THE SLUDGE COMPOSTING CAPABILITIES AT THE MUNICIPAL WASTE WATER PLANT “KLAIPĖDOS VANDUO”

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CONTENT

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ABRIAVATIONS

AP	Acidification potential criteria
CA	Citric acid
CSS	Compost of the sewage sludge
DM	Dry mass
GHG	Greenhouse gas
GWP	Global warming potential
HHA	Human health criteria in air
LCIA	Life cycle impact assessment
NMVOC	Non-methane volatile organic compounds
PTF	Polynomial trend line fit
SA	Smog formation potential for air emissions criteria
VOC	Volatile organic compounds

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1. INTRODUCTION

The waste water sewage sludge is attributable to the category of the bio-degradable waste that has to be treated properly, not to harm the environment and its components. The waste water sludge can contribute as a chemical and biological environmental pollution. The heavy metals contained in the sewage sludge can harm our environment. Growing requirements for the treatment of the sewage sludge produced by the waste water treatment plants results with ever increasing quantities of the sewage sludge, that force to search for modern and effective ways of its treatment. Application of the common ways of the sewage sludge treatment technologies can lead to the risks of environmental pollution as well, can lead to the intersection with the sustainable goals. One of the known and effective way of the stabilization of the sewage sludge is the composting of the sludge that reduces its quantities and stabilizes its structure (Zuokaitė, 2011).

Wastewater plant „Klaipėdos Vanduo“ while processing its waste water, produces the waste water sludge in amounts reaching the average of 12 568 tons of dewatered sludge every year. Since the year of 2014 the sewage sludge started to be stockpiled at the sludge storage sites located in proximity of the Klaipėda city. The steady amounts of the sewage sludge dry mass started to accumulate at the sludge storage sites since 2016, reaching the growth of the sludge quantities by addition of 2370 tons of dry mass every year.

At the wastewater plant „Klaipėdos Vanduo“ sewage sludge is dewatered and dried. During the phase of the sludge processing the produced biogas is used for further conversion to heat power and electricity that is used for own needs in the plant as well, is reused for sludge processing. In the final phase, the dried sludge is transported to the “Akmenės” cement plant located at 169 km from the “Klaipėdos Vanduo” for incineration as well, stockpiled at existing local sludge storage sites. Nevertheless, of the decrease of the processed wastewater since 1995 at „Klaipėdos Vanduo“ the stockpiled dewatered sludge amounts reached the 327 791 tons (60 066.4 tons of d.m.) at existing sludge storage sites. The arrangements of the sludge storage sites required investments reaching the 6 million EUR to make the sites suitable for the sewage sludge stockpiling in the ways of covering the sites with the "floating" type of geosynthetic coating and installation of the drainage system. By the date an existing sewage stockpiling sites are filled by 89.2% (KV, 2020). Obviously, an additional installations for stockpiling produced sludge at “Klaipėdos vanduo“ would be costly and the treatment of produced sludge in the future should be considered.

According to the Lithuanian national regulations (LAND 20-2005), the wastewater sewage (as well its compost) can be used for fertilization and re-cultivation in agriculture and forestry, when established requirements are met. Processing of the sewage sludge, using the composting process, fundamentally changes the properties of the final product (Sidełko et al., 2019). However, the compost products if not enriched with the mineral additives containing nutrients cannot be equalled directly to fertilizers although, it can be used to enrich the substrate purposed for planting as well, can be used to increase the quality of the soils. The minerals contained in compost enrich physical and chemical properties of the soils as well, its biological activity. Still, during the process of sewage sludge composting, the carbon reach components can be used to stabilize the compost as well, to increase the C/N ratios (optimal C/N ratio of the compost is >20) and reduce gas emissions during process (Zuokaitė, 2011).

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The aim of this research is to assess the possibilities of composting of the sewage sludge produced at wastewater plant; to assess the Life cycle impact (LCIA) of the composting process and to evaluate the sludge compost usage potential at Klaipėda district area.

2. LITERATURE REVIEW

2.1. Agriculture and forestry areas in Klaipeda city and its district

The total area of the Klaipėda city and Klaipėda district constitutes ~1420 km^2. The map of the Klaipėda district is shown in the Figure 1.

Figure 1. Red coloured area in the map **-** the Klaipėda district area (Wikimedia, 2020).

The summary of the sizes of the intended purpose of the areas for the agriculture and forestry in the Klaipėda city and its district is given in the Table 1 (on personal communication Karčauskienė, 2021).

Table 1. Klaipėda district reserved areas for agriculture and forestry.

PURPOSE OF THE LAND	KLAIPĖDA CITY, ha	KLAIPĖDA COUNTY, ha	TOTAL AREA, ha
Agricultural land	2047.69	69091.64	71139.33
Arable land	0.00	54666.24	54666.24
Forest land	2024.04	34798.62	36822.66
Forestry land	0.00	0.00	25312.30
Abandoned land	0.00	609.31	609.31
Total area	9795.16	132336.42	142131.58

The agriculture and forestry areas in the Klaipėda city and its district constitutes 79978.24 hectares.

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2.2. Requirements for the waste water sludge compost and it’s use in agriculture and forestry

The national regulation in Lithuania draws the requirements for the waste water sewage sludge and its compost usage in agriculture and forestry (LAND20-2005). One of the main and mostly actual requirements is the concentrations of the heavy metals in the sewage sludge and its compost. These concentrations are given in the Table 2.

Table 2. Requirements for waste water sludge to be used in agriculture (LAND 20-2005).

REQUEREMENS FOR SLUDGE TO BE USED IN AGRICULTURE								
mg/kg		**Zn**	**Cu**	**Cr**	**Cd**	**Pb**	**Ni**	**Hg**
CLASS	**I**	<300	<75	<140	<1.5	<140	<50	<1.0
	II*	300-2500	75-1000	140-400	1.5-20	140-400	50-300	1.0-8.0
	III**	>2500	>1000	>400	>20	>400	>300	>8.0

*Can be used every 3 years in agriculture except in planting industry of vegetables and fruits
**Forbidden to use

The class I sewage sludge and its compost can be used without any restrictions in agricultural and forestry areas. The class II sewage sludge and its compost can be used every 3 years in the same areas with the exception in the planting industry of vegetables and fruits used for food. However, the class III sewage sludge is forbidden to use in agriculture in Lithuania.

The quantities of the sludge that can be used in agriculture and forestry in Lithuania are drawn in the national legislation document (LAND 20-2005) allowing using the sludge (compost) with the rate of 33 tons per hectare at the areas for growing energetic plants, nurseries, at plantations of raw wood and shrubs, forestry plantations and greeneries. While cultivating damaged areas, it is allowed to use the sludge (compost) with the rate of up to 100 tons of sludge per hectare. Still the fertilizations rates depend on knowledge of the effectivity of the fertilization on the cultures planted and their purpose. I.e. during the cultivation experiments with the herbaceous plants purposed for biofuels the successful application of the compost of the sewage sludge (CSS) proved to be effective with the quantities of CSS of up to 30-110 tons per hectare of land (Bakšienė et al., 2020a). As well, the timber planted for biofuels was enriched with the compost of the sewage sludge with the quantities of up to 20-110 tons per hectare of land (Bakšienė et al., 2020b). Thus, the potential quantities of the composted sewage sludge usage in the agriculture and forestry areas constitute the land enrichment rate of within the 20-100 tons per hectare.

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2.3. Wastewater plant „Klaipėdos Vanduo“ storage sites

The sewage sludge is stockpiled in two storage sites at wastewater plant "Klaipėdos Vanduo", with accumulated quantity of 327 791 tons of sludge at these two sites. The map of the existing sewage sludge storage sites is depicted in the Figure 2.

Figure 2. Orto-photo of the waste water plant „Klaipėdos Vanduo“ existing sludge storage sites: Red mark – old sludge storage site; Blue mark – existing 2 sludge storage sites.

The dynamics of the produced sludge quantities at wastewater treatment plant "Klaipėdos Vanduo" during the period of 2013-2019 is given in the Figure 3.

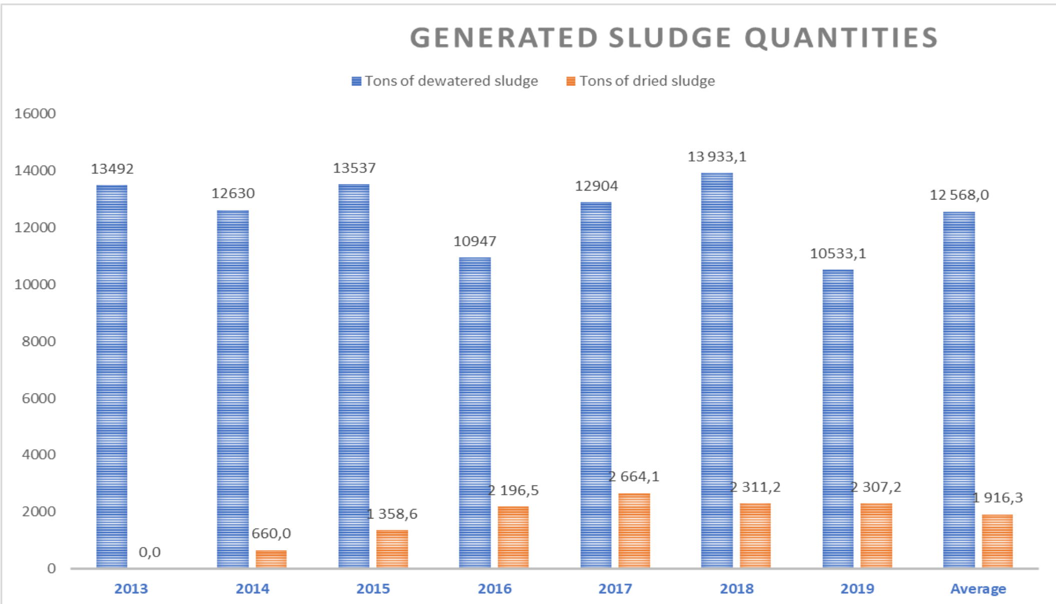

Figure 3. Waste water plant „Klaipėdos Vanduo“ produced sludge quantities in tons during the period of 2013-2019.

An average quantity of the sludge generated during the period of 2013-2019 results in 12 568 tons of dewatered sludge and the average quantity of 1916 tons of dried sludge every year, although the steady quantities of the dried sludge were produced during the period of 2016-2019 with the average yearly amount of the 2370 tons of the dry mass.

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Current situation of the filling of these existing sewage sludge stockpiling sites is given in the Table 3.

Table 3. Filling of the sewage sludge sites at waste water plant „Klaipėdos Vanduo“.

PARAMETER / SITE	EXISTING SITE	OLD SITE	TOTAL
Capacity of sites (dewatered sludge)	140 000 tons	227 600 tons	367 600 tons
Filling (dewatered sludge)	100 191 tons	227 600 tons	327 791 tons
Filling (dry mass of sludge)	21 146.8 tons	38 919.6 tons	60 066.4 tons
Filling (in percent)	71.6 %	100 %	89.2 %

The stockpiling sites by the date are filled by 89.2%, where an old site is already exploited by 100% and the existing site is filled with 71.6% of its capacity, having the limited resources, with the remaining capacity for the approximate duration of the < 3 years period with an average load of the generated sewage sludge.

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3. METHODS

The sludge monitoring data provided by the waste water plant “Klaipėdos Vanduo” were analysed. Concentration of the heavy metals of the dewatered sewage sludge having the sampling equal intervals in 2019 were analysed along with the data regarding produced sludge quantities. The data reported by Sidełko et al., (2019) was used - averages of 140 days sludge composting with 10 samplings in spring and autumn periods. These data, the changes of the concentrations of the heavy metals during the process of the sewage sludge composting, were analysed to apply the analogy for prediction of the change of concentrations of the heavy metals in the sewage sludge compost at the wastewater plant “Klaipėdos Vanduo”.

To model the polynomial trend line fits (PTF’s) the MS Excel® program was used. The PTF’s were derived fitting the 2nd order polynomial trend lines to the heavy metal concentrations data of the compost of the sewage sludge (CSS).

The Life cycle impact assessment of the sewage sludge composting process was implemented using the GaBi® software (GaBi, 2012). The flow parameters were used to model Life cycle impact assessment: quantity of the dried sewage sludge, produced at wastewater treatment plant equal to 1916.3 tons (main material); the amounts of additional raw materials – the 479.075 tons of straw; 479.075 tons of wood chips and 479.075 tons of mature compost (inoculum), where the ratio of the materials equal to 4:1:1:1 (higher C/N ratio) was used to model the material flows, using the $\pm$40% parameter of the statistical standard deviation due to resulting data of the produced sewage sludge quantities, during the period of the 2013 - 2019 (see as well, Sidełko et al., 2019 and Zuokaitė, 2011). The composting scheme for modeling was adopted from the end of life inventory of the open windrow composting of the biodegradable waste (UUID 0ce9ff2a-74de-4003-be0f-a44d6058851f) adopting it to the local site of “Klaipėdos Vanduo waste water treatment facility. The emissions of the flows for open composting process were provided: CH4 1000 g/per ton waste input; N_2O 110 g/t waste input; NH3 470 g/ton waste input; NMVOC 370 g/ton waste input, with the 50% of the DM rotting in the composting process. Modeling input parameters for the compost and the raw materials transportation were chosen according to the inventory of GHG emissions of the mid-size lorry: CO_2-127 g/t-Km; CO-0.25 g/t-Km; VOC-1.1 g/t-Km; HC-0.3 g/t-Km; NO_X-1.85 g/t-Km; PM-0.04 g/t-Km; SO_2-0.1 g/t-Km (Fan et al., 2018). Input parameters for the process of the compost pre-treatment, treatment and post-treatment (excavation, aeration and sieving) were chosen according to the assessment of the machinery equipment. The atmospheric emissions (mid-size equipment of rated power of 66 Kw) were the following: CO_2-316 g/Kw/h; CO-0.02 g/Kw/h; NO_X-2.83 g/Kw/h; HC-0.29 g/Kw/h (Heidari & Marr, 2015). The assumption has been made that the excavation equipment productivity is ~3 cycles per minute, thus the raw material excavation productivity is 90 m^3 per hour (Forconstructionpros, 2020), where compost density is 0.5 ton/-m^3 (Khater, 2014), resulting with 45 m^3 compost pre-treatment, treatment and post-treatment per hour.

The distance of the raw material transportation to the waste water sludge treatment polygon as well, as the distance for the transportation of the composting product to the agriculture facilities was chosen 23.55 km, the 50% of the longest road distance at Klaipėda district. The distance for transportation of sieving impurities to the „Dumpiai“ landfill for modelling was chosen as 1.5 km.

The comparison of the acquired Life Cycle Impact assessment (LCIA) indices of the wastewater sludge composting process and the wastewater sludge incineration was performed.

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For LCI assessment an available data of atmospheric emissions of the waste water sludge incineration were used, that is equal to the GHG emissions of CO_2 Equivalent 223.05 kg/ton of waste (Đurđević et al., 2019). Along, the emissions of the sewage sludge transportation to the incineration facility process were used, where the distance to the "Akmenės" cement plant incineration facility is 169 km.

4. RESULTS

4.1. Properties of the produced sludge

The analysis of the laboratory sampling results of the sewage sludge (completed by "Klaipėdos Vanduo") stockpiled at the waste water plant sewage sites in the period of 2019 are given in Table 4. During the stockpiling in 2019 all parameters revealed only slight changes.

Table 4. Parameters of the sludge produced at waste water treatment plant „Klaipėdos Vanduo" (period marks the sampling date).

Period	Cr	Cu	Ni	Zn	Pb	Cd	Hg	Total Nitrogen	Total Phosphorus	Dry matter	Organic matter
	mg/kg									%	
2019-01-08	42.8	251.0	27.2	780.0	21.9	1.40	0.34	55254.0	30882.0	89.3	68.0
2019-02-07	24.7	247.0	18.7	884.0	18.5	1.56	0.32	53226.0	27315.0	88.4	65.3
2019-03-04	31.2	242.0	17.4	952.0	23.2	1.24	0.59	50071.0	29804.0	94.5	64.1
2019-04-02	39.5	245.0	25.2	870.0	18.0	1.35	0.56	55340.0	32076.0	94.4	66.0
2019-05-07	32.7	245.0	18.2	865.0	19.3	1.26	0.26	66644.0	34615.0	92.5	67.3
2019-06-04	40.1	241.0	22.0	801.0	25.2	1.06	0.38	57915.0	30196.0	90.4	65.9
2019-07-09	41.2	269.0	21.1	798.0	23.3	1.03	0.28	57325.0	32308.0	89.3	67.6
2019-08-20	48.0	248.0	30.0	738.0	25.2	1.10	0.82	54251.0	29100.0	92.0	66.7
2019-09-17	40.1	282.0	22.2	704.0	22.4	0.75	0.37	50528.0	36500.0	89.4	65.2
2019-10-01	46.2	256.0	25.0	697.0	21.5	0.85	0.44	54826.0	31500.0	88.8	65.3
2019-11-12	46.5	250.0	32.5	756.0	34.3	1.10	0.39	47970.0	29500.0	93.5	63.8
2019-12-30	39.6	231.0	22.4	737.0	27.9	1.02	1.20	51650.0	27745.0	97.7	64.6
AVERAGE	39.4	250.6	23.5	798.5	23.4	1.14	0.50	54583.3	30961.8	91.7	65.8
CLASS	**I**	**II**	**I**	**II**	**I**	**I**	**I**	NA	NA	NA	NA

The slight increase of the *Zn*, *Pb* and *Hg* concentrations was observed in the sludge due to the processes of drying of the sludge as can be seen in the increase of the dry matter and loss of the organic matter in the compost (Sidełko et al., 2019). Although, all other concentrations of the heavy metals slightly decreased in 2019. Only, concentrations of the *Cu* and *Zn* fall in to the sewage sludge Class II, whereas rest of the heavy metals fall in to Class I.

4.2. Change of sludge compost properties during its processing

Sidełko et al., (2019), during their research with compost of sewage sludge compost, found that sludge compost has minor changes in their concentrations of heavy metals and valuable change of properties such as C/N ratio. After 140 days CSS has minor increase in concentrations. Of heavy metals. The summary of the change of the properties of CSS is given in Table 5.

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Table 5. Change of properties of composted sludge (Sidełko et al. 2019).

SLUDGE:WOODCHIPS+STRAW:MATURE COMPOST (RATIO 4:1:1)			
PARAMETER	**Sewage sludge**	**Compost 140 days**	**Change in %**
Organic Carbon mg/kg in dry matter	371.6	367.1	-1.2
Carbon tot % in dry matter	37.2	36.7	-0.5
Nitrogen tot % in dry matter	7.5	3.5	-4.0
Phosphorus tot % in dry matter	2.6	1.9	-0.7
C/N ratio	5.0	10.5	52.4
Dry matter %	18.5	45.1	26.6
SLUDGE:WOODCHIPS+STRAW:MATURE COMPOST (RATIO 8:1:2)			
PARAMETER	**Sewage sludge**	**Compost 140 days**	**Change in %**
Organic Carbon mg/kg in dry matter	371.6	350.4	-6.0
Carbon tot % of dry matter	37.2	35.0	-2.2
Nitrogen tot % of dry matter	7.5	3.6	-3.9
Phosphorus tot % of dry matter	2.6	2.8	0.2
C/N ratio	5.0	9.5	47.4
Dry matter %	18.5	47.5	29

The change of the concentrations of heavy metals during the process of composting is given in Table 6.

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Table 6. Change of concentrations of the heavy metals in compost, during sludge composting process (Sidełko et al., 2019).

AVERAGE SPRING+AUTUMN							
SLUDGE:WOOD CHIPS+STRAW:MATURE COMPOST (RATIO 4:1:1)							
Sample mg/kg D.M.	**Zn**	**Cu**	**Cr**	**Cd**	**Pb**	**Ni**	**Hg**
Sludge	524.5	238.6	26.6	0.50	28.6	11.1	0.507
Sample No.1	358.8	144.3	80.0	0.63	17.5	25.8	0.293
Sample No.2	282.9	132.1	36.8	0.63	16.6	12.9	0.248
Sample No.3	369.5	164.9	32.5	0.50	22.1	11.9	0.287
Sample No.4	356.6	164.1	47.0	0.75	18.3	16.5	0.284
Sample No.5	391.1	184.4	60.8	0.88	21.3	20.9	0.332
Sample No.6	408.8	191.3	48.6	0.38	22.9	16.1	0.351
Sample No.7	386.4	177.8	58.4	0.38	21.3	18.8	0.354
Sample No.8	424.3	194.8	52.8	0.75	26.0	17.9	0.334
Sample No.9	453.5	203.9	76.4	0.88	24.3	24.5	0.373
Sample No.10	382.9	193.0	55.8	0.63	22.5	18.8	0.397
SLUDGE:WOOD CHIPS+STRAW:MATURE COMPOST (RATIO 8:1:2)							
Sample mg/kg D.M.	**Zn**	**Cu**	**Cr**	**Cd**	**Pb**	**Ni**	**Hg**
Sludge	524.5	238.8	26.6	0.50	28.6	11.1	0.507
Sample No.1	407.0	181.9	40.1	0.40	20.4	13.3	0.412
Sample No.2	360.4	158.3	69.0	0.03	19.1	21.3	0.339
Sample No.3	395.1	172.0	52.0	0.28	21.3	16.4	0.421
Sample No.4	448.8	204.5	51.5	0.88	27.5	16.5	0.396
Sample No.5	457.9	207.0	84.7	0.90	24.7	25.5	0.399
Sample No.6	487.5	226.7	80.0	0.88	25.4	25.5	0.422
Sample No.7	486.0	217.0	61.7	0.88	25.1	20.0	0.450
Sample No.8	510.4	237.5	56.1	1.00	26.9	18.3	0.509
Sample No.9	506.1	233.9	75.8	0.63	26.1	24.0	0.464
Sample No.10	507.3	236.8	52.6	0.63	25.5	18.3	0.481

It was derived polynomial trend line fits (PTF's) from the data reported by Sidełko et al., (2019). The trend lines are derived for compost maturing in 140 days using the ratio of the materials equal to 4:1:1 (sludge:straw+wood chips:inoculum). In the Table 7 are provided equations for the polynomial trend lines fits for different heavy metals.

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Table 7. Polynomial trend line fit equations for heavy metals. *Y* marks the concentration of heavy metals in mg/kg, *X* marks the sample number from 1 to 10, *R-squared* value shows the trendline reliability (when R^2 is equal to 1, the trend line 100% fits the data).

HEAVY METAL	POLYNOMIAL 2nd ORDER FIT TRENDLINE	R^2
Zn	$y = -1.1354x^2 + 23.351x - 62.004$	0.86
Cu	$y = -0.7282x^2 + 14.908x - 23.171$	0.84
Cr	$y = 0.7704x^2 - 7.3709x - 14.269$	0.34
Cd	$y = 0.0033x^2 - 0.0281x + 0.0396$	0.62
Pb	$y = -0.081x^2 + 1.6687x - 2.2979$	0.72
Ni	$y = 0.2121x^2 - 2.0485x - 4.3$	0.37
Hg	$y = 0.0005x^2 + 0.0088x - 0.034$	0.65

Using PTF's data for heavy metals the change of the concentrations of the heavy metals for the composting of the sewage sludge generated at wastewater plant "Klaipėdos Vanduo" was predicted. The prediction of the concentrations of the heavy metals during composting of sewage sludge is given in Table 8.

Table 8. Predicted heavy metal concentration for composting process of the sewage sludge produced at wastewater plant „Klaipėdos Vanduo" during the period of 140 days with resulting sludge compost class.

PREDICTION OF CONCENTRATION OF HEAVY METALS IN SEWAGE SLUDGE AFTER 140 DAYS OF COMPOSTING							
Heavy metal type	**Zn**	**Cu**	**Cr**	**Cd**	**Pb**	**Ni**	**Hg**
mg/kg	856.47	303.69	28.46	1.23	29.69	19.93	0.64
LAND 20-2005 CLASS	**II**	**II**	**I**	**I**	**I**	**I**	**I**

Although, the predictions of the concentrations show slight increase for all heavy metals, after 140 days composting process the only *Zn* and *Cu* concentrations can be assigned to the II[nd] category, whereas all other concentrations can be assigned to the Class I.

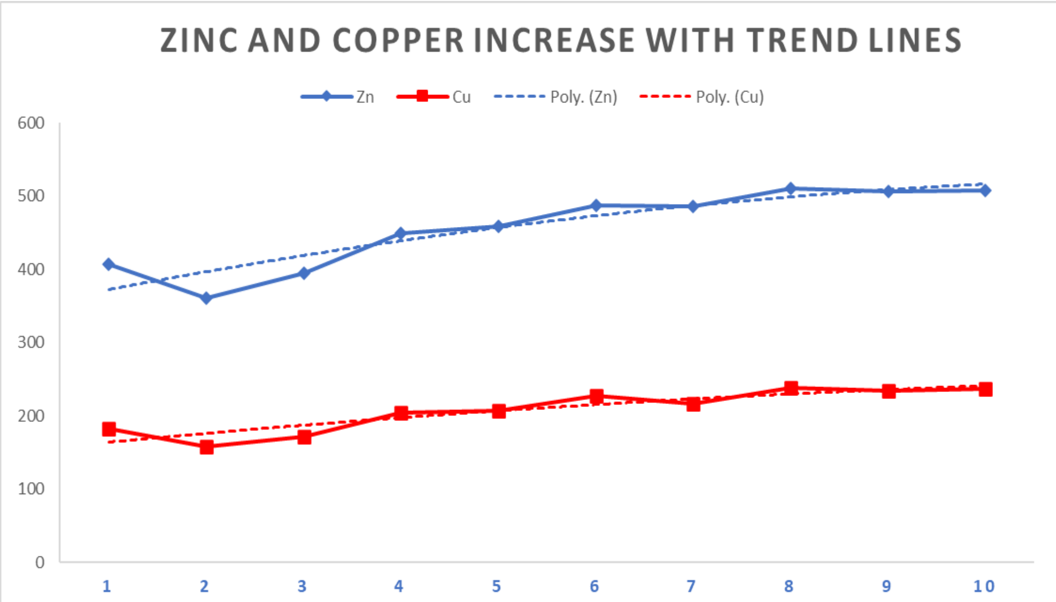

Figure 4. *Zn* and *Cu* concentration charts with resulting polynomial trend lines, during 140 days sludge composting period. *Y*-axis marks the units in mg/kg in dry mass, *X*-axis marks samplings.

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The charts of the *Zn* and *Cu* concentrations along with the resulting polynomial trend lines are presented in Figure 4.

4.3. Life Cycle Impact Assessment of the composting process

The LCIA was completed with modeling the process flows and using the open windrow composting scheme. The processes are listed as the transportation of the composting materials to the polygon: straw, wood chips and inoculum transportation → pre-treatment of the materials (mixing) → composting (rotting) → aeration during composting → after-treatment (sieving and separation of impurities) → transportation of sieving impurities to landfill and transportation of the recyclables to composting polygon → transportation of eco-fertilizer to the agriculture facilities. The modeling scheme is provided in the Figure 5.

The main material in the scheme is chosen the compost, as an elementary flow (GaBi, 2012) with the resulting emissions to the environment as a consequence of processes of composting chain.

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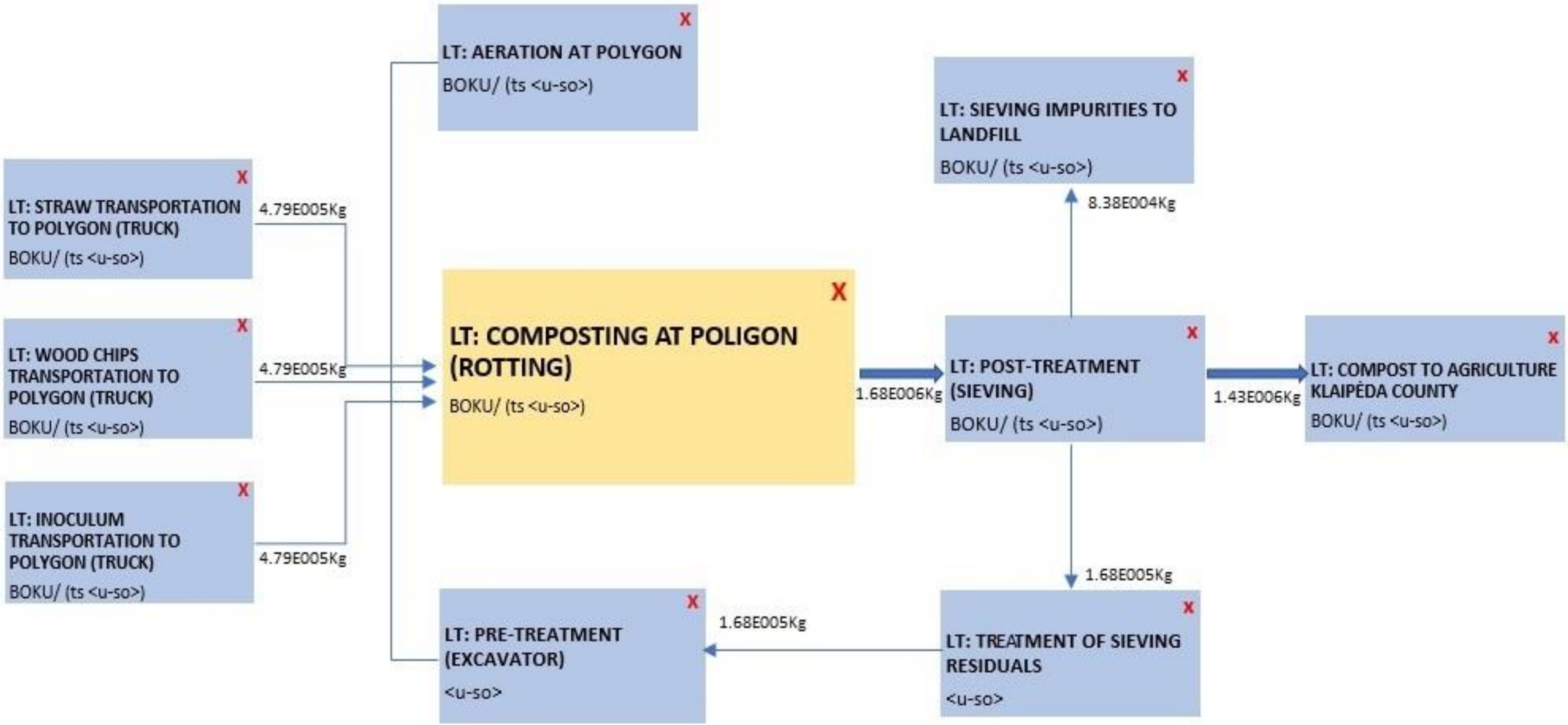

Figure 5. Modeled flows of the sewage sludge composting at wastewater plant „Klaipėdos Vanduo“ („*X*“ marks the valuable flows in the model).

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The modeling results of the LCIA show the total index of the Global warming (GWP) potential; as well, Air acidification criteria (AP); Human health criteria in air (HHA) and Smog Formation Potential for Air Emissions (SA), that are depicted in the Figures 6-9. The charts represent the separate indices of every modelled processes as well, as total indices (complete output is given in the ANNEX I).

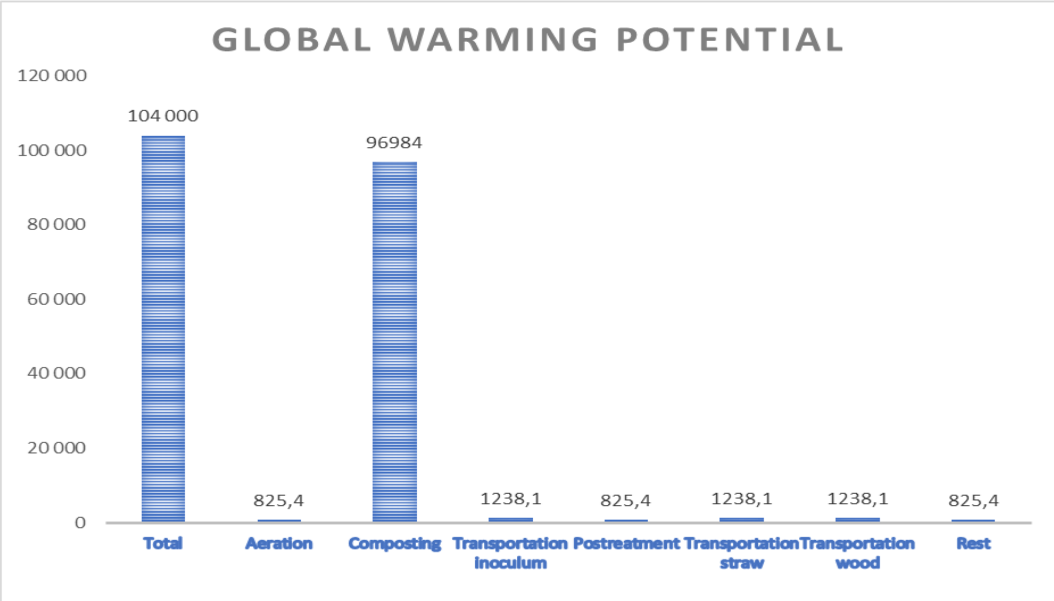

Figure 6. Modeled potential of the Global Warming Air. *Y*-axis marks the units in kg CO_2 Equivalent.

The GWP criteria is determined mostly by composting (rotting) process. The resulting total GWP for the 3353.5 tons of the renewable material (ratio 4:1:1:1) composting process reaches the 104.0 tons CO_2 Equivalent with inclusion of transportation of the materials across the Klaipėda district. The GWP per 1 ton of the renewable material composting process results with the 31 Kg of the CO_2Equivalent.

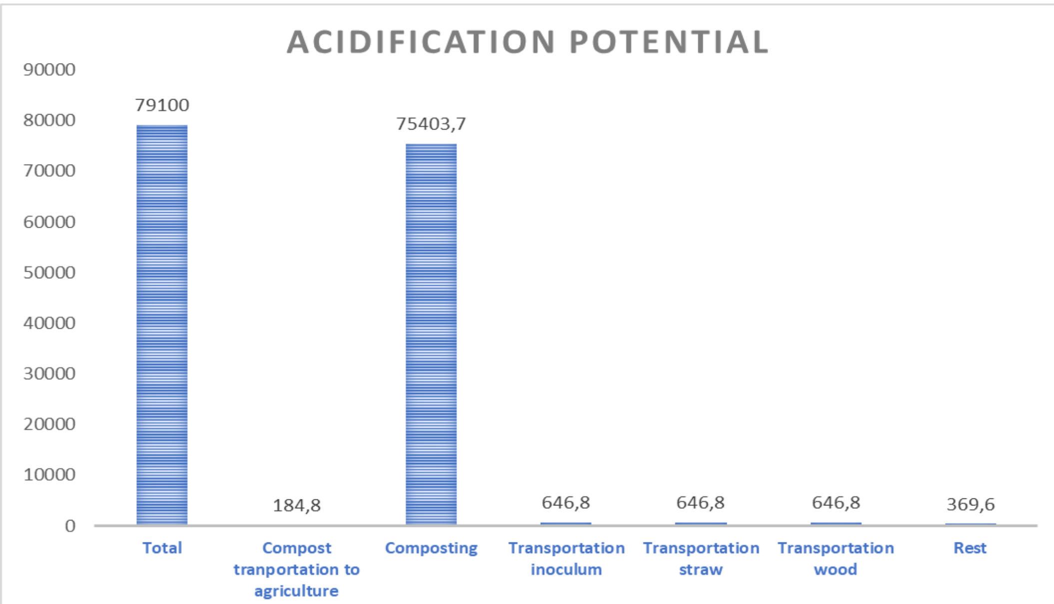

Figure 7. Modeled potential of the Acidification Air. Y-axis marks units in moles H+ Equivalent.

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Figure 7 reflects the Air acidification potential (AP) index. The rotting process determines the resulting total index of acidification as well, as in the GWP index, reaching the total value of 79.1 K H+moles Equivalent.

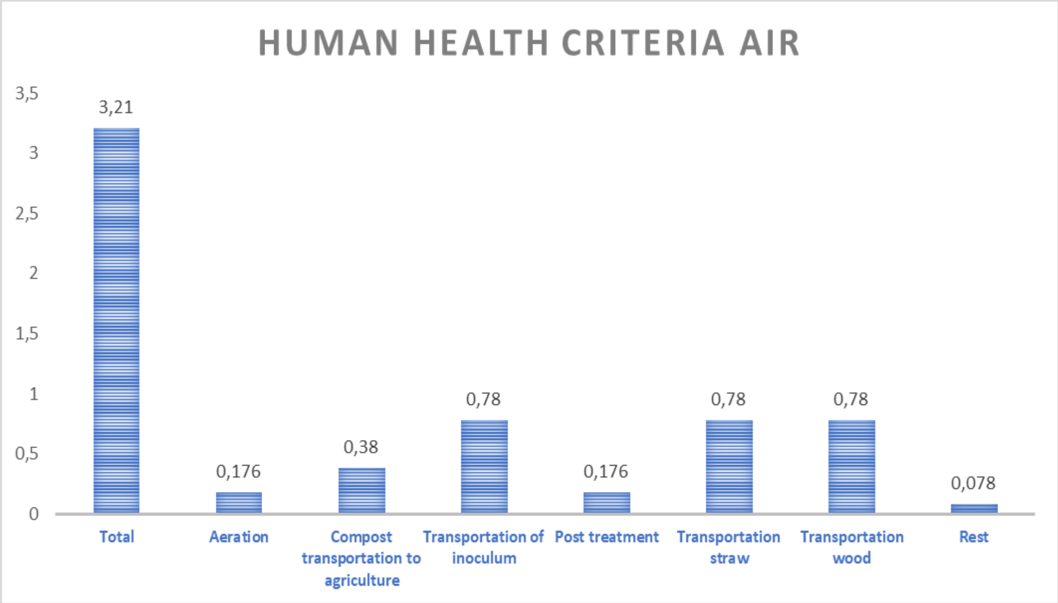

Figure 8. Modeled Human health criteria Air. *Y*-axis marks units in Kg PM10 Equivalent.

The modeling results of the Human health criteria in air reached its total value of 3.21 kg PM10 Equivalent (Particulate matter). In contrast to the GWP and AP modeled indices the HHA was mainly determined by the atmospheric emission of the machinery used for transportation, excavation and sieving (Figure 8).

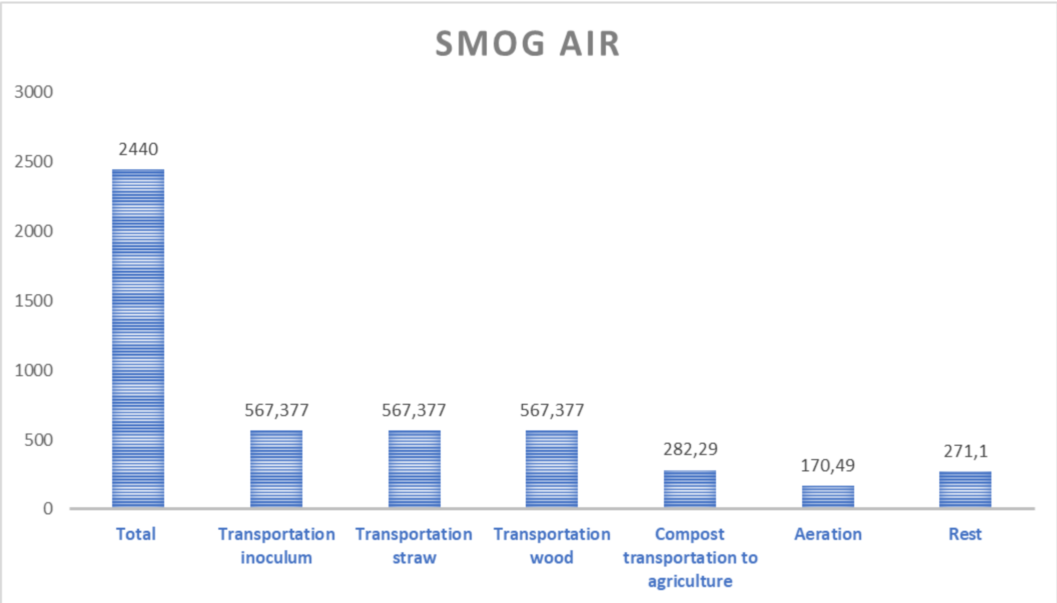

Figure 9. Modeled potential of the Smog Air. *Y*-axis marks the units in Kg 0_3 Equivalent.

The modelled total Smog Air index (Smog Formation Potential for Air Emissions) reached the value of the 2440 Kg 0_3Equivalent, where the value of the total index was determined mainly by the atmospheric emissions of the machinery used for transportation, excavation and sieving vehicles used in CSS composting processes.

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To compare the CSS composting model with an alternative scenario, the hypothetical environmental emissions of the sewage sludge incineration at incineration plant “Akmenės” cement were modeled using an available data. The modeled indices of the GWP criteria reached the value of the 750 tons CO_2 Equivalent, equal to atmospheric emissions of the 391.4 Kg of CO_2Equivalent per ton of incinerated sludge. The resulting total emissions and emission for 1 ton of CO_2 are 7.21 and 12.6 times higher than emissions of CSS composting scheme with inclusion of material transportation, excavation and sieving emissions. The Smog Formation Potential for Air Emissions for the sludge incineration emissions of the sewage sludge at plant “Akmenės” cement results in 16200 Kg 0_3Equivalent, that is 6.6 times higher in comparison with CSS composting scheme.

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4.4. Capabilities of the produced compost application in agriculture

At the Klaipėda district the arable areas purposed for agriculture reach the size of the 54666.2 hectares. The sewage sludge and its compost in these areas can not be applied for fertilization due to local legal regulations. In 40% of this area it is allowed to use the CSS of the Class I. Forestry areas in Klaipėda district constitutes the size of the 36822.66 hectares. Only in the small area of 760 - 1266 hectares the land fertilization can be done using the CSS due to legal background.

Abandoned land in Klaipėda district has an area of the size of the 609.3 hectares. In these areas the CSS can be used for fertilization without restrictions.

In total the CSS of the class II can be applied for the fertilization purposes in 1875.3 hectares at Klaipėda district with fertilization rate of 7-15 tons per hectare. This fertilization rate would allow to use up to 14000 tons of CSS produced at waste water plant "Klaipėdos Vanduo" in agriculture every year (personal communication Karčauskienė, 2021). The produced quantities of the CSS at "Klaipėdos Vanduo" plant reach the quantities of ~5000 tons per year with assumed 50% of the dry mass quantity. The application of CSS in agriculture would reduce the sludge quantities at existing stockpiling sites of the waste water treatment plant.

Its notable that treatment of the produced CSS using the phytoremediation techniques or other techniques would increase the qunatities of the CSS that could be used in agriculture in Klaipėda district areas.

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5. MAIN FINDINGS AND CONCLUSIONS

The acquired results reveal the potential of the municipal wastewater treatment plant "Klaipėdos Vanduo" produced sewage sludge composting and its application capabilities in agricultural areas. The analysis of the available data show that during the waste water sludge composting process lasting for 140 days, the concentration of the heavy metals increases only slightly due to increase of the dry mass, though after composting the CSS would fall in to the CLASS II according to the Lithuanian national legislation (LAND20-2005). Its found that municipal waste water treatment plant "Klaipėdos Vanduo" produced CSS after composting process would have the Zinc and Copper, the two heavy metals exceeding the concentrations regulated for CLASS I. These concentrations can be removed applying the phytoremdiation technology or other effective technologies such as solutions of the Citric acid, that has high removal of *Zn* and *Cu* efficiency (Zaleckas et al., 2012).

From the research findings a few main conclusions can be drawn:

- The composting of the sewage sludge produced at "Klaipėdos Vanduo" waste water plant only slightly increases the concentrations of heavy metals due to increase of its dry mass;
- The increase of heavy metals concentrations during composting process can be controlled using the phytoremediation or other removal techniques;
- The LCIA modelling of the sewage sludge composting show the environmental emissions less by 12.6 times comparing to incineration of compost at Akmen4 cement incineration plant;
- Analysis of the compost applicability at Klaipėda district reveals high potential of the compost usage for fertilization.

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ANNEX I

THE MODEL OUTCOME OF THE CSS COMPOSTING PROCESSESS

LT: STRAW TRANSPORTATION TO POLYGON (TRUCK) BOKU / ts <u-so>	
TRACI 2.0, Acidification Air [H+ moles eq.]	893
TRACI 2.0, Eutrophication [kg N eq.]	0.924
TRACI 2.0, Global Warming Air [kg CO2 eq.]	1.43E+03
TRACI 2.0, Human Health Criteria Air [kg PM10 eq.]	0.787
TRACI 2.0, Smog Air [kg O3 eq.]	569
LT: WOOD CHIPS TRANSPORTATION TO POLYGON (TRUCK) BOKU / ts <u-so>	
TRACI 2.0, Acidification Air [H+ moles eq.]	893
TRACI 2.0, Eutrophication [kg N eq.]	0.924
TRACI 2.0, Global Warming Air [kg CO2 eq.]	1.43E+03
TRACI 2.0, Human Health Criteria Air [kg PM10 eq.]	0.787
TRACI 2.0, Smog Air [kg O3 eq.]	569
LT: MATURE COMPOST TRANSPORTATION TO POLYGON (TRUCK) BOKU / ts <u-so>	
TRACI 2.0, Acidification Air [H+ moles eq.]	893
TRACI 2.0, Eutrophication [kg N eq.]	0.924
TRACI 2.0, Global Warming Air [kg CO2 eq.]	1.43E+03
TRACI 2.0, Human Health Criteria Air [kg PM10 eq.]	0.787
TRACI 2.0, Smog Air [kg O3 eq.]	569
LT: PRE-TREATMENT (EXCAVATOR) <u-so>	
TRACI 2.0, Acidification Air [H+ moles eq.]	55.7
TRACI 2.0, Eutrophication [kg N eq.]	0.0616
TRACI 2.0, Global Warming Air [kg CO2 eq.]	155
TRACI 2.0, Human Health Criteria Air [kg PM10 eq.]	0.0369
TRACI 2.0, Smog Air [kg O3 eq.]	34.5
LT: COMPOSTING AT POLYGON (ROTTING) BOKU / ts <u-so>	
TRACI 2.0, Acidification Air [H+ moles eq.]	7.53E+04
TRACI 2.0, Eutrophication [kg N eq.]	93.5
TRACI 2.0, Global Warming Air [kg CO2 eq.]	9.69E+04
TRACI 2.0, Smog Air [kg O3 eq.]	24.1
LT: AERATION AT POLYGON BOKU / ts <u-so>	
TRACI 2.0, Acidification Air [H+ moles eq.]	279
TRACI 2.0, Eutrophication [kg N eq.]	0.308
TRACI 2.0, Global Warming Air [kg CO2 eq.]	777
TRACI 2.0, Human Health Criteria Air [kg PM10 eq.]	0.185
TRACI 2.0, Smog Air [kg O3 eq.]	173
LT: POST-TREATMENT SIEVING BOKU / ts <u-so>	
TRACI 2.0, Acidification Air [H+ moles eq.]	279
TRACI 2.0, Eutrophication [kg N eq.]	0.308
TRACI 2.0, Global Warming Air [kg CO2 eq.]	777
TRACI 2.0, Human Health Criteria Air [kg PM10 eq.]	0.185
TRACI 2.0, Smog Air [kg O3 eq.]	173
LT: TREATMENT OF SIEVING RESIDUALS <u-so>	
TRACI 2.0, Acidification Air [H+ moles eq.]	55.7
TRACI 2.0, Eutrophication [kg N eq.]	0.0616
TRACI 2.0, Global Warming Air [kg CO2 eq.]	155
TRACI 2.0, Human Health Criteria Air [kg PM10 eq.]	0.0369
TRACI 2.0, Smog Air [kg O3 eq.]	34.5
LT: SIEVING IMPURITIES TO LANDFILL (TRUCK) BOKU / ts <u-so>	
TRACI 2.0, Acidification Air [H+ moles eq.]	9.87
TRACI 2.0, Eutrophication [kg N eq.]	0.0102
TRACI 2.0, Global Warming Air [kg CO2 eq.]	16
TRACI 2.0, Human Health Criteria Air [kg PM10 eq.]	0.0133
TRACI 2.0, Smog Air [kg O3 eq.]	6.2

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LT: COMPOST TO AGRICULTURE KLAIPEDA COUNTY BOKU / ts <u-so>	
TRACI 2.0, Acidification Air [H+ moles eq.]	447
TRACI 2.0, Eutrophication [kg N eq.]	0.462
TRACI 2.0, Global Warming Air [kg CO2 eq.]	716
TRACI 2.0, Human Health Criteria Air [kg PM10 eq.]	0.393
TRACI 2.0, Smog Air [kg O3 eq.]	285

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