



(RESEARCH ARTICLE)



Life cycle assessment of municipal solid waste in Loksa city: Case study of Loksa city

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Abstract

This research offers a thorough life cycle assessment (LCA) of municipal solid waste (MSW) management in Loksa City, Estonia. The goal is to look at the current waste management methods and find better, more environmentally friendly, and cost-effective options. The study examines the origins, composition, and volume of waste produced in Loksa City in 2019, totaling 772,191 tons, with a comprehensive classification into packaging, biodegradable, hazardous, recyclable, and mixed categories. We looked at the current ways of collecting trash and using containers, and then we broke down how to deal with recyclable, hazardous, and mixed waste. The study uses letters (like A, R, HWU, T1–T3) to figure out the total costs and possible profits from recycling, burning, and putting things in a landfill.

We looked at three options (I, II, and III) and one sub-option (IIIa). Alternative I, which includes partial recycling, sorting at a material recovery facility (MRF), and burning of leftover materials, was the best choice in terms of cost and the environment. Alternative II (direct incineration) and Alternative III (landfilling) were both more expensive and more dangerous to the environment than the other options. To make waste more sustainable in Loksa, the study suggests improving recycling processes, reducing reliance on landfills, and encouraging circular economy principles. Policy implications entail investment in MRF infrastructure and incentives for the segregation of biodegradable waste.

Keywords: Municipal Solid Waste (MSW); Life Cycle Assessment (LCA); Waste Management Alternatives; Circular Economy; Recycling and Incineration

1. Introduction

The enormous amount of waste created and, as a result, the enormous difficulty in eliminating it is still a problem in developed societies. This issue is rooted in the existing society's economic structure of production and consumption, which is rapidly producing waste. This rise in waste production puts people's health and the environment at risk (Tejedor, 2011).

To contribute to proper waste management, new tools must be designed and implemented that enable users to reduce the amount of waste produced while also enhancing waste management. Furthermore, the volume and composition of waste generated may be affected by a variety of factors such as the time of year, the environment, the level of growth, the standard of living, eating habits, and so on (Aranda Usón et al. 2012; Mendoza & Izquierdo 2007; Tchobanoglous et al. 1993).

Taking loksa city as a case study, the aim and objective of this report is to investigate and evaluate the various waste management options that could be recommended to the Loksa city municipality. And the objective is to look into the waste composition and quantities in Loksa city; to assess different methods of waste collection and container options; to assess into the different recycling options and to advise on the best Loksa city alternative.

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2. Source, composition and quantities

2.1. Sources of MSW

Information was obtained from Jats classificator, MSW with code 15 make up Loksa's total waste including paper and cardboard, plastics, metallic, mixed, glass and metallic packaging containing residues of or contaminated by dangerous substances. and with code 20 which includes household waste and related commercial, manufacturing, and institutional waste. The total amount of MSW produced in 2019 was 772,191 tons, municipal wastes of 679,075 and packaging waste 93,116. 2019 (Jats classificatory).

2.2. Composition and quantities

For composition and quantities more explanation will be given under table 1 and 2 below

Table 1 Packaging waste composition and quantity 2019, (Jats classificatory, 2019)

YEAR	WASTE SUBGROUP	WASTE CODE	WASTE TYPE	WASTE SUBGROUP NAME	TOTAL INCREASE IN TONS
2019	15 01	15 01 01	Paper and cardboard packaging	Packaging (including separately collected municipal packaging waste)	11.509
2019	15 01	15 01 02	Plastic packaging	Packaging (including separately collected municipal packaging waste)	15.934
2019	15 01	15 01 04	Metallic packaging	Packaging (including separately collected municipal packaging waste)	6.476
2019	15 01	15 01 06	Mixed packaging	Packaging (including separately collected municipal packaging waste)	25.178
2019	15 01	15 01 07	Glass packaging	Packaging (including separately collected municipal packaging waste)	27.133
2019	15 01	15 01 10 01	Metallic packaging containing residues of or contaminated by dangerous substances	Packaging (including separately collected municipal packaging waste)	6.886
				TOTAL	93.116

In TABLE 1 above we see all the composition and quantities of all packaging waste particularly for code 15 gotten from loksa city and they consist of paper and cardboard, plastics, metallic, mixed, glass and metallic packaging containing residues of or contaminated by dangerous substances. When we look more closer, we see that the highest percentage comes from Glass packaging with code 15 01 07 (27.133%)

Table 2 Municipal waste composition and quantity 2019, (Jats classifactory, 2019)

Year	Waste sub group	Waste code	Waste types	Waste subgroup name	Total increase in tons
2019	20 01	20 01 01	Paper and cardboard	Separately collected fractions (except 15 01)	19.336
2019	20 01	20 01 02	Glass	Separately collected fractions (except 15 01)	12.06
2019	20 01	20 01 08	Biodegradable kitchen and canteen waste	Separately collected fractions (except 15 01)	30.92
2019	20 01	20 01 11	Textiles	Separately collected fractions (except 15 01)	4.04
2019	20 01	20 01 36	Discarded electrical and electronic equipment other than those mentioned in 20 01 21*, 20 01 23* and 20 01 35*	Separately collected fractions (except 15 01)	0.06
2019	20 01	20 01 40	Metals	Separately collected fractions (except 15 01)	8.991
2019	20 01	20 01 99	Other fractions not otherwise specified	Separately collected fractions (except 15 01)	0.12
2019	20 01	20 01 21*	Fluorescent tubes and other mercury-containing waste	Separately collected fractions (except 15 01)	0.573
2019	20 01	20 01 35 14*	Discarded large equipment (any external dimension more than 50 cm) other than those mentioned in 20 01 21* and 20 01 23*, 20 01 35 11* to 20 01 35 13* containing hazardous components	Separately collected fractions (except 15 01)	5.36
2019	20 01	20 01 98*	Unsorted batches of medicines	Separately collected fractions (except 15 01)	0.038
2019	20 02	20 02 01	Biodegradable waste	Garden and park wastes (including cemetery waste)	0.1
2019	20 03	20 03 01	Mixed municipal waste	Other municipal wastes	542.453
2019	20 03	20 03 07	Bulky waste	Other municipal wastes	55.024
				TOTAL	679.075

Here, in TABLE 2 above we see all data for composition and quantities of Municipal waste represented as code 20 which are also collected in loksa city which includes household waste and related commercial, manufacturing, and institutional waste. Taking more closer look at table 2 the highest percentage of municipal waste comes from Mixed municipal waste (542.453) and the smallest percentage comes from unsorted batch sof medicines represented as code 20 01 98 (0.038%)

2.3. Composition of msw in loksa city

In loksa city, the MSW IN 2019 sums up to be 772.191 tons and they all comprise of plastic, glass, metal, paper and cardboard, biodegradable like kitchen, garden and other biodegradable, wood, hazardous, WEEE, other combustible materials, textile and cloths, other non-combustible material.

Table 3 The sorting study of 2019-2020 in Estonia (SEI, 2020)

Type of waste	Estonian average %
1.plastic	18
2.glass	6
3.metal	2
4.Paper and cardboard	17
5.Biodegradable wastes	32
6. Wood	1
7. Hazardous wastes	0,1
8.WEEE	0,9
9. Other combustible material	13
10.Textile and clothes	6
11.Other non-combustible material	4
Total	100

Table 3 above shows us the composition of mixed municipal solid waste in Loksa City for 2019. and the percentage content of the mixed MSW represented as, Plastic 18%, glass 6%, metal 2%, paper and cardboard 17%, biodegradable 32%, wood 1%, hazardous 0.1%, WEEE 0.9%, other combustible materials 13%, textile and clothes 6% and other non-combustible material waste 4%.

Table 4 composition of all the household waste in loksa city

Type of waste	Packaging	separately collected	other municipal waste	Mixed waste (%)
Paper and cardboard	11.509	19.336	92.21701	17.0%
Plastic	15.934	0.000	97.64154	18.0%
Wood	0.000	0.000	5.42453	1.0%
Metal	6.476	8.991	10.84906	2.0%
Glass	27.133	12.060	32.54718	6.0%
Textile	0.000	4.040	32.54718	6.0%
Biodegradable	0.000	30.920	173.58496	32.0%
Hazardous	6.886	0.038	0.542453	0.1%
WEEE	0.000	5.420	4.882077	0.9%
Other combustible material	0.000	0.120	70.51889	13.0%
Other non-combustible material	0	0.573	21.69812	4.0%
Mixed packaging	25.178	0	0	0.0%
Total	93.116	81.498	542.453	

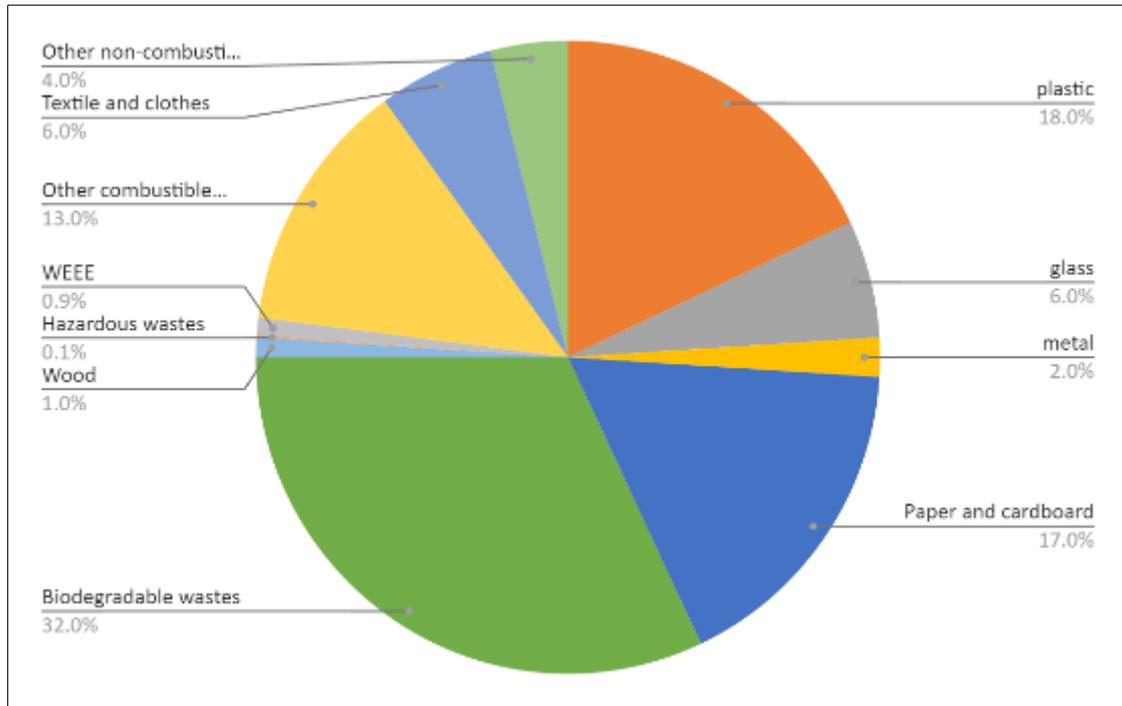


Figure 1 Composition of all the household waste in loksa city 2019

The data in TABLE 4 is used to establish the pie chart shown in FIGURE 1 For the year 2019, the pie chart depicts the percentage composition of all household waste produced in Loksa City.

3. Collection of mixed municipal solid waste in loksa city

In this section, all calculation and collection were done according to Estonian statistics based on housing census in 2011, in Loksa city as represented below

- Multi storey dwellings – 1291 (number of flats)
- Detached and semi-detached houses – 265.
- Total amount of houses, including multi storey houses – 329
- 64 are multi storey dwellings
 - 29 houses – with 216 flats (5-9 flats per house)
 - 22 houses – with 331 flats (10-19 flats per house)
 - 1 house – with 30 flats
 - 3 houses – 125 flats (40 flats in 2 houses, 45 flats in one house)
 - 4 houses – 220 flats (55 flats per house)
 - 2 houses – 120 flats (60 flats per house)
 - 1 house – 70 flats
 - 2 houses- 179 flats

Table 5 amount of municipal waste generated in houses and flats for loksa city

Sorting	QTY	UNIT
Mixed municipal waste (ton)	542.453	Ton
Mixed municipal waste in (kg)	542453	Kg
Population in 2019	2576	Individual
Mixed municipal waste per capital	210.5795807	Kg/individual
Number of houses	329	house
Number of detached/semi-detached houses	265	house
Waste accumulated in each houses	1648.793313	Kg/house
Number of flats	1291	flats
Number of houses with flat	64	House
Waste accumulated in each flat	81.73723628	Kg/flat/yr

2019, the number of houses and flats in Loksa city, as well as the amount of waste produced per person, house, and flat, are presented in TABLE 5. mixed urban waste accumulated per capita (per year) was 210.576 kg, waste accumulated per house was 1648.79 kg, waste accumulated per flat was 81.737 kg.

Table 6 Containers used in waste collection in Loksa CITY, TYPES AND COSTS

Containers type	Number	Buying price + VAT(EUR)	Total (EUR)
80l (40kg)	461	5.4	2487.24
770l (308kg)	7	23.4	163.80
240l (96kg)	265	6	1590.00
660l (264kg)	27	22.8	615.60
Rotos.660 (245kg)	30	22.8	684.00
Total	790		5540.64

TABLE 6 shows all the type and number of containers used during this collection and their prices including vat.

In Loksa, five different types of containers are used to collect MSW. The types and quantities of containers used are determined by the amount of waste accumulated per week. 80l (40kg), 240l (96kg), 770l (308kg), 660l (264kg), and Rotos.660(254kg) are the container types used.

The mixed municipal waste is collected using 329 containers, while the separately collected fraction is collected using 461 containers. The net cost of the containers and their emptying comes to 65,021.67 EUR (total cost of container 5540,64 EUR, and total cost of emptying all containers per year 59,481 EUR). Paper and cardboard, bulky waste, cardboard and paper packaging, plastic packaging, metallic packaging, mixed packaging, and glass packaging are among the waste types that have been collected separately in 2019.

Tables 7 and 8 show the processing details for both combined and separately collected waste.

Table 7 Detailed information on the collection of mixed municipal waste

Number of houses	Number of flats	Type of container	Number of containers	Msw accumulated a year/ multi storey (kg)	Amount of waste generated in a week (kg)	Waste generated in a house per week	Price for emptying the container in a week £	Price for emptying in a year £	Frequency of emptying the container
29	216	Rotos 660 (l) 245kg	29	17655.243	339.524	11.708	274.05	14250.60	1
22	331	660 (l) 264kg	22	27055.025	520.289	23.649	207.90	10810.80	1
1	30	Rotos 660 (l) 245kg	1	2452.117	47.156	47.156	9.45	491.40	1
3	125	660 (l) 264kg	3	10217.155	196.484	65.495	28.35	1474.20	1
4	220	770 (l) 308kg	4	17982.192	345.811	86.453	49.80	2589.60	1
2	120	660 (l) 264kg	2	9808.468	188.624	94.312	18.90	982.80	1
1	70	770 (l) 308kg	1	5721.607	110.031	110.031	12.45	647.40	1
2	179	770 (l) 308kg	2	14630.965	281.365	140.682	24.90	1294.80	1
265	0	240l (96kg)	265	436930.228	8402.504	31.708	1033.50	26871.00	1
TOTAL				542453.000	10431.788	611.194	1659.30	59412.60	

Table 7 represents all detailed information about the collection mixed municipal waste

Table 8 Separately collected waste fraction

Type of waste	Number of houses	Msw accumulated a year	Amount of waste generated in a week	Type of container	Number of containers	Frequency of emptying the container in a week	Prices for Emptying in a week	Prices for Emptying in a year
Paper and cardboard	329	19336	371.846	80l (40kg) / 5 houses	66	1	£0.66	£34.22
Bulky waste	329	55024	1058.154	80l (40kg) / 5 houses	66	1	£0.66	£34.22
Paper and cardboard packaging	329	11509	221.327	80l (40kg) / 5 houses	66	1	0	0
Plastic packaging	329	15934	306.423	80l (40kg) / 5 houses	66	1	0	0
Metallic packaging	329	6476	124.538	80l (40kg) / 5 houses	66	1	0	0

Mixed packaging	329	25178	484.192	80l (40kg) / 5 houses	66	1	0	0
Glass packaging	329	27133	521.788	80l (40kg) / 5 houses	66	1	0	0
TOTAL		160590	3088.269		461			£68.43

TABLE 8 here shows all the details of the separately collected waste fraction in code 15 01

3.1. The gross collection of symbol A

The gross cost is calculated by taking into account the cost of a garbage truck R16 (price 170 000 EUR) per year (which was calculated by dividing the truck's cost by ten years), the cost of emptying containers, the total cost of fuel per year, and the total cost of personnel (salary and benefits).

Table 9 gross cost of collection

Sorting	Amount	Unit
Total MSW accumulated per week	104.3178846	m ³
Price of truck per year	17000	£
Amount of truck needed	1	
Weekly cost of truck	326.9230769	£
Cost of emptying containers	£59,481.03	£
Total MSW accumulated per week	10.43178846	ton
Diesel consumption (L tonne ⁻¹)	1.5	l/ton
Total fuel consumption per week	15.64768269	l
Total fuel consumption per year	813.6795	l
Cost of Diesel in Estonia	1.219	£/l
Total cost of fuel per year	991.8753105	£
Workers	2	workers
Working hours	8	week
Salary	8	£
Weeks per year	52	week
Yearly salary for 2 workers	6656	£
Supervisor and Secretary Benefit	60000	£
Total cost for staffs	66656	£
SYMBOL A	£144,128.91	£

By multiplying the cost of emptying a single container by the total number of containers and the frequency of emptying the containers, the cost of emptying a container was calculated. Total annual fuel costs were calculated by multiplying total annual fuel consumption (assuming 1.5 liters per ton) by the Estonian fuel cost (1.219£). The average cost of employees is calculated by multiplying the number of collection crews by the number of hours worked each year, plus supervisor and secretary benefits.

The total gross cost Symbol A of 144,128.91 EUR was calculated by adding the total cross amounts of all four variables (truck price per year, cost of emptying container, total cost of fuel per year, and total cost for staffs).

4. Collection and treatment of recyclables in loksa city

The collection and treatment of recyclable waste in Loksa is presented in this chapter. Paper and cardboard, paper and cardboard packaging, plastic packaging, metallic packaging, mixed packaging, and glass packaging are all recyclable materials in this situation.

Table 10 collection of recyclable waste

RECYCLABLES	WASTE AMOUNT A YR	WASTE AMT A WEEK	FREQUENCY	FUEL COST PER YR	NO OF CONTAINERS (80L) 40KG
Paper and cardboard	19.336	371.85	1	35.36	66
Paper and cardboard packaging	11.509	221.33	1	21.04	66
Plastic Packaging	15.934	306.42	1	29.14	66
Metallic Packaging	6.476	124.54	1/mth	11.84	66
Mixed Packaging	25.178	484.19	1	46.04	66
Glass Packaging	27.133	521.79	1	49.61	66
TOTAL	105.566	2030.12		193.03	396

Here in TABLE 10, We presumed that the different wastes would be collected and transported separately. Separate containers were used for collection, and transportation took place on separate days. Due to the volume of waste generated by houses and flats, collection and emptying of containers for paper and cardboard, paper and cardboard packaging, plastic packaging, mixed packaging, and glass packaging is done once a week, while metallic packaging is done once a month. Each waste form is collected using 66 (80l (40kg) containers, for a total of 396 containers.

Table 11 value of recyclable waste in market

MATERIALS	DISTANCE ONE WAY	PRICE PAID AT MARTET STN (TN)	TOTAL SELLING COST	TOTAL FUEL CONSUMPTION
PAPER	140	32	493.52	3360
CARDBOARD	140	13	200.49	3360
METAL	116	200	2973.73	2784
PLASTIC	60	10	243.27	1440
GLASS	60	10	355.26	1440
WEEE	110	10	0	0
TOTAL			4266.27	12384

Table 11 shows the market value of the waste that was collected separately. The cost of transportation to and from the market station is also shown in the table. The transportation costs were measured using the two distances between the market stations. Fuel consumption was estimated to be 1.5 liters per kilometer, based on the price of diesel in Estonia 1.219 EUR/liter. We believed that mixed packaging waste was divided into three categories: metal, plastic, and glass packaging waste. That is, the total amount of mixed packaging waste was split into three parts and then added to the total amount of metal, plastic, and glass packaging waste.

4.1. Symbol R

Table 12 Symbol R

VARIABLES	AMT (£)
Price paid at market station	4266.27
Transportation costs	18576
drivers' salary	6656
fuel cost for collection	193.03
SYMBOL R	-21158.76

In TABLE 12 above, the symbol R (Recycling) was determined by subtracting the cross amount expended on waste collection and treatment from the selling price charged at market stations for recyclable waste. Recycling (symbol R) = price charged at market station – (transportation costs + salary for drivers+ fuel cost for collection) is the formula used in the calculation.

4.2. Corrected symbol R

The corrected symbol R was determined based on the assumption that separately collected waste is collected and transported to a material recovery facility (MRF) located 5 kilometers outside of Loksa. The distance to the MRF was measured using the frequency of separately collected waste collection. Since the calculations are based on the premise that the different waste fractions are obtained and transported separately.

Table 13 Transportation to MRF AND MS

Materials	MRF DISTANCE KM (TWOWAY) 1YR	Total yearly amt of waste (Ton)	Transport to MRF £	Frequency of MP (YR)	Amt of Waste Trans to MP (TON)	Distance to MS (KM) Two way	Transport to MS (£)
Paper	520	15.423	950.82	4	3.856	560	1023.96
Cardboard	520	15.423	950.82	4	3.856	560	1023.96
Metal	120	14.869	219.42	4	3.717	464	848.42
Plastic	520	24.327	950.82	4	6.082	240	438.84
Glass	520	35.526	950.82	4	8.881	240	438.84
Total	2200	105.566	4022.7				3774.02

The total distance covered and total amount charged at the market stations are shown in TABLE 13 above. The estimates also assumed a four-times-a-year frequency to the market station, owing to the fact that the separately obtained fractions must be processed for a period of time in order to obtain a certain amount before being transported to the marketplace.

Table 14 corrected symbol R

Variables	AMT (£)
Price paid at market station	4266.27
Transportation costs	7796.72
drivers' salary	6656
fuel cost for collection	193.03
Symbol R Corrected	-10379.48

Table 14 shows data for the corrected symbol R, which was determined using the information in table 13. The corrected symbol R is determined using the following factors: the price charged at the market station, transportation costs, driver salaries, and collection fuel costs. Nonetheless, the difference between the figure symbol R and the corrected symbol R is due to a difference in market station frequency which is 52 times per year for symbol R and 4 times per year for corrected symbol R. The table below contains all of the relevant information and estimates.

5. Collection and treatment of hazardous waste in loksa city

In this chapter, calculation was made for the collection and treatment of hazardous waste in loksa city.

Table 15 collected hazardous waste for loksa city

Waste subgroup	Waste code	Waste subgroup name	Waste type name	Total increase (ton)
15 01	15 01 10*	Packaging (including separately collected municipal packaging waste)	Metallic packaging containing residues of or contaminated by dangerous substances	6.886
16 01	16 01 04 01*	End-of-life vehicles from different means of transport (including off-road machinery) and wastes from dismantling of end-of-life vehicles and vehicle maintenance (except 13, 14, 16 06 and 16 08)		5.646
16 01	16 01 06	End-of-life vehicles from different means of transport (including off-road machinery) and wastes from dismantling of end-of-life vehicles and vehicle maintenance (except 13, 14, 16 06 and 16 08)		0.307
16 06	16 06 01*	Batteries and accumulators	Lead batteries	0.445
16 07	16 07 08*	Wastes from transport tank, storage tank and barrel cleaning (except 05 and 13)	Wastes Containing Oil	5.000
17 06	17 06 05*	Insulation materials and asbestos-containing construction materials	Construction materials containing asbestos	9.100
18 01	18 01 03	Wastes from natal care, diagnosis, treatment or prevention of disease in humans	Wastes whose collection and disposal is subject to special requirements	0.002
20 01	20 01 21*	Separately collected fractions (except 15 01)	Fluorescent tubes and other mercury-containing waste	0.573
20 01	20 01 35 04*	Separately collected fractions (except 15 01)	Discarded consumer equipment containing hazardous components, other than those mentioned in 20 01	5.360
20 01	20 01 98*	Separately collected fractions (except 15 01)	Unsorted batches of medicines	0.038
Total				33.357

Since all hazardous waste was carried to MRF, there was no expense for inter-city hazardous waste collection. For the entire year of 2019, TABLE 15 shows all hazardous waste types and amounts produced in Loksa.

5.1. Hazardous waste treatment

Table 16 Hazardous waste treatment

Waste code	Pricelist for treatment (£/ton)	Total cost of treatment (£)	Yearly frequency	Distance to eco pro (two-way km)	Yearly frequency kuusakoski as	Distance to kuusakoski as (two-way km)
15 01 10*	395	2719.97	4	480	1	120
16 01 04 01*	210	1185.66	4		1	
16 06 01*	0	0	4		1	
16 07 08*	30	150	4		1	
17 06 05*	50	455	4		1	
18 01 03*	3200	6.4	4		1	
20 01 21*	38000	21774	4		1	
20 01 35 04*	380	2036.8	4		1	
20 01 98*	2230	84.74	4		1	

Here in TABLE 16 Hazardous waste is transported from the MRF to the Eco-Pro treatment center, which is 60 kilometers away. Except for end-of-life vehicles, which are transported to Kuusakoski AS, which is 60 kilometers from Loksa city, all hazardous waste is transported to Eco-pro. The cost of hazardous waste treatment varies depending on the form and amount of waste transported to hazardous waste disposal facilities. Eco-pro is collected four times a year, while end-of-life vehicles are collected once a year by Kuusakoski AS. The frequency to Eco-pro and Kuusakoski AS is based on the amount of hazardous material to be handled.

5.2. Symbol HWU

The symbol HWU was determined by taking into account the costs of treatment, transportation, work and waiting time, as well as revenue from the sale of end-of-life vehicles.

Table 17 symbol HWU

Variables	Amount	Units
Revenue for end-of-life vehicle	80	£/ton
End-of-life vehicle	5.953	ton
Fuel consumption	1.5	l/km
Cost of fuel	1.219	£/l
Transport cost to Kuusakoski AS	1.3	£/km
Two-way transport cost to Eco-pro	877.68	£
Two-way transport cost to Kuusakoski AS	156	£
Total work time for loading/offloading cars	3	h

Uploading and offloading cost	45	£/h
Total cost of uploading/offloading work	135	£
Vacuum truck operation (per hour)	61	£/h
Total cost of vacuum truck operation	244	£
Cost for treatment	28412.57	£
Total cost for transport	1033.68	£
Cost for work and waiting time	379	£
Revenue from selling end-of-life vehicle	476.24	£
Symbol HWU	29349.01	£

In TABLE 17, transportation costs were calculated by adding the total cost of transportation to and from Eco-pro, as well as the cost of transportation to Kuusakoski AS (to and from). A vacuum truck operation with a fixed standby period on-site is one of the additional facilities used in the transportation. The total time spent packing, offloading, and transporting end-of-life vehicles was estimated to be 3 hours. The revenue from selling end-of-life vehicles was calculated by multiplying the selling cost of end-of-life vehicles at Kuusakoski AS 80 EUR/ton by the total weight of end-of-life vehicles (5,953 TON) as shown in table 17.

Symbol HWU = Treatment costs + transportation costs + work and waiting time costs - Revenue from end-of-life vehicle sales.

6. Calculation of alternative 1

The alternatives discussed in this section serve as a foundation for measuring and comparing various waste collection and treatment scenarios and their options.

6.1. Alternative I

Alternative I propose a scenario in which all mixed municipal waste is transported to an MRF, with the exception of recyclables, hazardous waste, and WEEE, which are collected separately. The waste transported to the MRF is processed in the MRF, where all metals and glass are removed, and the remaining pieces are used to make RDF, which is sent to Kunda (80% OR 0.8) and the remaining 20% is sent to the IRU for incineration.

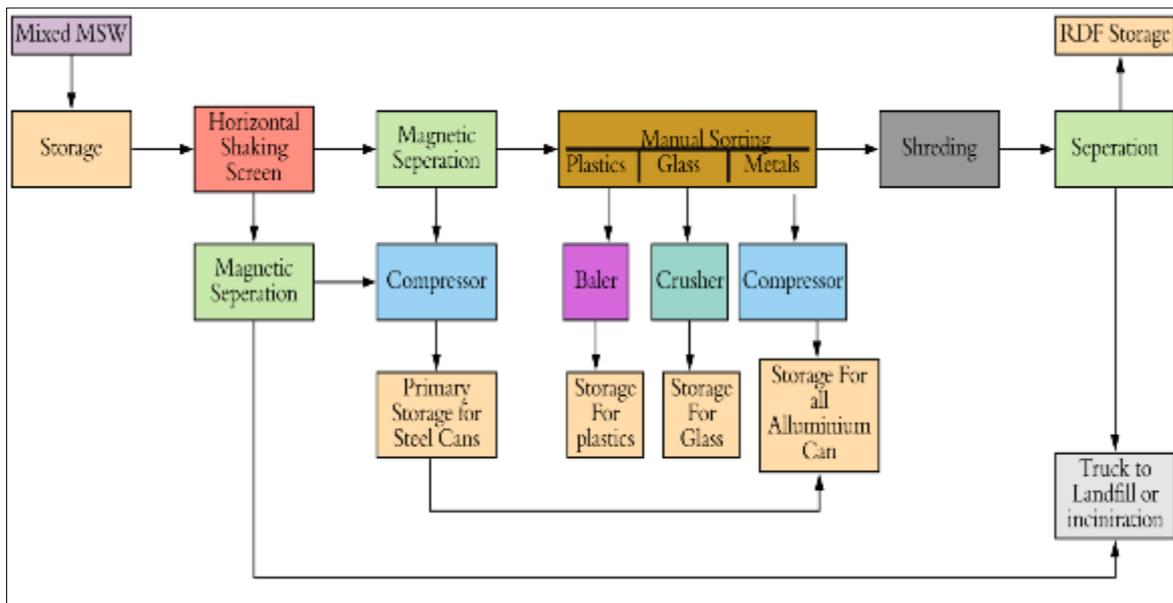


Figure 2 A scheme for solid waste processing facility

Table 18 symbol T1

Amt (tons)	Freq to MRF/yr	Total Distance to MRF (km/yr)	Fuel consumption (km/l)	Fuel cost (£/l)	Symbol T1 (£)
542.453	52	520	1.5	1.219	950.82

In TABLE 18, We calculate symbol T1 by multiplying total distance to MRF yearly BY diesel consumption BY Estonia fuel cost.

Table 19 Sorted amount AT MRF

Variables	Amt (%)	Amt (tons)
Glass in MSW	6	32.54718
Metal in MSW	2	10.84906
Total	8	43.39624
Non-recycled MSW		499.05676
RDF		399.245408
Residual Remains		99.811352

Table 19 Above present assumptions and sorted amount at MRF

Table 20 Symbol T2

VARIABLES (IRU)	AMT
Frequency	4
Distance	57.5
Total Distance	460
Transport Cost (£)	841.11
Gate Fee (£/ton)	35
Total Gate Fee (£)	3493.39732
SYMBOL T2	4334.50732

In TABLE 20, Based on the assumptions and information given in table 19, the symbols T2, was determined. The estimate of Symbols T2 (transport cost to IRU plus gate fee charged at IRU) took into account the total yearly distance to IRU, the cost of diesel fuel in Estonia 1.219£/l, and the assumed consumption rate of 1.5 liters per kilometer, as well as the total gate fee of 3037,74

Table 21 Symbol T3

Distance from MRF to Kunda	Frequency	Total distance	Symbol T3 (£)
65	52	6760	12360.66

In TABLE 21, diesel fuel in Estonia at a consumption rate of 1.5 liters per kilometer, plus the complete gate charge, The total yearly distance to Kunda, the cost of diesel fuel in Estonia 1.219£/l, and the assumed consumption rate of 1.5l/km were all factors in the Symbols T3 estimate.

Table 22 Symbol R RDF

PRICE (£/ton)	AMT OF RDF (tons)	SYMBOL R_RDF (£)
10	399.245408	3992.45408

In TABLE 22 above, The sale price of the RDF fraction was multiplied by the total amount of RDF generated at the MRF and transported to Kunda to calculate the symbol R RDF.

Table 23 Adjusted symbol R new calculation

Variables	AMT (£)
Price paid at market	1353574.18
Transportation costs	2457.50
Driver salary	6656
Fuel cost for collection	193.03
Symbol R	1344267.65
Symbol R Corrected	-10379.48

In TABLE 23 above, the modified symbol R was determined by re-evaluating and calculating the metal and glass fractions in the MRF-separated mixed municipal waste.

Table 24 Calculation of alternative 1

SYMBOLS	AMT (£)
SYMBOL A	144128.19
SYMBOL T1	950.82
SYMBOL T2	4334.50732
SYMBOL T3	12360.66
SYMBOL HWU	29349.01
SYMBOL R_RDF	3471.6992
CORRECTED SYMBOL R	-10379.48
ALTERNATIVE I	204974.37

In TABLE 24 above, the following factors were included in the Alternative I calculation

- Symbol A: Total cost of waste collection and container emptying Recycling revenue is denoted by the letter R.
- HWU stands for "total cost of hazardous waste use."
- The cost of transportation to the MRF is denoted by the symbol T1.
- Symbol T2: Gross gate fee charged at IRU plus transportation costs to IRU.
- T3: Cost of transportation to Kunda
- R RDF: Revenue from RDF (symbol R RDF)
- R symbol has been tweaked.
- The following formula was used in the calculation: Alternative I = A (MSW collection) + (T1 + T2 + T3) +HWU – R RDF – R_ (recycling)

7. Alternative II

Alternative II involves first calculating the annual transportation expense to the IRU power plant, which is 57.5 kilometers away. The annual transportation expense is calculated by multiplying the annual two-way distance to IRU by the assumed fuel consumption per km (1.5l) and the current diesel fuel price in Estonia (1.219 EUR/l). Table 25 below shows the gross annual transportation costs to IRU.

Table 25 Annual cost for transportation to IRU

WASTE TYPE	AMT
MSW	542.453 tons
Frequency	52
Distance (2-way)	115 km
Fuel cost	1.219 £/l
Fuel consumption	1.5 l/km
Annual Distance	5980 km
Annual Cost	32803.29 £

IN TABLE 25 ABOVE IT SHOWS THE GROSS ANNUAL TRANSPORTATION COSTS TO IRU POWER PLANT. BY MULTIPLYING ESTONIA FUEL COST BY THE ASSUMED DIESEL CONSUMPTION AND THE ANNUAL DISTANCE TO IRU

Table 26 Alternative II calculations

VARIABLES	AMT (£)
SYMBOL A	144128.19
IRU GATE FEE/TON	35
TOTAL GATE FEE	18985.855
TRANSPORT COST	32803.29
SYMBOL HWU	29349.01
SYMBOL R	-10379.48
ALTERNATIVE II	235645.825

IN TABLE 26 ABOVE, THE TOTAL IRU GATE FEE IS CALCULATED BY MULTIPLYING THE IRU GATE FEE PER TON (35 EUR) BY THE TOTAL AMOUNT OF WASTE TRANSPORTED TO THE IRU POWER PLANT (542.453 TONS), ANNUAL TRANSPORTATION COST TO IRU, SYMBOL HWU (TOTAL COST FOR HAZARDOUS WASTE UTILIZATION), AND SYMBOL R (TOTAL COST FOR HAZARDOUS WASTE DISPOSAL) (SYMBOL R: REVENUE FROM RECYCLABLES). ALTERNATIVE II WAS DETERMINED USING THE FORMULA ALTERNATIVE II = (A + GATE FEE + TRANSPORTATION COST + HWU) - R FOR THE ENTIRE CALCULATION.

8. Alternative III

Alternative III involves first calculating the annual transportation expense to Tallinn Landfill, which is 52 kilometers away. The annual transportation expense is calculated by multiplying the annual two-way distance to Tallinn Landfill by the assumed fuel consumption per km (1.5l) and the current diesel fuel price in Estonia (1.219 EUR/l).

Table 27 Annual cost for transport to Tallinn landfill

Waste type	AMT
MSW	542.453 tons
Frequency (yr)	26
Distance (2-way)	104 km
Fuel cost	1.219 £/l
Fuel consumption	1.5 l/km
Annual Distance	2704 km
Annual Cost	29665.584 £

IN TABLE 27 ABOVE, it shows the gross annual transportation costs to TALLINN LANDFILL BY multiplying Estonia fuel cost BY the assumed diesel consumption and the annual distance to TALLINN LANDFILL

Table 28 calculation of alternative III

Variables	AMT (£)
SYMBOL A	144128.19
LANDFILL GATE FEE/TON	76.2
TOTAL GATE FEE	41334.9186
TRANSPORT COST	29665.584
SYMBOL HWU	29349.01
SYMBOL R	-10379.48
ALTERNATIVE III	254857.1826

IN TABLE 28 ABOVE, Symbol A, total landfill gate fee (calculated by multiplying the landfill gate fee per ton (76.2 EUR) by the total amount of waste to be landfilled (542.453tons), annual transport expense to Tallinn landfill, Symbol HWU, and Symbol R are all taken into account in the Alternative III estimate. = (A + gate fee + transportation cost + HWU) – R

8.1. Alternative IIIA

Alternative IIIa depicts a situation in which all biodegradable waste in mixed waste must be collected separately and landfilled. The sum charged (gate fee) for waste landfilling is the difference between alternatives III and IIIa. Biodegradable waste landfilling costs 37.80 EUR, which is roughly two times less than mixed waste landfilling.

Table 29 All data for calculating alternative IIIA

VARIABLES	AMOUNT	UNIT
Amt of MSW	542.453	TON
Fraction of biodegradable waste (%)	32	PERCENT
Fraction biodegradable (TON)	173.58496	TON
Gate fee (BIO)	37.8	£
Gate fee (MSW)	76.2	£
Frequency to landfill (BIO)	4	YR
MRF yearly frequency	26	YR
Frequency to landfill (MSW)	52	YR

Distance to landfill (2-way)	104	KM
Distance to MRF (2-way)	10	KM
Fuel cost	1.219	£/L
Fuel consumption	1.5	L/KM
Annual distance to landfill (MSW)	5408	KM/YR
Annual distance to landfill (BIO)	416	KM/YR
MRF annual distance	260	KM/YR

IN TABLE 29 ABOVE, The base line data and amounts needed for the measurement of alternative IIIa are shown. The estimate is based on the assumption that biodegradable waste accounts for 32 percent of mixed municipal waste, as stated in the Estonian sorting report for 2019-2020. The total volume of mixed waste is 542.453 tons, with 173.585 tons of biodegradable waste (32 percent), a gate fee of 37,8 EUR per ton for biodegradable waste, and a gate fee of 76.2 EUR per ton for MSW. For biodegradable waste, the frequency to landfill is 26 times per year, and for mixed waste forms (mixed municipal waste and biodegradable waste), the frequency to MRF is 52 times per year. Multiplying the frequency to landfill by the two-way distance to landfill yields the annual distance to landfill. Multiplying the frequency to MRF by the two-way distance to MRF yields the annual distance to MRF.

Table 30 calculation of alternative IIIA

Variables	Amount (£)
Transport to landfill (MSW)	9888.528
Transport to landfill (BIO)	760.656
Transportation cost (total)	10649.184
T1 (to MRF)	950.82
SYMBOL A	144128.19
Gate fee MSW	28107.74465
Gate fee BIO	6561.511488
SYMBOL HWU	29349.01
SYMBOL R	-10379.48
Alternative III(a)	230125.9401

IN TABLE 30 ABOVE, Transportation to the landfill (MSW), transportation to the landfill (BIODEGRADABLE) total transportation cost, T1 (transportation cost to MRF), symbol A, total gate fee (biodegradable), total gate fee (mixed), symbol HWU, symbol R are all factors included in Alternative IIIa's calculation. Alternative IIIa is determined using the following formula: $\text{Alternative IIIa} = (A + \text{biodegradable gate fee} + \text{mixed gate fee} + \text{transportation expense} + T1 + \text{HWU}) - R$

9. Comparison of alternatives and conclusions

In this chapter, we are going to check the gross cost calculation for each alternative, create a table where all gross costs for three alternatives are presented and provide conclusions and recommendation.

9.1. Comparison

In achieving this, we have to compare and assess the best alternative based on how they environmentally perform well and the range of cost analysis of these alternatives

Table 31 comparison of all alternatives

ALTERNATIVES	AMT (£)
ALTERNATIVE I	204974.3665
ALTERNATIVE II	235645.825
ALTERNATIVE III	254857.1826
ALTERNATIVE IIIa	230125.9401

10. Conclusion

TABLE 31 above, as the part of the goal is to create a Circular Economy, we have to choose the best alternative that will be suitable to achieve this as regards waste management. And also, the government also encouraged composting every year more than 200 million tonnes of waste are produced in the world, and LANDFILLS pose plenty of the environmental impact (Pollution of ground water, emission of methane, a greenhouse gas, and disruption of ecosystem and bird migration).

Alternative III seems to be more expensive because of the landfill, Alternative I seems to appear to be the cheapest among all alternatives

Alternative I AND IIIA seems to be cheaper in terms of cost than all other alternatives

Therefore, Alternative I is the most preferably option

Recommendations

Only incineration with little to no energy recovery due to the low heat-value waste and the environmental impact of waste creation should be deposited or compost for the remaining fraction of the non-recycled waste form.

The government can also cut cost for the landfills as it seems to be increasing annually

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