EVALUATING THE ECONOMIC IMPACT OF IMPLEMENTING FILL LEVEL SENSORS IN HSY MUNICIPAL SOLID WASTE COLLECTION

Lappeenranta–Lahti University of Technology LUT

Master's programme in Circular Economy, Master's thesis

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ABSTRACT

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Evaluating the economic impact of implementing fill level sensors in HSY municipal solid waste collection

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As waste volumes grow and sorting practices become more widespread, the environmental impacts of waste collection increase. Utilizing sensor technology has the potential to reduce the environmental footprint of waste collection and enhance the economic viability of operations. The aim of this study is to evaluate the economic impact of implementing fill level sensors in mixed waste underground containers of HSY (Helsinki Region Environmental Services) and identify strategies to realize economic benefits.

The method of this study is data analysis and calculational methods. The analysis was performed by calculating fill levels for mixed waste collected with crane loading in HSY waste management area. Based on these calculations, it was estimated how much the number collection events would reduce and what kind of economic impact it would have for HSY.

The main findings of this study are that 33% of the emptying events are done with less than 50% fill level and there is some variation on the fill levels on monthly basis. The findings show that implementing fill level sensors would lead to 225 000 € increase of expenses and 700 000 € decreased of income. Considering both, reduction of income and increase of expenses, would result to annual -925 000 € financial impact for HSY.

Due to the expected reduction in emptying events resulting from the purposeful utilization of fill level sensors the economically viable implementation of these sensors requires adjusting the cost structure to be financially sustainable. In practice, this could mean providing fill level sensors as an additional paid service, transitioning to a completely weight-based billing system, or covering costs through a basic fee.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUTin energiajärjestelmien tiedekunta

Ympäristötekniikka

Petra Paananen

Täyttöastesensoreiden käyttöönoton taloudellisten vaikutusten arviointi HSY:n jätteenkeräyksessä

Ympäristötekniikan diplomityö

2024

55 sivua, 14 kuvaa, 10 taulukkoa ja 3 liitettä

Tarkastajat: Professori Mika Horttanainen, D.Sc. (Tech.), Logistiikkapäällikkö Tero Salo M.Sc. (Tech.)

Avainsanat: älykäs jätehuolto, täyttöastesensori, kunnallinen jätehuolto, jätteenkeräys

Jätemäärien kasvun ja lajittelun lisääntymisen seurauksena myös jätteenkeräyksen ympäristövaikutukset kasvavat. Sensoriteknologian hyödyntäminen voi auttaa pienentämään jätteenkeräyksen ympäristövaikutuksia ja tukea toiminnan taloudellista kannattavuutta. Tämä työn tarkoituksena on arvioida, millaisia kustannusvaikutuksia olisi täyttöastesensoreiden käyttöönotolla HSY:n sekajätteen syväkeräyksessä ja tunnistaa, miten sensoreiden käyttöönotosta saataisiin taloudellisia hyötyjä.

Tutkimuksen menetelmänä käytettiin data-analyysiä ja laskennallisia menetelmiä. Analyysi suoritettiin laskemalla nosturilla tyhjennettävien sekajäteastioiden täyttöasteet HSY:n jätteenkeräysalueella. Näiden laskelmien perusteella arvioitiin, kuinka paljon keräystapahtumien määrä vähenisi ja millaisia taloudellisia vaikutuksia sillä olisi HSY:lle.

Tutkimuksen tärkeimmät havainnot ovat, että 33% tyhjennyksistä tehdään alle 50% täyttöasteella ja että täyttöasteissa on jonkin verran kuukausittaista vaihtelua. Tulokset osoittavat, että täyttötasosensorien käyttöönotto johtaisi 225 000 euron kustannusten lisääntymiseen ja 700 000 euron tulojen vähenemiseen. Ottaen huomioon sekä tulon vähenemisen että kustannusten lisääntymisen, tästä seuraisi HSY:lle vuotuinen -925 000 €:n taloudellinen vaikutus.

Laskelmiin perustustuvan tyhjennystapahtumisen vähenemisen vuoksi täyttöastesensorien tarkoituksenmukainen käyttö edellyttäisi kustannusrakenteen sovittamista. Käytännössä tämä voisi tarkoittaa täyttötasosensorien tarjoamista lisämaksullisena palveluna, siirtymistä täysin painopohjaiseen laskutusjärjestelmään tai kustannusten kattamista perusmaksun avulla.

ABBREVIATIONS

AI	Artificial Intelligence
HSY	Helsinki Region Environmental Services Authority HSY
IoT	Internet-of-Things

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1 Introduction

Due to population and economic growth, material production and consumption are increasing. The lifecycle of produced material ends up as waste, resulting in the growth of waste streams. With the mounting volume of waste, it becomes apparent that effective waste management is crucial for mitigating environmental and health risks. Additionally, efficient waste management has the potential to reduce the demand for virgin materials. (Ritchie & Mathieu, 2023.)

Considering the growing waste streams, globally the most significant challenge in waste management is mismanaging of waste. Mismanagement of waste is a global issue, particularly evident in low-income countries, where waste management primarily involves open dumping and burning, resulting in air, soil, and water pollution, marine debris, and social problems such as direct exposure of waste pickers to hazardous materials. (Ferronato & Torretta, 2019.) Volumes of mismanaged plastic waste is illustrated in the figure 1.

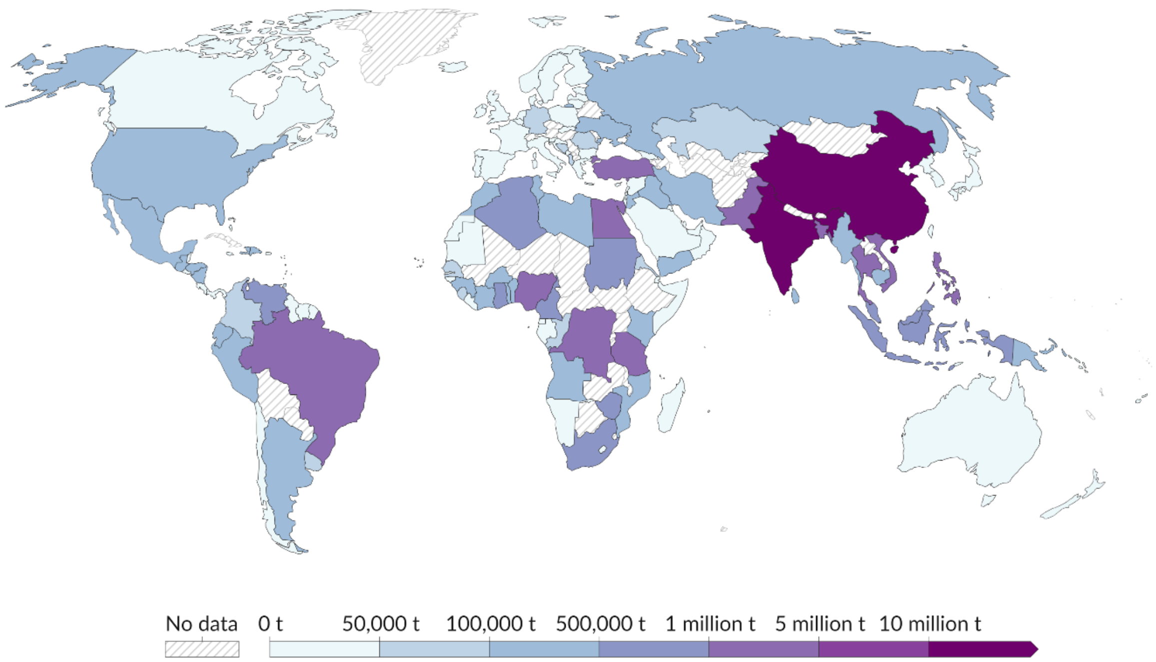

Figure 1. Mismanaged plastic waste, 2019. (Meijer et al., 2021)

In the 2000s, the quantity of municipal waste in EU countries has remained relatively stable, fluctuating between 479 and 530 kg per capita per year, whereas in Finland, the range is considerably broader, spanning from 458 to 629 kg per capita per year (figure 2). During the first decade of the 21st century Finland had a lower accumulation of municipal waste per capita compared to the EU average. The amount of municipal waste generated in Finland grew from 2000 to 2021 from 502 to 629 kg per capita per year, currently exceeding the EU average significantly. (Syke, 2024.)

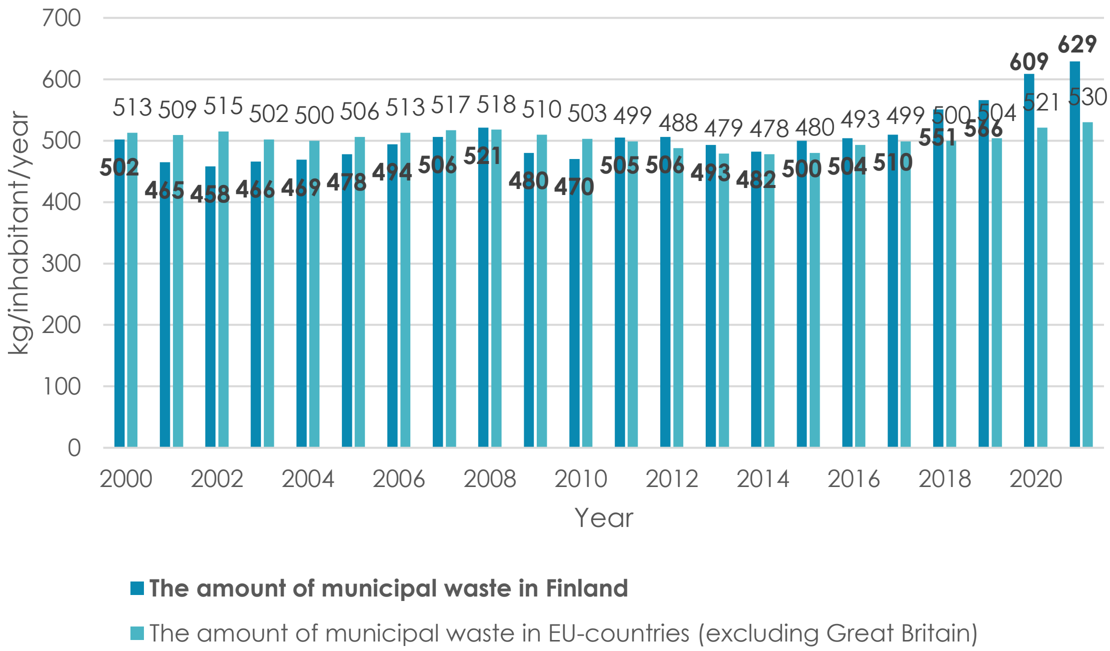

Figure 2. The amount of municipal waste per capita in Finland and in EU-countries, 2000-2021, (Syke, 2024)

Due to growing waste streams, also environmental impacts of waste management increases. The most significant environmental impacts of waste management are caused by the release of methane during the decomposition process of organic matter in landfills (Syke, 2023). Additionally, waste management contributes to greenhouse gas emissions through activities such as waste incineration, energy consumption, and vehicle combustion engines. Other environmental impacts of waste management include air pollution from waste incineration and vehicles, ecosystem changes due to land use change, and soil and water contamination resulting from improper waste treatment or inadequate landfill structures. Furthermore, waste management consumes significant amounts of natural resources, such as energy, materials, and water.

The European Union is taking actions to reduce the environmental impacts of waste management. For example, the environmental impact of waste management can be mitigated in accordance with the waste hierarchy outlined by the European Commission (2023). This hierarchy prioritizes waste prevention and reduction, reuse, recycling, and energy recovery, with disposal considered as the last resort (Figure 3). In practical terms, minimizing the quantity and harmfulness of waste involves designing products and packaging for material efficiency and sustainability, as well as advocating for the use of safe and environmentally friendly materials. Furthermore, waste generation can be influenced by raising environmental awareness and guiding consumers toward responsible choices. Promoting reuse, which involves using a product again for its original purpose, can be achieved by designing products for repairability, by facilitating repair services and supporting platforms that enable product resale and donation. Recycling, the process of utilizing discarded items as material, can be most effectively promoted by improving source separation practices and, as a secondary measure, by employing manual or mechanical sorting methods. Additional strategies to reduce the environmental impact of waste management include avoiding the landfilling of organic materials, optimizing waste transportation for efficiency, and capturing and utilizing landfill gas emissions.

Figure 3. Waste hierarchy (European Commission, 2023).

Alongside the increase in waste volume, recycling and source separation are also on the rise. The European Union has set recycling targets, aiming for a recycling rate of 55 percent by 2025 and 65 percent by 2035 (Syke 2024). As waste volumes increase and recycling and source separation efforts expand, the demand for waste transportation is anticipated to rise, highlighting the need for advancements in waste transport management. Leveraging the capabilities of modern technologies can facilitate the evolution of waste transportation towards a more intelligent and sustainable approach, introducing smart waste management practices.

Smart waste management utilizes modern technologies such as data analytics and artificial intelligence, the Internet-of-Things (IoT), and smart waste bins to enhance waste management processes. The implementation of smart waste management can help optimize material flows, generate economic benefits, and reduce the environmental impact of waste management. Smart waste management operates at various levels and consists of multi-component systems. (Sosunova, 2023.)

This thesis is commissioned by the Helsinki Region Environmental Services Authority HSY (hereafter HSY). The transition towards smart waste management offers many new opportunities, which also support the realization of Helsinki Region Environmental Services Authority HSY's strategic objectives. In accordance with HSY's strategic goals, the organization aims for carbon-neutral waste management and strives to act as a developer of the circular economy and an influencer with data, without forgetting the economic aspects. HSY's purpose is to develop recycling-incentivizing services and improve the productivity, cost-effectiveness, and impact of its services (HSY, 2024.)

Utilizing sensor technology can be part of the transition towards smart waste management. Real-time measurement of waste container fill levels offers opportunities for automatization of processes, planning optimal emptying schedules, improving logistical efficiency by reducing unnecessary driving and thereby reduce the costs and environmental impacts, while also providing valuable information to both HSY and its customers.

The aim of this study is to assess the feasibility of implementing fill level sensors and the influencing factors, as well as to determine the conditions under which the adoption of fill level sensors can result in economic advantages in Helsinki region waste management. This study serves as a preliminary study about the economic impacts of implementing fill level sensors in HSY waste management.

2 HSY Waste Management

HSY is joint municipal authority, and the largest public environmental services provider in Finland. HSY produces municipal water and waste management services as well as information about the capital region and the environment. HSY employs almost 800 persons and has a turnover of over 350 million euros per year. (HSY, 2023 a.)

HSY is responsible for duties assigned to municipalities in the Waste Act (646/2011) in Helsinki, Espoo, Vantaa and Kauniainen, and also in Kirkkonummi upon a separate agreement (figure 4). These duties involve for example collecting mixed, recoverable, and hazardous waste, treating biowaste, after-care of landfills, and recovering landfill gas. (HSY, 2023 b.)

Figure 4. Map of HSY Waste Management Operating Area.

About 1,2 million residents live in the HSY waste management operating area, the capital region and Kirkkonummi. By legal obligation, residential properties, vacation homes, municipal services and administration must join HSY's waste management system and adhere to waste management regulations. Household waste and other municipal solid waste (as defined in Section 32 of the Waste Act, excluding hazardous waste) fall under HSY's property-based waste collection.

Waste collection in HSY Waste management operating area is managed by HSY Waste Management Transport Services unit. Currently the unit employs a total of 22 employees. HSY's waste collection is implemented through competitive procurement services in accordance with procurement laws. Waste collection is tendered by waste type, loading method and geographical area, typically for five-year periods. Therefore, HSY does not have its own waste collection vehicles or waste collection personnel, but the waste collection is operated by private contractors who win each competitive tender. During the contracting periods, HSY monitors and supervises the contractors.

HSY manages waste collection customer service and is responsible for the services to customers. A waste contract is established with each customer property. The minimum scope (e.g., waste types and collection frequencies) of services is determined by waste management regulations. However, customers have the flexibility to choose additional waste fractions and, if needed, a more frequent collection schedule. The waste management regulations define also e.g., the longest permitted collection intervals for different waste fractions, requirements for the waste collection location, driveways, transfer lanes, locks and allowed collection times. Customers can only deviate from waste management regulations with the approval of an exception granted based on an official decision. The responsibilities and obligations of waste collection are described in the following process diagram in a simplified form (figure 5).

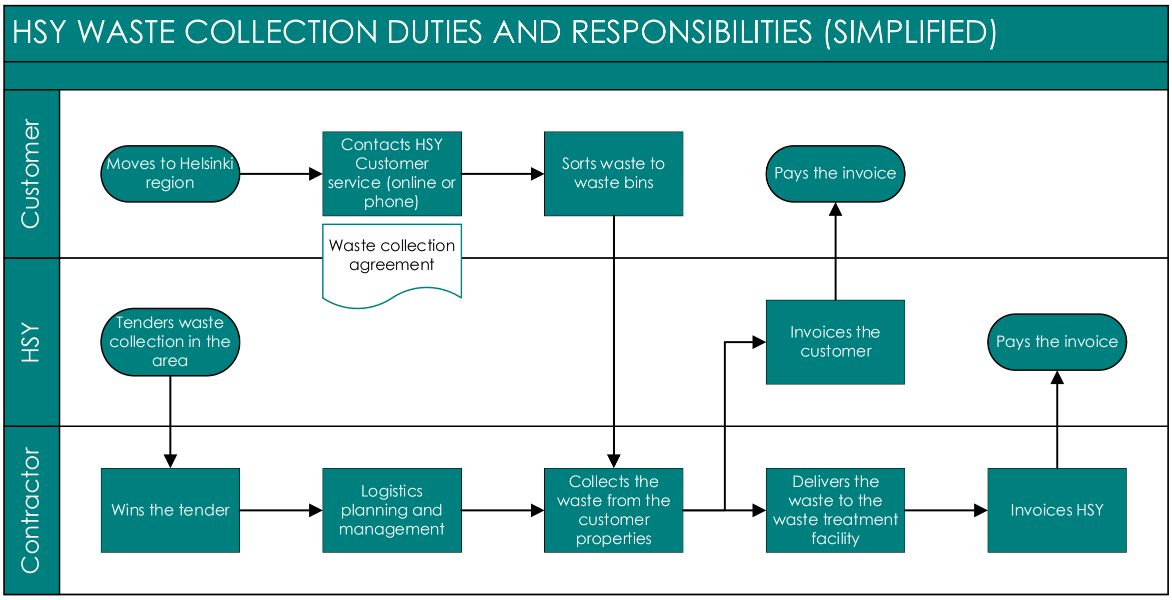

Figure 5. Process chart of HSY's waste collection responsibilities.

As presented in the figure 5, customer is responsible for making a waste collection agreement with HSY and sorting the waste. HSY is responsible for organizing waste collection and communicating and invoicing the customer. Contractor is responsible for collecting the waste according to a contract based on tender and invoicing HSY as agreed.

2.1 HSY Waste Collection Operations

Waste collection chain includes following operations:

- storing waste in the waste collection equipment such as waste bin or container during pickup intervals,
- collection operations done by waste collection staff typically with mechanically loading waste trucks and
- transportation to treatment facility, transfer station or landfill.

Waste collection logistics is more complex in urban areas and complexity increases as number of waste types and collection methods increases. (Thiesen, 2002.)

HSY collects mixed waste, biowaste, carton packages, plastic packages, glass packages, and small metal items from the customer properties. The collection of paper waste is organized by the producer association. The minimum waste collection services for properties are mixed waste and biowaste (excluding biowaste if the biowaste is composted at the property). Properties with five or more apartments must have a collection service in addition for carton packages, plastic packages, glass packages, and small metal items. (Figure 6).

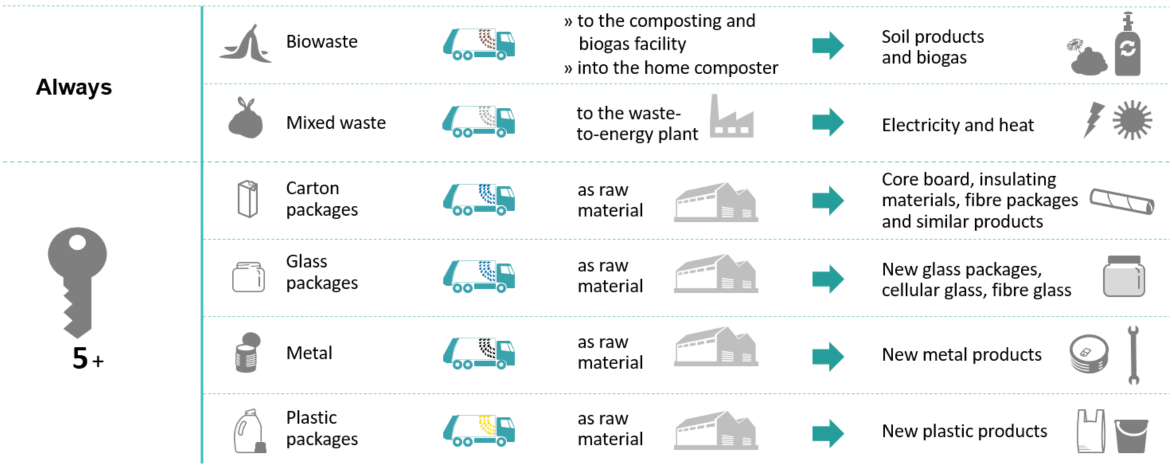

Figure 6. Utilization of waste types collected from properties (HSY, 2023 b)

The waste is collected from customer properties with equipment suitable for mechanical loading. The collection equipment must be also suitable for the waste fraction, (considering the properties of waste), hot washing, it must meet occupational safety requirements, and the size of the container and the emptying interval must be fitted for waste generated. Allowed collection equipment are wheelie bins, front loader containers, underground containers, skips and roller cages. (HSY, 2022 a.)

Collection method (also loading method) is linked to the waste collection equipment type. For example, wheelie bins can be emptied with back loader vehicle and underground containers are emptied with a waste truck with a crane.

Currently HSY utilizes static waste collection, meaning that all the containers have a predetermined collection interval, routes are somewhat similar within a certain cycle and waste containers on the route are emptied regardless of the waste amount (Salo, 2017). Static waste collection requires that primary routing is done somewhat manually.

Planning of waste collection routes has long been primarily a heuristic process, where it is important to consider regional rules and regulations, as well as guidelines for the placement of collection points and the determination of collection schedules. Simultaneously, it is crucial to consider available resources such as vehicles and drivers, and their efficient utilization. It is generally recommended that routes are designed to start and end near main roads. In hilly areas, the routes should start from uphill, and the final pickup should be done closest to the disposal site. In congested areas, it is important to collect waste as early as possible, and locations that produce an unusually large amount of waste should be serviced in the morning. Creating routes is typically an iterative process, and not all guidelines apply to every situation. (Thiesen, 2002.)

Currently at HSY contract area codes are manually added to the waste collection agreement in the waste collection management system. Based on the contract areas, a masterplan for routing is done by the contractor and approved by HSY. Based on the masterplan, the pickup tasks are generated to the default route. In the driver's application waste collection staff have their day's work list and pick up locations visible and they can choose routing method between closest spot method or previously saved route. At the end of the work shift, the driver can choose to save the days route if they wish to do so.

The increased sorting of waste leads to a rise in the number of emptying events as properties increasingly have multiple waste bins. Consequently, the heuristic planning of emptying tasks becomes more challenging, and computer-assisted tools become increasingly essential. (Burger et al, 2018.)

Alongside static waste collection and heuristic route planning, the use of fully or partially dynamic waste collection, automated routing and route optimization is increasing. In dynamic waste collection, collection intervals vary, and routes are based on calculations and optimization. Partially dynamic waste collection is combination of static waste collection and dynamic waste collection, and the collection interval can only vary within pre-set rules. (Salo, 2017.)

In 2024 HSY is implementing new waste collection management system, which enables (among other properties) more automatization in routing based on geographical location, navigation capabilities and route optimization.

2.2 Mixed Waste in HSY Waste Management

In 2021 HSY collected over 400 000 tons of waste from their 83 000 customer properties and waste bins and containers were emptied about 8,8 million times (table 1). The amount of collected waste changes from year to year as result of e.g., changes in the regulations and waste production behaviour.

Table 1. The amounts (tons) of waste collected from the customer properties of HSY (HSY, 2022 b)

	2017	**2018**	**2019**	**2020**	**2021**
Mixed waste	192 792	188 595	179 213	184 308	180 147
Cesspools and septic tanks	64 773	137 727	134 220	136 399	141 571
Biowaste	38 582	40 037	42 058	43 821	44 799
Carton packages	7 419	7 503	10 651	13 400	16 816
Plastic packages	1 560	2 444	4 237	6 021	7 103
Glass packages	3 288	3 597	3 821	4 239	4 397
Mixed waste from hospitals	2 768	2 506	2 259	2 369	3 161
Small metal items	1 508	1 580	1 744	2 026	2 166
Other	1 931	2 045	1 187	1 127	881
Waste from sewage screening	902	872	926	962	689
Biological waste from hospitals	213	190	191	165	192
Total	315 736	387 096	380 507	394 837	401 922

In the table 1, changes resulting from the increase in sorting are evident, particularly in the amounts of packaging waste. Also, the covid-19 pandemic, which resulted people spending more time at their homes, is seen as increase in waste amounts, and especially in mixed waste amounts, which had a decreasing trend before the pandemic years.

In 2021 45% (180 000 tons) of the collected waste was mixed waste and mixed waste bins and containers were emptied 4,9 million times resulting on average weight of an emptying at 36,8 kg (table 2).

Table 2. Development of HSY mixed waste collection (HSY, 2022 b)

	2017	2018	2019	2020	2021	2022
Number of emptying events (*1000)	5 684	5 889	5 268	5 079	4 895	4 809
Change from the previous year (%)		+3,6	-10,5	-3,6	-3,6	-1,8
Amount of waste (tons)	192 792	188 595	179 213	184 308	180 147	169 847
Change from the previous year (%)		-2,2	-5,0	+2,8	-2,3	-5,7
Weight per emptying (kg)	33,9	32,0	34,0	36,3	36,8	35,3
Change from the previous year (%)		-5,6	+6,2	+6,7	+1,4	-4,0

From 2017 to 2022 the amount of mixed waste reduced on average by 2,5% per year, but the annual changes have varied significantly. For example, from 2018 to 2019 the amount of collected mixed waste reduced 5%, but from 2019 to 2020 the amount increased 2,8% due to covid-19 pandemic. From 2021 to 2022 the amount of mixed waste reduced 5,7%. (HSY, 2022 b.)

From 2017 to 2022 the average weight per emptying has been varying between 32 kg and 36,8 kg, a significant 13% variation. For example, in 2022 mixed waste bins and containers were emptied approximately as many times as in 2021, while the amount of collected mixed waste was reduced by 10 300 tons (-5,7%) (HSY, 2023 e). This indicates that it is likely that the waste bins were emptied emptier than previous year. In general, the variation in the average weight per emptying are due to changes of collection equipment, changes in the waste composition, or changes in the fill level.

Mixed waste collected from HSY's customer properties is transported to Vantaa Energy's waste-to-energy power plant. Without separate pre-treatment or further sorting the waste is incinerated and the heat from the incineration process is utilized in the production of electricity and district heating. Besides energy, the incineration process produces slag, boiler and fly ash and APC (Air Pollution Control) waste, which are treated at HSY’s eco-industrial centre in Ämmässuo, Espoo. (HSY, 2023 d.)

As source separation increases, the amount of mixed waste will continue to decrease, and the composition of mixed waste is likely to change. HSY studies the composition of mixed waste typically in three-year intervals and it was last studied in 2021. The study showed that households produce on average of 130 kg of mixed waste per year and that 80% of households mixed waste could have been recycled (figure 7) (HSY, 2023 c).

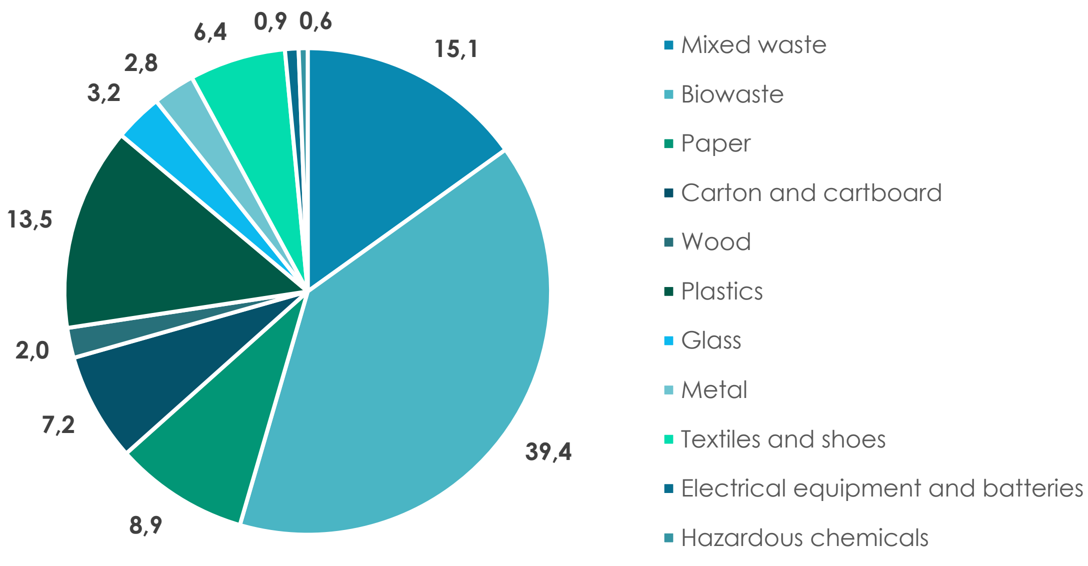

Figure 7. Composition of mixed waste in HSY area in 2021 (%). (HSY, 2023 c)

According to the mixed waste composition study (HSY, 2023 c) the largest waste fraction in household mixed waste is biowaste, which covers for 39,4% of the waste. Second largest fraction is actual mixed waste, which could not be recycled. Other significant shares are paper 8,9%, carton and cardboard 7,2% and plastics 13,5%.

The bulk density of mixed waste depends on the composition of the mixed waste, handling and storing conditions. Typical bulk density values used for mixed waste collected in underground containers in Finland are between 75 – 90 kg/m^3 (Rautavuori, 2023; Salo, 2017).

2.3 Mixed Waste Collected in Underground Containers

The benefits of underground containers are reduced space requirements, extended emptying intervals and decreased odour issues resulting from cooler storage conditions during summer. Underground containers are also considered durable. Executing the emptying with crane reduces occupational risks for the collection staff. (Viherympäristö, 2023.) Collecting waste in underground containers saves time and fuel compared to collection done from wheelie bins. In Tampere it was studied that to collect one ton of waste from wheelie bins took over 40 minutes and four litres of fuel and from underground containers it took only 22 minutes and three litres of fuel. (Saarinen, 2014.)

Underground containers have become more common over the last two decades and are now a standard practice in waste management. In HSY's waste collection number of underground containers has been steadily increasing since 2005, as illustrated in figure 8.

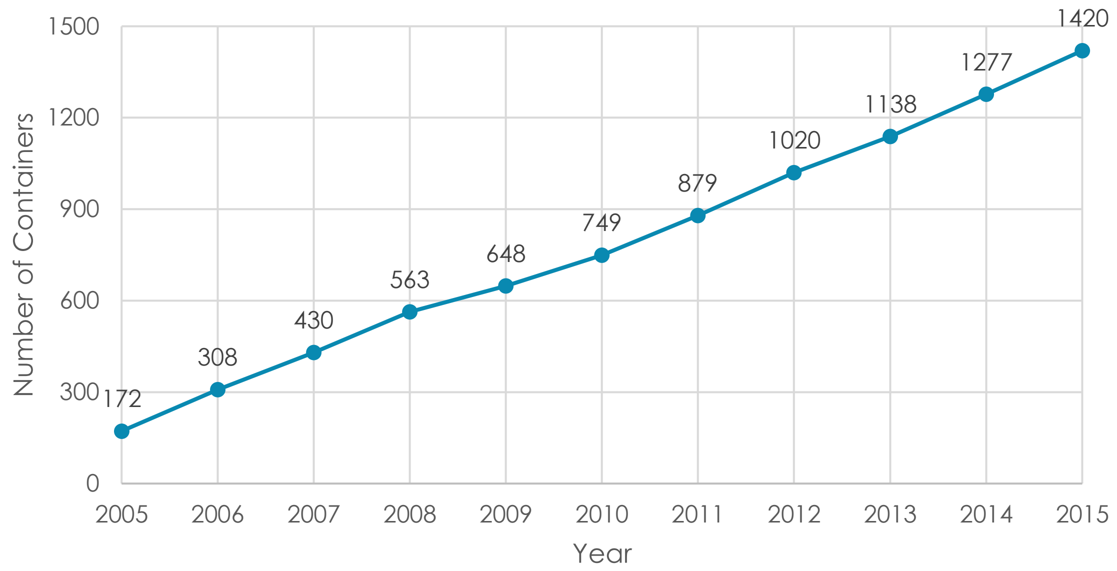

Figure 8. Development of the number of underground containers in HSY's waste collection. (Salo, 2017)

At the end of 2023 in HSY's waste collection there was 2183 collection agreements and 2816 containers that had mixed waste collected with crane loading. Most of them, 2681 containers in 2088 services, were underground containers and the rest, 135 containers in 96 services were on-ground containers that were emptied with crane loading. In 2023 underground and on-ground containers that require crane loading were emptied about 115 000 times.

Given the prevailing trends, it can be anticipated that the popularity of underground containers will continue to grow. This phenomenon is further supported by the increased awareness of the method and its associated benefits.

3 Waste Collection Economics

Waste management costs can be divided into capital costs and operating costs. Capital costs include, for example, land, buildings, equipment, and other long-term investments. Operating costs include expenses such as personnel costs, electricity bills, rent, maintenance, and repair costs. Alternatively, waste management costs can be categorized depending on the nature of the waste management operation, for example

- waste collection costs,
- waste transportation costs,
- waste processing costs,
- landfill costs,
- waste incineration costs,
- composting costs and
- recycling costs. (Merrild & Christensen, 2011.)

Typically, waste collection covers for two thirds of the costs of waste management (Nilsson, 2011). The total cost of waste collection is influenced by factors such as the chosen collection system including service level, collection frequency, quantity of waste fractions collected, and the amount of waste collected per stop. The highest costs typically arise from waste containers, vehicles, waste collector salaries, and fuel. It is common for household waste collection to be outsourced to external contractors, allowing expenses such as waste collector salaries, vehicles, fuel, and contractor profits to be classified as outsourcing costs. The transportation costs of waste depend on the number of vehicles in use, distances, administrative and personnel expenses. Transportation costs also encompass any costs incurred at transfer stations. (Merrild & Christensen, 2011.)

Waste management costs are typically funded through customer fees, municipal or state budgets, or partly from revenue from sales (Merrild & Christensen, 2011). If waste collection is financed through customer fees the pricing model plays a significant role in shaping the organization's revenue streams. Fees may be structured per emptying event, based on the weight of the waste, through fixed monthly or annual subscriptions, or a combination of these approaches. Additionally, supplementary charges may apply for extra services like bin rentals. In cases where pricing is based on a fixed rate per emptying event, revenue directly correlates with the number of emptying events. Conversely, when pricing is weight-based, fluctuations in waste volume directly influence revenue. However, if services are sold with fixed monthly or annual fees, the immediate quantity of waste and services provided may not have a direct impact on the revenue stream.

When aiming for cost-effectiveness, it is important to consider the cost impacts of different waste management activities on each other. For example, cost savings in waste collection by reducing service levels may lead to increased processing costs and extending collection intervals may result in a higher capital investment in waste containers. (Merrild & Christensen, 2011.)

3.1 HSY Waste Collection Economics

In 2022 HSY's operating revenues were 404,2 million euros, out of which 102,5 million euros came from waste management sales revenues. The operating expenses in 2022 were 212,6 million euros, out of which 99,5 million euros for purchasing of services, 48,6 million euros for personnel expenses, 39,2 million euros for purchasing of materials and 25,3 million euros for other operating expenses. The relative shares of HSY's operating revenues and expenses are presented in the figure 9. (HSY, 2023 e.)

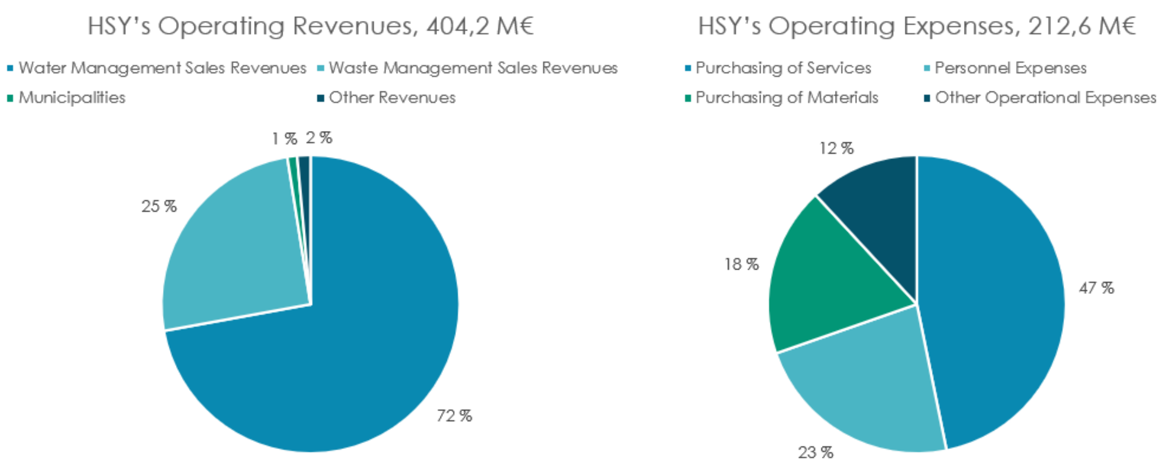

Figure 9. Relative shares of HSY's operating revenues and expenses (HSY, 2023 e.)

In the fiscal year 2022, HSY’s financial result showed a surplus of 12,1 million euros. Nevertheless, the revenue from customer fees did not fully offset the investments, which amounted to 211 million euros, resulting in an increase in indebtedness during the fiscal year. At the end of 2022, HSY's outstanding loans amounted to 1 905 million euros. The equity ratio at the end of the fiscal year was 27%. Additionally, year 2022 presented financial challenges due to factors such as energy crisis, limited availability of raw materials, increasing inflation, rising interest rates, and the consequent growth of economic recession risks. However, HSY’s result for the fiscal year 2022 can be considered good. (HSY, 2023 e; Fred, 2023.)

As seen in figure 9. HSY waste management sales revenues cover for 25% of HSY’s operating revenues. In 2022 HSY waste management operating expenses were 80,2 million euros, which covers for 37,7% of HSY’s operating expenses. HSY Waste Management operating revenues and expenses are presented in more detailed breakdown in the table 3.

Table 3. HSY Waste Management Operating Revenues and Expenses in Euros (HSY, 2023 e.)

Operating Revenues:		**104 525 000**
	Waste Collection Fees	85 571 000
	Waste Treatment Fees	8 783 000
	Other Sales Revenues	8 456 000
	Other Operating Revenues	1 714 000
Operating Expenses:		**-80 187 000**
	Personnel Expenses	-8 522 000
	Purchases of Waste Collection and Transportation Services	-34 132 000
	Purchases of Other Services	-33 094 000
	Materials, Supplies, and Goods	-3 104 000
	Other Operating Expenses	- 1 335 000
Operating Profit		**24 337 000**
Income and Expenses of Financing		**1 776 000**
Overall Profit		**26 113 000**
Depreciation		**-16 854 000**
Net Income for the Financial Year		**9 259 000**
	Change in Deviation of Depreciation	487 000
Excess or Deficiency for the Financial Year		**9 745 000**

In 2022 HSY waste management operating revenue was 104,5 million euros, out of which waste collection fees covered for 82%. 8% of the revenue came from waste treatment fees, 8% from other sales revenues and 2% from other operating revenues which includes e.g., fee revenues, grants and subsidies and rental revenues. In 2022 operating expenses were 80,2 million euros, out of which 42% for purchases of waste collection and transportation services, 41% for purchases of other services, 11% for personnel expenses, 4% for materials, supplies and goods and 2% for other operating expenses, for example rentals and waste tax. Relative shares of operating revenue and expenses are presented in figure 10.

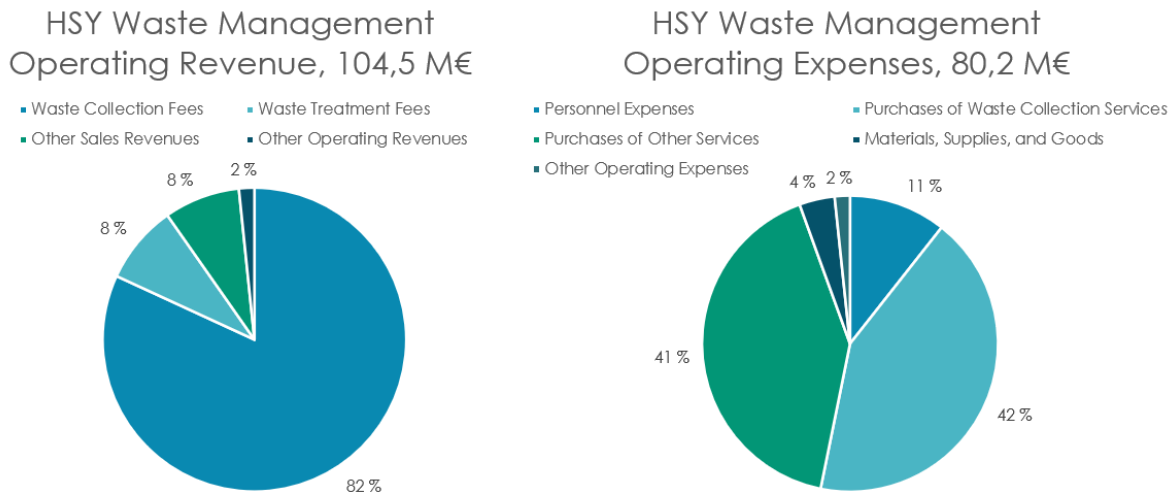

Figure 10. Relative Shares of HSY Waste Management Operating Revenue and Operating Expenses (HSY, 2023 e.)

As seen in figure 10, fees from waste collection cover for most of HSY waste management operating revenue. 40% of the waste collection fees is used for purchasing waste collection services.

Waste collection and transportation services are purchased from private waste collection contractors chosen via competitive procurement process. The contracting prices are set during the competitive procurement process. Typically the prices are per emptied container and therefor contractors income is highly dependent on the number of waste bins emptied, but also sanctions and bonuses, defined in the contract, are applied.

3.2 HSY Waste Collection Fees

HSY waste management customer fees are based on a tariff, that is updated annually and approved by the board of HSY. The waste tariff prices should encourage customers to adhere to the priority order of the EU waste hierarchy, which means prioritizing waste reduction and minimizing harmfulness, as well as enabling the recyclability of waste materials. The fees in the waste tariff are designed to encompass all expenses associated with HSY's legal waste management duties, including waste collection, transportation, treatment, providing information and guidance, administration, aftercare of landfills and construction of required infrastructure. (HSY, 2023 f.)

Waste collection fees include waste collection, waste treatment and container rent. Waste treatment fees are charged only for the waste fractions HSY is resposible of treating, like mixed waste and biowaste. Larger containers, like undergroud containers, skips and compressors, treatment fee is based on the actual weight of the container. In these cases containers are weighted durign the pickup. Container rent is charged when waste is collected in container owned by HSY or contractor. Rental fees can be charged by weekly basis or be included to the collection fee. Additionally fees are charges for excess waste left out side of the collection equipment, moving the waste container if emptying the waste container requires moving the equipment manually over 10 meters, damaged or lost waste containers, changing a container on customers request, padlocks, lining sacs for biowaste and annual fees of regional mixed waste collection point for customer's whose properties are not accessible by waste collection vehicle. (HSY, 2023 g.)

Budgeting waste collection is done based on the waste volumes, numbers of emptied containers, number of containers rented and contracting prices. In current situation budget preparation is especially challenging considering the deviations in waste generation development caused by the COVID-19 pandemic and government agenda that might lead to changes in waste legistlation and as result, changes in municipal waste management.

4 Fill Level Sensors in Solid Waste Collection

Sensor is a device that produces electrical signals based on detected physical, chemical, or biological changes in the environment. Fill level sensors are designed to measure and indicate fill level or capacity of a container or receptacle. Fill level sensors utilize various measurement technologies, such as ultrasound, pressure sensors, sonars, radars, optical sensors, or weight measurement. The technology and the measuring equipment are chosen based on the application and substances or materials they are intended to monitor and the goals of the monitoring.

Fill level sensors have been utilized in wide range of applications for example, different industries utilize fill level measurement to monitor the fill level of tanks, pipes, and reactors for the purpose of enhancing and supervising processes. In vehicles and airplanes fuel tank fill levels are monitored, and in households dishwashers and washing machines utilize fill level measurement to optimize the amount of water.

In solid waste management fill level sensors are typically used for measuring the fill level of large, closed containers, skips or compactors to optimize timing of container emptying and/or automatize processes that would otherwise require human action e.g., ordering an extra emptying for a container. The goal is to increase collection efficiency, save money and time and reduce environmental burden. In solid waste collection context typical technologies for fill level sensors are ultrasound, pressure, and radar technologies. (Salo, 2017; Wastebook, 2023.)

Burger et al. (2018) have shown by computer simulation that introducing fill level sensors, IoT (Internet-of-Things) approach and dynamic routing can reduce the time used for the waste collections. Ferrer & Alba (2019) have introduced a cost-free intelligent software, BIN-CT, that reduces the travelled distance by 20%, generates routes that are 33,2% shorter than the reference company's routes and enhance the service level by decreasing overfilling by fill level prediction.

Typical challenge in waste collection is that the bins and containers are emptied before they are full. According to a study conducted in 2014 in Tampere, surface containers were typically emptied when they were 60-70% full, while underground containers were emptied only 50% full (Saarinen, 2014). According to a study conducted in 2017 in HSY area, underground containers were emptied on average 58-68% full and 21% of underground container pickups were done under 50% fill level (Salo, 2017). Both studies utilized surface level measurement in the waste containers.

Efficiency of waste collection can be enhanced through careful sizing of equipment by adjusting number of equipment and size and emptying intervals. Lack of suitable emptying intervals may lead to reducing risks of overfilling by choosing more frequent emptying interval. Changes to the sizing can be made easily to wheelie bins but as underground containers are installed somewhat permanently, options for resizing are more limited. (Saarinen, 2014; Salo 2017.) Due these reasons and the higher one-time emptying costs, it is justified to primarily utilize fill level sensors in larger containers, skips and compressors instead of wheelie bins.

Since waste collection circumstances in Finland vary in terms of temperature and humidity, there are special requirements for the fill level sensors (Saarinen 2014). Only two widely known fill level sensor providers have provided their services especially for Finnish waste management: Enevo and Wastebook. Currently it seems, that Enevo is not active in Finnish market (Enevo, 2024; Linikko, 2018; Tivi, 2020).

4.1 Experiences of Utilizing Fill Level Sensors in Waste Collection

Utilizing fill level sensors in waste collection can produce a lot of positive impacts, such as reduced costs and increase customer satisfaction. Also, challenges have been identified e.g., false notifications and challenges adapting to a new way of working. (Happonen, 2023; Linikko, 2018; Rinki, 2014.)

It has been recognized that generated waste volumes vary for example due different seasons, holidays, and vacation seasons. In locations, where it is difficult to predict the filling interval due to varying waste volume generation, the benefits of fill level sensors are reduction of unnecessary emptying visits, reduced overfilling, and automatization of emptying request which result to reduced costs and more efficient time use. (Linikko, 2018; Rinki, 2014.)

In 2023, Wastebook, a company specializing in intelligent waste services, joined forces with Hauru, an environmental company based in Oulu, to introduce fill level sensors in waste management. Approximately 2,000 fill level sensors were installed, serving around 30,000 residents. According to the representative of Hauru (Happonen, 2023) the implementation of fill level sensors brought substantial benefits to Hauru, including a notable 19% increase in revenue, a reduction of approximately 37% in operational waste management costs, and an overall cost reduction of about 22%. Hauru acquired 30% more new customers, while the frequency of waste collection decreased by 30%. The estimated return on investment was approximately 2 years. For residents and end-users, the most significant advantages were the reduced number of waste collection truck visits, lowered hidden waste management costs (such as property cleaning expenses), and increased control over individual waste management options. (Happonen, 2023.)

In 2022, a housing company in Espoo, installed Wastebook's Jaete-sensors in underground containers to measure their fill levels. Based on the data, it was determined that the mixed waste container was emptied at an average fill level of 39%. Based on the fill level data, the collection interval was reduced in three out of seven containers, resulting in a 21% savings in waste management expenses. (Happonen, 2023.)

Rosk'n Roll, a municipal waste management organisation in southern Finland, has utilized fill level sensors in mixed waste containers and cardboard containers. The most common, yet infrequent issues reported with sensor usage included unnecessary fire alarms due to false overheating notifications, sensor malfunctions, and data transmission problems between systems. The benefits of the sensors were a 25% reduction in waste management costs, a decrease in overfilling leading to reduced environmental impacts, and improved customer satisfaction. The most significant advantage was perceived to be timely emptying of the containers. (Linikko, 2018.)

For Paperinkeräys Oy, a producer responsibility organization, the utilization of fill level sensors uncovered contractor misconduct. The sensor data was in conflict with the emptying reports provided by the contractor and as a result, the organization transitioned to using sensor-verified emptying as the basis for contractor billing. (Rinki, 2014.)

4.2 Fill Level Sensors in HSY Waste Collection

Currently fill level sensors are utilized in HSY Waste Collection in few locations, like parks, where filling of the underground container is difficult to predict. In this case fill level is monitored by staff of the municipality and emptying request is done by calling HSY customer service.

Besides current use, fill level sensors have been utilized in a study conducted by Salo in 2017, which introduced a concept proposal for value creation implementing fill level based partially dynamic collection for HSY. The concept introduced partially dynamic routing integrated to existing static waste collection and existing routes and examined it from perspective of customers, contractors, and HSY. In practice partially dynamic routing allows variation of collection interval only within pre-set rules. Typically, there are pre-set weekdays, when collection is done in a certain area and based on the fill level sensor data it is analysed (either automatically or heuristically) whether the container should be emptied or not.

The study conducted by Salo (2017) included a fill level sensor pilot that was conducted in 2016 between March and October. In the pilot 26 fill level sensors were installed to front loader containers in Otaniemi and 54 fill level sensors were installed to underground containers in Lauttasaari.

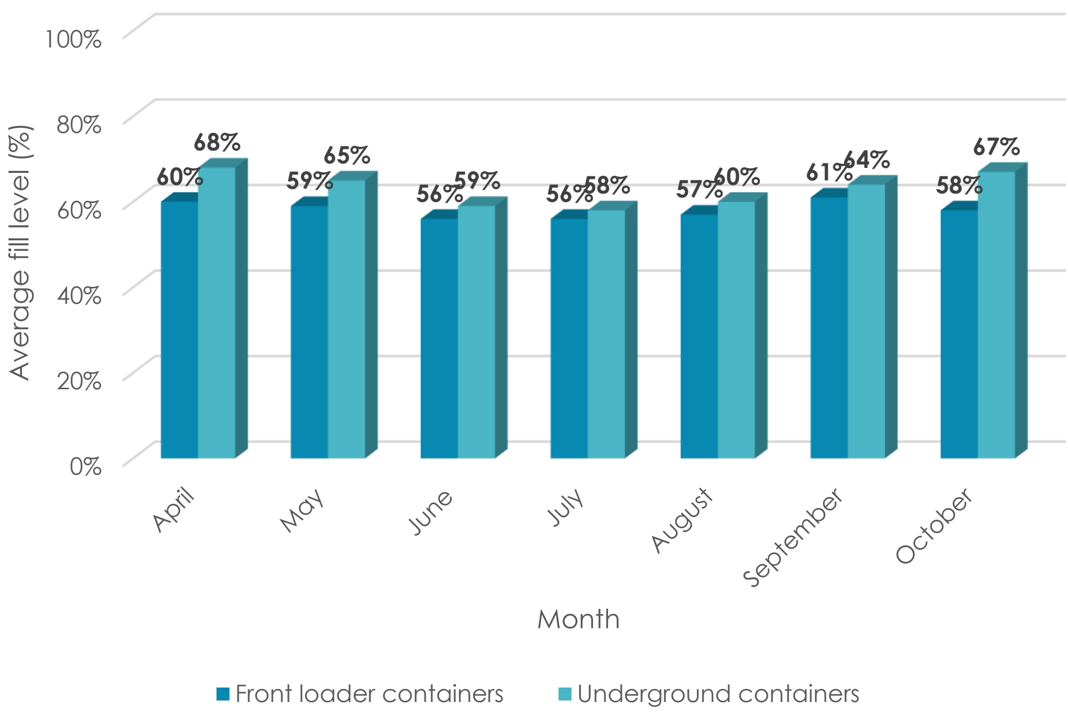

Figure 11. Average fill levels (%) in HSY's pilot in 2016 (Salo 2017).

The pilot showed that the average fill level varies more significantly in underground containers than in front loader containers, varying by at least 10 percentage points, and decreasing during summer.

Table 4. Fill levels of collection in HSY's pilot in 2016 (Salo 2017).

	Underground Container Pickups (n=1200)		**Front loader Container Pickups (n=1427)**	
Fill level range	**Collections**	**Percentage**	**Collections**	**Percentage**
<10%	1	0,1%	9	0,6%
10-19%	7	0,6%	67	4,7%
20-29%	34	2,8%	111	7,8%
30-39%	58	4,8%	180	12,6%
40-49%	151	12,6%	184	12,9%
50-59%	256	21,3%	231	16,2%
60-69%	286	23,8%	186	13,0%
70-79%	189	15,8%	132	9,3%
80-89%	116	9,7%	106	7,4%
90-99%	76	6,3%	97	6,8%
100%	26	2,2%	124	8,7%

The pilot showed that about one fifth (20,9%) of underground container collection were done with under 50% fill level and 66% of underground container collection were done with under 70% fill level. 38,6% of front loader container collection were done with under 50% and 67,8% were done with under 70% fill level. It is in evident that there is room for improvement. The pilot also showed that even locations with optimal 70-89% average fill level, occasionally have lower fill level and therefor would benefit from dynamic collection. The technology was considered suitable and reliable enough for household waste collection. Considering the variations in fill levels, it has been recognized that improving fill level effectiveness requires dynamic elements. (Salo 2017.)

According to Salo (2017), customers have a positive attitude toward fill level measurement and dynamic collection. Customers concerns include technical challenges and the potential cost increase associated with implementation of new technology. From the contractors' perspective, dynamic collection diminishes their position compared to the current static collection due to increased uncertainties. Municipal authorities staff recognize both possible benefits and risks. Unfortunately, lack of evidence hinders the adoption of new technology.

From financial perspective, with current pricing models and contracts, implementing fill level based partially dynamic collection would produce financial benefits to most of the customers involved. On contrary, proposed concept would reduce financial income of contractors and HSY. Out of the three stakeholders, customers benefit the most from the proposed concept. (Salo 2017.)

It has been recognized that to facilitate the decision making, waste collection efficiency should be assessed more widely and, in addition, determine the specific conditions under which the adoption of fill level sensors and dynamic collection can be beneficial for all stakeholders (Salo, 2017).

As noted, unfortunately fill level sensors do not provide all the benefits to all stakeholders under all the circumstances. The following chapters examine the use of fill level sensors in HSY waste management through data analysis and calculational methods. Based on this analysis, options are presented to balance benefits among different stakeholders.

5 Materials and Methods

The data sets used in this thesis are drawn from HSY's logistics systems, reporting environments and files that contain data from fill level sensors utilized in the pilot conducted by Salo (2017). The data processing has been performed in Excel spreadsheet software.

5.1 Bulk density of mixed waste

The data for the calculations for the bulk density of the mixed waste originated from two sources: data for the volume originated from files containing fill level sensor data from 2016 to 2019 and data for the weight of the mixed waste originated from HSY's logistics system, to where the collection personnel manually feed the data from the scale of the waste collection vehicle.

The raw data for the volume of mixed waste included the following data columns:

- ID
- Site
- Site name
- Address
- City
- Site content type
- Content type
- Content type name
- Time (Europe/Helsinki)
- Frozen
- Fill level before
- Fill level after
- Volume (l)
- Weight (kg)
- Partial
- Container slot:ID
- Container slot:Name

- Container slot:Time (Europe/Helsinki)
- Container slot:Fill level before
- Container slot:Fill level after
- Container slot:Volume (l)
- Container slot:Weight (kg)
- Container slot:Confidence
- Confidence

Sample of data (Data sample 1) is presented in appendix 1. The columns utilized in the bulk density calculations included the following columns:

- Site name (Street address),
- Time (Europe/Helsinki) (Date and time of the emptying event, detected by the sensor) and
- Fill level before (Percentual fill level, detected by the sensor) and
- Volume (l) (Calculated volume of the emptying event).

Data for the weight of the waste was default data set added with the weight information drawn from HSY's logistics system and included the following data columns:

- UA (= contract zone id),
- AP (= route id),
- Urak (= contractor),
- Palvelutunnus (= service id),
- Nouto-osoite (= pickup address),
- Jp (= number of the pickup point of the service),
- Jätep.omin. (= additional information about the pickup point),
- Postinro (= postal code),
- Kunta (= city),
- Jätelaji (= waste type),
- Työ (= task type),
- Tila (= status),
- Suunniteltu (= planned pickup date),
- Kayntiaika (= actual pickup date and time),
- Tehty (= actual pickup date),

- Työlistan päivä (= date of the work list),
- Työlistan nro (= work list id),
- Kuormaustapa (= loading method),
- Yritys (= organization),
- Tekijä (= contractor and name of performer),
- Asiamies (= waste management coordinator),
- Kuorma (= load id),
- Reknro (= register number),
- Ajojärj1 (= dispatcher1),
- Ajojärj2 (= dispatcher2),
- Tulostettu (= printed),
- Pesuvuosi/kierros (= wash year/round),
- Pesujakso (= wash period),
- Painot (= weight, kg) and
- Noutorytmi (= pick up day).

Sample of the data (Data sample 2) is presented in appendix 2. The columns utilized in the bulk density calculations included the following columns:

- Nouto-osoite (= pickup address),
- Kayntiaika (= actual pickup date and time) and
- Painot (= weight, kg).

The utilizable data was limited by availability of matching data; only the data that had a matching information regarding location (address) and timestamp (date) from fill level sensors and from HSY's logistics system was utilized for the calculations. The matching data used for the calculations covered time period from 1st of January 2018 to 2nd of January 2019, contained data from 49 different pick-up locations and covered 1 726 pick-up events. The volume and the weight of the event were matched by address and date.

The bulk density of mixed waste was calculated based on 1726 pick-up events, where mixed waste collected in underground containers and data for the volume and weight was available. For each of the pick-up event the bulk density was calculated:

$$\rho_e = \frac{m_e}{V_e}$$

where ρ_e is the bulk density of the event, m_e is the reported mass of the pickup event (from the data column: Painot (= weight, kg)) and V_e is the measured volume of the mixed waste (from the data column: Volume (l), converted to cubic meters). Calculated volume of the emptying event). From the results per event average value, median and standard deviation were calculated.

5.2 Fill level calculation for underground containers, which do not have fill level measurement

The data set used for fill level calculations was drawn from the reporting environment of HSY. The data origins from HSY's logistics system and is extracted to the reporting environment through integration. The data set included the collection data of mixed waste collected from underground and on-ground containers that were emptied with a crane. Data set contained the following columns:

- Palvelutunnus (= service id),
- Suunniteltu päivä (= planned pickup date),
- Kuittauksen pvm (= actual pickup date),
- Jätelaji (= waste type),
- Nouto-osoite (= pickup address),
- Kunta (= city),
- Kuormaustapa (= loading method),
- Astiakoko/irtojäte (= size of the collection equipment/excessive waste),
- Astialaji (= type of the collection equipment),
- Jätepiste nro (= number of the pickup point of the service),
- Noutotiheys (= pickup frequency),
- Suunniteltu määrä (= planned amount of emptied equipment),
- Toteutunut määrä (= actual amount [of emptied equipment or weight]) and
- TARKISTUS (= verification).

Sample of the data (Data sample 3) is presented in appendix 3.

The data set covered one year time period, from 1st of July 2022 to 30th of June 2023, 1982 different pick-up locations and 215 284 rows of data, which includes separate rows for each of the emptying event and the weight of emptying event.

The data was cleaned by removing erroneous rows, such as rows with incorrect type of the collection equipment (19 rows) and rows with an actual value below 1 (3618 rows). The data was corrected for the sizes of the collection equipment, so that the sizes that were in litres were converted to cubic meters and 4 m^3 sizes were changed to 3 m^3 and 6 m^3 sizes were changed to 5 m^3 sizes to better reflect the real situation. The rows of each event were set in order by arranging the data set by size of the collection equipment, number of waste collection point, address, and actual pick-up date. After the arranging operation, the dataset was checked with if-functions to recognize the events that had accurate and reliable data.

For each event the average weight per emptied equipment was calculated:

$$m_{eq} = \frac{m_e}{n}$$

where m_{eq} refers to the mass per emptied equipment, m_e refers to the reported mass of the event and n refers to the number of emptied equipment within the event.

The rows that had extremely high weight per emptied equipment (>1000kg) were checked and 7 out of 12 rows were deleted due to the data being incompatible. The clean data included 103 997 events.

For each event the volume per emptied equipment was calculated:

$$V_{eq} = \frac{m_{eq}}{\rho}$$

where V_{eq} refers to volume of emptied equipment, m_{eq} refers to mass of emptied equipment and ρ refers to the average bulk density calculated based on measured fill levels and reported weights.

For each event the fill level percentage was calculated:

$$\text{fl\%} = \frac{V_{eq}}{V_2}$$

where fl% refers to the fill level percentage, V_{eq} refers to volume of emptied equipment and V_2 refers to the overall volume of the equipment.

The values were calculated for 103 997 pickup events. The calculated fill levels per event were used to calculate the mean, median, standard deviation, and distribution. The same values were calculated also separately for each month.

5.3 Economics

Utilization of fill level sensors impacts the economy of HSY's waste management in two ways: decreasing waste collection fees and increase of costs.

Decrease of waste collection fees is calculated based on the waste management service fees for 2023. The emptying fee consists of a so-called transport fee, which is a fixed one-time fee for the emptying event, and a treatment fee, which depends on the weight of the waste. In 2023 the transport fee for underground and on-ground containers that require crane loading was 42,62 € (including VAT 24%) or 34,37 € (VAT 0%) and treatment fee was 197,49 €/ton (including VAT 24%) or 159,27 €/ton (VAT 0%). It is assumed that implementing fill level sensors would not significantly reduce the amount of mixed waste and therefor the calculations only consider the reduction of the transport fee based on the reduced number of pickup events.

As mentioned in the section 3.1, 40% of the waste collection fees is allocated for covering immediate expenses; purchasing waste collection services. When the workload decreases, these immediate expenses can be eliminated. Therefore, the decrease in income can be assumed to be about 60% of the transport fee (34,37 €, VAT 0%) multiplied by the assumed number of reductions of pickup event.

The decrease of income was calculated:

$$x = 0{,}6 * 34{,}37\,€ * k$$

where x refers to the decrease of income, 0,6 is the assumed decrease taking into a consideration the reduced contractor expense, 34,37 € being the transport fee and k referring to the number of pickup event reduction. Assuming implementing fill level based partially dynamic collection, all the emptying events with less than 50% fill level rate can be postponed to the next emptying interval or even further. To simplify the calculations, k is assumed to equal the number of the emptying events with less than 50% fill level rate.

The increase in costs includes expenses related to fill level sensors that is based on offer from Wastebook and the assumed increased need for labour. The increase in labour is estimated to be around 0,5 full-time worker equivalents, with an estimated cost of approximately 50,000 euros per full-time worker equivalent per year.

6 Results

6.1 Bulk density of the mixed waste

The calculated average bulk density of the mixed waste was 72 kg/m^3, the median was 71 kg/m^3 and the standard deviation was 22 kg/m^3. Values were between 14 – 210 kg/m^3, and the deviation of the values is 200 kg/m^3. The distribution of the values is presented in the figure 12.

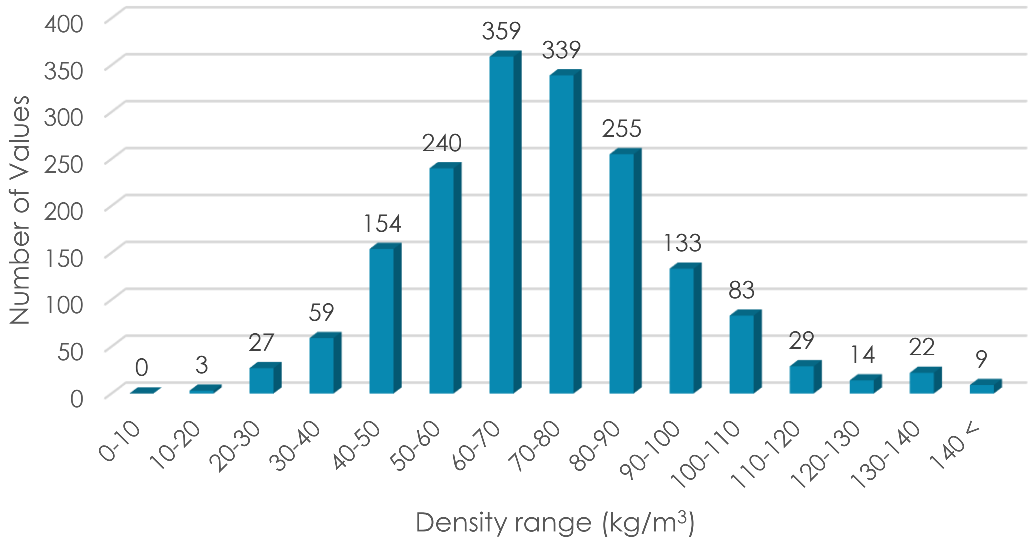

Figure 12. Distribution of the bulk density values.

As seen in the figure 12, the range 60 – 70 kg/m^3 has the most values, 359 pieces. The range 60 – 80 kg/m^3 has 698 values out of the total 1726, which covers for 40% of the values. Most of the bulk density values are within the range of 50 - 90 kg/m^3. This range covers for 1193 out of 1726 values, which equals 69% of the values. The range from 40 to 100 kg/m^3 covers 1480 values out of 1726 values, which equals 86% of the values.

6.2 Fill levels

Fill level values were calculated for 104 000 events, by using the calculated average bulk density, 72 kg/m^{3}. The calculated average fill level was 65%, the median was 60% and standard deviation 37%. The distribution of the values is illustrated in the figure 13 and presented more detailed in the table 5.

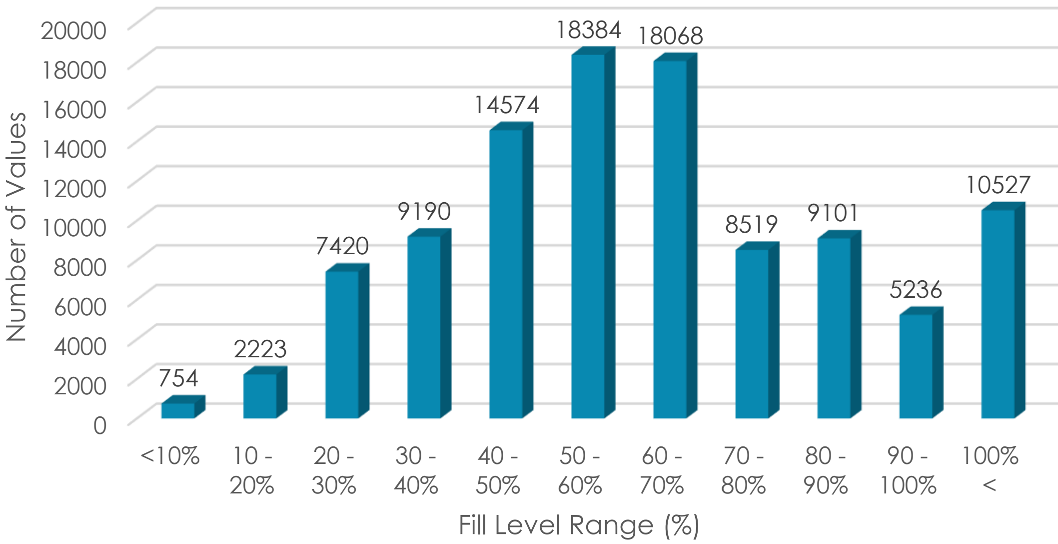

Figure 13. Distribution of the calculated fill level values.

As seen in the figure 13 most of the fill level values (18 400 pieces, 18%) were within the range of 50–60%. Second largest share (18 100 pcs, 17%) were within the range of 60–70%. Third largest share (14 600 pcs, 14%) were within the range of 40–50%. All together the three largest ranges cover for 49% of the pickup events.

Table 5. Distribution of the calculated fill level values

Fill level range	Number of Events	Percentual share
< 10%	754	0,7
10–20%	2223	2,1
20–30%	7420	7,1
30–40%	9190	8,8
40–50%	14574	14,0
50–60%	18384	17,7
60–70%	18068	17,4
70–80%	8519	8,2
80–90%	9101	8,8
90–100%	5236	5,0
100% <	10527	10,1
Fill level range	**Number of Events, cumulative**	**Percentual share, cumulative**
< 10%	754	0,7
< 20%	2977	2,9
< 30%	10397	10,0
< 40%	19587	18,8
< 50%	34161	32,8
< 60%	52545	50,5
< 70%	70613	67,9
< 80%	79132	76,1
< 90%	88233	84,8
< 100%	93469	89,9
ALL	103996	100,0

As seen in the table 5, 19% (19 600 pcs) of the emptying events were done with less than 40% fill level and 33% (34 200 pcs) of the emptying events were done with less than 50% fill level. Over 100% fill levels occurred in 10% (10 500 pcs) of the emptying events.

Fill levels with less than 50% occurred in 1813 of 2081 pickup locations, which covers for 87% of the pickup locations.

6.3 Monthly variation of fill levels

Monthly variations were studied by calculating the fill level rates for each month.

Table 6. Monthly variation of calculated fill levels

	July	August	September	October	November	December
Average Fill Level (%)	62	63	63	65	64	65
Median (%)	56	57	57	61	58	61
Standard Deviation (%)	41	36	36	35	30	31
	January	**February**	**March**	**April**	**May**	**June**
Average Fill Level (%)	65	70	65	71	64	60
Median (%)	63	64	60	64	58	56
Standard Deviation (%)	32	38	33	48	38	37

There is some varying in the key figures on the monthly basis. The average fill level varies from 60% to 71% and the median varies from 56% to 64%. Lowes average fill level rate is in June and highest average fill level rate is in April.

Table 7. Distribution of calculated fill levels by month.

	Number of Events	Percentual share	Number of Events	Percentual share	Number of Events	Percentual share	Number of Events	Percentual share
	2022							
	July		August		September		October	
< 10%	61	0,7%	53	0,6%	49	0,6%	31	0,4%
10-20%	200	2,5%	91	1,0%	144	1,6%	150	1,8%
20-30%	620	7,6%	786	8,6%	695	7,9%	589	7,0%
30-40%	814	10,0%	815	8,9%	744	8,5%	634	7,6%
40-50%	1179	14,5%	1410	15,5%	1332	15,2%	1162	13,8%
50-60%	**1639**	**20,1%**	**1731**	**19,0%**	**1675**	**19,2%**	1528	18,2%
60-70%	1357	16,6%	1602	17,6%	1595	18,2%	**1677**	**20,0%**
70-80%	748	9,2%	797	8,7%	694	7,9%	683	8,1%
80-90%	614	7,5%	727	8,0%	728	8,3%	762	9,1%
90-100%	311	3,8%	422	4,6%	425	4,9%	452	5,4%
100% <	610	7,5%	687	7,5%	664	7,6%	728	8,7%
	2022				2023			
	November		December		January		February	
< 10%	35	0,4%	42	0,5%	59	0,7%	36	0,5%
10-20%	140	1,6%	133	1,5%	168	1,9%	113	1,5%
20-30%	596	6,8%	611	7,1%	553	6,2%	405	5,5%
30-40%	710	8,1%	691	8,0%	758	8,6%	560	7,6%
40-50%	1312	15,0%	1215	14,1%	1206	13,6%	897	12,1%
50-60%	**1677**	**19,2%**	1499	17,4%	1300	14,7%	1240	16,7%
60-70%	1572	18,0%	**1551**	**18,0%**	**1982**	**22,4%**	**1281**	**17,3%**
70-80%	727	8,3%	797	9,2%	779	8,8%	630	8,5%
80-90%	814	9,3%	855	9,9%	725	8,2%	750	10,1%
90-100%	412	4,7%	455	5,3%	453	5,1%	392	5,3%
100% <	743	8,5%	779	9,0%	876	9,9%	1107	14,9%
	2023							
	March		April		May		June	
< 10%	52	0,5%	84	0,9%	87	0,9%	153	1,7%
10-20%	196	2,1%	183	2,0%	276	2,9%	329	3,6%
20-30%	613	6,5%	521	5,6%	754	7,9%	777	8,5%
30-40%	829	8,7%	641	6,9%	886	9,3%	1108	12,1%
40-50%	1290	13,6%	857	9,2%	1361	14,3%	1353	14,7%
50-60%	**1819**	**19,2%**	1190	12,8%	**1583**	**16,6%**	**1503**	**16,3%**
60-70%	1583	16,7%	1085	11,7%	1469	15,4%	1314	14,3%
70-80%	720	7,6%	519	5,6%	692	7,2%	733	8,0%
80-90%	843	8,9%	703	7,6%	888	9,3%	692	7,5%
90-100%	469	4,9%	**1928**	**20,8%**	511	5,4%	427	4,6%
100% <	1070	11,3%	1579	17,0%	1038	10,9%	804	8,7%

As highlighted in the table 7 the distribution of fill level values varies on monthly basis. During seven months out of twelve, most of the fill level values fall within the range 50-

60%. During October, December, January and February most of the values are within the range 60-70%. April appears as an exception, with the majority of calculated fill levels falling within the 90-100% range. The distribution is also illustrated in the figure 14.

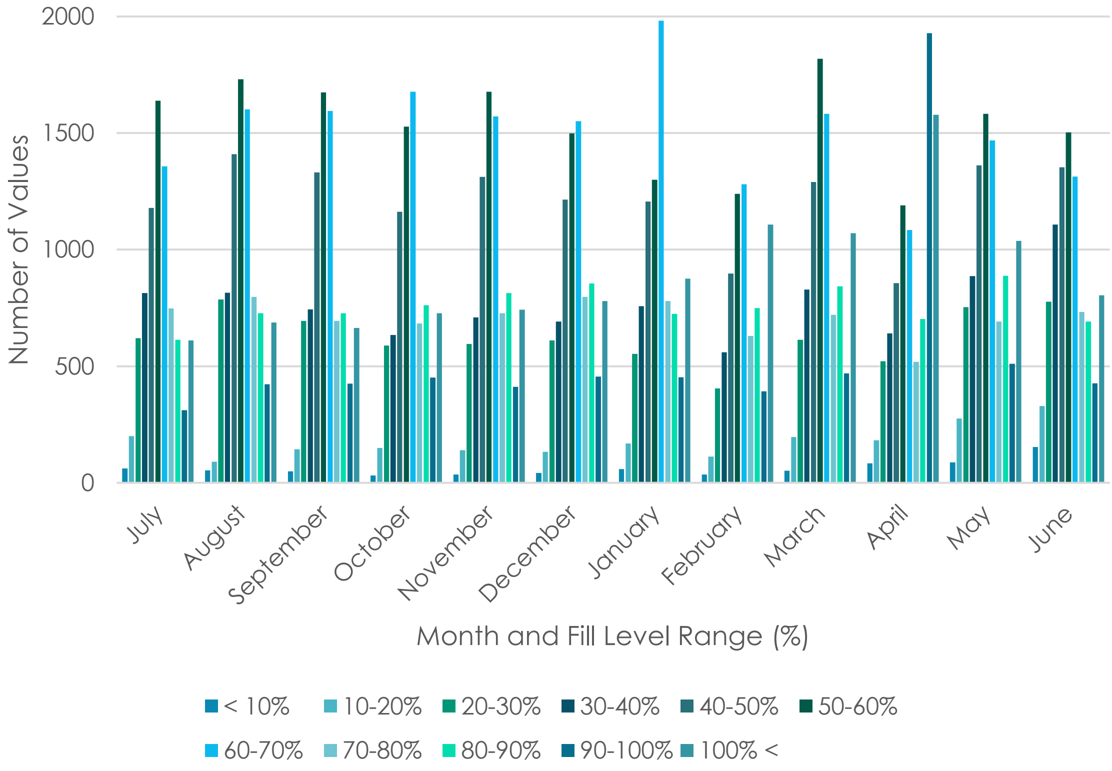

Figure 14. Distribution of calculated fill levels by month

In the figure 14 the exceptionally high calculated fill level rates in April are notably highlighted.

Table 8. Distribution of calculated fill levels by month, cumulative

	Number of Events	Percentual share	Number of Events	Percentual share	Number of Events	Percentual share	Number of Events	Percentual share
	2022							
	July		**August**		**September**		**October**	
< 10%	61	0,7%	53	0,6%	49	0,6%	31	0,4%
< 20%	261	3,2%	144	1,6%	193	2,2%	181	2,2%
< 30%	881	10,8%	930	10,2%	888	10,2%	770	9,2%
< 40%	1695	20,8%	1745	19,1%	1632	18,7%	1404	16,7%
< 50%	2874	35,3%	3155	34,6%	2964	33,9%	2566	30,6%
< 60%	4513	55,4%	4886	53,6%	4639	53,0%	4094	48,8%
< 70%	5870	72,0%	6488	71,1%	6234	71,3%	5771	68,7%
< 80%	6618	81,2%	7285	79,9%	6928	79,2%	6454	76,9%
< 90%	7232	88,7%	8012	87,8%	7656	87,5%	7216	85,9%
< 100%	7543	92,5%	8434	92,5%	8081	92,4%	7668	91,3%
ALL	8153	100,0%	9121	100,0%	8745	100,0%	8396	100,0%
	2022				**2023**			
	November		**December**		**January**		**February**	
< 10%	35	0,4%	42	0,5%	59	0,7%	36	0,5%
< 20%	175	2,0%	175	2,0%	227	2,6%	149	2,0%
< 30%	771	8,8%	786	9,1%	780	8,8%	554	7,5%
< 40%	1481	16,9%	1477	17,1%	1538	17,4%	1114	15,0%
< 50%	2793	32,0%	2692	31,2%	2744	31,0%	2011	27,1%
< 60%	4470	51,2%	4191	48,6%	4044	45,6%	3251	43,9%
< 70%	6042	69,1%	5742	66,6%	6026	68,0%	4532	61,2%
< 80%	6769	77,5%	6539	75,8%	6805	76,8%	5162	69,7%
< 90%	7583	86,8%	7394	85,7%	7530	85,0%	5912	79,8%
< 100%	7995	91,5%	7849	91,0%	7983	90,1%	6304	85,1%
ALL	8738	100,0%	8628	100,0%	8859	100,0%	7411	100,0%
	2023							
	March		**April**		**May**		**June**	
< 10%	52	0,5%	84	0,9%	87	0,9%	153	1,7%
< 20%	248	2,6%	267	2,9%	363	3,8%	482	5,2%
< 30%	861	9,1%	788	8,5%	1117	11,7%	1259	13,7%
< 40%	1690	17,8%	1429	15,4%	2003	21,0%	2367	25,7%
< 50%	2980	31,4%	2286	24,6%	3364	35,2%	3720	40,5%
< 60%	4799	50,6%	3476	37,4%	4947	51,8%	5223	56,8%
< 70%	6382	67,3%	4561	49,1%	6416	67,2%	6537	71,1%
< 80%	7102	74,9%	5080	54,7%	7108	74,5%	7270	79,1%
< 90%	7945	83,8%	5783	62,2%	7996	83,8%	7962	86,6%
< 100%	8414	88,7%	7711	83,0%	8507	89,1%	8389	91,3%
ALL	9484	100,0%	9290	100,0%	9545	100%	9193	100,0%

In the table 8 monthly variations are presented. The percentual share of calculated fill levels less than 40% vary between the highest value 26% in June and lowest value 15% in April. The percentual share of calculated fill levels less than 50% vary between the highest value 41% in June and lowest value 25% in April.

6.4 Economic impact

If applying Salo's (2017) proposal of partially dynamic routing, in theory all the emptying events with less than 50% fill level could be postponed to next emptying interval. As mentioned previously, to simplify the calculation, it is assumed that the number of emptying events would reduce by the number of emptying events done with less than 50% fill level rate.

Table 9. Decrease of Annual Income

Fill level range	**Number of Events**	**Percentual share**	**Decrease of income (k€)**
< 50%	34 161	32,8	704

Based on this simplified calculations, which results are presented in the table 9, HSY's income would be reduced by approximately 700 k€. This amount takes into account also the reduced contractor fees. 700 k€ counts for about 0,8% of the annual waste collection fees.

The increase in expenses includes costs related to sensors, their usage and increase in labour costs. If the sensors are acquired as a service, with a total of 2 816 sensors, and their usage incurs an annual expense of approximately 200 k€ (Happonen, 2024). In addition, the increase in labour is estimated to be around 0,5 full-time equivalents, with an estimated cost of approximately 50 k€ per full-time equivalent which results to 25 k€ per year. The overall increase in costs would be about 225 k€.

Considering both, reduction of income and increase of expenses, would result to 925 k€.

7 Discussion

The calculated bulk density, 72 kg/m^3, seems fairly low compared to typically used bulk density values used for mixed waste collected in underground containers in Finland, 75–90 kg/m3 (Rautavuori, 2023; Salo, 2017). Also, the calculated bulk density of mixed waste is subject to various uncertainties. The weights used in the calculations are manually input by drivers, posing a risk for human errors. Additionally, the data shows a predominant tendency towards whole numbers, suggesting that figures are likely to be rounded or estimated by the waste collection personnel. Furthermore, the bulk density calculations are based on data from 2018 and considering the observed trends in waste quantities (section 2.2), it is not only possible but also probable that the waste composition has changed over the past five years, leading to a corresponding change in bulk density. The wide range of values (14–210 kg/m^3) also raises concerns about potential human errors or factors that are not apparent by merely analysing the raw data.

On the other hand, a substantial proportion (418 pcs, 24%) of a reasonably large sample falls within the range (75–90 kg/m^3) mentioned in the literature, which enhances the credibility of the result. Additionally, both high and low values in bulk density can be explained. High values may be due, for example, to waste with a high bulk density such as soil, construction waste, and moist organic waste. Lower values could be caused by items like expanded polystyrene and empty cardboard boxes, which increase measured fill rate in relation to their weight.

The same uncertainties mentioned in the context of mixed waste bulk density also apply to fill levels: the weights used in the calculations are manually input by collection personnel, the same risk for human errors and undesirable practices apply to the fill levels as to the bulk density. The similar patterns (predominant tendency towards whole numbers and the wide range of values) are noticeable in the dataset used for calculating the fill levels as they were noticeable in the dataset used for calculating the bulk density.

Again, large sample should decrease the impact of human errors on the results, and same reasoning of the high and low values apply to the fill level as to the bulk density. On the other hand, the accuracy of calculations could be enhanced by employing a smaller dataset. This would enable a more detailed examination of erroneous and suspicious rows, facilitating the identification of their causes and allowing for a more thorough and specific removal of erroneous rows and correction of the data.

It must be noted that the results deviate from the result of study by Salo (2017) where fill levels were measured with Enevos's system. In the table 10 the deviation between results of this thesis and Salo's study are presented.

Table 10. Comparing results of fill level value distribution between Salo's study (2017) and results of this thesis.

	Salo 2017	**Paananen 2024**	**Difference**
<10%	0,1%	0,7%	+0,60%
10-19%	0,6%	2,1%	+1,50%
20-29%	2,8%	7,1%	+4,30%
30-39%	4,8%	8,8%	+4,00%
40-49%	12,6%	14,0%	+1,40%
50-59%	21,3%	17,7%	-3,60%
60-69%	23,8%	17,4%	-6,40%
70-79%	15,8%	8,2%	-7,60%
80-89%	9,7%	8,8%	-0,90%
90-99%	6,3%	5,0%	-1,30%
100% (<)	2,2%	10,1%	+7,90%

The deviating percentual shares illustrated in the table 10, might indicate that weight based calculational methods are not very reliable in case of fill levels. On the other hand, fill level measurement does not take into account lightweight materials that could be easily compacted, like empty cardboard boxes. Most accurate results would be obtained by using both methods simultaneously.

Reliability would be improved by obtaining weight information directly from the weighing devices into the system, thereby mitigating the impact of human errors and undesired practices. Additionally, it would be beneficial to systematically determine the correlation between the measured fill level and the reported weight based on the current mixed waste composition.

As evidenced by the results, fluctuations in fill level rates are common, with even as many as 87% of collection points experiencing fill rates below 50%. Additionally, significant monthly variations are observed. Nevertheless, it is apparent that the utilization of fill rate sensors and semi-dynamic collection methods could potentially release resources. While this study primarily focuses on the economic implications from HSY's perspective, it is important to acknowledge that the adoption of fill rate sensors would enhance the efficiency of waste management and yield a plethora of benefits. Careful consideration should be given to the implementation model to ensure the equitable distribution of the benefits generated by fill rate sensors.

Possible models for implementing fill level sensors are:

- HSY provides an interface through which customers can optionally submit data generated by fill level sensors. This facilitates automatized emptying requests based on fill levels.
- HSY provides fill level sensors for customers for a monthly fee. Customers can utilize the data generated by the sensors to optimize emptying intervals and gathering data about waste quantities.
- HSY utilizes fill level sensors for optimizing waste collection and offers customers waste bin emptying services based on either waste quantity or a fixed monthly fee.

However, all options lead to reduction of emptying events and with current cost structure, negative economic impact. To prevent an increase in the HSY’s net indebtedness, financial efficiency is essential. Therefore, the reduction in income and the increase in expenses resulting from the implementation of fill level sensors should be addressed before deciding to deploy them.

Due to the expected reduction in emptying events resulting from the purposeful utilization of fill level sensors the economically viable implementation of these sensors requires adjusting the cost structure to be financially sustainable. In practice, this could mean providing fill level sensors as an additional paid service, transitioning for example to a completely weight-based billing system or covering costs through a basic fee.

When adjusting the cost structure, consideration must also be given to the incentive nature of collection fees; waste collection should be priced in a manner that supports the EU waste hierarchy, encouraging waste reduction and recycling. Moreover, in the cost structure model, efforts should be made to ensure that all stakeholders - HSY, customers, and contractors - derive benefits from the implementation of fill level sensors.

It should be noted that in addition to leveraging fill level sensors, there are other methods for optimizing waste collection. For example, making emptying requests through an application when the waste bin is full, or implementing more versatile collection schedules can help adapt routes to be more efficient. Collection schedules such as every third week, twice in three weeks, or three times in two weeks could enable finding an optimal emptying interval through flexible collection without disrupting static routes.

8 Conclusions

The aim of this study was to evaluate the conditions under which the implementation of fill level sensors would be economically viable. Despite uncertainties in the research factors, it is clear that the adoption of fill level sensors would reduce the number of tasks and, consequently, the service fees collected from customers, while increasing costs associated with the implementation of fill level sensors.

In conclusion, the judicious use of fill level sensors may be economically sustainable only if there is a modification in customer pricing. This could involve a shift towards a billing system where a larger portion of charges is based on the weight of the collected waste. Alternatively, the decreased margin could be compensated through the introduction of a basic fee.

Given the considerable variation in customer pricing structures across different organizations, it is crucial to acknowledge that the findings of this study are specifically applicable to the context of the organization under examination.

However, a comprehensive adjustment to customer pricing necessitates strong political and operational commitment from the entire organization. Such a change should be approached through a broader examination, taking into account the expected trends and development needs in waste management for the coming years. This provides a recommended avenue for further research in the future.

Also, it is noteworthy that the advantages of fill level sensors are not confined to economic benefits alone. They can also contribute to other positive outcomes, including environmental gains through optimized routes, enhanced control and supervision of emptying tasks, and potentially improved customer satisfaction.

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Appendix 1. Data sample 1

ID	Site	Site name	Address	City	Site con	Conte	Conten	Time (Europe/Helsinl	Froze	Fill l	Fi	Volume (l)	Weight (kg)	Partial	Contain	Containe	Container slot:Time (	Con	Co	Contain	Contain	Con	Con
36006702	323508	LAUTTASAA	LAUTTASAA	Helsinki	516537	2177	Mixed	2019-01-02 11:48:39	TOSI	71	0	3552,660578	248,68624	EPÄTOSI	377269	Mixed 1	2019-01-02 11:48:39	71	0	3552,7	248,69	100	100
35999481	323481	POHJOISKA	POHJOISKA	Helsinki	516510	2177	Mixed	2019-01-02 11:09:49	TOSI	100	0	5000	350	EPÄTOSI	377242	Mixed 1	2019-01-02 11:09:49	100	0	5000	350	100	100
36001351	323494	POHJOISKA	POHJOISKA	Helsinki	516523	2177	Mixed	2019-01-02 11:05:49	TOSI	81	0	2432,985722	170,309001	EPÄTOSI	377255	Mixed 1	2019-01-02 11:05:49	81	0	2433	170,31	100	100
36001175	323492	GYLDENINT	GYLDENINT	Helsinki	516521	2177	Mixed	2019-01-02 10:58:02	TOSI	100	0	5000	350	EPÄTOSI	377253	Mixed 1	2019-01-02 10:58:02	100	0	5000	350	100	100
36000830	323476	OTAVANTIE	OTAVANTIE	Helsinki	516505	2177	Mixed	2019-01-02 10:47:27	TOSI	66	0	3282,171487	229,752004	EPÄTOSI	377237	Mixed 1	2019-01-02 10:47:27	66	0	3282,2	229,75	100	100
36000450	323502	PAJALAHDE	PAJALAHDE	Helsinki	516531	2177	Mixed	2019-01-02 10:36:44	TOSI	72	0	2152,611567	150,68281	EPÄTOSI	377263	Mixed 1	2019-01-02 10:36:44	72	0	2152,6	150,68	100	100
36000272	323495	PAJALAHDE	PAJALAHDE	Helsinki	516524	2177	Mixed	2019-01-02 10:31:19	TOSI	59	0	2966,720577	207,67044	EPÄTOSI	377256	Mixed 1	2019-01-02 10:31:19	59	0	2966,7	207,67	100	100
36006266	323477	HEIKKILÄNT	HEIKKILÄNT	Helsinki	516506	2177	Mixed	2019-01-02 10:28:59	TOSI	69	0	3439,720748	240,780452	EPÄTOSI	377238	Mixed 1	2019-01-02 10:28:59	69	0	3439,7	240,78	100	100
35999987	324060	KOILLISVÄYI	KOILLISVÄY	Helsinki	517123	2177	Mixed	2019-01-02 10:19:09	TOSI	83	0	2490,459135	174,332139	EPÄTOSI	377952	Mixed 1	2019-01-02 10:19:09	83	0	2490,5	174,33	100	100
35999986	323500	MELKONKA	MELKONKA	Helsinki	516529	2177	Mixed	2019-01-02 10:18:26	TOSI	99	0	4951,624741	346,613732	EPÄTOSI	377261	Mixed 1	2019-01-02 10:18:26	99	0	4951,6	346,61	100	100
36001702	323470	LAUTTASAA	LAUTTASAA	Helsinki	516499	2177	Mixed	2019-01-02 10:14:34	TOSI	43	0	2169,91936	151,894355	EPÄTOSI	377231	Mixed 1	2019-01-02 10:14:34	43	0	2169,9	151,89	100	100
35999732	324063	ITÄLAHDEN	ITÄLAHDEN	Helsinki	517126	2177	Mixed	2019-01-02 10:13:58	TOSI	100	0	5000	350	EPÄTOSI	377955	Mixed 1	2019-01-02 10:13:58	100	0	5000	350	100	100
35999474	323468	LAUTTASAA	LAUTTASAA	Helsinki	516497	2177	Mixed	2019-01-02 10:10:02	TOSI	49	0	2439,793159	170,785521	EPÄTOSI	377229	Mixed 1	2019-01-02 10:10:02	49	0	2439,8	170,79	100	100
35998967	323506	HAAHKAKU	HAAHKAKU	Helsinki	516535	2177	Mixed	2019-01-02 09:56:28	TOSI	57	0	2848,458877	199,392121	EPÄTOSI	377267	Mixed 1	2019-01-02 09:56:28	57	0	2848,5	199,39	100	100
35998833	323482	HAAHKATIE	HAAHKATIE	Helsinki	516511	2177	Mixed	2019-01-02 09:52:27	TOSI	53	0	2642,721257	184,990488	EPÄTOSI	377243	Mixed 1	2019-01-02 09:52:27	53	0	2642,7	184,99	100	100
35998837	323473	PAJALAHDE	PAJALAHDE	Helsinki	516502	2177	Mixed	2019-01-02 09:49:53	TOSI	44	0	2222,253011	155,557711	EPÄTOSI	377234	Mixed 1	2019-01-02 09:49:53	44	0	2222,3	155,56	100	100
35998748	323490	POHJOISKA	POHJOISKA	Helsinki	516519	2177	Mixed	2019-01-02 09:47:16	TOSI	48	0	1451,84841	101,629389	EPÄTOSI	377251	Mixed 1	2019-01-02 09:47:16	48	0	1451,8	101,63	100	100
35998522	323467	LAHNARUO	LAHNARUO	Helsinki	516496	2177	Mixed	2019-01-02 09:41:38	TOSI	56	0	2806,204613	196,434323	EPÄTOSI	377228	Mixed 1	2019-01-02 09:41:38	56	0	2806,2	196,43	100	100
35999996	323486	ISOKAARI 4	ISOKAARI 4	Helsinki	516515	2177	Mixed	2019-01-02 09:36:03	TOSI	38	0	1915,197795	134,063846	EPÄTOSI	377247	Mixed 1	2019-01-02 09:36:03	38	0	1915,2	134,06	100	100
35998161	323478	HAKOLAHD	HAKOLAHD	Helsinki	516507	2177	Mixed	2019-01-02 09:28:47	TOSI	87	0	4363,248219	305,427375	EPÄTOSI	377239	Mixed 1	2019-01-02 09:28:47	87	0	4363,2	305,43	100	100
36004069	323493	ISOKAARI 1	ISOKAARI 1	Helsinki	516522	2177	Mixed	2019-01-02 09:23:13	TOSI	92	0	4623,239375	323,626756	EPÄTOSI	377254	Mixed 1	2019-01-02 09:23:13	92	0	4623,2	323,63	100	100
35997225	324062	VASKINIEMI	VASKINIEM	Helsinki	517125	2177	Mixed	2019-01-02 08:54:20	TOSI	57	0	1699,411258	118,958788	EPÄTOSI	377954	Mixed 1	2019-01-02 08:54:20	57	0	1699,4	118,96	100	100
35997328	323524	KATAJAHAR	Katajaharju	Helsinki	516553	2177	Mixed	2019-01-02 08:48:03	TOSI	71	0	3565,889532	249,612267	EPÄTOSI	377288	Mixed 1	2019-01-02 08:48:03	71	0	3565,9	249,61	100	100
35998665	323503	KATAJAHAR	KATAJAHAR	Helsinki	516532	2177	Mixed	2019-01-02 08:44:42	TOSI	66	0	3281,007261	229,670508	EPÄTOSI	377264	Mixed 1	2019-01-02 08:44:42	66	0	3281	229,67	100	100
35996756	323480	TELKKÄKUJA	TELKKÄKUJA	Helsinki	516509	2177	Mixed	2019-01-02 08:40:59	TOSI	68	0	3413,195878	238,923711	EPÄTOSI	377241	Mixed 1	2019-01-02 08:40:59	68	0	3413,2	238,92	100	100
35996364	323475	LAHNALAHD	LAHNALAHI	Helsinki	516504	2177	Mixed	2019-01-02 08:29:37	TOSI	30	0	886,208043	62,034563	EPÄTOSI	377236	Mixed 1	2019-01-02 08:29:37	30	0	886,21	62,035	100	100
35996212	323505	LUOTEISVÄ	LUOTEISVÄ	Helsinki	516534	2177	Mixed	2019-01-02 08:22:38	TOSI	68	0	3381,671199	236,716984	EPÄTOSI	377266	Mixed 1	2019-01-02 08:22:38	68	0	3381,7	236,72	100	100
35996029	323491	LAUKKANIEI	LAUKKANIE	Helsinki	516520	2177	Mixed	2019-01-02 08:18:05	TOSI	100	0	2993,737981	209,561659	EPÄTOSI	377252	Mixed 1	2019-01-02 08:18:05	100	0	2993,7	209,56	100	100
35995910	323507	LUOTEISVÄ	LUOTEISVÄ	Helsinki	516536	2177	Mixed	2019-01-02 08:13:50	TOSI	43	0	1280,778808	89,654517	EPÄTOSI	377268	Mixed 1	2019-01-02 08:13:50	43	0	1280,8	89,655	100	100
35995779	323499	KATAJAHAR	KATAJAHAR	Helsinki	516528	2177	Mixed	2019-01-02 08:09:34	TOSI	90	0	2706,831313	189,478192	EPÄTOSI	377260	Mixed 1	2019-01-02 08:09:34	90	0	2706,8	189,48	100	100
35995625	323472	KATAJAHAR	KATAJAHAR	Helsinki	516501	2177	Mixed	2019-01-02 08:04:54	TOSI	74	0	3713,065108	259,914558	EPÄTOSI	377233	Mixed 1	2019-01-02 08:04:54	74	0	3713,1	259,91	100	100
35717864	323470	LAUTTASAA	LAUTTASAA	Helsinki	516499	2177	Mixed	2018-12-26 10:28:22	TOSI	72	0	3619,371213	253,355985	EPÄTOSI	377231	Mixed 1	2018-12-26 10:28:22	72	0	3619,4	253,36	100	100
35717703	323468	LAUTTASAA	LAUTTASAA	Helsinki	516497	2177	Mixed	2018-12-26 10:24:18	TOSI	54	0	2693,189145	188,52324	EPÄTOSI	377229	Mixed 1	2018-12-26 10:24:18	54	0	2693,2	188,52	100	100
35717637	323489	KAUPPANEL	KAUPPANEL	Helsinki	516518	2177	Mixed	2018-12-26 10:20:01	TOSI	85	0	4266,255447	298,637881	EPÄTOSI	377250	Mixed 1	2018-12-26 10:20:01	85	0	4266,3	298,64	100	100

Appendix 2. Data sample 2

UA	AP	Urak	Palvelutu	Nouto-osoi	Jp	Jätep.omin.	Post	Kunta	Jätelaji	Työ	Tila	Suunniteltu	Kayntiaika	Tehty	Työlistan pä	Työlistan nro	Kuormaustapa	Yrity	Tekijä	Asian	Kuorm	Rek	Aj	Aj	Tu	Pe	Pe	Pain	No
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	1.1.2019	2.1.2019 11:00:23	2.1.2019	1.1.2019	2019/117	Nosturityhjennys	HSY	Tumik / Leh	Palok	50057	VZC	0	0				360	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	25.12.2018	25.12.2018 15:54:16	25.12.2018	25.12.2018	2018/36342	Nosturityhjennys	HSY	Tumik / Tuil	Palok	96193	CLM	0	0				340	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	18.12.2018	18.12.2018 11:20:42	18.12.2018	18.12.2018	2018/35626	Nosturityhjennys	HSY	Tumik / Palo	Palok	95324	CLM	0	0				200	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	11.12.2018	11.12.2018 09:40:49	11.12.2018	11.12.2018	2018/34917	Nosturityhjennys	HSY	Tumik / Joki	Palok	94366	CLM	0	0				320	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	4.12.2018	3.12.2018 13:18:55	3.12.2018	4.12.2018	2018/34213	Nosturityhjennys	HSY	Tumik / Kart	Palok	93376	VZC	0	0				160	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	27.11.2018	27.11.2018 09:29:31	27.11.2018	27.11.2018	2018/33510	Nosturityhjennys	HSY	Tumik / Kurl	Palok	92605	VZC	0	0				260	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	20.11.2018	20.11.2018 09:07:50	20.11.2018	20.11.2018	2018/32801	Nosturityhjennys	HSY	Tumik / Kart	Palok	91678	VZC	0	0				170	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	13.11.2018	13.11.2018 10:53:31	13.11.2018	13.11.2018	2018/32095	Nosturityhjennys	HSY	Tumik / Kurl	Palok	90731	VZC	0	0				200	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	6.11.2018	6.11.2018 10:36:41	6.11.2018	6.11.2018	2018/31388	Nosturityhjennys	HSY	Tumik / Leh	Palok	89919	CLM	0	0				250	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	30.10.2018	30.10.2018 10:45:38	30.10.2018	30.10.2018	2018/30676	Nosturityhjennys	HSY	Tumik / Joki	Palok	89015	CLM	0	0				190	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	23.10.2018	23.10.2018 09:57:30	23.10.2018	23.10.2018	2018/29975	Nosturityhjennys	HSY	Tumik / Leh	Palok	88076	CLM	0	0				140	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	16.10.2018	16.10.2018 10:17:05	16.10.2018	16.10.2018	2018/29270	Nosturityhjennys	HSY	Tumik / Kart	Palok	87173	VZC	0	0				155	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	9.10.2018	9.10.2018 10:08:50	9.10.2018	9.10.2018	2018/28558	Nosturityhjennys	HSY	Tumik / Kurl	Palok	86258	VZC	0	0				190	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	2.10.2018	2.10.2018 10:10:07	2.10.2018	2.10.2018	2018/27845	Nosturityhjennys	HSY	Tumik / Joki	Palok	85178	CLM	0	0				220	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	25.9.2018	25.9.2018 11:24:08	25.9.2018	25.9.2018	2018/27145	Nosturityhjennys	HSY	Tumik / Joki	Palok	84342	CLM	0	0				320	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	18.9.2018	18.9.2018 09:42:15	18.9.2018	18.9.2018	2018/26449	Nosturityhjennys	HSY	Tumik / Kart	Palok	83471	VZC	0	0				300	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	11.9.2018	11.9.2018 10:25:31	11.9.2018	11.9.2018	2018/25748	Nosturityhjennys	HSY	Tumik / Kart	Palok	82535	VZC	0	0				200	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	4.9.2018	4.9.2018 10:09:44	4.9.2018	4.9.2018	2018/25009	Nosturityhjennys	HSY	Tumik / Kurl	Palok	81665	CLM	0	0				160	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	28.8.2018	28.8.2018 09:33:39	28.8.2018	28.8.2018	2018/24310	Nosturityhjennys	HSY	Tumik / Ågr	Palok	80813	VZC	0	0				280	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	21.8.2018	21.8.2018 09:35:43	21.8.2018	21.8.2018	2018/23619	Nosturityhjennys	HSY	Tumik / Leh	Palok	79897	CLM	0	0				260	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	14.8.2018	14.8.2018 10:34:46	14.8.2018	14.8.2018	2018/22915	Nosturityhjennys	HSY	Tumik / Kurl	Palok	79045	VZC	0	0				220	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	7.8.2018	7.8.2018 10:26:10	7.8.2018	7.8.2018	2018/22215	Nosturityhjennys	HSY	Tumik / Kurl	Palok	78170	VZC	0	0				210	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	31.7.2018	31.7.2018 09:17:42	31.7.2018	31.7.2018	2018/21519	Nosturityhjennys	HSY	Tumik / Kurl	Palok	77266	VZC	0	0				230	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	24.7.2018	24.7.2018 08:30:04	24.7.2018	24.7.2018	2018/20821	Nosturityhjennys	HSY	Tumik / Kurl	Palok	76408	VZC	0	0				130	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	17.7.2018	17.7.2018 10:16:21	17.7.2018	17.7.2018	2018/19775	Nosturityhjennys	HSY	Tumik / Kurl	Palok	75588	VZC	0	0				150	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	10.7.2018	10.7.2018 09:31:04	10.7.2018	10.7.2018	2018/19000	Nosturityhjennys	HSY	Tumik / Ågr	Palok	74851	CLM	0	0				220	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	3.7.2018	3.7.2018 09:22:29	3.7.2018	3.7.2018	2018/18296	Nosturityhjennys	HSY	Tumik / Ågr	Palok	73920	CLM	0	0				395	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	26.6.2018	26.6.2018 09:21:24	26.6.2018	26.6.2018	2018/17590	Nosturityhjennys	HSY	Tumik / Ågr	Palok	73022	CLM	0	0				320	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	19.6.2018	18.6.2018 09:02:22	18.6.2018	19.6.2018	2018/16874	Nosturityhjennys	HSY	Tumik / Kurl	Palok	71788	CLM	0	0				220	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	12.6.2018	12.6.2018 10:51:02	12.6.2018	12.6.2018	2018/16173	Nosturityhjennys	HSY	Tumik / Kurl	Palok	70888	VZC	0	0				210	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	5.6.2018	5.6.2018 11:31:35	5.6.2018	5.6.2018	2018/15468	Nosturityhjennys	HSY	Tumik / Kurl	Palok	70007	CLM	0	0				310	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	29.5.2018	29.5.2018 10:33:41	29.5.2018	29.5.2018	2018/14759	Nosturityhjennys	HSY	Tumik / Palo	Palok	69120	CLM	0	0				165	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	22.5.2018	22.5.2018 09:35:22	22.5.2018	22.5.2018	2018/14052	Nosturityhjennys	HSY	Tumik / Leh	Palok	68223	CLM	0	0				220	ti
80	13421	Tumik	BB11-010	GYLDENINT	1	Ei saa hurjastella pihas	200	Helsinki	Syväkeräys	Tyhjennys, Vakio	Valmis	15.5.2018	15.5.2018 10:25:07	15.5.2018	15.5.2018	2018/13346	Nosturityhjennys	HSY	Tumik / Kurl	Palok	67237	VZC	0	0				260	ti

Appendix 3. Data sample 3

Palvelutı	Suunniteltu päivä	Kuittauksen pvm	Jätelaji	Nouto-osoit(	Kunta	Kuormaustapa	Astiakoko/irtojäte	Astialaji	Jätepiste nro	Noutotiheys	Suunniteltu määrä	Toteutunut määrä	TARKISTUS
BB11010(	5.7.2022	5.7.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	5 m3	syväsäiliö	1	1 krt/viikko	1	1	OK
BB11010(	5.7.2022	5.7.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	paino	punnittu	1	1 krt/viikko	0	140	OK
BB11010(	12.7.2022	12.7.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	5 m3	syväsäiliö	1	1 krt/viikko	1	1	OK
BB11010(	12.7.2022	12.7.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	paino	punnittu	1	1 krt/viikko	0	180	OK
BB11010(	19.7.2022	19.7.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	5 m3	syväsäiliö	1	1 krt/viikko	1	1	OK
BB11010(	19.7.2022	19.7.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	paino	punnittu	1	1 krt/viikko	0	160	OK
BB11010(	26.7.2022	26.7.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	5 m3	syväsäiliö	1	1 krt/viikko	1	1	OK
BB11010(	26.7.2022	26.7.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	paino	punnittu	1	1 krt/viikko	0	130	OK
BB11010(	2.8.2022	2.8.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	5 m3	syväsäiliö	1	1 krt/viikko	1	1	OK
BB11010(	2.8.2022	2.8.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	paino	punnittu	1	1 krt/viikko	0	200	OK
BB11010(	9.8.2022	9.8.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	5 m3	syväsäiliö	1	1 krt/viikko	1	1	OK
BB11010(	9.8.2022	9.8.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	paino	punnittu	1	1 krt/viikko	0	100	OK
BB11010(	16.8.2022	16.8.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	5 m3	syväsäiliö	1	1 krt/viikko	1	1	OK
BB11010(	16.8.2022	16.8.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	paino	punnittu	1	1 krt/viikko	0	150	OK
BB11010(	23.8.2022	23.8.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	5 m3	syväsäiliö	1	1 krt/viikko	1	1	OK
BB11010(	23.8.2022	23.8.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	paino	punnittu	1	1 krt/viikko	0	185	OK
BB11010(	30.8.2022	30.8.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	5 m3	syväsäiliö	1	1 krt/viikko	1	1	OK
BB11010(	30.8.2022	30.8.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	paino	punnittu	1	1 krt/viikko	0	200	OK
BB11010(	6.9.2022	6.9.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	5 m3	syväsäiliö	1	1 krt/viikko	2	0	OK
BB11010(	6.9.2022	6.9.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	paino	punnittu	1	1 krt/viikko	0	0	OK
BB11010(	6.9.2022	7.9.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	5 m3	syväsäiliö	1	1 krt/viikko	1	1	OK
BB11010(	6.9.2022	7.9.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	paino	punnittu	1	1 krt/viikko	0	200	OK
BB11010(	13.9.2022	13.9.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	5 m3	syväsäiliö	1	1 krt/viikko	1	1	OK
BB11010(	13.9.2022	13.9.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	paino	punnittu	1	1 krt/viikko	0	210	OK
BB11010(	20.9.2022	20.9.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	5 m3	syväsäiliö	1	1 krt/viikko	1	1	OK
BB11010(	20.9.2022	20.9.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	paino	punnittu	1	1 krt/viikko	0	140	OK
BB11010(	27.9.2022	27.9.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	5 m3	syväsäiliö	1	1 krt/viikko	1	1	OK
BB11010(	27.9.2022	27.9.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	paino	punnittu	1	1 krt/viikko	0	170	OK
BB11010(	4.10.2022	4.10.2022	Sekajäte	GYLDENINT	Helsinki	Nosturityhjennys	5 m3	syväsäiliö	1	1 krt/viikko	1	1	OK