Investigation for landfill mining feasibilities in the Nordic and Baltic countries: overview of project results

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Abstract

Landfills are considered as places where the life cycle of products ends and materials have been "disposed forever". The landfill mining (LFM) approach can deal with former dumpsites and this material may become important for circular economy perspectives within the concept "Beyond the zero waste". Potential material recovery should include perspectives of recycling of critical industrial metals where rare Earth elements (REEs) are playing more and more important role. Real-time applied LFM projects in the Baltic Sea Region countries, Sweden, Finland, Estonia, Latvia and Lithuania, have shown the potential of fractions of excavated waste. Analytical screening studies have extended a bit further the understanding of fraction contents of excavated, separated and screened waste in a circular economy perspective including recycling and energy recovery. The Swedish Institute and other national programs and private authorities have supported the research.

Keywords: landfill mining, waste excavation, coarse and fine fractions, recycling, energy recovery .

1. Introduction

The proposition that landfilling is the lowest waste management priority [1], has long been a textbook truth. This is reflected not only in the European Union (EU) law, but also in the practical situation by implementation of circular economy principles – waste recycling and energy recovery from waste are predominated in majority of EU15, while, in the new EU countries, the trend for landfilling reduction is significant. Herewith landfilling can cease to be the last waste management priority and in fact become a function of waste temporary storage and noticeable element of circular economy due to growing interests for urban and landfill mining for material and energy recovery. Currently many academic institutions and authorities from Nordic and Baltic countries are in close cooperation regarding participation in several common projects for investigation of landfill mining feasibilities. This activity is also expressed, both by membership of some Swedish, Danish, Finish and Estonian authorities in EURELCO (European Enhanced Landfill Mining Consortium) and by participation of Danish, Swedish, Finish, Estonian, Latvian and Lithuanian universities in COST activity "Mining of European Antroposhere" (MINEA).

The aim of this study is to assess the potential for materials recycling and fuel recovery from closed and operating MSW landfills in the Nordic and Baltic EU countries based on the statistical data on municipal solid waste (MSW) landfilling and waste fractions' decomposition properties. The obtained assessment data are compared with results of practical investigation in the selected landfills.

2. Overview of situation on waste management and landfilling in the target countries

Before evaluation of MSW management status in each target country the main waste generation influencing factors, as population size and gross domestic product (GDP) per capita, in the investigated period 1995-2015 are shortly characterized (Fig. 1 and 2).

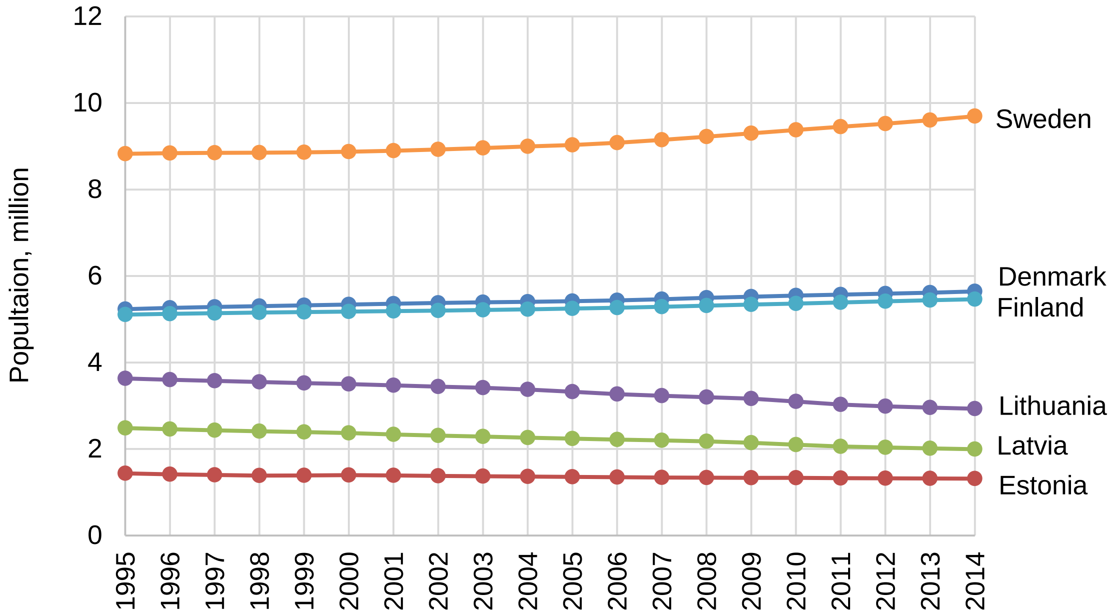

Fig. 1 Population dynamics in the Nordic and Baltic countries, 1995-2014 [2]

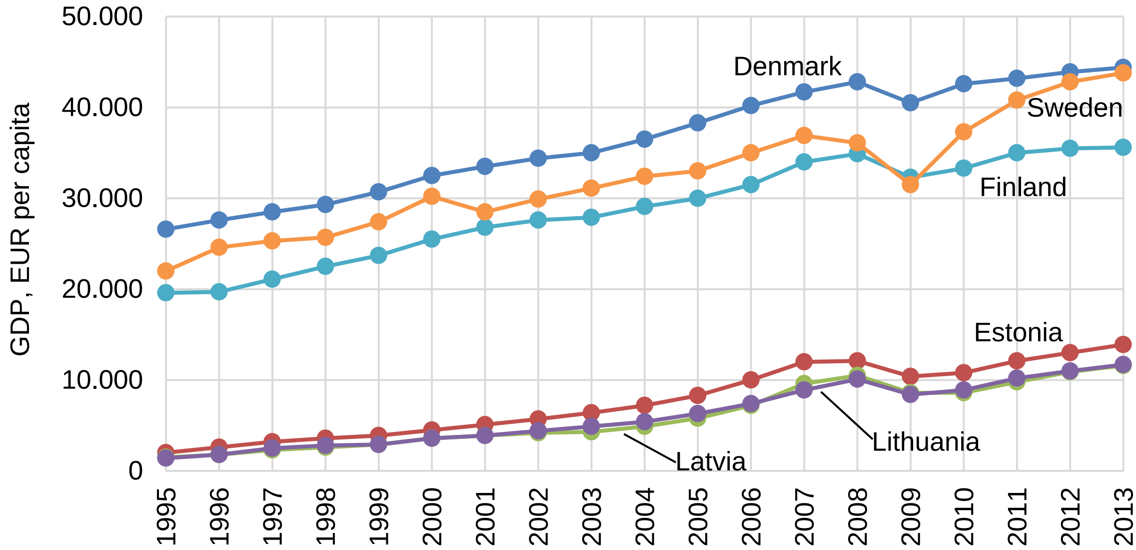

Fig. 2 Dynamics of GDP per capita in the Nordic and Baltic countries, 1995-2013 [3]

The common trend of increase in GDP per capita for all target countries is observed, only global economic crisis in 2008 resulted in a certain drop. However, the gap between GDP in Nordic and Baltic countries respectively still remains significant. Also, in the Baltic countries the significant decrease of population number due to economic emigration is characteristic, Estonia has the lowest decrease. Meanwhile the population number in Nordic countries is growing due to immigration from Middle and East Europe and third countries, directly influencing the rate of waste generation.

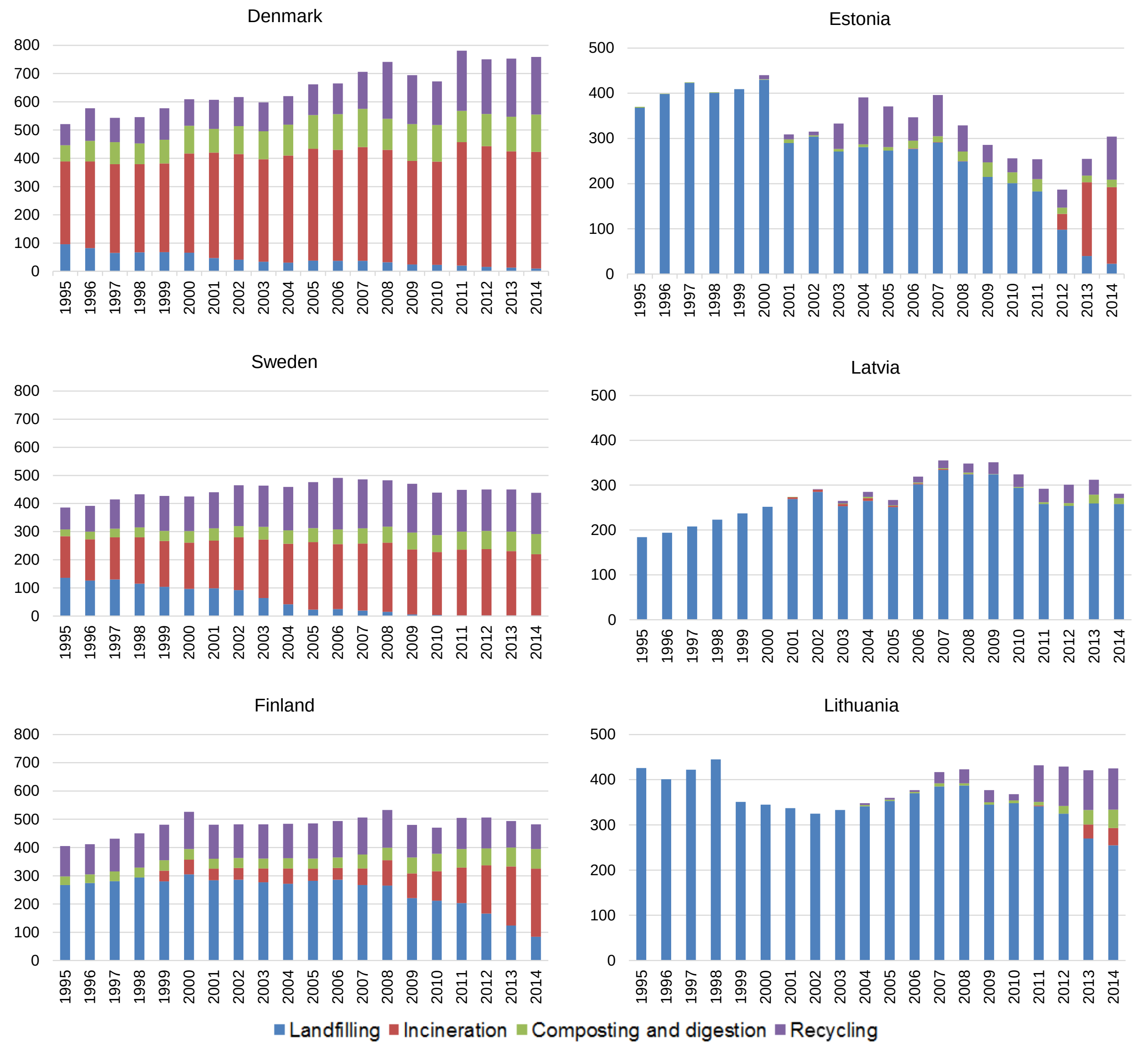

Fig. 3 MSW generation and treatment in the Nordic and Baltic countries, 1995 – 2014, kg per capita [4]

By assessing the MSW and domestic packaging waste (DPW) common generation per capita the linear correlation with GDP per capita is evident because annual fluctuation of waste amounts essentially coincides with GDP fluctuation. In Denmark and Sweden, the necessary reduction of MSW landfilling has been achieved before 15–20 years, and now the flows of MSW and DPW are recycled or incinerated. In Finland, the landfilling reduction has been achieved 5 years ago. Similar development tendency now can be observed in Estonia. Currently, Lithuania approaches 50% MSW and DPW recovery and other use, while, in Latvia, the situation of MSW treatment remains unsatisfactory.

Although, Denmark is the greatest waste generator among the target countries (on average, 650 kg/ca between 1995 and 2014), its total amount of accumulated waste in landfills is the smallest – less than 5000 kt (see Fig.4). Meanwhile, Lithuania and Finland have the highest cumulative landfilled waste amount (23700 kt and 25800 kt, respectively), hence having the highest potential for landfill mining with respect to the overall recoverable amount.

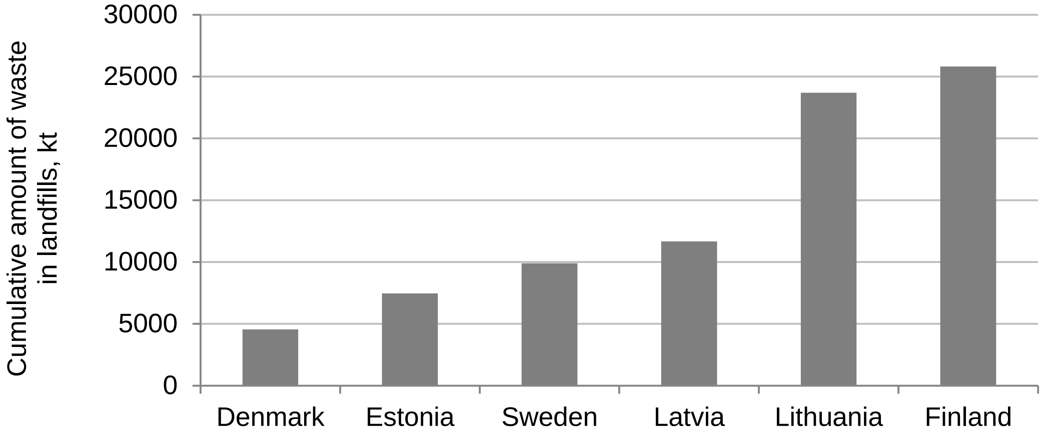

Fig. 4 Amount of MSW accumulated in landfills in the Nordic and Baltic countries, 1995 – 2014 (developed based on [4])

In Denmark, 3 115 landfill sites have been registered. Most of these are old dumpsites without permits, liner- and leachate collection systems and approximately 500 are considered as potential risk to the environment, as they have a content of hazardous chemical substances. All landfills have been registered as "contaminated sites" and today some of them have an active remediation to protect the groundwater. Currently in Denmark, a total of 41 active landfills are in operation. 6 of them are industrial landfills and the rest are landfills owned by municipal waste management companies (public sector) [5].

In Sweden, less than 1% of trash ends up in landfills. Landfill is only a small part of the operation at a modern waste treatment plant. Most waste treatment plants also sort waste materials for reuse, recycling and energy recovery. Sometimes landfill sites also serve as temporary storage for waste fuel and waste that falls under producer responsibility, such as paper and glass. Plants often treat biodegradable waste and contaminated excavated material. Closed landfill sites must be capped. Together these landfills cover an estimated area of 25 km^2. Every year, approximately 6-8 million tons of material are used for capping landfill sites. Materials such as slag, sludge, ash and contaminated soil are used in the various capping layers. Most of the landfill sites closed due to stricter regulations, introduced in 2008, will be capped by 2030 [6].

The number of landfills in Finland has been declining strongly during the past years because of the strict requirements for the base structure of landfills. Currently 167 landfills for soil, 27 landfills for hazardous waste, 37 landfills for permanent waste, 137 landfills for regular waste (inc. municipal waste) and 29 other landfills are in operation [7].

In Estonia, the number of MSW landfills has diminished from 350 in 1990-ies until in 2009 all remaining incompliant landfills were closed for disposal. All the waste in Estonia is currently transported to five centralized landfilling sites. All landfills which were closed in 2009 had to be capped by July 2013 [8].

There were listed 558 dumpsites in Latvia in 1990's. As a result of Council Directive 1999/31/EC on the landfill of waste [9] the strategy "500-" was developed intending closure and remediation of the dumpsites, development of waste management regions and construction of sanitary landfills. At the moment almost all dumpsites are closed, and ten waste management regions with 11 sanitary municipal solid waste landfill sites are in operation, one landfill for hazardous waste and one landfill for asbestos containing waste are constructed [8,10].

Lithuania counted up to 844 of closed MSW landfills of different sizes and 2 closed landfills for construction and demolition waste, where during their operation time more then 3.4

million tons of waste have been landfilled. Regarding the EU support many of these landfills have been already remediated, the largest of which have installed landfill gas collection systems. Currently, in Lithuania 11 modern regional MSW landfills are exploited [11].

3. Research objects and methods

3.1 Desk research: assessment of landfilled waste composition

First, the average composition of the generated MSW and DPW was estimated. To this purpose, the dependencies of MSW fractions (food and yard waste, paper and cardboard, glass, metals, other) contents on common MSW waste generation per capita (it corresponds the prosperity level) have been estimated according to Beigl et al. (2004) [12]. This dependency is characterized by simple linear equation, where both share of fraction and common MSW amount may be expressed in the same units:

$$MSW_{fraction} = a \cdot MSW + b, \quad (1)$$

where *a* is the slope coefficient of the equation, and *b* is the intercept coefficient. *a* and *b* values for each MSW fraction are presented in Table 1.

Table 1. Slope *a* and intercept *b* for estimation of MSW fractions in the common MSW flow

MSW fraction	Slope *a*	Intercept *b*
Food and yard waste	0.1624	77.5
Paper and cardboard	0.3547	58.130
Glass	0.1368	-19.701
Plastics and composites	0.1624	-21.207
Metals	0.0246	7.046
Other	0.1592	14.450

Further it is considered that the composition of landfilled waste remains the same as for the common flow. Meanwhile, the share of sub-fractions in some other fraction is defined , i.e. wood 3%, textile 60%, leather and rubber 12%, inert material 25%.

After decomposing, the remaining preserved amount of each MSW fraction in landfill is calculated with respect to retention time of landfilled materials and decay rate [13]:

$$FRACTION\ j^{n}_{rem.} = \sum_{i=1}^{n} FRACTIONj^{i}_{land.} \cdot \exp[-k(n-i)], \quad (2)$$

where $FRACTION\ j^{n}_{rem.}$ is the total amount of MSW fraction *j* remained after landfilling and decomposing within *n* year period; $FRACTIONj^{n}_{land.}$ - within the year *i* landfilled MSW *j* fraction amount; *k* – rate constant for waste fraction decay.

The amounts of coarse and fine fractions are estimated after consideration that coarse fraction ($COARSE^{n}_{rem}$) includes remained paper, plastic, glass, metals and other fractions. Herewith the fine fraction includes the mineral part of all decayed waste fraction, remained biowaste in the form of humus and soil added during landfilling as cover material – 20 % per landfilled MSW mass unit.

Thus, coarse and fine fractions formed in landfills in *n-th* year are calculated as follows:

$$COARSE^{n}_{rem} = \sum FRACTIONj^{n}_{rem} - BIOWASTE^{n}_{rem} \quad (3)$$

$$FINE_{rem}^{n} = \left[\sum\left(FRACTIONj_{land}^{n} - FRACTIONj_{rem}^{n}\right)\cdot\left(100 - DMj\right)\cdot\left(100 - ODMj\right)\right] + BIOWASTE_{rem}^{n} + GROUND^{n}$$
(4)

$$GROUND^{n} = MSW^{n} \cdot 20\%, \quad (5)$$

where DMj is the dry material content, %, for each MSW j fraction; $ODMj$ is the organic dry material content, % DM, for each MSW j fraction; $BIOWASTE^{n}{}_{rem}$ is the biowaste (food and yard
waste) fraction remained in landfill as humus within n year
; $GROUND^{n}$ is the soil added during landfilling as cover material within n year; MSW^{n} is the landfilled MSW amount within n year.

Alongside the energetic potential, PJ, stored in landfills in the form of refuse derived fuel or RDF ($U^{n}{}_{rem}$) is calculated as follows:

$$U^{n}{}_{rem} = \Sigma(FRACTION\, j^{\,n}{}_{rem} \cdot Hj), \quad (6)$$

where Hj is the heat value of fraction j, MJ/kg. Values of k, DM, ODM and H for all MSW fractions are presented in Table 2.

Table 2. Indicators characterizing MSW properties

MSW fraction	**Decay rate *k***	**Dry material *DM*, %**	**Organic dry material *ODM*, % DM**	**Heat value *H*, MJ/kg**
Food and yard waste	0.185	20	95	-
Paper and cardboard	0.07	90	94	15.81
Plastics and composites	0.004	96	90	32.8
Glass	0.002	96	-	-
Metals	0.01	96	-	-
Wood	0.04	80	98.5	17.1
Textile	0.07	85	97.5	18.51
Leather and rubber	0.04	85	90	17.45
Inerts	0.002	88	0	-

3.2 Field research: selected landfills in the target countries

Several projects of closed or operating landfills have been selected for field research in each target country. Overall, three landfill sites of shredder residues in Denmark, two closed MSW landfills in Sweden and Finland, and one - in Estonia, four operating MSW landfills in Latvia, and two operating MSW landfills and one closed landfill for construction and demolition waste in Lithuania were assessed. The locations, names and technical information important for investigation of landfills are presented in the Tables 3 and 4. The morphological composition of extracted samples has been established by sieving, manual sorting and weighting.

4. Results

The theoretical calculation results of average content of landfilled and decayed waste, as well as recycling and energy production potential in each target country are presented in Table 5. Field research results regarding landfilled waste composition in the selected landfills are presented in Tables 6 and 7.

Table 3 Location and technical characteristics of selected landfills in the Nordic countries

Country	Denmark			Sweden		Finland	
Region	Falster	Copenhagen	Odense	Stockholm	Simrishamn	South Karelia	Northern Savo
Landfill name	Gerringe	AV Miljø	Odense Nord Miljøcenter	Högbytorp	Måsalycke	Lappeenranta	Kuopio
Type of landfilled waste	MSW	MSW	Shredder residue	MSW and industrial wastes	MSW	MSW, C&D, landwaste	MSW
Year for starting of exploitation				1964	1975	1972	2001
Year of closure/end of exploitation	Still operating	Still operating	Still operating	Still operating	2008	2001	2011
Landfilled waste amount, kt	460 000	1 600 000	903177	35000		1 056	
Year of investigation	2011	2016	2010	2014	2000	2012	2012
Project promoter	REFA I/S	AV MIljø	DHI, SDU	Ragn-Sells AB	SYSAV	LUT	VTT
Method of sampling/investigation	Excavation	Excavation	Excavation	Excavation	Excavation	Sampling & examination prior to landfilling	Drilling
Maximum depth of investigated layers, m	14	4	22	4	8		31

Table 4 Location and technical characteristics of selected landfills in the Baltic countries

Country	Estonia		Latvia				Lithuania		
Region	Torma	Saaremaa	Valmiera	Ventspils	Liepaja	Riga	Alytus	Vilnius	Vilnius
Landfill name	Torma	Kudjape	Daibe	Pentuļi	Ķīvītes	Getliņi	Takniškės	"Bionovus"	Kazokiškės
Type of landfilled waste	MSW	MSW	MSW	MSW	MSW	MSW	MSW	C&D	MSW
Year for starting of exploitation	2000	1971	2004	2004	2004	2005	2009		2009
Year of closure/end of exploitation	Still operating	2009	Still operating	Still operating	Still operating	Still operating	2012	2014	Still operating
Landfilled waste amount, kt	300 000 t		367205	188734	526857	3199120	329		

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<tr><th>Country</th><th colspan="2">Estonia</th><th colspan="4">Latvia</th><th colspan="5">Lithuania</th></tr>
<tr><td>Year for investigation</td><td>2015</td><td>2013</td><td>2015</td><td>2015</td><td>2015</td><td>2012</td><td>2014</td><td>2014</td><td colspan="3">2014</td></tr>
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<tr><td>Method of sampling/investigation</td><td>Excavation</td><td>Excavation</td><td>Sampling & examination prior to landfilling</td><td>Sampling & examination prior to landfilling</td><td>Sampling & examination prior to landfilling</td><td>Sampling & examination prior to landfilling</td><td>Drilling</td><td>Excavation</td><td colspan="3">Excavation</td></tr>
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Table 5 Theoretically established average MSW composition and resources potential after landfilling and decay in the Nordic and Baltic countries

Country	**Denmark**	**Sweden**	**Finland**	**Estonia**	**Latvia**	**Lithuania**
Number of existing landfills (exploited and closed in the period of 1995-2015)	~105	~ 300	~370	~370	~570	~ 840
Landfilled MSW amount at 1995-2015, kt	4 551	9 898	25 820	7 461	11 670	23 691
Possibly added ground at 1995-2015, kt	910	1 980	5 164	1 492	2 334	4 738
Waste amount in landfills with added ground after decomposing, kt, of which	4 353	9 049	24 526	7 979	10 661	22 391
fine fraction with added ground, kt	2 153	4 815	11 835	4 668	5 397	11 321
coarse fraction, kt	2 200	4 234	12 691	3 311	5 264	11 070
Established average landfills' composition, %:						
fine fraction with added ground	49,46	53,21	48,25	58,50	50,62	50,56
coarse fraction	50,54	46,79	51,75	41,50	49,38	49,44
combustible, of which	*31,70*	*27,81*	*34,65*	*25,41*	*30,97*	*31,12*
paper and cardboard	12,20	9,44	12,85	9,07	11,30	11,73
plastics	13,19	12,42	12,55	10,12	10,69	11,56
wood	0,33	0,34	0,58	0,33	0,44	0,39
textiles	4,78	4,41	7,67	4,72	6,94	6,02
rubber and leather	1,21	1,21	1,00	1,18	1,60	1,42
uncombustible, of which	*18,84*	*18,98*	*17,09*	*16,08*	*18,41*	*18,32*

Country	**Denmark**	**Sweden**	**Finland**	**Estonia**	**Latvia**	**Lithuania**
glass	11,14	10,41	10,47	8,36	8,62	9,52
metals	3,14	3,60	3,48	3,35	4,41	3,83
inerts	4,56	4,97	3,13	4,38	5,37	4,96
Heat value, MJ/kg	23,36	23,92	22,63	23,17	22,38	22,73
Energetic potential for excavated RDF, PJ	32,24	60,18	192,32	46,98	73,91	158,41
Energetic potential for RDF pyrolysis oil, PJ	14,51	27,08	86,55	21,14	33,26	71,29

Table 6 Morphological composition and resource potentials for selected landfills in the Nordic countries

Country	**Denmark** [13]			**Sweden**		**Finland**	
Landfill name	Gerringe	AV Miljø	Odense Nord Miljøcenter	Högbytorp	Måsalycke [14]	Lappeenranta	Kuopio [15]
Established common waste content, %:							
coarse fraction	49,1	44	12	24	54	100,0	48,0
fine fraction	50,9	56	88	76	46	-	52,0
Size of coarse fraction, mm	>25	>25	>45	>40	> 50	-	> 20
Coarse fraction content, %							
combustible, of which	41,9	43,0	70,1	7,2	15,1	10,2	43,0
paper	-	3	-	1,1	5,2	10,2	6,0
plastics	-	-	41,9	1,8	2,6	-	24,0
other combustible, of which	-	40	28,2	4,3	7,2	0,0	13,0
wood	-	-	7,1	3,6	5,3	-	6,0
nappies, san. towels	-	-			0,3	-	-
textiles	-	-	0,5	0,6	1,2	-	7,0
rubber	4,1	-	20,6	0,05	0,3	-	-
leather	-	-	-	-	-		-
biowaste, of which	-	-	-	-	-	32,9	0
food waste	-	-	-	-	0,3	-	-

Country	**Denmark** [13]			**Sweden**		**Finland**	
garden waste	-	-	-	-	0,6	-	-
uncombustible, of which	-	-	-	-	-	13,5	5,0
glass, ceramics	-	-	0,25	1,4	0,2	5,0	
metal	0,8	1	17,6	0,2	0,9	3,2	4,0
stones, etc.	2,3	-	5	6,8	7,4	-	-
other, of which	-	-	-	-	-	1,3	0
electronics	-	-	0,25	-	0,0	-	-
hazardous waste	-	-	-	-	0,1	1,3	-
miscellaneous•	-	-	6,8	8,4	29,4	-	-

Table 7 Morphological composition and resource potentials for selected landfills in the Baltic countries

Country	**Estonia**		**Latvia**				**Lithuania** [16,17]				
Landfill name	Torma	Kudjape	Daibe	Pentuļi	Ķīvītes	Getliņi	Takniškės	Bionovus	Kazokiškės		
Established common waste content, %:											
coarse fraction	46,0	NDA*	NDA*	NDA*	85,2	53,8	46,0		NDA*		
fine fraction	54,0	NDA*	NDA*	NDA*	14,8	46,2	54,0		NDA*		
Size of coarse fraction, mm	> 40				>40	> 20	> 40		>20		
Coarse fraction content, %											
combustible, of which	*26,2*	*22,4*	*25,2*	*21,0*	*31,6*	*47,1*	*64,0*	*26,8*	*74,1*	*48,9*	*26,2*
paper	3,2	5,6	8,0	5,7	16,2	1,0	15,3	0,0	0,0	3,8	3,2
plastics	8,3	11,0	11,8	4,7	11,8	21,0	7,1	22,9	50,6	21,6	8,3
other combustible, of which	14,7	5,8	5,4	10,6	3,6	25,1	41,7	3,9	23,5	23,5	14,7
wood	3,7	0,5	3,2	2,0		0,5	20,0	0,2	1,6	5,5	3,7
nappies, san. towels											
textiles	9,2					2,9	24,6	4,2	2,3	20,2	18,0
rubber	1,8		5,3	2,2	8,6	0,7		2,5	1,4	1,8	0,0
leather											

Country	**Estonia**		**Latvia**				**Lithuania** [16,17]				
Landfill name	Torma	Kudjape	Daibe	Pentuļi	Ķīvītes	Getliņi	Takniškės	Bionovus	Kazokiškės		
biowaste, of which			64,96	51,7	51,9	36,5	0	0,0	*60,6*	*22,7*	*49,2*
food waste						29,5					
garden waste						7,0					
uncombustible, of which	9,1	11,0	12,7	23,1	27,1	14,5	6,7	36,0	*12,6*	*3,2*	*1,9*
glass, ceramics	1,3	0,5	9,7	18,9	23,3	8,2	0,3		8,9	1,7	1,9
metal	5,2	0,5	3,0	4,2	3,8	3,2	3,6	6,0			
stones, etc.	2,0	10,1				3,1		30,0	3,7	1,5	0,0
other, of which		6,44				17,4	0,06	0,0			
electronics							0,02				
hazardous waste	0,7	0,5				0,2	0,04				
miscellaneous•		6,0				17,2					

*NDA – no data available

5. Conclusions

The Nordic and Baltic countries have close cooperation relations in solving environmental issues, including waste management. The experience of the Nordic countries is successfully transferred to the Baltic countries, e.g. currently almost all MSW generated in Estonia are stopped for landfilling due increased incineration and recycling. Despite noticeable progress in field of recycling and incineration, landfilling remains the main MSW disposal method in Latvia and Lithuania. Meanwhile many academic and industrial partners from the Nordic and Baltic countries started to collaborate in several projects regarding establishment of landfill mining feasibilities with resource recovery target. Theoretically obtained composition of landfilled and decomposed waste remains similar in all target countries, but practical investigations in selected landfills are different and even contradictory. However, in all cases obtained potential for solid recovered fuel, glass and metals seems realistic and suitable for extraction.

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