waste mass consolidated in a large volume is decomposed. Of great importance is here the quality of cleaning the waste disposal infiltrate which contains various components of dangerous pollutions corresponding to the composition of disposed waste. At the waste landfills also non-methane volatile organic compounds (VOC) are created along with some amount of N₂O, NO_x and CO gases.

In turn, composting processes mostly give rise to CO_2 and NH_3 or NH_4 , which can also contain Cd, Hg, Pb, Cr, Cu, Zn and other heavy metals [4, 8, 13, 16].

Concerning the models of WM development in the Piejūra region, namely, disposal of unsorted waste on landfills without (Scenario 1) and with (Scenario 2) energy gain, these correspond to the greatest negative impact on the environment; therefore, measures toward CO_2 emissions reduction will in the future be indicative of this development.

However, as the results obtained show, already such minor improvements in the WM processes as organic mass separation and stabilisation in bio-cell at the landfill (Scenario 3) make possible a substantial GHG emissions reduction by 2020: 37 843 t in CO₂ eq. (~ 36% as compared with the basic scenario). In turn, Scenarios 4 and 6 are practically identical in terms of environmental impact: 24 788 t in CO₂ eq. and 25 077 t in CO₂ eq. (both correspond to ~ 24% against the basic scenario). As concerns the digestion of organic waste in anaerobic medium

(Scenario 5), this treatment causes the impact expressed by 32 487 t CO₂ eq. (~ 31% against the basic scenario). The least negative impact is achievable in Scenario 7 – i.e. waste treatment and industrial incineration of its remaining part, with the total CO₂ emissions being only 6 391 t CO₂ eq. (~ 6% as compared with the basic scenario).

5. CONCLUSIONS

The life-cycle assessment approach to the WM development planning applied in the research using WAMPS program allows the WM planners, organisers and implementators to easier comprehend and estimate the WM-related environmental impact according to the chosen model.

As evidenced by the results obtained, the disposal of unsorted household waste on landfills – both with and without gas collection and regeneration systems – creates the greatest environmental impact. Contrastingly, any of the other offered technologies makes it possible to avoid the direct organic mass disposal on landfills thus providing a substantial GHG emissions reduction.

Development of bio-waste sorting at the source allows not only reducing the amount of disposed waste but also decreasing the moisture content of the not sorted waste mass. As a result, the models should be preferred with inclusion of waste incineration technologies.

At the landfills equipped with systems for collection and regeneration of gases and where large masses of waste are disposed it is advisable that for stabilisation of organic waste the bio-cell technology is used. This would give an additional opportunity for producing biogas needed for such treatment. In turn at the landfills where the waste mass amounts are minor and the landfill gas regeneration is not effective. the organic mass composting could be recommended.

The model on the organic waste digestion under anaerobic conditions is to a large extent linked to the state policy for production of biogas and promotion of its consumption; at the same time. this model implies that the bio-wastes are of good quality as well as of known origin and composition, without foreign admixtures.

Although the results obtained characterise the chosen WM models from the environmental aspect only, they identify the future directions for development of the WM systems as well as the investigations needed for estimation of the economic and social issues that would determine the introduction of these models into practice in municipalities and regions.

ACKNOWLEDGEMENTS

Acknowledgement to the European Social Fund (ESF) agreement No: 2009/0180/1DP/1.1.2.1.2/09/IPIA/VIAA/017 for the doctoral research grant award to D. Arina.

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LATVIJAS ATKRITUMU SAIMNIECĪBAS ATTĪSTĪBA UN TĀS RADĪTĀS IETEKMES UZ VIDI SAMAZINĀŠANAS MODELĒŠANA

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Kopsavilkums

Klimata pārmaiņu samazināšanas pasākumi Latvijā atkritumu saimniecības sektorā ir īpaši svarīgi. jo bioloģiski sadalāmo atkritumu apglabāšana ir viens no būtiskākajiem SEG emisiju avotiem valstī. Pētījumā modelēti virkne sadzīves atkritumu apsaimniekošanas modeļi. kas ietver plašāk izmantotās biomasas pārstrādes metodes un samazina tiešu organiskās masas apglabāšanu cieto sadzīves atkritumu poligonos. Atkritumu apsaimniekošanas modeļu radītās vides ietekmes novērtēšanai izmantota WAMPS (*Waste Management Planning System*) programma, kas balstīta uz atkritumu apsaimniekošanas procesu dzīves cikla novērtējumu vienā no desmit Latvijas atkritumu apsaimniekošanas reģioniem – Piejūra. Iegūtie kvantitatīvie rezultāti norāda. ka organiskās atkritumu masas pārstrāde un stabilizēšana, izmantojot biotehnoloģijas vai termisko pārstrādi, būtiski samazina atkritumu apsaimniekošanas radīto negatīvo vides ietekmi. līdz pat 6% attiecībā pret esošās atkritumu saimniecības vides ietekmi.

02.08.2013.