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Sustainable Waste Collection Strategy: A Transition from Curbside to Collective Containers in Brussels

Author:
Francisco Cardoso

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Supervisor's:
Emmanuel Mossay

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UNIVERSITÉ CATHOLIQUE DE LOUVAIN
Louvain School of Management
Place des Doyens, 1 bte L2.01.01, 1348 Louvain-la-Neuve, Belgique | **www.uclouvain.be/lsm**

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Abbreviations and Acronyms

APB	Agence Bruxelles-Propreté
ASL	Automatic Side Loaders
BCR	Brussels Capital Region
DSNY	Department of Sanitation of New York
MASS	Memetic Algorithm with Sequential Split
PMC	Plastic bottles, Metal packaging, drinks Cartons, etc.

1. Introduction

Throughout history, the problem of waste management has been closely tied to the development of human civilizations. From the earliest days of human settlements during the Stone Age, as discussed by Havlíček and Kuča (2017), waste management became a necessary concern as communities began to generate refuse from their daily activities. Agnoletti and Neri (2014) also emphasize that the increase in urban populations during antiquity significantly exacerbated waste management issues, leading to the first organized efforts to deal with waste in cities.

As societies transitioned through various stages of urbanization, the production of waste increased significantly. In modern times, the ways of living have evolved to produce more waste than ever before, driven by industrialization, consumerism, and technological advancements. This has led to an ongoing challenge: what to do with the ever-increasing amounts of waste. Addressing this problem effectively is crucial and involves determining the best methods for waste disposal and management.

In contemporary urban environments, smart city strategies have identified waste collection as one of the critical logistics activities. Effective waste management impacts the quality of life, city attractiveness, traffic congestion, urban environmental conditions, and municipal budgets (Gruler, Quintero-Araujo, Calvet & Juan, 2017). Therefore, finding optimal solutions for waste management remains a vital aspect of urban planning and sustainability efforts.

1.1. Research Question

1.1.1. Justification for Analysis

Brussels, like many growing cities, faces significant challenges in managing its urban waste. The current kerbside collection system, while widespread, is often criticized for its inefficiency, high operational costs, and environmental impact. The transition to a collective container system presents an opportunity to address these issues and is a commonly used system. By concentrating waste collection points, it is possible to streamline collection processes, reduce traffic congestion from collection vehicles, and lower carbon emissions. Moreover, such a system can potentially enhance overall urban cleanliness by reducing the number of bins on the streets.

1.1.2. Dimensions of the Problem

By comparing Brussels’ Capital Region (BCR) waste management practices with those of other cities that have implemented collective container systems, valuable insights can be gained. Cities such as Rotterdam and New York, known for their progressive waste management strategies, serve as benchmarks for best practices.

The feasibility of transitioning to a collective container system must be thoroughly investigated. This involves assessing logistical challenges, financial implications, and potential resistance from the public and other stakeholders. Recommendations for a feasibility study will help understand if the proposed solution is not only effective but also practical and implementable.

Exploring the role of technology in modernizing waste collection is crucial. Innovations such as smart containers equipped with sensors can optimize collection schedules, reduce operational costs, and improve service efficiency. Evaluating how such technologies can be integrated into Brussels' waste management strategy is an extra component of this research.

1.1.3. Research Question Formulation

How can the transition from kerbside waste collection to a collective container system enhance the effectiveness, efficiency, and sustainability of waste management in Brussels, considering the experiences of other cities and the potential integration of advanced technologies?

1.2. Analysis Model

The research approach for study combines theoretical frameworks from urban planning, environmental sustainability, and waste management studies with empirical methods. This multifaceted approach is essential to comprehensively analyse the current waste collection system in Brussels and the benchmark cities and evaluate the feasibility and benefits of transitioning to a collective container system.

1.2.1. Theoretical Frameworks

The study will draw on urban planning theories to understand how waste collection systems impact city infrastructure, traffic patterns, and public spaces. This framework will help assess the spatial and logistical implications of shifting to a collective container system.

Established theories and models from waste management studies will provide a basis for assessing the effectiveness, efficiency, and practicality of different waste collection systems. These theories will guide the analysis of operational costs, collection frequencies, and waste processing capabilities.

1.2.2. Empirical Methods

The research will involve data collection and analysis to evaluate the performance of the current kerbside system. Due to the non-existence of a common standard between those cities, it is hard to compare the data from all the cases. Data on the current performance of Brussels and the opinion of its inhabitants will be analysed. Those were collected through APB and a survey made especially for this study, respectively

Comparative case studies of other cities that have successfully implemented collective container systems will be conducted. Rotterdam will serve as a benchmark, offering insights into best practices, challenges, and outcomes. A recent plan from New York City will also be analysed, because of the depth of their analysis. These case studies will highlight the potential benefits and pitfalls of adopting a similar system in Brussels.

Interviews with waste management professionals working for the Agence Bruxelles-Propreté (APB) and Bruxelles Environnement will provide information on the current system’s strengths and weaknesses. These interviews will also gather perspectives on the proposed transition, including potential resistance and support. This information will be used to highlight some points made in the case studies. Stakeholder input is crucial for understanding the social and political feasibility of the collective container system. Internal reports and studies will also be analysed.

2. Literature Review

To take a comprehensive look on the topic, a review will be made of the work that has already been done on different pillars: benefits and implementation of collective containers, logistic problems and network optimisation, and waste management in the context of urban strategy. Additionally, some studies that have been conducted specifically for Brussels will be summed up.

2.1. Collective Containers

2.1.1. Benefits

Specific literature about collective containers is rare, but some literature can be associated with that. For example, research (Wagner & Broaddus, 2016) in urban and suburban areas in the United States of America on litter produced from curbside recycling collection using open-top bins identifies the primary causes of litter. Those include overflowing bins, bin design, wind and other weather conditions, the transfer process of the curbside to the vehicle, and animal or human scavengers. The study found the average pieces of litter generated and assessed economic impacts, mainly the cleanup costs. Other direct impacts from litter include the impairment of storm collection drains. Indirect impacts include reduced aesthetics, property values, and tourism and increased marine litter. It is much more difficult to attach a monetary value to these impacts due to their nature. The study highlights the potential benefits of switching to larger, covered bins to reduce litter and associated costs. The results suggest that modifying the curbside collection system could significantly decrease litter generation by emphasizing litter prevention over collection speed, thus improving overall waste management efficiency.

As this study is made for open-top bins, it can be seen as a middle point in Brussels' case; not even having bins for the trash bags would suggest that the litter generated could be higher. As curbside collection can be the source of litter generation, even when using bins, the use of larger, covered bins is recommended; and this description fits the definition of collective containers. With the right means, this study could also be replicated in Brussels to have more quantitative data on the problem.

2.1.2. Optimal Location

Some work has been done on how to decide where to place collective containers. A recent study by Nevrlý, Somplak, Smejkalova, Lipovský, and Jadrný (2021) explores the optimal placement of municipal waste containers using a multi-objective mixed-integer linear programming model. The study focuses on balancing various criteria including walking distance, the number of collection points, purchase costs of containers, and collection service duration. Conducted as a case study in the Czech Republic for plastic waste, the research demonstrates the importance of a comprehensive approach to infrastructure planning in waste management. The results indicate that a model minimizing deterioration from optimal values across all criteria provides the most balanced solution. For instance, the model achieved a 23% lower purchase cost compared to other multi-objective models, albeit with a slight increase in walking distance. This study highlights the significant trade-offs between economic efficiency and service quality in waste management, providing valuable insights for cities that want to optimize their waste collection systems.

Using Barcelona as a case study, Bautista and Pereira (2006) investigated the challenge of optimally placing waste collection points in urban areas. The study establishes a relationship between the problem, the set covering problem, and the MAX-SAT problem. It develops a genetic algorithm and a GRASP heuristic to solve each formulation, tested with real data from Barcelona. The findings emphasise the importance of strategic location planning to enhance efficiency and service quality in municipal waste management. The study highlights the need for a Decision Support System to aid planners in making informed decisions, incorporating Geographical Information Systems for accurate data integration and analysis. By leveraging these advanced algorithms, cities can improve waste collection efficiency, reduce operational costs, and enhance environmental sustainability.

2.2. Logistics

In analysing a network for strategic waste management, various parameters must be considered to optimize efficiency and effectiveness. Van Engeland, Beliën ,De Boeck and De Jaeger (2018) outline several key factors that should be accounted for in the design and operation of waste management networks.

Cost parameters play a crucial role in the network analysis. These include transportation, collection, processing, and operating costs. Fixed costs incurred when opening new facilities or purchasing trucks, should also be included, even though allocating the costs can be hard.

Technical parameters are vital for network analysis. These include capacities,

referring to the maximum throughput of facilities and the constraints on waste processing, storage, or transportation. Delays, including transportation delays, must also be considered.

Uncertainty in parameters is another significant aspect. This includes the variability in demand and return quantities of waste, influenced by seasonal changes, population dynamics, and economic activity. Additionally, legislative changes, such as new laws and regulations that alter waste streams, must be accounted for.

Environmental and social considerations are critical for a holistic network analysis. The environmental impact of waste management activities, including emissions, resource depletion, and ecological disturbances, must be evaluated. Social impacts, such as public health and community acceptance of waste management strategies, should also be considered to ensure the network is socially sustainable.

Optimisation and solution methods include various sophisticated techniques. Stochastic programming incorporates probability distributions for uncertain parameters to provide robust solutions. Interval optimization represents parameters as intervals and finds solutions feasible across all possible values. Robust optimization focuses on minimizing the maximum deviation across all scenarios. Heuristic methods, such as Genetic Algorithms and Particle Swarm Optimization, are employed to find good solutions within a reasonable time.

Finally, several constraints must be addressed in network design. Flow conservation ensures that the amount of waste entering the system equals the amount exiting. Demand satisfaction involves meeting the waste processing requirements of the served population. Processing and storage capacities must adhere to limits on waste handling at any facility. Proximity and frequency of collection points and schedules should maximize efficiency while minimizing public inconvenience. Mitigating environmental nuisances such as odour, noise, and traffic congestion associated with waste processing facilities is essential for community acceptance.

These parameters and considerations provide a comprehensive framework for analysing and optimizing waste management networks, ensuring they are economically viable, environmentally sustainable, and socially acceptable.

A major change in waste collection system in Europe was originated by the EU Directive 2018/851 (2018) that aimed to enforce a clear separation of organic waste. The APB started collecting food waste in all of Brussels in January 2017, at the same time as other important changes like ensuring weekly collections of blue and yellow trash bags, generalising the collection of green trash bags, the end of night collections, and a whole new collection schedule (Agence Bruxelles-Propreté, 2018). This provided the household with the possibility of using a new orange bag for the food waste. Since May 2023, following the instructions of the EU, separating organic waste has become compulsory. Amid those changes, APB also stopped a satellite project in the Matonge neighbourhood, where collective containers were installed. Too many incivilities were committed, and that forced them to put a premature stop to this initiative and return to the curbside collection.

The routing problem of waste collection in Brussels has not been extensively studied. A study by Lavigne, Beliën, and Dewil (2021) involves a high-level model for bio-waste that considers depots for each district and processing facilities. By district, they mean collection zones that follow the same schedule, and not municipalities per se. The total waste to be collected is aggregated per district. With sufficient data, the collection could be analysed at a more granular level, such as per street or house, enabling a fair comparison with collective containers. However, gathering such detailed data for a population exceeding 1.2 million is challenging.

They developed a model that considers various parameters like facility capacity, vehicle capacity, shift durations, and demand. Their study highlighted the complexity of the routing problem due to these factors. A more optimized version of their model was published in the European Journal of Operational Research, which was applied to the Brussels Capital Region using 145 districts as pick-up locations. It extends the previous work by introducing a Memetic Algorithm with Sequential Split (MASS) for solving complex waste collection problems. This approach includes multiple depots, intermediate processing facilities, and capacity restrictions per facility, alongside partial pick-ups. MASS first generates feasible initial solutions considering shift durations and vehicle capacities, then improves these solutions through local search. The algorithm was tested on various instances, demonstrating high-quality solutions. For the Brussels case, scenarios with alternative municipal bio-waste collection and treatment were compared, highlighting the impact of different strategies on costs and operational efficiency (Lavigne, Inghels, Dullaert, & Dewil, 2022).

In summary, while the current research provides a framework for understanding and optimizing waste collection in Brussels, it shows the significant data collection challenges and the need for detailed, municipality-level analysis to improve waste management strategies effectively.

With recycling gaining more importance, local authorities must adapt their curbside waste collection systems to support more thorough sorting. Thus, examining the transportation aspects of waste collection is crucial (Zbib & Wøhlk, 2019). In Denmark, Zbib and Wøhlk (2019) analysed four main methods for curbside waste collection and their transport requirements.

Collect to incinerate is when all waste types are collected in a single stream using single-compartment vehicles and incinerate it. It is the simplest method but is not environmentally friendly Collect, then sort is when waste is co-mingled during collection by single-compartment vehicles and sorted at treatment facilities. It makes collections easier but brings higher sorting costs and less efficient compression.

Sort, then collect by single-compartment vehicles requires citizens to sort waste into multiple bins, with each type collected separately. It reduces need for central sorting but relies on trusting citizen sorting. Sort, then collect by multi-compartment vehicles uses multi-compartment vehicles to collect sorted waste, allowing for efficient vehicle use but still dependent on citizen sorting.

The study found that sorting waste increases transportation distance and the number of routes. The multi-compartment vehicle system was most efficient in terms of distance, while single-compartment vehicles required fewer routes but longer distances. Evaluating these methods helps optimize waste collection strategies for cost-effectiveness and efficiency.

2.3. Urban Strategy

Esposito, Clement, Mora, and Crutzen (2021) explore the approaches of smart city strategies in the BCR, emphasizing differences with the Wallonia region and how these strategies are shaped by their unique socio-economic contexts. One key aspect of these smart city strategies is their link to waste management, which is a critical component of urban sustainability and smart city initiatives.

In the Brussels region, the approach integrates various ICT solutions to address a wide range of urban challenges, including waste management. This comprehensive strategy aims to enhance the quality of urban services, improve environmental sustainability, and promote civic participation. These efforts are part of a broader goal to create a more efficient and sustainable urban environment.

The comparison between Brussels and Wallonia illustrates that while both regions aim to improve waste management through smart city initiatives, their approaches differ based on their socio-economic conditions. It underscores the importance of context-specific smart city strategies in addressing urban challenges, including waste management. It highlights that effective waste management solutions must be tailored to the socio-economic realities of each region, and thus an in-depth analysis of these strategies should be put into the light of each city's own reality

Another study on the benefits of technology for waste management was presented by D’Agostini, Venturi, and Vigo (2022). It discusses it based on a case study from Delft on the integration of technology and data in urban waste management strategies, emphasizing its role in enhancing efficiency and sustainability. Technological innovations, such as the deployment of underground waste containers equipped with sensors, monitor fill levels and optimize collection routes, thereby reducing vehicle mileage and emissions. The utilization of real-time data mapping and integration with various data sets, including resident feedback, enhances waste management operations by providing actionable insights. Urban strategies focus on the strategic placement of waste containers to maximize accessibility and minimize disruption to public spaces, effectively balancing the needs of waste management with existing urban infrastructure. Community engagement is crucial, with increased resident involvement in waste management practices, such as the adoption of containers and community-led cleanliness initiatives. Operational efficiency is achieved through the transition to new collection vehicles and the optimization of routes based on sensor data, resulting in significant reductions in labour costs and environmental impact. The paper also addresses challenges such as illegal dumping, container maintenance, and the necessity for extensive communication and incentivizing measures to encourage proper waste sorting. By leveraging these advancements, cities can substantially improve their waste management systems, aligning with broader sustainability and circular economy goals.

2.4. Brussels’ Situation

The BCR is one of the three regions in Belgium, consisting of 19 municipalities and housing nearly 1 249 597. It has an average of 2.14 people/household and is a real international city, with 77.36% of the population being of foreign origin (Statbel, n.d.). The region is highly urbanised, with an average population density of 7 642 inhabitants/km^2(Institut Bruxellois de Statistiques et d’Analyse, n.d.) with central municipalities having much higher population densities, like Saint-Josse-ten-Noode which has the highest population density with 23.322 inhabitants/ km^2(Statbel, n.d.) This density poses significant challenges for waste management, including limited space for sorting waste in homes and public areas, and difficulties in managing bulky waste due to the urban landscape and lower car ownership rates among residents.

Municipal waste in Brussels, which includes household waste and similar non-household waste, is primarily collected by the APB, the para-regional organisation responsible for waste collection and treatment. Some municipalities also manage part of the collection services. Various actors handle specific waste streams, such as extended producer responsibility programs, neighbourhood composting, and social economy initiatives (Bruxelles Environnement, 2020a).

Multiple waste collection methods are employed in Brussels. Door-to-door collection is applied to residual waste (white waste), paper/cardboard (yellow waste), packaging (blue waste), food waste (orange waste), green waste, and glass in certain buildings. Waste is collected either in bags or rolling bins, twice a week for residual waste, and weekly for other streams. Some vertical housing units have underground containers for packaging and paper/cardboard. Drop-off points, or "bubbles", are used for glass (with 560 sites), clothing, and used cooking oils.

Brussels also has five container parks/recycling centres known as “recyparks”. ABP manages three regional recyparks accessible to all residents, while two are communal and limited to specific municipalities. These parks accept bulky waste, hazardous waste, construction and demolition debris, green waste, and tyres. Use is free for individuals within certain limits but chargeable for businesses. Around 100 temporary collection points, operated by ABP, are available for household hazardous waste. Municipalities may also organise occasional bulky waste collections in partnership with ABP, allowing residents to dispose of limited amounts of such waste. Residents can also request the free removal of up to 3 m^3 of bulky waste per year, with additional volumes charged. This service is also chargeable for construction waste.

Specific waste streams are managed through various other methods, such as donations to social enterprises, mandatory take-back programs for electrical and electronic equipment, glass packaging deposits, and medicine collection at pharmacies.

A major instrument to promote selective collection is the sorting obligation introduced in 2010 for households and in 2014 for businesses. This obligation covers packaging waste , or PMC (plastic bottles and flasks, metal packaging, and drink cartons), paper/cardboard, glass packaging, green waste, and take-back obligation waste (electrical and electronic equipment, batteries, used oils, etc.). Non-compliance results in stickers on waste bags indicating the issue and directing residents to the ABP website for information. Fines may also be imposed, and random checks of white bags are conducted to identify and penalise those not sorting their packaging and paper/cardboard waste.

Overall, the BCR employs a diverse and complex waste management system to address the challenges posed by its high population density and urban environment. The system aims to encourage sorting and recycling through a combination of mandatory sorting regulations, varied collection methods, and targeted enforcement measures.

In the same study, Bruxelles Environnement lays out some practical recommendations, especially for bio-waste and containerisation. They propose generalising the sorting of bio-waste by motivating sorting through mandatory regulations and reducing the frequency of white bag collections to encourage bio-waste sorting. To promote comfortable sorting, they recommend providing appropriate equipment to those who sort waste and monitoring the quality of sorting to ensure compliance. Additionally, they suggest offering tailored services for non-household entities.

Regarding containerisation, Bruxelles Environnement (2020b) recommends studying the feasibility of containerising waste collection based on the available space in homes or common areas and addressing current issues with bags such as cleanliness and handling. They also propose considering containerisation specifically for bio-waste collection and better understanding the performance of waste collection using shared containers.

This last point led to a new and ongoing study from APB (2024) for the Association of Cities and Regions for Sustainable Resource Management (ACR+) as they consider developing "sorting spaces"- underground container points for different waste fractions. Since 2018, around twenty such spaces have been established, particularly in large buildings and new or renovated projects, due to growing demand from stakeholders. The study aims to analyse similar systems in other dense European cities to understand how these solutions can improve municipal waste management in various contexts.

2.4.1. Sorting Spaces

The concept of "sorting spaces," involving underground containers for different waste fractions, has been implemented in various European cities to improve waste collection efficiency. These systems aim to rationalize collection points, increase capacity, and ensure urban integration.

Common goals include optimizing space, improving cleanliness, and overcoming challenges related to bagged waste collection in dense urban areas. Generally, the same waste fractions (residual waste, PMC, paper/cardboard, bio-waste) are collected, though there are notable differences. For instance, bio-waste collection faces due to misuse and maintenance needs, but a solution could be controlled openings. Most underground containers have similar capacities (around 5 m^3) and some are equipped with compressors to increase capacity. Cities usually group containers, but sometimes they are placed individually due to space constraints. In this case, residual waste is prioritised, and it is normal to see single residual waste containers through the city.

The number of points depends on the user base and collection frequency from 100 households per point to 470 residents per point with daily collections. Successful implementation requires balancing proximity to residents (100-250 meters) and minimising nuisances.

Cities have different timelines and approaches for deploying sorting spaces. It is continuously evaluates and to expand the network or to remove some spaces due to cost and safety. Criteria for site selection include local waste production, accessibility, and subsurface conditions. Stakeholder involvement and clear guidelines are crucial.

Common issues exist, like traffic blockages, accessibility, misuse by unauthorised users, public space competition, overfilling, and illegal dumping are significant challenges. Some solutions to those problems involve strategic placement, controlled access, and engaging stakeholders in planning and management.

2.4.2. Operational Impacts

The operational impacts of collective burier containers vary depending on the system they replace or complement. Implementing sorting spaces often requires new collection vehicles, especially in cities that previously used rear-loading trucks. Large-capacity trucks and container-cleaning vehicles are necessary, though additional vehicles are needed for illegal dumps. Frequencies and routes differ widely. The main strategies are daily collections, usually in hotter climates, and the use of sensors to optimize schedules and routes. Seasonal adjustments are also made to manage odours.

Switching to crane-equipped vehicles reduces staffing needs from three to one per vehicle, improving working conditions by reducing physical strain and accidents. Regular cleaning and maintenance are crucial, with costs varying by waste type. Eco-designed containers ensure easier repairs, while daily cleaning maintains urban integration and reduces illegal dumping.

Transitioning to underground containers can streamline collection by concentrating points and reducing emptying frequencies, especially with sensor-assisted route optimisation.

2.4.3. Economic Impacts

The economic impacts of sorting spaces also depend largely on the preexisting waste management system.

On one hand, it represents a high investment, knowing that implementing underground containers is expensive, averaging around €20,000 per container. Maintenance can cost €400-€500 per container per year, comprising a significant part of the sorting space costs.

On the other hand, significant savings can be achieved through reduced labour costs optimised collection routes, reduced collection frequencies, and shorter travel distances.

Maintenance Costs:

Additional factors influence the economic balance. For example, improved sorting performance can reduce residual waste treatment costs. However, these savings are context-specific and may not apply where residual waste disposal is cheaper. For some cities, the study suggests that dense areas with proximity and a high number of users per container make sorting spaces economically viable. Conversely, less dense areas are less cost-effective. Combining systems (e.g., container collection with door-to-door bio-waste collection) can increase overall costs. Thus, the economic impact of underground containers is once again context-dependent, influenced by parameters like the number of users, network size, and container lifespan.

2.4.4. Performance Impacts

The study of the various European cities shows mixed results regarding the sorting performance of underground containers.

It can increase the capture rates and sorting quality, attributed to better container management, suitability for large waste volumes, and controlled openings that reduce contamination. Success is also linked to extensive communication efforts. Incentivising tariffs likely motivates better sorting and reduces residual waste. However, issues like bio-waste contamination are present. Some see underground containers as limited and emphasize the need for additional measures, such as effective communication, to improve sorting behaviour.

For some cities, sorting performance with underground containers has been moderate, even with controlled openings aimed at improving quality.

Data is sparse, but controlled and differentiated openings for various waste types contribute to better sorting quality, and acceptable impurity rates were reported despite high capture rates, thanks to controlled openings.

In summary, while underground containers can enhance sorting performance, their effectiveness depends on local policies, incentivising measures, and comprehensive communication strategies.

2.4.5. Cleanliness Impacts

Assessing the cleanliness impacts of sorting spaces relies heavily on observations rather than objective data. All cities report the presence of illegal dumping, a significant issue for municipalities and residents. While underground containers have not necessarily increased illegal dumping, they have concentrated it around the containers. This can arise from problems like malfunctioning or overfilled containers, highlighting the need for prompt issues resolution. Several cities use video surveillance and mobile enforcement agents to address these challenges, though the effectiveness of these solutions is hard to gauge.

In summary, while underground containers can improve cleanliness by concentrating waste, they also require effective management and targeted approaches to mitigate illegal dumping and maintain overall cleanliness.

2.4.6. Impacts on Households

Various case studies have conducted satisfaction surveys regarding sorting spaces, providing insights into resident expectations. Generally, residents express satisfaction with underground containers. They appreciate the system's flexibility, the cleaner aspect compared to bag collection, and the better visual integration of containers. Some negative feedback comes from elderly or mobility-impaired individuals who find it difficult to transport waste or operate the controlled openings.

Despite generally positive feedback, increased satisfaction has not necessarily led to higher participation in sorting waste. Additional complementary measures are needed to encourage better sorting habits among residents.

2.4.7. Lessons for Brussels

While it's challenging to draw definitive conclusions from the distinct case studies on sorting spaces, several key insights and considerations for their use, advantages, and limitations emerge.

They offer a flexible and convenient solution for residents and buildings with limited storage space for waste sorting, provided containers are placed within an acceptable distance from residences. With a minimal ground footprint, these containers can handle large waste volumes, making them suitable for dense urban areas or those with a high concentration of waste producers.

They can help keep sidewalks free of bags or bins, improving pedestrian flow and cleanliness. They are also better for small households and temporary residents; it gives them more flexible waste disposal options. High storage capacity and fill-level monitoring can optimize collection routes.

Some conditions for success can be listed. Good sorting performance depends on container proximity to residences, controlled access, and complementary measures like communication and incentives. More users per container and a dense network reduce operational costs, but mixed systems (underground containers plus door-to-door collection) can be costly.

This new system also brings challenges. Finding suitable locations is hard and collaboration with other municipal services is crucial. The necessary investment maintenance costs are significant. A hybrid system with door-to-door collection in the same area is complex and expensive. Ensuring the system is user-friendly and free from significant issues (e.g., container functionality, cleanliness) is essential for public acceptance but hard to gauge.

Due to the nature of the containers, openings can make it difficult to dispose of larger items like cardboard boxes. Last, illegal dumping is a recurring issue that requires effective monitoring and targeted solutions.

The success of sorting spaces depends on detailed implementation, quality service, and complementary measures to promote sorting behaviour, such as direct communication, monitoring, and incentivizing through pricing. It is more suitable for high-density areas, with vertical housing and dense urban zones, where bag collection poses cleanliness issues. Regular revaluation and adaptation are necessary to address specific challenges and evolving waste management needs.

3. Data collection

3.1. Data on Brussels' Current Performance

The analysis of waste tonnage data from 2014 to 2022 provides insights into the evolving waste management practices and their impact on different waste categories.

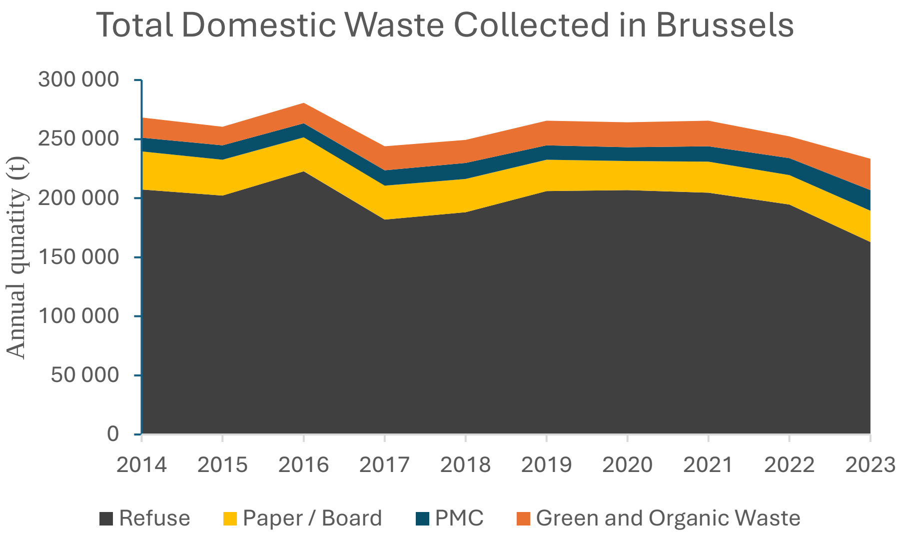

Figure 1: Total Domestic Waste Collected in Brussels

Source: Edwin Wansi (2024)[1]

As shown in Figure 1, the total domestic waste collected has had some variations during the last 10 years. From 2014 to 2023, refuse tonnage showed fluctuations, peaking in

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[1] See Appendix A

2016 at 222,749.48 tonnes and experiencing a significant decline to 162,807.22 tonnes by 2023. Paper/board waste initially decreased from 32,185.55 tonnes in 2014 to 24,681.08 tonnes in 2020, but then saw a slight increase to 26,520.94 tonnes by 2023. PMC (plastic, metal, and carton) remained relatively stable until 2020, followed by a steady increase, reaching 17,472.42 tonnes in 2023. Green and organic waste exhibited an overall upward trend, peaking dramatically at 26,466.84 tonnes in 2023, after a previous peak in 2021 and a slight decrease in 2022. These trends indicate a notable decline in refuse, a slight rebound in paper/board waste, and significant increases in both PMC and green/organic waste, especially in the most recent year.

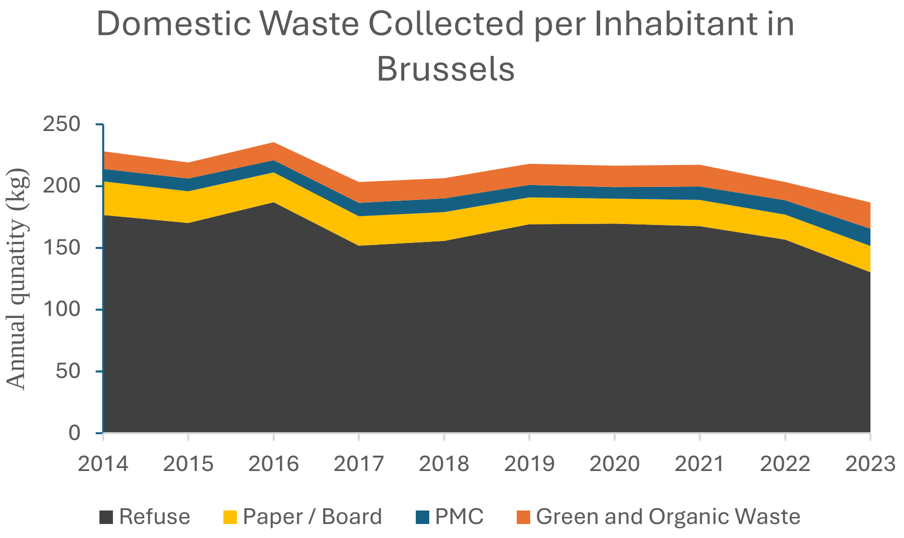

Figure 2: Domestic Waste Collected per Inhabitant in Brussels

Source: Edwin Wansi (2024)[2] and Statbel (2024) at https://statbel.fgov.be/sites/default/files/files/documents/bevolking/5.1%20Structuur%20van%20de%20bevolking/Population_par_commune.xlsx

As can be seen by comparing Figure 2 to Figure 1, the waste tonnage per inhabitant shows trends similar to the total tonnage, reflecting the overall waste management dynamics. The introduction of organic sorting in 2017 significantly impacted these trends, leading to a noticeable increase in green and organic waste per inhabitant, particularly peaking in 2023. This shift also corresponds with a decrease in refuse per inhabitant, which has declined steadily since its peak in 2016. The per-inhabitant data aligns with the general trends observed in the total tonnage, providing a clear per capita perspective on the reduction in refuse and paper/board waste, and the increase in PMC and organic waste.

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[2] See Appendix A

3.2. Survey for Brussels’ Residents

A survey was conducted to understand better the opinion of Brussels inhabitants relative to the current system and collective containers. Even though the response rate was low, with only 115 responses, some good insights emerged.

First, curbside collection offers several advantages, with 34% of respondents appreciating the flexibility it provides in taking out the trash whenever they want. Additionally, 18% believe it reduces bad smells in their house, and 34% feel it helps them recycle more effectively. It also aids 32% in maintaining a good cleaning schedule at home, and 62% value not having to walk somewhere to dispose of their trash bags. However, there are notable disadvantages as well. A significant portion, 34%, finds sidewalk collection less hygienic, 42% believe it takes up too much space on the sidewalk, and 58% feel it causes a lot of litter in the streets. Moreover, 60% of respondents are concerned about being dependent on specific collection days, while only 6% see no disadvantage to this method.

Based on the survey responses on the ranking of trash types for containerization, blue trash bags and white trash bags emerged as the top priorities, nearly equally favoured by respondents. These two types of trash are seen as the most critical to containerize, and that is correlated with the higher volume and the frequency with which they are disposed of. Following them, orange trash bags and yellow trash bags were less prioritized but still considered important.

In terms of walking distance to the containers, most respondents prefer shorter walking distances to dispose of their waste in collective containers. A significant portion, 32.9%, is willing to walk up to 100 meters, while 18.4% are comfortable with up to 50 meters, and another 18.4% prefer a distance of only 25 meters. Additionally, 14.5% of respondents do not want to walk any further than their curbside or sidewalk. Only a small percentage are open to walking greater distances, with 9.2% willing to go up to 200 meters and just 1.3% willing to walk up to 500 meters. This suggests a strong preference for convenience, with most people preferring minimal walking distances for waste disposal.

Given the limited number of responses, these survey results should be interpreted with caution. A more extensive survey at the Brussels scale would provide more reliable insights, capturing the diverse needs and preferences across different neighbourhoods. This would help ensure that waste management strategies are tailored to the specific requirements of each municipality, leading to more effective and informed decision-making.

4. Analyses

In order to look at the Brussels case, more transitions from curbside collection to collective containers were researched. Some good examples can be observed in Amsterdam, Barcelona and Paris, but two specific cases were chosen: Rotterdam and New York. As explained in the next parts, these two transitions are in different stages. The context of the two cities have also some differences with Brussels, but also a lot of similarities. These cases highlight the critical factors discussed in the literature review, including the benefits of collective containers, optimal location strategies, logistics, and urban strategy considerations. By comparing these experiences with Brussels' current situation, we can draw lessons that are directly applicable to improving waste management in the Brussels-Capital Region.

4.1. Rotterdam Case Study

With a population of 670 425, a population density of 3 081.7 people/km^2, and an average of 1.89 people/household (Gemeente Rotterdam, n.d.) Rotterdam is the second-largest city in the Netherlands.

Rotterdam faced significant waste management challenges due to its dense urban environment and high-rise buildings (van den Elzen, 2021). The traditional system of curbside waste collection was inefficient, unsanitary, and led to various public health risks. In response, the city undertook a comprehensive transformation of its waste collection system, shifting to underground containers. The following part comes from the report co-authored by van den Elzen (2021) that summarises this transition.

Before the transformation, Rotterdam’s waste collection system involved residents placing bin bags on the curbside, exactly like Brussels, which resulted in littering, pest infestations, and unsanitary conditions for waste workers. The inefficiency was compounded by standardized collection routes that did not account for real-time demand.

In 1996, Rotterdam's Waste Management Department initiated the use of underground containers. Key steps included evaluating necessary storage capacity based on the number of inhabitants, ensuring containers were within a short walking distance from households, and collaborating with the engineering department to identify suitable locations for containers. The system was piloted in a neighbourhood with known waste issues, leading to a city-wide rollout over ten years. By 2021, Rotterdam had 6,664 underground containers serving over

270,000 tons of waste annually. That is roughly one container for a hundred people, with containers strategically placed within a short walking distance for residents, typically within 250 meters. Those containers are sometimes grouped, with the four types of waste, or sometimes alone, due to space restrictions. As shown in Figure 3, the distribution of each waste type varies from neighbourhood to neighbourhood.

☑ Rest
☑ GFE
☑ Glas
☑ Papier
☑ Textiel
☑ Broodbakken

Figure 3: Interactive Map of Rotterdam's Waste Containers

Source: Gemeente Rotterdam (2024) at https://kaartlaag.rotterdam.nl/container#51.8409/4.1944/51.9775/4.7217/brt/7545,7546,7547,7548,7549,8477///51.93101775,4.27687952

For Brussels, a similar approach would require around 12,500 containers if the same ratio of residents per container is maintained. But as seen in the “Sorting Spaces” section of the APB report (2024), this number can greatly vary from one city to the other. Also, as shown in the survey, inhabitants' needs seem to vary, and residual waste and PMC should be prioritised. From the survey, the walking distance to the containers is also an important criterion. 250 m, like in Rotterdam, seems to be too high for most of the respondents. Decreasing this distance will inevitably increase the number of sorting spaces needed. This could provide a framework for determining the number of containers needed and their optimal locations within the city. The studies by Nevrlý et al. (2021), and Bautista and Pereira (2006), emphasising the importance of optimal container placement using multi-objective models, and provide a concrete way of doing that.

The underground containers are sealed and inaccessible to animals, reducing pest problems and bad odours due to lower temperatures underground. Containers are equipped with fill-level sensors that provide data for optimizing collection routes and frequencies, and as described by D’Agostini et al. (2022) directly contribute to enhancing operational efficiency reducing vehicle mileage and emissions. Live data mapping and integration of various data sets, including resident complaints and LED indicators on containers, further enhance system efficiency. This overall could help in Brussels becoming a smarter city, in lines with the ideas developed by Esposito et al. (2021).

Initially, the system was managed by the waste management department with minimal resident involvement. However, over time, community engagement increased. Neighbours can now select container locations, and since 2015, residents have been able to 'adopt' containers, keeping the areas around them clean. This reflects the importance of social considerations in waste management networks, as discussed by Van Engeland et al. (2020). Pilots in certain boroughs have introduced compactors to double container capacity, particularly valuable in dense inner-city areas. Experiments with narrower containers and automated sensor signalling aim to fit within existing infrastructure constraints.

Rotterdam’s waste management strategy is aligned with its broader circular economy goals. The short-term target is to decrease residual waste per inhabitant from 296kg in 2018 to 249kg by 2022. By 2030, Rotterdam aims for circularity in all sectors, reducing primary resource use by 50% and creating thousands of jobs. By 2050, the city aspires to be fully circular, making waste an obsolete concept.

Rotterdam’s shift to underground containers has significantly improved waste collection efficiency, public health, and sanitation while fostering community involvement and aligning with long-term sustainability goals. This model serves as an example of success for other cities facing similar waste management challenges. It is important to remember that this transition started 28 years ago. It is now rooted inside the city management and people habits and is continuously improving thanks to technological advances and constant monitoring.

Brussels, with its own high population density and urban challenges, could benefit significantly from adopting Rotterdam's model. The literature suggests that effective waste management in dense areas requires both strategic planning and community involvement (Van Engeland et al., 2020), both of which are evident in Rotterdam’s case. By focusing on high-density neighbourhoods like Saint-Josse-ten-Noode, Brussels can begin a phased implementation, much like Rotterdam did, to gradually transition to collective containers while addressing logistical and social challenges.

4.2. New York City Case Study

Another very interesting case is the one from New York. Even though this city has a whole other dimension compared to Brussels and Rotterdam, it is interesting to note that this model was also analysed for one of the biggest cities in the world. With a population of around 8.5 million, a density of about 11 315.65 inhabitants / km^2, and an average of 2.56 people per household (United States Census Bureau, n.d.)

Recent efforts by the Department of Sanitation of New York (DSNY) have focused on encouraging individual bins with new setout rules, piloting shared containers citywide and conducting a feasibility study for a comprehensive containerization strategy ((New York City Department of Sanitation [DSNY], 2023).

This feasibility study will be the main base for this analysis.

4.2.1. Current Situation

New York City generates approximately 10,886 metric tons of residential and institutional waste daily, out of a total of about 19,958 metric tons of total daily waste, including commercial waste. The DSNY manages the collection from 3.5 million households, 1,400 public schools, and various government and non-profit institutions. The remaining waste is handled by private carters The waste collection operations involve multiple streams: refuse, metal/glass/plastic, and paper/cardboard. Organics collection is available in Queens and will expand citywide by 2024.

Historically, New Yorkers could set out waste in bags on the curb, but new rules now incentivize using individual bins, especially for businesses. Currently, about 11% of waste is already containerized, primarily in public schools, and large residential buildings, using roll-on/roll-off containers or front-loading containers.

4.2.2. Containerisation Challenges

New York City's high population density, generates a significant amount of waste in a limited space. This creates challenges for waste containerization, as the city lacks alleyways or suitable underground spaces to hide containers. Decades of complex infrastructure development further complicate the situation. The city's built environment, with its unique layout and dense infrastructure, poses significant challenges for container placement. The lack of appropriate space for large containers means that many areas cannot accommodate the necessary infrastructure without significant changes or compromises. Placing trash on New York City's streets competes with high-demand curb space used for parking, bike lanes, and more. Shared containerization will reduce sidewalk clutter and improve access for collection vehicles, but implementing this would reduce residential street parking by about 10%, with up to an 18% reduction in some areas.

For Brussels, this would translate to a potential reduction of about 13 000 to 23 600 parking spaces if a similar approach is adopted, considering the city's parking infrastructure (parking.brussels, n.d.). This is a critical consideration for policymakers, as it involves trade-offs between improved waste management and the availability of parking, which could affect public acceptance of the new system. There will always be a trade-off between that solution and available curbside.

Snow accumulation and other weather-related issues present operational challenges for mechanized collection models. The need to keep streets clear and functional during snowfalls can interfere with the placement and access to waste containers. Large-wheeled containers are problematic in snowy conditions, so any containerization plan must incorporate a strategy for snow removal to ensure shared containers are accessible for collection. Paired with Brussels street configuration, with sometimes narrow streets, the idea that different neighbourhoods may require different types of waste collection systems (individual bins versus shared containers) becomes more inevitable.

DSNY provides door-to-door waste collection with 8,200 workers operating 2,000 trucks on 7,200 weekly routes. Collection frequency, currently two to three times per week for refuse and once per week for recycling, is determined by factors such as waste volume, environmental impact, and cost. Introducing shared containers, which typically require daily or twice-daily collections in other cities, would necessitate a temporary increase in staffing and fleet size to manage the additional service levels until residential behaviour adjusts. In high-density areas, maintaining current collection frequencies would demand an impractically large number of shared containers.

Containerization in NYC requires a fleet compatible with either stationary or wheeled shared containers. Stationary containers are optimal for high-density areas but require new trucks. Wheeled containers, which can work with existing DSNY trucks, are quicker to implement but less suitable at scale due to smaller capacity, frequent wheel breakages, and issues with theft and snow. Stationary containers can be serviced by automatic side loaders (ASL) or hoist trucks, with DSNY preferring ASLs. However, neither ASLs nor hoist trucks are currently available at scale in the U.S. Developing the necessary fleet for stationary containers would take at least three years and significant investment. In the same way, Brussels should study the impacts on their fleet, and the different parameters highlighted by Zbib and Wøhlk (2019) helping choosing between multi-compartment vehicles, which reduce the total distance traveled, and single-compartment vehicles, which require fewer routes.

The presence of two different paradigms also presents a serious problem. New York City's separate collection systems for residential and commercial trash complicate citywide containerization. Residential trash is collected by DSNY, while commercial trash is handled by over 90 private carters, creating issues in mixed-use neighbourhoods. Even with the new Commercial Waste Zone law, shared containers for commercial waste are impractical. This is also the case in Brussels, and partnership with private waste management companies should be explored, to make the system as efficient as possible.

Improvements can include using individual bins for small businesses, enforcing new set out time rules, and incentivizing on-site loading docks in large office complexes to facilitate in-building containerization.

4.2.3. Model Evaluation and Viability

The study concludes that 89% of the city's residential streets, accounting for 77% of the total residential waste, can be containerized without occupying more than 25% of the available street space. This would involve repurposing up to 10% of curb space on blocks with residential buildings. This way, there will be less fixed available curb space, in contrast with the current system where available curb space only decreases on collection days. For Brussels, as highlighted by the survey, this is still an important point.

The evaluation reveals that on 50% of residential streets, individual bins are a practical solution. However, on 39% of the streets, shared containers are necessary due to higher waste volumes that individual bins cannot accommodate. The remaining 11% of streets present significant challenges to containerization due to high waste volumes relative to street space and other constraints like bike lanes and bus stops.

Collection frequency also impacts viability. About 80% of street sections can be containerized without altering the current collection frequency, while an additional 9% require increased frequency to be viable. However, 11% of streets, primarily in high-density areas, cannot be containerized even with doubled collection frequency.

The study emphasizes that any containerization model must be tailored to the specific needs of each street section based on residential density and waste output. Shared containers are suitable for mid-to-high-density areas, while individual bins are best for low-density areas.

Furthermore, the study discusses the technical and operational considerations for implementing shared stationary containers, highlighting the need for new infrastructure and fleet developments, as well as the potential necessity of increasing collection frequency in high-density areas to manage waste volumes effectively. Challenges include competition for curb space with other uses such as parking and bike lanes, significant operational adaptations for new container models, and the need for extensive community engagement and behavioural change for successful implementation.

Overall, the report suggests that containerization is a viable solution for most of New York City's residential streets, provided that careful planning and substantial investment in new infrastructure and operational changes are made to address the specific challenges of each neighbourhood. New York's analysis of containerization also touches on the environmental and social impacts, which Van Engeland et al. (2020) identified as critical components of a sustainable waste management network. The need for new infrastructure and community engagement in New York aligns with the lessons from Rotterdam and reinforces the idea that Brussels must consider both technical and social factors in its transition.

4.3. Plan for Brussels

The literature highlights the benefits of collective waste containers and the importance of having a clear and complete optimisation problem behind it. The integration of technology is mostly beneficial in support of the efficiency of this model. On one hand, Rotterdam's successful implementation of underground containers since 1996 serves as a practical model, highlighting community engagement and technological integration to improve waste management. On the other hand, New York City's feasibility study addresses challenges like space constraints and operational adaptations for containerization. This provides a solid foundation for developing a waste management strategy tailored to Brussels

Key Steps in Containerisation

Feasibility Study and Pilot Program:

Drawing from Rotterdam's phased implementation and New York's detailed feasibility analysis, Brussels should start with a targeted feasibility study focusing on areas with the highest waste generation and densest populations. A pilot program in a high-density area like Saint-Josse-ten-Noode could test the system’s effectiveness and public response.

Infrastructure Development:

Using real data, evaluate the necessary storage capacity based on local population density and waste generation rates and ensure proximity by placing containers within a convenient distance for residents. It is important to not forget to collaborate with municipal services to identify suitable locations that do not interfere with existing infrastructure and public space uses.

Technology Integration:

Technology is a necessary support for all of the operation. Leveraging the technological advancements used in Rotterdam, such as fill-level sensors, will provide real-time data for optimizing collection routes and frequencies, reducing vehicle mileage and emissions. Paired with that, a monitoring system that integrates data from sensors, resident feedback, and maintenance logs will ensure efficient operations. Data analysis and machine learning models can also help in implementing seasonal adjustments for bio-waste collection to manage odours and maintain cleanliness. This could also help mitigate some of the logistical challenges identified in New York.

Community Engagement and Education:

As this change will affect directly the inhabitant of Brussels, engaging with Brussels residents, much like in Rotterdam, will be crucial for the success of the program. Allowing them to suggest container locations and participate in the system's upkeep will give life to the transformation. This can be helped by the launch of comprehensive communication campaigns to educate residents on the new system, its benefits, and proper waste sorting practices. Hopefully, like in Rotterdam, people will get involved and a potential 'adopt-a-container' program could be launched, where community members take responsibility for keeping container areas clean.

Operational Adjustments:

This change will have important impacts on the current garbage truck fleet. They will need to be replaced or equipped to be compatible with both stationary and wheeled containers. Supported by the technology, the collection frequencies should be optimised based on sensor data to prevent overfilling and manage waste effectively, especially in high-density areas. However, policymakers must carefully consider the potential impact on parking, as seen in New York, and communicate these changes clearly to the public.

Evaluation and Scaling:

A central point is regularly assessing the pilot program's performance, as practised in Rotterdam, using key metrics such as cleanliness levels, collection efficiency, and resident satisfaction. In reaction to that, issues should be addressed promptly to refine the system, focusing on minimizing illegal dumping and ensuring container accessibility. This way, APB could gradually expand the system citywide based on pilot program learnings, prioritizing areas with the highest waste generation and most significant challenges.

Implementing collective waste containers in Brussels offers a robust solution to the city’s waste management challenges. By leveraging technology, engaging the community, and learning from successful models in other cities, Brussels can significantly enhance its waste collection efficiency, cleanliness, and overall urban environment, aligning with broader sustainability and circular economy goals. Regular revaluation and adaptation are necessary to address specific challenges and evolving waste management needs.

5. Critical Setbacks and Implications

Overall, the study underscores the necessity for context-specific solutions in waste management. There is no universal formula that can be applied across different cities or regions, as each has unique characteristics and challenges that must be addressed individually. One of the significant setbacks encountered in the study is the scarcity and non-uniformity of data. This variability makes it challenging to conduct objective data analysis and draw meaningful comparisons between different case studies and their degrees of success. Without consistent and comprehensive data, evaluating the effectiveness of various strategies becomes problematic.

Furthermore, many of the available reports are extensive but often include subjective opinions. This subjectivity can cloud the analysis, making it difficult to derive clear, actionable insights. As those reports are mainly backed by the respective sanitation or waste departments of the cities, a certain political agenda could have influenced them. There is sometimes a lack of scientific back-up, but it can be comprehensible because of the scarcity of literature on this specific subject.

The complexity of the problem is another critical issue, as it involves numerous parameters, such as logistical considerations, environmental impact, cost, and social factors. These diverse elements need to be balanced carefully to develop an effective waste management strategy. Assessing people's perceptions and reactions to such changes adds another layer of difficulty. Public acceptance and behavioural adjustments are crucial for the successful implementation of new systems, but these factors are inherently challenging to measure and predict. This complexity requires not only technical and logistical solutions but also robust community engagement to be able to really assess how the resident feel about it and how they will adhere to these changes.

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Appendices

Appendix A : Data from APB, provided by Edwin Wansi

Tonnages (en tonnes)	2014	2015	2016	2017	2018
tout-venant	207,450.76	202,157.42	222,749.48	181,855.20	188,008.16
papiers/cartons	32,185.55	30,454.46	28,803.18	28,778.33	28,352.73
PMC	11,695.69	12,136.09	11,820.77	12,865.93	13,356.90
déchets putrescibles (jardin et organiques)	16,830.97	15,606.13	17,337.80	20,353.73	19,713.45

Tonnages (en tonnes)	2019	2020	2021	2022	2023
tout-venant	206,093.87	206,852.81	204,765.32	194,492.29	162,807.22
papiers/cartons	26,562.77	24,681.08	26,077.56	25,018.85	26,520.94
PMC	12,178.11	11,444.27	13,160.80	14,447.04	17,472.42
déchets putrescibles (jardin et organiques)	20,814.85	21,183.25	21,694.88	18,259.44	26,466.84

UNIVERSITÉ CATHOLIQUE DE LOUVAIN
Louvain School of Management
Place des Doyens, 1 bte L2.01.01, 1348 Louvain-la-Neuve, Belgique | **www.uclouvain.be/lsm**