Environmental and Climate Technologies
2021, vol. 25, no. 1, pp. 121–135
https://doi.org/10.2478/rtuect-2021-0008
https://content.sciendo.com

Life Cycle Assessment-Based Approach to Forecast the Response of Waste Management Policy Targets to the Environment

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***Abstract* – Inadequate municipal waste management, associated with a dominance of waste landfilling and low efficiency of resource and energy recovery, is the major challenge towards circular economy targets for some European Union countries, including Latvia. The aim of the study is to evaluate environmental performance from implementation of waste management policy goals in waste management systems of Latvia applying life cycle assessment methodology. The waste management system in Latvia was evaluated for two scenarios: baseline situation (based on statistical data from 2016) and future scenario – 2030. Baseline scenario assessment results show the existing material and energy recovery potential from municipal solid waste generated in Latvia. Meanwhile, results obtained from the 2030 scenario demonstrated that boosting recovery rates of plastic by 20 % and organic waste by 20 % can contribute to the minimization of life cycle environmental impacts (human health, resources, climate change, ecosystems) by 1.8 % and organic by 3.6 % correspondingly.**

***Keywords* – Circular economy; National targets; Policy decision-making tool**

1. INTRODUCTION

In 2016, around a quarter or 25.2 % of total municipal waste generated in Latvia was recycled and in 2018 this indicator did not change – 25.2 %, thus it can be concluded that the development of waste treatment and recycling in Latvia is in the process of stagnation. In Latvia the proportion of municipal waste recycling compared to the EU 28 average is almost twice lower. Similarly, in Estonia, this indicator is low – 28.1 % in 2016 and 28.0 % in 2018, while in Lithuania this rate is slightly above the EU average – 48 % in 2016 and 52.5% in 2018, which is the best indicator among the three Baltic States [1]. An assessment of waste recycling in the Baltic States shows that nearly 100 kg of waste per capita is being recycled in Estonia and Lithuania, while in Latvia this rate was 92 kg per capita in 2015. However, in 2016 there is a significant drop of only 62 kg per capita, which is more than twice the EU average (140 kg per capita in 2016). While the amount of waste landfilled differs sharply among the Baltic countries – from approximately 38 kg per capita in Estonia to 263 kg per capita in Latvia [2].

Life cycle assessment (hereinafter – LCA) methodology has been used to assess the environmental impact of products and services in many different sectors, including municipal solid waste management [3], [4]. A life cycle analysis was performed for waste management in Latvia nowadays and in 2030 based on ISO 14040:2006 and ISO 14044:2006 standards [5] and the model built in *SimaPro*.

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2. METHODS AND METHODOLOGY

Municipal waste (hereinafter – MW) is a resource that can be used as a recovered and/or recycled material, and for generating energy. The present study presents the life cycle assessment of Latvia's MW management system for two scenarios – present situation or business as usual (hereinafter called LV2016) and future waste management scenario (hereinafter LV2030) which foresees the achievement of the 2030 waste management targets.

2.1. Goal and Scope

In order to assess the life cycle-based environmental impacts of MW management in Latvia, an LCA model was developed for LV2016 and LV2030 scenarios in *SimaPro* software.

Description of the scenarios proposed:

- Scenario 1 (LV2016) – corresponds to the current MW management situation in Latvia in 2016, based on statistical data.
- Scenario 2 (LV2030) – based on the National Waste Management Plan for 2013–2020 [6] (at the time of this study, the NWMP for 2021–2028 was not approved yet, and thus the National Waste Management Plan for 2013–2020 is used), the Sustainable Development Strategy for Latvia 2030 [7] and other planning documents at national and EU level as European Council Directive 1999/31/EC 'Landfill Directive' [8], Directive 2008/98/EC of the European Parliament and of the Council 'Waste Framework Directive' [9].

2.2. Functional Unit and System Boundaries

A functional unit is a quantitative indicator representing systems or products used as a reference value, which defines the specification for a particular system as well as the key parameters contained therein [10]. Since one scenario is a forecast scenario, a functional unit was designed as a variable and defined as the amount of MW generated per capita in Latvia. Respectively, the functional unit for the LV2016 scenario is 0.410 tonnes/y per capita and for the LV2030 scenario 0.400 tonnes/y per capita as forecasted by Latvia's Sustainable Development Strategy for 2030 and the National Waste Management Plan 2013–2020 [9], [11], [12]. The boundaries of scenarios LV2016 and LV2030 are reflected in Fig. 1.

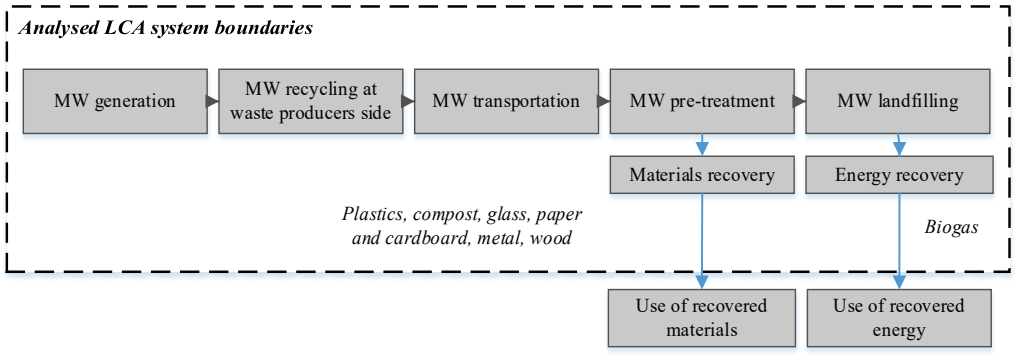


Fig. 1. Technological boundaries of the analysed system.

The *gate-to-grave* approach is selected for the present study. The analysed system starts from waste collection and ends with energy recovery, material recovery processes and waste

landfilling process. Once the waste is collected, it is transported to landfill or recycling sites, and therefore the energy consumed by transport and related emissions are also taken into account. Later MW enters a waste pre-treatment facility – material recovery is carried out from the recycling-eligible MW, while the organic waste and the non-recycling fraction are delivered to the landfill site. The biogas collection system located at the landfill site produces a landfill gas which is purified and transferred to a cogeneration-type incineration plant where electrical energy and heat energy are generated (further use of produced electrical and thermal energy as well as recovered materials are not analysed within the present LCA model). The main pollution flows are the emissions from transport use and landfill gas, emissions associated with energy generation and use as well as leachate.

2.3. Model Limitations and Assumptions

The LV2016 scenario model is based on the existing municipal waste management system in Latvia for 2018 (see the description in Chapter 3.1). Inventory data (see Annex) of LV2016 comprises statistical data and the operational data of waste management plants.

The LV2030 scenario model is a forecast model and includes several assumptions defined below:

- the model is focused on the strategic Latvian and EU waste management targets for 2030 and assumes that these objectives will be achieved – the share of recycled waste (% of waste collected annually) will be up to 80 % in 2030, the EU's overall target for 2030 is to increase MW recycling to 65 %, increase recycling of packaging waste (plastic, wood, glass, paper, paperboard) to 75 %, reduce the share of MW stored in landfills to 10%, and to permit the disposal of sorted MW in landfills [13];
- the model is based on the same distribution of waste as LV2016 scenario, as there are no specific forecasts for the composition of the MW in 2030 (each type of waste will be in the same proportion (%) in 2030 as in 2016);
- the modelling of LV2030 was based on the current state of the waste management technologies and practices (for example, infrastructure to reduce energy consumption for transport, recycling and material/energy recovery efficiency) and no projections of potential future improvements or reinvestment have been considered;
- the model does not consider the available capacity of landfills and materials and energy required to build a new landfill (in practice, a part of the national landfills will be filled in the next decade, but in the real situation there should be built new landfills in the next decade and it will have a significant impact to all impact categories);
- waste transportation distances will remain unchanged by 2030, only the volume (weight) of transportable MW will change and reach 0.400 tonnes per capita in 2030;
- whereas, in the current situation, biogas is derived from a mixed MW fraction and the organic fraction that is best suited for the production of biogas is not distinguished, in the LV2030 scenario, the landfill gas will only be obtained from the organic MW fraction, which will significantly increase the quality and quantity of biogas [14];
- the studies carried out show that, on average, 249 m^3 CH_4/t MW can be obtained from mixed MW, but an average of 370 m^3 CH_4/t MW can be obtained from the organic fraction, which means that the amount of biogas produced per 1 t of disposed MW will increase by approximately 32.7 % [7], [14].

3. SCENARIO DESCRIPTION

The LCA model scheme shows all processes, input and output flows included in the model. The analysed waste management scheme corresponds to the process stages reflected in Fig. 1, meanwhile the description of the stages will be provided in the next chapters and the Annex.

3.1. Scenario LV2016

The baseline scenario of 2016 includes analysis of waste management in Latvia. The analysis includes calculations of material recovery indicator (MRI), energy recovery indicator (ERI) and cost indicator (CI) for each of 10 waste management regions (WMR): Eastern Latgale, South Latgale, Liepaja, Maliena, Piejura, Pieriga, Ventspils, Vidusdaugava, North Vidzeme. By combining all these individual indicators into one common indicator it is possible to evaluate the waste management system of Latvia and each WMR [15]. The value added for ERI/MRI is increasing as the value of CI increases and it is logical that increasing the cost will also increase environmental performance, which in this case means increasing the efficiency of the material and energy recovery. The highest environmental performance is evaluated in the North Vidzeme WMR (15.1 %), Ventspils WMR (12 %) and Zemgale WMR (11.9 %). In assessing the sustainability of waste management system for each WMR, the best result is to achieve the most efficient waste management system (more recovered materials and energy) at the lowest possible cost [15].

The LV2016 scenario includes all streams and operations with MW to represent and show the current situation of waste management system in Latvia. At the beginning, an input flow of 0.410 t MW per capita, representing collected MW in Latvia in 2016. From the waste collection point to the landfill, approximately 30 km are being measured, which means that the transport distance multiplied by cargo mass is 12.3 tkm. The average distribution of MW in Latvia used in the model is as follows: organic fraction – 32 %, paper – 18.2 %, plastics – 12.6 %, glass – 25.2 %, metal – 3.2 %, wood – 3.8 %, textiles – 2 %, other MW – 3 % [16], [17].

Energy recovery from MW is explained as the extraction of biogas (landfill gas), which is burned in a cogeneration plant, resulting in the production of heat and electricity. Based on data from 2016, 0.702 GJ thermal energy and 0.725 GJ electricity were produced from MW per capita in Latvia [16], [18]. It should also be noted that in scenario LV2016, the organic fraction is landfilled with the unsorted fraction, which has a significant impact not only on the quantity of biogas but also on its quality. Leachate is generated from landfilling of MW. Air pollution, consisting mainly of methane and carbon dioxide, and other gases and compounds, comes from waste landfilling and the leachate [19].

The second, priority waste management activity – recovery of materials from MW. It appears that the sorting and recycling of incoming waste consumes the electricity needed to operate the sorting line and recycling technologies. In light of the scientific literature analysis [20], it was established that per 1 t of MW, an average of 0.226 MWh or 0.062 GJ electricity is consumed for sorting and processing. Material recovery data are based on statistical data of 2016 [16], [21], [22].

The average distance of MW transport was assumed to be 30 km based on an analysis of several Environmental Impact Assessment (EIA) reports of the Latvian WMR landfills, as well as calculation of direct distances between waste generation sources and MW treatment facilities (recycling, recovery, disposal). Pollution arising from the waste storage and leachate basin is determined taking into account the analysis of scientific literature and the EIA reports [23]–[26].

3.2. Scenario LV2030

The LV2030 model represents the future forecast of Latvia's waste management system if the targets of the defined European and national waste management policy documents are reached. The main EU and Latvia waste management targets for 2030 has been defined in Chapter 2.3 [6], [12], [13], [27], [28].

As stated previously, the functional unit used within the study is amount of MW generated per capita in Latvia respectively in 2016 and 2030. In order to determine the functional unit for the LV2030 scenario, forecasted demographical changes in the country and amount of MW generated were calculated. The present population trends in Latvia demonstrate a gradual decline over the period 2010–2019 [29], [30] According to the Eurostat forecast for 2030 – 1.74 million people Latvia in 2030 [29], which is also used as a raw data for the LV2030 scenario. To define the amount of MW generated in 2030, a correlation analysis of statistical data on population and amount of MW generated in Latvia from 2010–2017 is performed [30]. This forecast confirms the waste management dilemma: the population is shrinking, while the volume of MW generated in the country is increasing [6], [7]. Based on the above-mentioned information, the amount of MW generated in Latvia per capita in 2030 was determined in an indicative way and is equal to 400 kg per capita, while the total amount of generated MW will be 697 584 tonnes and population of the country is 1.74 million people. As a result, the LCA of the LV2030 scenario will demonstrate quantitative impact on resource consumption, human health, ecosystem quality and climate change, if Latvia reaches the European and national waste management targets. The current situation shows that the proportion of different types of polymers (plastics) is increasing, but many information campaigns are currently taking place in Latvia and at a global level, focusing on reducing the use of plastic packaging, so it is not accurate to forecast the situation and distribution in 2030 [31].

The LV2030 scenario should take into account that a more efficient sorting of MW will take place and, according to the EU and Latvian national planning documents, MW recycling will increase significantly. It should be stressed here that the organic fraction, which will be better separated from the unsorted MW, will improve the quality and increase quantity of generated biogas [14]. The Annex comprises the raw data used for the LV2030 scenario. All forecasted indicators, including energy and material recovery, were identified in the context of the waste management targets mentioned in the EU and Latvian regional planning documents. Similarly, in terms of energy recovery and recycling volumes, energy consumption for recycling, pollution and leachate associated with landfilling were identified [32]. Pollution from MW landfills includes emissions from both the waste storage and the [33]–[36]. Only the main sources of pollution are listed and added as output in LCA model.

4. LIFE CYCLE ASSESSMENT

Life cycle impact assessment (LCIA) quantifies the overall impact of resource consumption and environmental emissions at different stages of a product life cycle [37]. Based on the material and energy flows defined in the life cycle inventory (also see Annex), the life cycle impact assessment (LCIA) is carried out according to the IMPACT 2002+ methodology using LCA software *SimaPro v.6* [34].

4.1. Life Cycle Impact Assessment Results

As stated previously, the LCIA is performed for Latvia's waste management system in 2016 (historical data based) and actions to be undertaken by 2030 (forecasted data based) to understand the environmental benefits obtained by the upcoming waste management targets in Europe.

Comparative LCIA results of the main environmental impacts of LV2016 and LV2030 scenarios are reflected in Table 1. As illustrated, glass production has a relatively large impact, as glass is one of the dominant types of waste collected in Latvia and, secondly, the process of producing glass is energy-intensive – high consumption of resources and high energy consumption linked to the specification of the technological process. This indicator represents part of glass recycled and other part as unsorted MW landfilled. Collection and transportation of glass and plastic waste has the greatest impact – 41.24 mPt for glass waste and 13.95 mPt for plastic waste for LV2030, accordingly 42.26 mPt and 14.28 mPt for LV2016.

TABLE 1. ENVIRONMENTAL IMPACT RESULTS FOR LV2016 AND LV2030 SCENARIOS

Activity		Impact (mPt), LV2016	Impact (mPt), LV2030
MW transportation		5.33	5.20
Collected	glass	42.26	41.24
	metal	8.48	8.28
	paper/ cardboard	4.06	3.96
	plastic	14.28	13.95
	wood	0.03	0.03
	textile	84.96	82.49
Electricity used for pre-treatment		0.31	0.72
Energy from MW	electricity	–38.33	–46.94
	thermal energy	–5.92	–7.35
Recycled	glass	–16.91	–33.39
	plastic	–5.72	–11.29
	paper/ cardboard	0.00	–1.04
	metal	–4.18	–8.25

The most significant environmental impact reduction is dedicated to energy recovery action. Production of electricity from biogas reduces the overall impact of Latvia's waste management system by 38.33 mPt in LV2016 and by 46.94 mPt in LV2030, while the generated thermal energy by 5.92 mPt in LV2016 and 7.35 mPt in LV2030. Recycling actions (glass, plastics, metal, paper, etc.) are likely to reduce the environmental impact of the waste management system by approximately 50 % more comparing LV2030 and LV2016 scenarios.

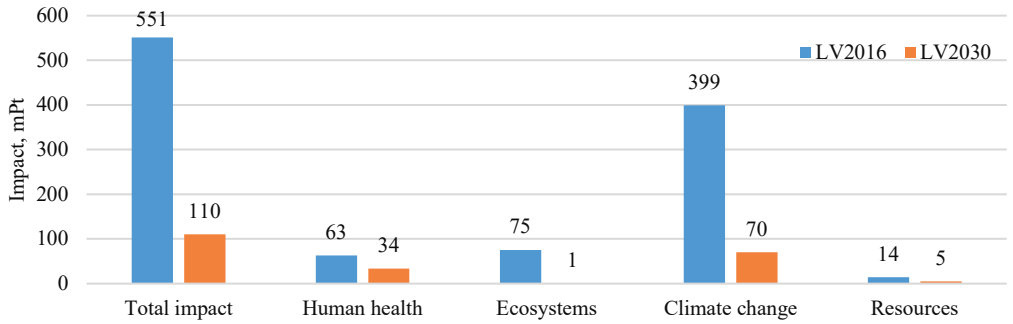


Fig. 2. Comparison of the life cycle analysis of both scenarios in the environmental impact categories of the results.

The overall impact assessment shows that the environmental impacts of the scenario LV2030 is approximately 80 % lower compared to the LV2016 scenario – 551 mPt per capita in 2016 and 110.1 mPt per capita in 2030 (Fig. 2). The main preconditions for such an impact reduction are the increase in MW sorting and recycling volume, a reduction in the amount of MW landfilled in waste sites and the separation of the biodegradable fraction from the total flow that improves the quality and volume of biogas [38].

The highest contribution of waste management strategies to environmental impact reduction results in impact on ecosystems – up to minus 98 % comparing with LV2016. That can be explained as reduction of pollution (in the air and ground).

At the level of impacts to climate change, the LV2030 scenario brings a reduction of about 82 % generated by reduced generation of waste, production of material values, transport, the extraction and consumption of fossil energy. Waste management has a significant effect on human health as exposure of bioaerosols from landfills and treatment plants are considered [39]. The impact of disposal of liquid and solid municipal and other waste on environment and their emittance of greenhouse gases into the atmosphere are significant due to pollution caused by non-sustainable waste management system. The previous researches advocate that instead of producing resources and disposing of waste by incineration or degradation, the minimal production from virgin materials and total recycling of wastes drastically reduces the emissions that would otherwise have had damaging effects on climate change, human health and ecosystem quality [40], [41].

A European Commission Study on the Environment Report showed that reduced dependence on fresh production of goods and overall source segregation of MW, followed by recycling, gives the lowest net flux of greenhouse gases, compared with other options for industrial production processes and treatment of bulk MW [42]. As seen from LCIA, implementation of the EU waste management targets leads to the reduction of impacts on human health by 53 %. Summarizing, it can be concluded that the 2030 waste management targets set by the EU and Latvia are likely to significantly reduce the entire life cycle impacts of the waste management system on human health, ecosystem quality, climate change, resource consumption through recycling, and energy recovery actions.

4.2. Sensitivity Analysis of the Life Cycle Assessment Environmental Impacts

As part of the LCA sensitivity analysis, it was decided to analyse the dependence of changes (with a change step [–40 %; –20 %, +20 %, +40 %] – see Table 2) in the amounts of recycled plastic and separated organic fraction to environmental impacts categories. The selection of these two parameters is based on an increased dominance of plastic products on the Latvian and international markets. The second parameter chosen, which will be changed to determine

its sensitivity in the overall waste management system, is the amount of organic fraction generated/collected. This choice is accepted because the organic fraction is the most suitable for biogas production because it is biodegradable and can therefore be used for energy extraction. The composition of the organic fraction in an anaerobic environment is the most efficient way to release methane, which is the main indicator of the quality of biogas [43]. Sensitivity analysis will be performed for the LV2030 scenario only, to show how changes in selected parameters may influence the future situation.

TABLE 2. SELECTED SENSITIVITY FACTORS

Changes in factors	**–40 %**	**–20 %**	**0 %**	**20 %**	**40 %**
Recycled plastic (t per capita), LV2030	0.024	0.033	0.041	0.049	0.057
Organic fraction (t per capita), LV2030	0.077	0.102	0.128	0.154	0.179

The results of the LCA, reflected in the previous chapter, showed that the role of energy (electricity and thermal energy) generated from MW in reducing the environmental impact of the waste management system is significant and therefore changes in the organic fraction in the overall structure of the MW lead to greater impact changes. The results of the sensitivity analysis of scenario LV2030 are shown in Fig. 3. In the case of scenario LV2030, the overall impact of the waste management system is seen to be increasing by 2 mPt (1.8 %) if recycled plastic amount decreases by 20 %, meaning that more resources will be used and more pollution will be caused if recycled plastic will be replaced by new plastic products. If the amount of recycled plastic is reduced by 40 %, the impact of the proposed waste management system will increase by 5 mPt (4.5 %).

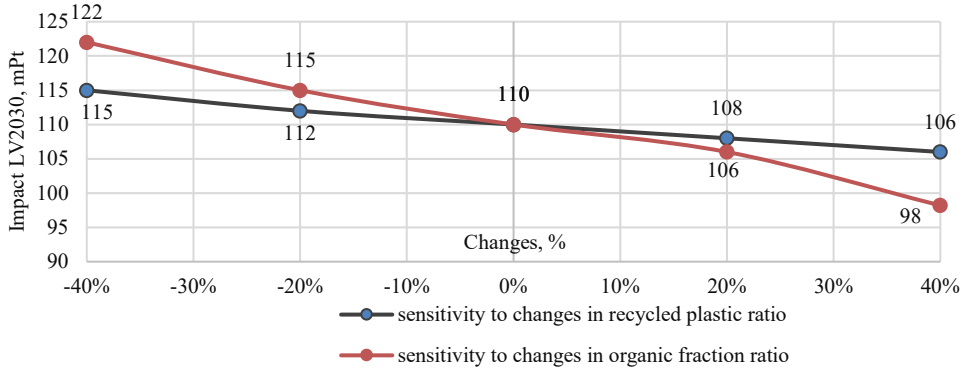


Fig. 3. Results of the sensitivity analysis of LV2030 scenario.

The increase in recycled plastic amount appears to be less conducive to a reduction of the environmental impact of the overall waste management system. If the organic recycled plastic amount increases by 20 %, the impact will reduce by 2 mPt (1.8 %) and the overall impact would reach 108 mPt, while a 40 % increase would reduce the overall impact of the waste management system by 4 mPt (3.6 %). This function is not linear and a more substantial change in recycled plastic amount will change the overall environmental impact of the waste management system more significantly.

5. DISCUSSIONS AND CONCLUSIONS

Within the present research, a life cycle analysis of waste management was carried out in two scenarios LV2016 and LV2030. Scenario LV2016 corresponds to the current waste management situation in Latvia in 2016, based on statistical data. Scenario LV2030 is based on the future national and EU targets in the waste management field. The results of the life cycle analysis for both scenarios showed that increasing waste recycling and reducing the amount of MW landfilled can significantly reduce the impact of the waste management system on climate change, resource consumption, human health and the quality of ecosystems.

Results of the research presented through the overall impact assessment show that the impact of scenario LV2030 is approximately 5 times lower (or 80 % lower) compared to the LV2016 scenario. The main preconditions for such an impact reduction are the increase in MW sorting and recycling, a reduction in the amount of MW landfilled in waste sites and, separately, the removal of the biodegradable fraction from the total flow, with a view to improving the quality and volume of biogas.

To demonstrate an application of the developed model for decision makers as well as to test the model itself, the sensitivity analysis carried out showed that changes in the parameters of scenario LV2030 – the amount of plastic recycled and organic fraction – lead to greater reduction in the overall waste management system's impact on climate change, human health, the quality of ecosystems and resources, as explained by the increased importance of these parameters in this scenario. The study also shows that the scenario-based LCA analysis could be helpful for the decision-making process to achieve the best possible waste management system efficiency.

At the time of submission of the current study, the new Waste Management State Plan for 2021–2028 (WMSP 2021–2028) is being developed in Latvia [44]. The plan is aimed to wider introduction of the European Union's circular economy principles in Latvian waste management system, setting out the following objectives.

1. Preventing waste generation and its amounts.
2. Ensuring rational use of waste as a resource.
3. To ensure that the waste generated is not hazardous or poses a low risk to the environment and human health.
4. Ensure the *reduction of landfilled waste* and the disposal of waste in a safe way for human health and the environment.

The new plan intends for significant changes in operations of the national waste management system. This in turn might have an impact on the results achieved in the current study, including:

- ***The composition and quantity of recovered and landfilled waste.*** Considering the new EU targets for the management of specific waste streams (e.g. textiles, packaging, biodegradable waste) [8], [9], [45], [46], forecasts on the amounts of waste streams generated, recovered and landfilled are updated in the WMSP 2021–2028.
- ***Number of WMR/waste management landfills***. There are currently 10 municipal WMR in Latvia. During the development of the WMP 2021–2028, the assessment of the potential changes in the amounts of waste generated and the corresponding demand for waste management services and its capacity in every WMR was performed. It was concluded that in three WMR the amount of waste managed has decreased during the reporting period (2020 and 2035), while in the remaining WMR the amount of waste has increased. The successful achievement of the objectives set in the WMP 2021–2028 requires centralization of the waste management system, thereby ensuring a

larger amount of waste to be managed in one place, enabling more efficient investment in the development of recycling and recovery technologies. Therefore, in the new programming period, it is planned to reduce the number of waste management regions from 10 WMR to 5 WMR.

– ***Specialization of the landfill sites***. The new WMP 2021–2028 defines that the development of five WMR should respect the principle of specialization of the landfill sites within these regions, i.e. specializing the functions of the landfills. The following waste management landfill specializations are foreseen within the next WMP 2021–2028: (A) Preparation for recycling and recovery; (B) Recycling of biodegradable waste (biogas extraction); (C) Recycling of biodegradable waste (biodegradable waste composting); (D) Disposal.

The above-mentioned WMP 2021–2028 activities might have an effect to the following assumptions defined within the current studies:

– the amount of waste landfilled and the environmental impacts caused by the landfilled waste;
– the amount of waste incinerated and its impact to the environment;
– the amount of recovered waste (by specific types of recovery actions) and its impact to the environment;
– the average distance to transport the waste from the waste generation source to recycling/recovery/landfilling sites;
– the environmental impact generated from production and installation of new waste management infrastructure (recycling sites, incineration plants, composting areas, etc.).

Considering the above stated arguments, it would be recommended upon the approval of the new WMP 2021–2028, to re-establish the developed decision-making model and to carry out a simulation in accordance with the quantitative parameters extracted from the WMP 2021–2028.

ANNEX

INVENTORY DATA USED FOR SCENARIO LV2016 AND LV2030, DESCRIPTION AND DATA SOURCES

Data	Unit of measure	Value		Description	Data source
		LV2016	LV2030		
Specification of waste					
Unsorted MW	t/per capita	0.410		This indicator reflects amount of MW in tonnes generated per capita in Latvia in 2016 based on the following morphological composition of MW: organic fraction – 32 %, paper/paperboard – 18.2 %, plastic – 12.6 %, glass – 25.2 %, metal 3.2 %, wood 3.8 %, textiles – 2 %, other MW – 3 %.	[16], [17]
			0.400	LV2030 scenario 0.400 tonnes/y per capita as forecasted by Latvia's Sustainable Development Strategy for 2030 and the National Waste Management Plan. This indicator reflects amount of MW in tonnes generated per capita in Latvia in 2030 based on the following morphological composition	[16], [17]

				of MW: organic fraction – 32 %, paper/paperboard – 18.2 %, plastic – 12.6 %, glass – 25.2 %, metal 3.2%, wood 3.8 %, textiles – 2 %, other MW – 3 %	
Produced (avoided) products					
Electricity	GJ/per capita	0.725		The amount of electricity generated is determined on the basis of statistical data on electricity generated from MW in Latvia in 2016 (energy from landfill gas).	[16], [47], [48]
			0.888	The amount of energy biogas (heat and electricity) was calculated incl. such factors as an increase in the quality and quantity of biogas, secondly, the population will fall more rapidly than the size of MW, which leads to the conclusion that energy production per capita will grow.	[16], [18], [21], [49], [50]
Thermal energy	GJ/per capita	0.702		The statistical data and the 'Landfill Report 2016' [16] were used to determine the amounts of heat generated from MW biogas in CHP plants. Since this section includes products that have been eliminated, it was assumed in the model that heat from landfill biogas would replace heat generated in combustion of natural gas, which is a fossil energy resource. Thus, the model is made with the assumption that increasing heat from landfill (biogas), decreases use of natural gas. It was adopted to show importance of energy recovery from MW and how the impact would change to all impact categories if fossil energy will be replaced with renewable energy as biogas.	[16], [18], [47], [48]
			0.871	The quantities of recycled/recovered packaging were determined on the basis of achievement of the EU waste management targets. The EU's overall target for 2030 is to increase the amount of MW recycled to 65 %, while recycling of various packaging materials will increase to 75 %.	[11], [16], [18], [21], [27], [49], [50]
Glass packaging	t/per capita	0.040	0.08	The quantities of recycled/recovered packaging were determined *via* statistical data and landfill reporting data showing the amount of recovered/recycled packaging in 2016 and 2030. It is explained as 80 % of MW collected will be recycled in 2030 and 75 % of packing waste in 2030 will be recycled, due to main EU and Latvia waste management targets for 2030.	[12], [16], [21], [22], [47], [51][56]
Polymers packaging	t/per capita	0.020	0.04		
Paper/paperboard packaging	t/per capita	0.029	0.059		
Metal packaging	t/per capita	0.005	0.010		
Wood packaging	t/per capita	0.006	0.012		
INPUTS					
Materials/transport/energy used					

Waste transportation distance	km	30	30	The average distance between MW collection point (waste producer) and waste pre-treatment site (recycling, recovery, disposal) is assumed as 30 km.	[16], [23]
Electricity consumption	GJ/per capita	0.006	0.014	This indicator reflects the energy consumption of sorting/recycling technological lines. The data are derived from an analysis of related waste management companies' pollution permits, where electricity consumption is indicated, as well as from other countries' experience. Since the recycling of waste will increase significantly in LV2030, this will boost the amount of electricity used for MW pre-treatment activities.	[11], [21], [51], [57], [58]
OUTPUTS					
Pollution/emissions/waste/co-products					
Methane (CH_4)	t/per capita	0.428	0.064	In order to determine the amount of pollution from landfill and cogeneration plants, an analysis of the air surveys submitted by landfill sites in 2016 was carried out, as well as the studies carried out and the experience of other countries. It should be highlighted that only major sources of pollution are reflected. The amount of pollution has been determined based on the amount of MW disposed in landfills and the amount of energy produced. Emissions to air: methane, carbon dioxide, VOC, carbon monoxide, hydrogen sulfide, hydrogen chloride. Emissions to land: cadmium, chromium, lead, zinc. In order to determine the amount of pollution from landfill, a proportional conversion from LV2016 scenario was carried out. It is known that the EU's target for 2030 is to dispose at landfills not more than 10 % of the amount of MW collected, and to ensure energy recovery from landfills.	[6], [16], [21], [49], [51], [59]
Carbon dioxide (CO_2)	t/per capita	0.341	0.051		
Volatile organic compounds (VOC)	t/per capita	0.0062	0.0009		
Carbon monoxide (CO)	t/per capita	0.0222	0.003		
Hydrogen sulfide (H_2S)	t/per capita	0.0355	0.005		
Cadmium (Cd)	t/per capita	0.00001	0.000001		
Chromium (Cr)	t/per capita	0.000002	0.0000004		
Lead (Pb)	t/per capita	0.000008	0.000001		
Zinc (Zn)	t/per capita	0.00013	0.00002		
Hydrogen chloride (HCl)	t/per capita	0.011	0.001		
Leachate	t/per capita	0.014	0.009	The amount of leachate is determined from the data of landfills management companies' pollution permits, as well as the results of scientific studies. The amount of leachate has been calculated taking into account the amount of MW that is being landfilled accordingly in 2016 and 2030.	[9], [21], [49], [51], [57], [58], [60], [61], [63], [64]

Amount of MW disposed in landfills	t/per capita	0.265	0.04	The amount of MW disposed in landfill is calculated as a difference between collected MW and recycled/recovered MW. In line with the EU's 2030 target on reduction the share of landfilled MW to 10%, the amount of unsorted MW that would be disposed of at landfill sites in Latvia is calculated.	[2], [16], [21], [31], [49], [51], [57], [61], [62]
Compost from MW	t/per capita	0.042	0.068	The amount of compost produced from MW is defined acc. to statistical data for LV2016. The amount of compost produced in LV2030 is calculated based on the amount of waste landfilled and amount of biogas produced.	[16], [21], [49], [51], [53], [61], [63], [64]

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