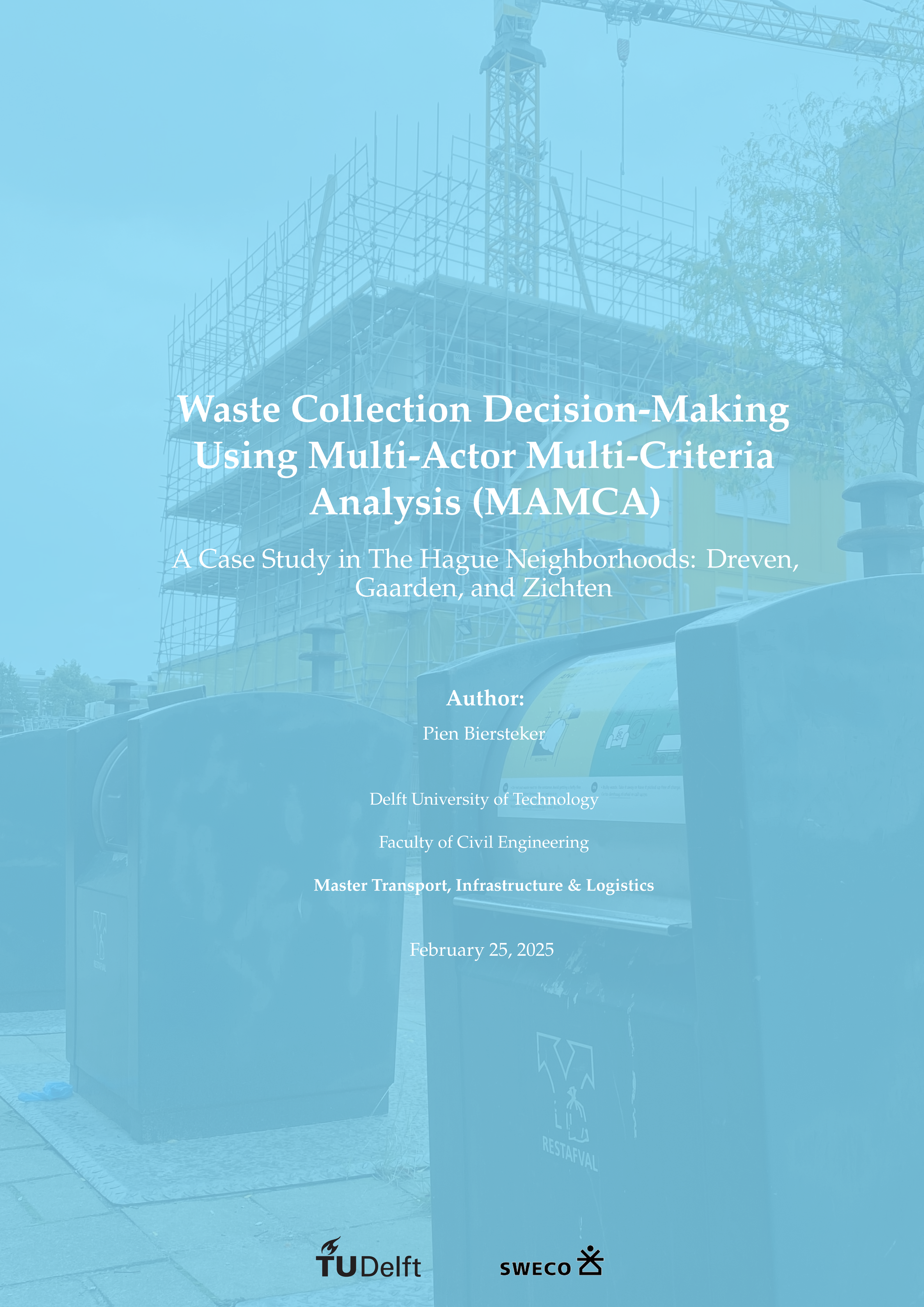

Waste Collection Decision-Making Using Multi-Actor Multi-Criteria Analysis (MAMCA)

A Case Study in The Hague Neighborhoods: Dreven, Gaarden, and Zichten

Author:

Pien Biersteker

Delft University of Technology

Faculty of Civil Engineering

Master Transport, Infrastructure & Logistics

February 25, 2025

TU Delft   SWECO

Waste Collection Decision-Making Using Multi-Actor Multi-Criteria Analysis (MAMCA)

A Case Study in The Hague Neighborhoods: Dreven, Gaarden, and Zichten

by

Pien Biersteker

to obtain the degree of Master of Science

Student number:	4888375	
Project duration:	September 2, 2024 – February 28, 2025	
Thesis committee:	Dr. J.M. (Jaap) Vleugel,	TU Delft, Chairman
	Dr. J.A. (Jan Anne) Annema,	TU Delft, Supervisor
	Dr.ir. A.J. (Arjan) van Binsbergen,	TU Delft, Supervisor
	Sacha Raven,	Sweco, Supervisor
	Julia van der Heide,	Sweco, Supervisor

This thesis is confidential and cannot be made public until February 28, 2025.

TU Delft SWECO

Preface

Everyone interacts with waste on a daily basis, yet few people truly think about the system behind it. We throw things away without a second thought. However, there is an entire world of logistics and organization involved in managing household waste. Where your responsibility ends after you throw something in the bin – or worse, throw it out on the street – the complex process behind the scenes begins. I became fascinated by this during an elective course I took in Sweden: Waste Management. I discovered how interesting and complex the world behind waste is, inspiring me to pursue my thesis in this field.

That's how I connected with Sweco, an engineering consulting firm that works on waste management projects. One of their clients, Staedion, a housing corporation in The Hague, was redeveloping the neighborhoods of Dreven, Gaarden, and Zichten. The municipality required Staedion to implement indoor waste collection in new buildings. However, the initial plans to use roll containers raised concerns about pests, high costs, and limited groundfloor space. Staedion was unsure how to proceed, and I delved into this challenge, quickly realizing the complexity and the many stakeholders involved.

Throughout this journey, I received valuable support from my thesis committee, for which I am grateful. First, I want to thank Jaap Vleugel, who guided me even before my thesis officially started, helping me find a suitable topic and providing continuous feedback despite his demanding schedule. I also thank Jan Anne Annema for his insightful advice, which strengthened the academic quality of my thesis. Their combined guidance not only contributed to the success of this research, but also made the process enjoyable.

I am also grateful to Sweco for their support and for making me feel at home within the team. A special thanks goes to Sacha Raven and Julia van der Heide, who were always available for feedback and connected me with experts in the Netherlands and Sweden. Their mentorship not only deepened my understanding of waste management, but also taught me valuable networking skills.

My thanks extend to Staedion. Everyone I contacted was eager to meet me, giving me a deeper understanding of Dreven, Gaarden, and Zichten. A special thanks to Rob van der Varst and Antoinette Epping. I also appreciate the openness of Heijmans, HMS, and the Municipality of The Hague, who participated in interviews. Finally, I thank the NVRD for allowing me to attend waste management conferences and providing valuable connections within the industry.

Lastly, I want to thank my family, partner, and friends for their support throughout my thesis. They provided much-needed distractions and valuable moments for brainstorming. A special thanks to my friends from Stockholm, where my interest in waste management first emerged.

With this thesis project, my student years come to an end. I thoroughly enjoyed my studies, the courses offered, and the vibrant life in Delft. I hope you enjoy reading my thesis and gain insight into the fascinating and complex world of waste management.

Pien Biersteker (Rotterdam, February 2025)

Summary

Efficient waste management is a key component of the circular economy, where waste is seen as a valuable resource rather than merely a residual product. Despite significant efforts to prevent and minimize waste, a completely waste-free world remains unrealistic, making the reintegration of waste into the economy essential. The European Union has set ambitious recycling targets—55% by 2025, 60% by 2030, and 65% by 2035—which further underline the need for highly efficient waste collection systems that minimize pollution and maximize resource recovery.

The literature highlights that effective stakeholder collaboration is crucial for efficient waste management. However, there is a notable lack of structured methodologies to systematically integrate diverse stakeholder preferences into waste collection decision-making. The Multi-Actor Multi-Criteria Analysis (MAMCA) offers a promising framework, but its application has been largely limited to transportation studies, leaving a significant gap in its systematic use for urban waste collection planning.

This study applies the Multi-Actor Multi-Criteria Analysis (MAMCA) for the first time in waste collection decision making, using the neighborhoods of Dreven, Gaarden, and Zichten in The Hague as a case study. The Hague faces significant challenges in household waste collection, particularly in high-density urban areas. Only a small portion of household waste is separated, and the amount of residual waste per capita remains high. Causing the city to fall behind many other Dutch municipalities in effective waste management. Furthermore, as the most densely populated city in the Netherlands, The Hague has a notable lack of available public space for waste collection facilities. With ongoing redevelopment plans that include an additional 3,500 housing units in these neighborhoods, this area provides an ideal case study for exploring innovative waste collection approaches. The municipality has mandated indoor collection for new buildings, raising stakeholder concerns about high costs, space limitations, and pest issues. Disagreements among stakeholders regarding the most suitable system further emphasize the need for a structured decision-making framework, which this study addresses through the application of MAMCA.

This study provides an answer to the following research question: *How can the waste collection for household waste in the neighborhoods of Dreven, Gaarden, and Zichten be best organized and implemented, taking into account all stakeholders involved?* To answer this question, the research followed a structured process consisting of several key steps: (1) problem definition, (2) analysis of the current process, (3) stakeholder analysis, (4) definition of requirements and criteria, (5) design of alternatives, and (6) results: evaluation of criteria scores for each alternative.

The current waste collection system relies mainly on underground containers (ORACs) for residual waste, with limited separation for recyclables such as paper, glass, and plastic, and no organic waste collection. Key issues include illegal dumping, inefficient waste separation, and high waste taxes for The Hague's residents. Stakeholder interviews reveal strong disagreements: the municipality advocates for indoor waste collection, while housing corporation Staedion, developer Heijmans, and waste collection service HMS raise concerns about increased costs and logistical challenges.

Based on the stakeholder analysis, this study includes the Municipality of The Hague, housing corporation Staedion, developer Heijmans, and waste collection company HMS in the MAMCA, as they have the most direct influence on the decision-making process.

Considering the performance of the current system, along with the objectives and interests of the stakeholders, the following evaluation criteria were established to assess the five waste collection alternatives using the MAMCA method. Additionally, requirements were formulated to serve as guidelines for designing potential waste collection alternatives.

1. **Costs**: Investment, operational, waste tax for residents, and resident service fees.
2. **Space usage**: Indoor and outdoor footprint.
3. **Ease of use**: User-friendly for both residents and waste collection workers
4. **Sustainability**: Impact on transport movements and waste separation potential.
5. **Ease of implementation**: Required infrastructure modifications.

All stakeholders were surveyed to determine their criteria preferences by comparing each criterion against the others. This resulted in weighted values per stakeholder, indicating the relative importance of each criterion.

Based on stakeholder interviews and an analysis of current waste collection performance in The Hague, requirements were defined as design guidelines, and various waste collection alternatives were subsequently developed:

- **Baseline (A.0)**: Current ORAC System, continuing the existing setup with potential capacity adjustments.
- **Alternative 1 (A.1)**: Indoor Roll Containers, where waste is stored inside buildings and manually placed outside for collection.
- **Alternative 2 (A.2)**: Indoor Press Containers, which compact waste before collection to reduce frequency and required space.
- **Alternative 3 (A.3)**: Underground Press ORACs (SIDCON), which compact waste underground to optimize storage and minimize transport.
- **Alternative 4 (A.4)**: Underground Waste Transport System (OAT), a vacuum-based pipeline network that directly transports waste to a central collection facility.

The MAMCA results in Figure 1 reveal that underground press ORACs perform best overall, scoring highly on cost efficiency, space optimization, and ease of implementation. This alternative retains the benefits of underground waste storage while increasing capacity through compaction, reducing collection frequency, and has the potential for better waste separation. The system also allows for gradual, data-driven implementation, where new ORACs can be introduced based on collection frequency data—identifying the optimal locations for press ORAC implementation as well as aligning with infrastructure depreciation cycles.
Like any study, this research has limitations. MAMCA remains inherently subjective, as outcomes depend on which stakeholders are interviewed and how criteria are prioritized. Additionally, the impact of each criterion per alternative was estimated—calculations for investment costs, operational costs, and space usage were made, while other criteria were scored on a qualitative scale. For the estimates, all stakeholders with expertise were consulted; however, not every stakeholder was able or willing to verify the costs, and some estimates were based on logical

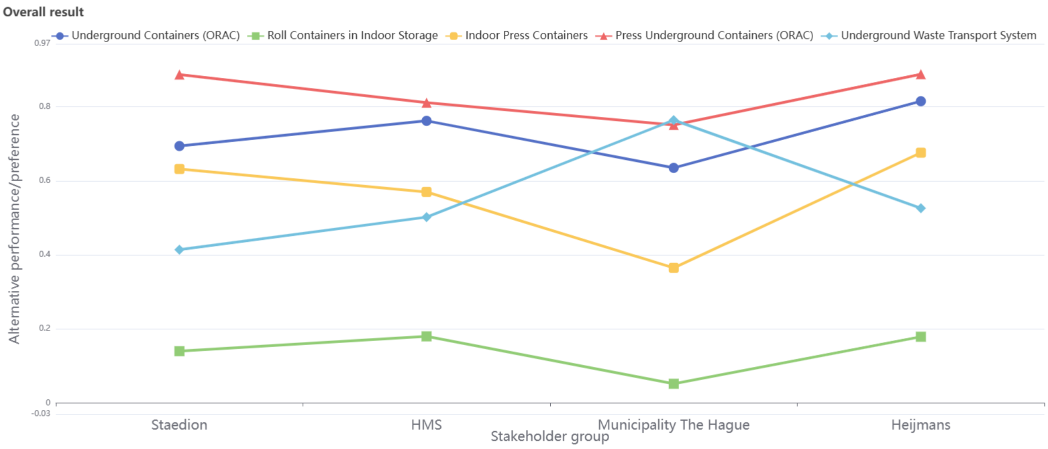

Figure 1: MAMCA Results

reasoning rather than independent verification. The majority of these estimates have, however, been verified.

Future studies could conduct a more in-depth financial analysis of each alternative, as this study focused on high-level estimations to compare options. Additionally, further research could examine the exact number of transport movements and the sustainability impact of each alternative, provided that the necessary data becomes available. Moreover, residents were not included in the analysis since they do not directly influence decision-making. However, the interaction between waste collection systems and user behavior is crucial. Future research could explore how residents interact with different waste collection systems and how their behavior can be influenced to improve efficiency and sustainability.

The results emphasize the importance of structured stakeholder collaboration in waste management decision-making. Despite this study showing that indoor roll containers are the least preferred option, it will be implemented in the first phase of the redevelopment. Significant investments have already been made in indoor waste rooms and roll containers, whereas this capital could have been allocated to a more widely supported alternative, such as underground press ORACs. A collective decision-making process could ensure that investments align with long-term stakeholder interests, rather than committing resources to a system that may later prove inefficient or costly.

MAMCA highlights how decisions made in isolation can have unintended consequences for other stakeholders. While an alternative may seem cost-effective or convenient for one party, it may impose financial or logistical burdens on others. A key recommendation is to explore cost-sharing mechanisms, where stakeholders such as Staedion and Heijmans contribute to underground press ORACs instead of investing in indoor waste facilities and roll containers. A shared financial approach would promote a more sustainable and efficient waste collection system that better serves all stakeholders while optimizing long-term costs and operational efficiency.

This research contributes to the broader academic discourse on urban waste management, demonstrating how multi-actor multi-criteria decision analysis can enhance waste collection system planning. The insights gained are valuable not only for The Hague but also for other high-density urban areas seeking to optimize waste management in a sustainable and stakeholder-inclusive manner.

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List of Abbreviations

Below is a list of abbreviations used in this research along with their explanations:

Abbreviation	**Explanation**
MAMCA	Multi-Actor Multi-Criteria Analysis
OAT	Underground Waste Transport System (Ondergronds Afval Transport-systeem)
ORAC	Underground Refuse Collection Container (Ondergrondse Afval Container)
PMD	Plastic, Metal, and Drink Cartons
GFT	Organic Waste (Groente-, Fruit- en Tuinafval)
DGZ	Dreven, Gaarden, and Zichten (study area)
HMS	Household Waste Collection Service

Table 1: List of Abbreviations Used in This Research

1
Intro

This chapter first introduces the research in section 1.2, providing a global context on waste management challenges and sustainability goals. In section 1.3, the social and scientific relevance of the study is discussed, leading to the formulation of the key research questions. Next, section 1.4 presents a review of existing literature in the waste management research domain. Finally, section 1.5 details the methodology used in this study, including its justification and the different project phases.

1.1. Report Outline

This report consists of several chapters, each containing sections and subsections. Intro (chapter 1) provides an introduction to the research, including the literature review and the methodology.

Case Study Background (chapter 2) offers all the necessary information specific to the case study. First, the problem definition is presented. Then, the current waste collection process is analyzed. Subsequently, a stakeholder analysis is conducted to determine which stakeholders are involved in the collection process and which are the most important in the decision-making process, and therefore need to be incorporated into the MAMCA.

Design (chapter 3) focuses on the various waste collection alternatives. First, requirements are established that the designs must meet, and the criteria important for comparing the alternatives in the MAMCA are determined. Additionally, the stakeholders identified as most crucial in the decision-making process from the stakeholder analysis were asked to rank these criteria; their preferences are also included in this chapter. Finally, the impact of each alternative is estimated—explaining how these estimates were derived and presenting the outcomes.

Outcome (chapter 4) is dedicated to the results. It presents the findings of the MAMCA, answers the research question, discusses the study, and provides recommendations.

1.2. Introduction

Although much attention is directed towards reducing waste through strategies such as prevention, minimization, and reuse [European Commission, 2023], the complete elimination of waste from modern society remains unrealistic. Waste generation will inevitably continue, making it essential to focus on reintegrating waste into the economy. Within the framework of the circular economy, waste is increasingly seen as a resource rather than an end product. This perspective aligns with the European Union's (EU) objectives to transform waste into secondary raw materials, enhance recycling, and promote reuse. EU legislation sets binding targets for recycling municipal waste, mandating a 55% recycling rate by 2025, 60% by 2030, and 65% by 2035 [European Union, 2022].

Efficient waste management systems are crucial for achieving these goals while addressing environmental concerns. Approximately 50% of global greenhouse gas emissions and over 90% of biodiversity loss result from the extraction and use of primary raw materials

[European Commission, 2020]. Circular waste management systems, supported by efficient waste collection, play a critical role in reducing these impacts and contributing to climate targets. In the Netherlands, municipalities are responsible for household waste collection, but methods vary widely across regions. While some municipalities implement source separation (sorting waste at home), others rely on post-separation (sorting waste at processing facilities), which often leads to inefficiencies and confusion among residents [Milieu Centraal, 2022].

The Hague, in particular, faces significant challenges in waste management. Residents generate an average of 256 kg of residual waste per capita annually, with only 34% of waste being separated [Centraal Bureau voor de Statistiek (CBS), 2024]. Additionally, The Hague imposes the highest average waste tax among large Dutch cities, at €436 per household [Gemeente Den Haag, 2024a]. Compared to cities such as Amsterdam, Utrecht, Rotterdam, and Eindhoven, The Hague lags behind in achieving higher separation rates and reducing residual waste [Centraal Bureau voor de Statistiek (CBS), 2024].

The city's challenges are compounded by its status as the most densely populated city in the Netherlands, characterized by a high prevalence of high-rise buildings. Managing waste collection and separation in high-density urban areas presents unique difficulties, making The Hague a particularly suitable research area for this study. Specifically, the neighborhoods of Dreven, Gaarden, and Zichten, which are currently undergoing significant redevelopment, offer a compelling case study. These neighborhoods will see an addition of 3,500 new homes in the coming years [Gemeente Den Haag, nd], leading to a significant increase in population density. Currently, there is substantial disagreement among stakeholders about the most suitable waste collection system for these neighborhoods, as detailed in section 2.3. This makes Dreven, Gaarden, and Zichten an ideal case study for exploring new waste management strategies.

This research uses the neighborhoods of Dreven, Gaarden, and Zichten as a case study to explore the application of the Multi-Actor Multi-Criteria Analysis (MAMCA) in waste management. The MAMCA is a structured approach that incorporates the perspectives and preferences of all relevant stakeholders to evaluate different waste collection alternatives. Proposed systems will include various options such as indoor collection, underground residual waste containers (ORACs), and innovative technologies like smart waste sensors. These alternatives will be systematically assessed using the MAMCA, focusing on criteria such as sustainability, operational efficiency, and stakeholder acceptance.

The importance of stakeholder collaboration in waste management is consistently highlighted in the literature section 1.4. However, there is currently no widely recognized method for systematically evaluating waste collection systems while integrating diverse stakeholder perspectives. This study addresses this gap by applying the MAMCA to develop a waste collection system in a redeveloped urban area. It also contributes to the literature by demonstrating how structured stakeholder involvement can improve the implementation of waste management innovations.

By examining the unique characteristics and challenges of Dreven, Gaarden, and Zichten, and fostering collaboration among key stakeholders such as the municipality, housing corporations, waste collection services, and residents, this research aims to identify a tailored and sustainable solution for optimizing waste collection systems. The findings will not only provide practical recommendations for these neighborhoods but also offer insights into the broader application of the MAMCA in urban waste management projects.

Figure 1.1: Research Area Dreven, Gaarden and Zichten [DGZ, Den Haag, 2025]

1.3. Research Relevance and Questions

This section first substantiates the scientific and then the social relevance of this research. Ultimately, these lead to the research questions that guide this study.

1.3.1. Scientific Relevance

Stakeholder collaboration is widely recognized in the literature as essential for the success of waste collection systems, as discussed in the literature implementation factors Table 1.4.2. However, a structured method for systematically weighing and balancing stakeholder priorities remains unexplored. This gap can result in waste collection decisions being driven by short-term considerations and individual stakeholder interests rather than long-term collective benefits.

By applying the Multi-Actor Multi-Criteria Analysis (MAMCA), this study introduces a structured framework for integrating stakeholder preferences into decision-making processes. It examines whether different choices would emerge if all stakeholders collaborated rather than prioritizing short-term convenience or cost reduction for one's own benefit. This research fills a gap in the waste management literature by systematically assessing stakeholder perspectives and their impact on decision-making.

Using the neighborhoods of Dreven, Gaarden, and Zichten in The Hague as a case study, this research explores how stakeholder priorities shape the design and implementation of waste collection systems. By evaluating various waste collection alternatives, the study demonstrates how MAMCA can provide actionable insights for developing sustainable waste collection solutions. Through the application of this novel methodology to a real-world case, this research contributes to advancing scientific knowledge on waste collection strategies and the role of stakeholder collaboration in sustainable urban waste management.

1.3.2. Societal Relevance

As urban areas continue to expand and densify, effective waste collection should be a critical concern for local communities. The insights gained from this research can contribute to more sustainable waste collection strategies that align with the needs and expectations of various stakeholders.

In the context of the redevelopment plans for the neighborhoods of Dreven, Gaarden, and Zichten (DGZ), there is a disagreement among stakeholders regarding the most suitable waste collection method, as discussed in section 2.3. DGZ is already a densely populated area, and the development plans for 3,500 additional homes will significantly increase the number of residents. This makes DGZ a particularly interesting case study for applying the MAMCA (Multi-Actor Multi-Criteria Analysis), given the current differences in stakeholder preferences and the anticipated challenges of waste collection in a high-density urban environment.

This research aims to contribute to a solution that is broadly supported by the stakeholders involved in DGZ. By methodically identifying and addressing the specific waste management challenges in these neighborhoods, this study seeks to provide actionable recommendations for waste collection systems that are both effective and aligned with stakeholder preferences.

Moreover, this research fosters mutual understanding among stakeholders by highlighting their preferences and the aspects of waste collection that each party considers important. The practical goal of this study is to recommend the waste collection alternative that best meets the criteria deemed important by all stakeholders.

Additionally, this research is particularly relevant given that The Hague performs poorly in terms of waste separation compared to other major cities in the Netherlands [Centraal Bureau voor de Statistiek (CBS), 2024]. Effective waste separation is essential for meeting the European Union's recycling targets, which mandate that 55% of municipal waste must be recycled by 2025, rising to 60% by 2030 and 65% by 2035 [European Commission, 2023].

Improving waste management practices in The Hague is therefore crucial not only for local sustainability efforts but also for ensuring compliance with EU regulations.

1.3.3. Research Questions

The primary goal of this research is to apply the MAMCA (Multi-Actor Multi-Criteria Analysis) to investigate stakeholder perspectives and develop a site-specific waste collection design for the neighborhoods of Dreven, Gaarden, and Zichten. Although the importance of multi-stakeholder collaboration in waste management is frequently emphasized in the literature, the MAMCA has not yet been specifically applied in this domain. This study addresses this gap by introducing a structured decision-making process that prioritizes long-term, collective benefits over short-term, individual interests. The central research question guiding this study is:

How can the waste collection for household waste in the neighborhoods of Dreven, Gaarden, and Zichten be best organized and implemented, taking into account all stakeholders involved?

In order to answer the main research question the following sub-research questions are formulated:

1. What is the current waste collection process, and what policies govern it?
2. Who are the key stakeholders in the decision-making process for the waste collection alternatives, and what are their objectives and criteria?
3. What are the requirements and criteria for the future waste collection system?
4. Which innovative waste collection methods can be implemented?
5. How do proposed designs score on the identified criteria, and which design is most suitable for implementation?

1.4. Literature Review

In this section, a literature review is conducted to examine the existing body of knowledge on waste management practices and the factors that influence effective waste collection and recycling. This review aims to establish the purpose and scope of the research by assessing what has already been investigated in the field. It delves into various technological, socio-economic, and infrastructural solutions implemented in urban settings to address household waste challenges. Additionally, it explores behavioral aspects and the role of socio-demographic factors influencing waste management.

The literature review served as the first step in this research, aimed at identifying the gaps in current literature and understanding where further investigation is required. It helps to determine the possible research aims where the case study of the Dreven, Gaarden, and Zichten neighborhoods in The Hague could benefit from. By analyzing past research and case studies, the review identifies key strategies and innovations that inform the development of an optimized waste collection system for these neighborhoods. Additionally, it highlights gaps in knowledge, such as the lack of methodological approaches for integrating stakeholder preferences into waste management decisions.

1.4.1. Methodology

The Bryman systematic approach is a detailed method for conducting literature reviews, encompassing four main steps [Bryman, 2016]. The process begins with defining the purpose and scope of the review. Next, a comprehensive search is conducted to find relevant studies. In the third step, the identified literature is filtered based on the criteria set in the initial phase, ensuring that only studies aligned with the defined purpose and scope are included. Finally, the selected studies are analyzed and synthesized to uncover patterns, gaps, key concepts, and theories. This approach promotes a structured and transparent process, providing a thorough overview of the research landscape.

Purpose and Scope

The aim of this literature review is to investigate existing research on waste management, with an emphasis on waste and resource collection in urban settings, while identifying gaps in the current body of knowledge. This review will explore how both spatial considerations and personal factors shape residents' waste disposal behavior and will highlight innovations in waste collection systems. Furthermore, it will evaluate the advantages and disadvantages of various waste collection methods, specifically focusing on source separation and post-collection sorting, and will examine the roles of key stakeholders within the waste management process.

Search Technique for Relevant Studies

A comprehensive search was conducted using the keywords outlined in Table 1.1 to identify studies that align with the purpose and scope of the research. Scopus was the primary search engine utilized, focusing on scientific papers published in academic journals. Additionally, the TU Delft Repository was consulted. An important selection criterion was the number of citations each article received, as this reflects its impact and relevance in the field. However, exceptions were made for highly relevant articles or very new articles even if they lacked significant citations.

The snowballing technique was also employed, where references within the selected articles pointing to other frequently cited works were reviewed and included when relevant. After the initial search, broader search terms were explored using the operator OR instead of AND, yielding additional articles. Only the most relevant, highly cited articles were retained. This rigorous selection process resulted in a curated collection of academic sources, forming the foundation for the literature review. To ensure accessibility and inclusivity, only publicly available publications were used. Since a significant number of studies originated from regions outside Europe, an additional targeted search was conducted specifically for studies within the European context in subsection 1.4.3. This step was taken to ensure relevance to the research area, as European studies align more clo sely with the policies, socio-economic conditions, and infrastructural challenges pertinent to the case study of Dreven, Gaarden, and Zichten. To ensure accessibility and inclusivity, only publicly available publications were incorporated.

Table 1.1: Search Terms and Criteria for Literature Review

Concept Groups	Waste Collection Methods; Technological Innovations; Implementation Factors; Socio-Demographics; Environmental Factors; Policy
Keywords	*Waste Collection Methods:* waste collection, waste collection methods, waste collection systems, source separation, post-collection sorting, curbside collection
	Technological Innovations: technological innovations, smart waste bins, sensor-based waste collection, automated waste collection, AI waste management, robotic waste sorting, blockchain waste tracking
	Implementation Factors: implementation challenges, implementation barriers, implementation factors, key success factors, policy implementation
	Socio-Demographics: socio-demographics, income, education, age, household size, population density, urban infrastructure
	Policy: municipal waste policy, waste regulations, circular economy, sustainability policy
Truncation	(Waste Collection Methods) AND (Technological Innovations) AND (Implementation Factors) AND (Socio-Demographics) AND (Policy)

1.4.2. Literature Review

All articles identified through the search terms outlined in subsection 1.4.1 were thoroughly analyzed and categorized into six main areas: Behavioral Factors in Waste Separation, Waste Separation, Innovations in Waste Management, Policy and Regulatory Issues, and Implementation.

Behavioral Factors in Waste Separation

Several studies examine behavioral factors influencing waste separation. As shown in Table 1.2, one key factor is time constraints—an Indonesian study introduced the term "hustle culture," referring to people being too busy with daily life to prioritize waste separation and sustainability goals [Soesilo and Alfarizi, 2024]. Other studies highlight factors such as income, residential location, and environmental awareness, particularly in relation to willingness to pay for waste management services [Suryawan and Lee, 2023]. Household size, convenience, economic considerations, motivation, and education also play a role in waste separation behavior [Popova and Sproge, 2021].

Additionally, research on waste reuse rather than just waste separation reveals conflicting findings. While one study found no significant relationship between income and reuse behavior, another study on willingness to pay suggested that income does influence participation in waste management services [Suryawan and Lee, 2023, Rusman, 2020]. Similarly, education had no impact in some cases but was a key factor in a Latvian study on waste separation [Popova and Sproge, 2021]. Gender showed no significant influence, whereas mobility did—people with easier access to waste disposal facilities were more likely to engage in reuse initiatives [Rusman, 2020].

These mixed findings make it difficult to draw clear conclusions, as studies focus on different aspects: some on waste separation, others on willingness to pay for waste management services, and others on waste reuse behavior. Further research could be conducted to determine which factors are precisely relevant; however, this falls outside the scope of this study. While socio-demographic characteristics are not the primary focus of this research, it is examined as background information on the neighborhoods of Dreven, Gaarden, and Zichten. In the Case Study Background section (chapter 2), key socio-demographic aspects such as education levels, migration background, and population density are considered based on available data to provide a more comprehensive case study analysis.

Table 1.2: Literature research on Behavioral Factors in Waste Separation

Reference	**Socio-Demographic Factors**
[Soesilo and Alfarizi, 2024]	"Hustle Culture"
[Suryawan and Lee, 2023]	Income, location (slum vs. non-slum), and environmental awareness as key determinants in citizens' willingness to pay (WTP) for municipal solid waste management (MSWM) services.
[Popova and Sproge, 2021]	Household size and type, Convenience, Economic Factors, Motivation and Education
[Rusman, 2020]	Age: Younger citizens prefer online platforms; older citizens prefer convenience-based options like waste disposal centers. ; Income, Gender, Education: Minimal influence on waste management preferences. Those able to bring waste prefer disposal centers, but having a driver's license reduces this likelihood.

Waste Separation Methods

The literature review on waste separation methods, as summarized in Table 1.3, underscores the critical importance of source separation for effective waste management. Numerous studies highlight that sorting waste at the source—such as separating recyclables, organic waste, and hazardous materials—is crucial for reducing environmental pollution and improving the efficiency of waste processing [Jin and Li, 2023, Anuardo et al., 2022]. Source separation is regarded as the first line of defense against waste contamination, and educational initiatives are needed to promote proper separation of household waste [Zaman, 2022]. In some cases, post-sorting technologies, such as automated sorting and material recovery facilities (MRF), are explored as supplementary methods to enhance processing efficiency [Rena et al., 2022, Kerdlap et al., 2019].

The research also highlights technologies like QR code tracking systems and image recognition to support source separation by providing feedback on sorting accuracy and correcting errors during processing [Anuardo et al., 2022, Zaman, 2022]. However, the general consensus is that waste should be sorted at the point of generation, as unsorted waste compromises recycling quality and leads to inefficiencies in processing [Popova and Sproge, 2021, Kurniawan et al., 2021]. Community-based models, such as the Zero-Waste Approach in Sukunan, demonstrate how source separation combined with recycling and composting can significantly reduce landfill waste [Kurniawan et al., 2021]. Studies indicate that source separation in Chinese pilot cities results in higher waste treatment efficiency compared to post-separation, leading to increased resource recovery and less landfill use [Yang et al., 2018].

Even within relatively small cities like Almere, there are various waste separation and collection methods in place. These range from underground waste transport systems to rolling bins for different waste categories [Liu et al., 2023]. This variety stands in contrast to cities like Amsterdam, where source separation is not implemented, and waste is sorted after collection [van Zoelen, 2020].

From the literature, it can be concluded that source separation yields the best results. However, this approach is not applied uniformly throughout the Netherlands. There is a scope for interesting research into why waste management policies differ significantly among municipalities in the Netherlands, although this is not the focus of the present study. Nonetheless, this research incorporates the existing literature's finding that source separation yields the best waste management outcomes. Ultimately, source separation potential is one of the criteria against which the alternatives are compared, in order to assess the potential of each alternative for effective source separation.

Table 1.3: Literature research on Waste Separation Methods

Reference	**Waste Separation Methods**
[Suryawan and Lee, 2023]	Source separation through a Waste bank management
[Jin and Li, 2023]	Source separation is essential for effective waste management and reducing environmental pollution.
[Anuardo et al., 2022]	Sort waste at the source into recyclables, organic, and hazardous materials. Automated sorting categorizes by material or size, while QR codes enhance tracking accuracy. Organic vs. non-organic separation ensures proper biodegradable waste treatment.
[Zaman, 2022]	While post-sorting technologies aid waste processing, the article emphasizes that source separation and household education are key to reducing contamination, with technology correcting errors later in the process.
[Rena et al., 2022]	It highlights source separation at the household level and mentions automated sorting and material recovery facilities (MRF) as examples of post-sorting to improve processing efficiency.
[Popova and Sproge, 2021]	Waste should be sorted at the place of generation (households or businesses). It argues that transporting unsorted waste leads to lower-quality sorting and recycling processes.
[Kurniawan et al., 2021]	Zero-Waste Approach: Sukunan's community-based model focuses on source separation, recycling non-organic waste, and composting organic waste to reduce landfill waste.
[Kerdlap et al., 2019]	High-Value Mixed Waste Processing (Post-Sorting): Advanced technologies process mixed waste streams, extracting valuable materials for reuse or recycling. This increases resource recovery and reduces landfill waste.
[Yang et al., 2018]	Source separation shows better performance in improving waste management efficiency in pilot cities by enabling more effective recycling, reducing landfill waste, and optimizing the overall waste processing system.
[Liu et al., 2023]	Rolling bins for low-rise housing separate organic waste, residual waste, and PMD. Underground containers handle organic waste, paper, PMD, glass, and residual waste. Almere's underground transport system moves sorted waste via air currents to central storage. Above-ground containers collect organic waste, paper, PMD, textiles, and residual waste. Waste collection platforms like the Upcyclecentrum accept 48 types of recyclables.

Innovations in Waste Management

The literature highlights a variety of technological innovations aimed at improving the efficiency and sustainability of waste management systems, as shown in Table 1.4. AI-based automated waste sorting systems, alongside near-infrared (NIR) spectroscopy and hyperspectral imaging, have demonstrated significant potential for accurate material identification and waste sorting [Kurniawan et al., 2024, Abdallah et al., 2020]. Additionally, smart bins equipped with sensors and real-time data monitoring allow for more efficient collection by tracking fill levels and optimizing collection routes through dynamic route planning [Kurniawan et al., 2024, Hao et al., 2024, Popova and Sproge, 2021]. IoT-enabled systems and blockchain technology provide integration, transparency, and better management of waste streams through real-time tracking and decentralized information management [Suryawan and Lee, 2023, Chowdhury et al., 2023]. Furthermore, machine learning models are being used to detect waste contamination, improving sorting accuracy and efficiency [Zaman, 2022, Rena et al., 2022].

Other promising innovations include vacuum waste collection systems, which use underground pipelines to transport waste, particularly in high-density urban environments like hospitals, and waste-to-energy technologies, which convert waste into renewable energy [Anuardo et al., 2022, Kurniawan et al., 2024, Liu et al., 2023]. Finally, smart waste audits and post-sorting high-value waste processing are gaining attention as methods to extract valuable materials and improve resource recovery rates [Kerdlap et al., 2019].

Previous studies have shown that source separation yields the best results, and although interesting research could focus on improving the post-sorting process, this study concentrates on the collection process, which ends when the truck leaves the street. However, conclusions from the literature are incorporated into this research, such as the use of smart bins equipped with sensors to monitor fill levels for an efficient, data-driven emptying process. In addition, the vacuum waste collection systems with pipelines is evaluated as an alternative. The existing body of literature helps identify innovative methods in this sector and highlights key considerations for an efficient collection process, such as the importance of fill-level sensors.

Table 1.4: Innovations in Waste Management

Reference	Innovations
[Kurniawan et al., 2024]	AI sorting, NIR spectroscopy, hyperspectral imaging, smart bins, dynamic route planning, gamified recycling, digital engagement platforms, waste-to-energy, blockchain for tracking, real-time monitoring, IoT integration.
[Hao et al., 2024]	Smart tech: IoT bins, real-time tracking, route optimization for better efficiency and recycling rates.
[Suryawan and Lee, 2023]	IoT and ICT systems for real-time monitoring, rewards/punishments, optimizing waste services.
[Chowdhury et al., 2023]	Blockchain for information management, cyber-physical systems, Industry 4.0 tech (IoT, Big Data), machine learning for waste categorization.
[Anuardo et al., 2022]	Satellite tracking for waste collection, QR code tracking for accountability, vacuum waste collection in hospitals/cities.
[Zaman, 2022]	Machine learning for waste contamination, IoT linking waste systems, sensors and RFID for tracking, automation for sorting and recycling.
[Rena et al., 2022]	Digital tracking (apps, GPS, sensor bins), automated sorting with robots.
[Popova and Sproge, 2021]	Sensors to monitor waste levels, automated sorting with robotics and AI.
[Kerdlap et al., 2019]	Smart waste audits, smart collection, high-value mixed waste post-sorting.
[Abdallah et al., 2020]	AI applications for forecasting of waste characteristics, waste bin level detection, process parameters prediction, vehicle routing, and SWM planning.

Policy and Regulatory Issues

The literature highlights various policy and regulatory approaches aimed at improving waste management systems as shown in Table 1.5. Government incentives, such as subsidies for recyclers and manufacturers, play a crucial role in ensuring compliance with waste regulations and enhancing collection rates [Hao et al., 2024]. Policies tailored to slum communities, combined with pricing strategies and payment options, ensure accessibility for lower-income citizens and promote sustainable waste management through public participation and smart infrastructure investments [Suryawan and Lee, 2023]. Stronger central control and coordination are also identified as key factors, with financial support and clear regulations being essential for the successful implementation of waste separation programs [Jiang et al., 2023].

Mandatory policies enforce waste separation through legal frameworks and fines, while advocacy policies encourage participation via education, rewards, and incentives [Jin and Li, 2023]. The Cleaner Production Promotion Law (CPPL) in China supports waste reduction, reuse, and recycling, with cities like Shanghai implementing mandatory sorting and incentive systems to reward proper disposal practices [Anuardo et al., 2022]. Collaboration between governments, private sectors, and start-ups is highlighted, especially through Public-Private Partnerships (PPP), which enhance infrastructure and promote sustainability in waste management [Rena et al., 2022].

Municipal regulations that offer flexible pricing for unsorted waste, along with local government incentives and infrastructure development, further support waste management efforts

[Popova and Sproge, 2021]. Economic instruments like volume-based waste fees, as seen in Germany's Baden-Württemberg, are cited as effective tools for encouraging waste reduction and recycling [Kurniawan et al., 2021]. Overall, eco-innovation policies and economic measures, such as charges and incentives, are pivotal in fostering a shift towards a circular economy and reducing waste generation [Gardiner and Hajek, 2020].

Policies and regulations play a crucial role in waste management, as household waste collection is primarily a government responsibility. Determining which policies and regulations could be effectively implemented in Dreven, Gaarden, and Zichten is an important research avenue, especially given the challenges related to bulky waste in the neighborhood. However, this study does not focus solely on residents but rather on the overall decision-making process to identify the most suitable waste collection alternative while considering all relevant stakeholders. Future research could explore additional policies, including economic incentives, to encourage residents to manage and separate their waste more effectively.

What can be drawn from the existing literature is the importance of collaboration between governments, the private sector, and start-ups in developing effective waste management solutions. This study focuses on the collective decision-making process and examines the roles of both public and private stakeholders. A strong collaboration between these parties is essential to ensure the successful implementation of a waste collection system that aligns with both policy objectives and stakeholder interests.

Implementation Factors

The literature consistently highlights several key factors for the effective implementation of waste management systems, with stakeholder collaboration being a central theme, as shown in Table 1.6. Successful waste management depends on cooperation between governments, private sector entities, waste collection firms, recycling facilities, and local communities [Kurniawan et al., 2024, Hao et al., 2024, Suryawan and Lee, 2023]. This collaboration optimizes resource use and logistics while addressing the infrastructure and technological needs required for efficient waste management [Chowdhury et al., 2023, Jiang et al., 2023].

In addition to collaboration, the development of a strong infrastructure is essential. Adequate waste processing and collection facilities, integrated with smart technologies, ensure that waste management systems are scalable and effective [Hao et al., 2024]. Moreover, implementing site-specific policies that account for the unique environmental, organizational, and technological conditions of each location enhances the success of these systems [Tan et al., 2024]. Tailoring waste management solutions to specific local conditions—such as waste composition and generation rates, which can vary based on climate, socioeconomic conditions, and population density—is crucial for designing policies that reflect the actual needs of the community [Javaid et al., 2022].

Another critical aspect is the involvement of the community. Community-based solid waste management (CBSWM) systems, where residents actively participate in waste management activities like recycling and composting, can reduce government costs and foster local economic opportunities [Kurniawan et al., 2021]. However, community engagement is not included in this study. As previously mentioned, this could be a valuable subject for future research, specifically on how to encourage communities to separate waste and handle household waste more responsibly.

Overall, a comprehensive approach that includes collaboration, infrastructure development, and site-specific policies is key to successful waste management. However, a gap in the literature exists regarding a detailed stakeholder analysis specific to the Dreven, Gaarden, and Zichten areas. While stakeholder collaboration is consistently emphasized as a critical factor, the reviewed studies do not specify a structured methodology for analyzing or facilitating this collaboration.

Table 1.5: Literature research on Policy and Regulatory Issues

Reference	Policies and Regulations
[Hao et al., 2024]	Policy Support: Government incentives, such as subsidies for recyclers and manufacturers, to encourage compliance with waste management regulations and improve collection rates.
[Suryawan and Lee, 2023]	Policies for slum communities, different pricing strategies for accessibility, and sustainable waste management policies addressing infrastructure, public participation, and investment in smart waste systems.
[Jiang et al., 2023]	Stronger central control and coordination for waste separation, including financial support, clear regulations, and shared responsibility for performance.
[Jin and Li, 2023]	Mandatory policies enforce waste separation through laws and fines, while advocacy policies encourage participation through education, rewards, and incentives.
[Anuardo et al., 2022]	The Cleaner Production Promotion Law (CPPL) promotes waste reduction, reuse, and recycling. Regulations in cities like Shanghai enforce mandatory sorting and offer incentives for proper disposal.
[Rena et al., 2022]	Collaboration between governments, the private sector, and start-ups, highlighting Public-Private Partnerships (PPP) to improve waste management infrastructure and sustainability.
[Popova and Sproge, 2021]	Municipal regulations promote waste sorting, with flexible pricing for unsorted waste and local government incentives and infrastructure.
[Kurniawan et al., 2021]	Economic instruments: Volume-based waste fees to encourage waste reduction and recycling, based on models from Germany's Baden-Württemberg.
[Gardiner and Hajek, 2020]	Eco-innovation policies and economic instruments (charges and incentives) to promote circular economy and reduce waste generation.

This lack of a defined approach highlights a research gap. Conducting such an analysis is essential to align stakeholder goals and ensure that all parties are actively involved in developing sustainable and effective waste management solutions.

1.4.3. Additional Literature Search for Comparable Areas

Following Bryman's literature review method [Bryman, 2016], the initial Scopus search for scientific studies on waste collection predominantly identified research in Asian contexts, with limited findings for Europe or the Netherlands. To bridge this gap, supplementary searches were conducted via Google Scholar, Google (for Dutch-language documents), and the TIL repository. Given the focus on the neighborhoods of Dreven, Gaarden, and Zichten in The Hague, a targeted search was performed to identify literature on comparable European urban areas.

A study on waste management in Zagreb emphasizes source separation as the most effective approach for household waste, stressing the need for strong community engagement. To facilitate this, it recommends expanding "green islands" and recycling yards, implementing automated sorting facilities, and introducing mechanical separation for mixed waste to enhance recycling. The study also highlights the importance of public education to improve the quality of separated

Table 1.6: Literature research on Implementation Factors

Reference	Implementation Factors
[Kurniawan et al., 2024]	Stakeholder collaboration, Infrastructure, Policy support, Public engagement
[Tan et al., 2024]	Inter linkage between environmental, organizational, and technological factors ; Site-specific policy development
[Hao et al., 2024]	Collaboration and Partnership: Effective collaboration between public and private sectors, including waste collection firms, government entities, and recycling facilities, to optimize resources and logistics ; Infrastructure Development.
[Suryawan and Lee, 2023]	Collaboration among stakeholders
[Chowdhury et al., 2023]	Interorganizational Collaboration, Technological Infrastructure
[Jiang et al., 2023]	Effective cooperation between central government, local governments, and separation enterprises is essential for successful waste management.
[Anuardo et al., 2022]	Successful waste management requires collaboration among organizations, governments, and academia to develop, implement, and optimize effective solutions.
[Javaid et al., 2022]	Waste composition and quantity vary by location, climate, socioeconomic conditions, and disposal methods. Understanding this is key to selecting effective waste treatment policies.
[Kurniawan et al., 2021]	Community-Based Solid Waste Management (CBSWM): The community actively manages waste, reducing government costs and creating local economic opportunities through recycling and composting.

materials and advocates for improved recycling infrastructure and efficient waste transport systems [Ribić et al., 2017].

Research from Porto introduces the "BinIt" project, aimed at raising awareness of waste disposal and recycling through a multi-faceted approach. This includes a web app to guide proper waste disposal and the "Garbage Gladiator" bin, designed to encourage correct waste behavior through educational campaigns and gamification, targeting sustainable changes in urban waste practices [Boresta et al., 2024].

In the Netherlands, studies on improving waste separation in high-rise buildings have found that providing residents with kitchen waste containers and convenient in-home storage facilities positively influences waste sorting habits. Moreover, maintaining long-term motivation through continuous interventions, such as regular communication and feedback on recycling, has proven effective [VANG Huishoudelijk Afval, 2020]. Another Dutch study explores behavioral factors influencing household waste practices, suggesting interventions like raising awareness, fostering positive attitudes, and simplifying the waste separation process [Mulder et al., 2021].

Two additional studies in from the TIL repository offer context-specific insights. The first explores the reuse of materials such as furniture through initiatives like repair cafés and thrift stores, which contribute to waste reduction and resource recovery by promoting reuse and upcycling. However, this study focuses on material reuse rather than waste collection and separation, making its applicability limited to behavior change strategies [Rusman, 2020]. The second study, focused on Almere, explores both reuse and waste collection, emphasizing the alignment of technical and social aspects. Despite Almere being smaller than The Hague, the findings on community-led initiatives and systematic waste mapping offer relevant lessons for improving circularity and reducing energy use in waste management [Liu et al., 2023].

Research on comparable areas emphasizes community engagement as a crucial factor in waste management, highlighting its role in the successful implementation of waste collection alternatives. Findings also reinforce that source separation consistently leads to better waste management outcomes, while automated post-sorting technologies should primarily serve as a complement rather than a replacement. Additionally, education has been shown to improve waste separation rates, and gamification can be an effective tool to influence waste behavior positively.

Overall, the insights from comparable areas align closely with the findings from the broader literature review, rather than introducing fundamentally different conclusions. However, a significant gap remains in the literature—while stakeholder collaboration is widely recognized as essential, no structured methodology or framework has been developed to systematically assess or improve this collaboration.

1.4.4. Conclusion Literature Review

The literature review highlights several gaps in the field of waste management. This research focuses on addressing one specific gap: the absence of a method to systematically improve stakeholder collaboration for the successful implementation of waste collection systems. Stakeholder collaboration is frequently identified in the literature as a critical factor. However, no specific methodology currently exists to systematically evaluate or enhance this collaboration.

Given the existing disagreements among stakeholders in the neighborhoods of Dreven, Gaarden, and Zichten (DGZ) regarding future waste collection methods, this study centers on stakeholder collaboration as its primary focus. These neighborhoods, which are undergoing significant redevelopment, provide a relevant and practical case study for this research. The identified challenges make DGZ an ideal setting for exploring solutions that incorporate diverse stakeholder perspectives.

This research aims to address these gaps by applying the Multi-Actor Multi-Criteria Analysis (MAMCA), further elaborated in section 1.5. The MAMCA provides a structured approach for involving stakeholders in the decision-making process and aligning their preferences with sustainable and practical waste collection alternatives. To date, the MAMCA has not been applied in the domain of waste management, representing an opportunity to contribute to the academic literature by demonstrating its applicability. By systematically engaging stakeholders, this research aims to advance both the theory and practice of waste management, ensuring that future waste collection systems in DGZ are developed through a collaborative and inclusive process.

1.5. Methodology

This section outlines the methodology employed in this research. As identified in the literature review (section 1.4), there is a gap in the existing literature regarding methods that effectively bring stakeholders together in the field of waste management. To address this, the Multi-Actor Multi-Criteria Analysis (MAMCA) is applied in this study to compare waste collection alternatives and involve various stakeholders in the decision-making process to determine the most suitable system.

The central method used in this research is the MAMCA, which will be explained in detail in subsection 1.5.1. Figure 1.2 illustrates the phases of the MAMCA, which also form the basis for this research.

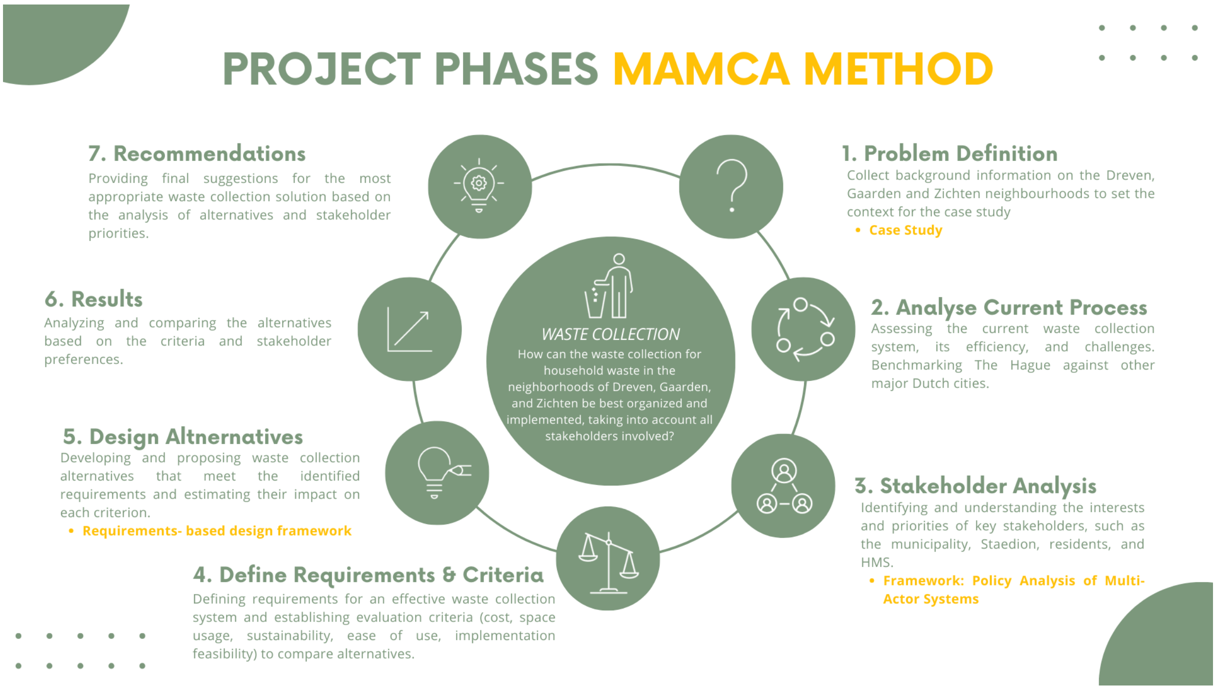


Figure 1.2: Project Phases

The MAMCA consists of several steps, and different methods are applied for specific steps within the MAMCA framework. Figure 1.3 provides an overview of the methods used in this research. The primary focus is on the MAMCA, with two additional frameworks developed for the stakeholder analysis and the design of the various waste collection alternatives.

Additionally, this research includes a case study to examine whether the MAMCA can be successfully applied in the waste management domain, focusing on the case of Dreven, Gaarden, and Zichten.

Finally, the 'tools' outlined in Figure 1.3 represent various resources employed during the execution of the different project phases.

1.5.1. Multi-Actor Multi-Criteria Analysis

MAMCA (Multi-Actor Multi-Criteria Analysis) is a decision-making framework that allows for the integration of multiple stakeholder viewpoints when evaluating policy or system designs [Macharis et al., 2010a]. It was selected for this study because the existing literature emphasizes the critical role of stakeholder collaboration in waste management systems. Effective waste collection requires alignment between municipal authorities, waste management companies, housing corporations, and residents. By applying MAMCA, this study ensures that stakeholder

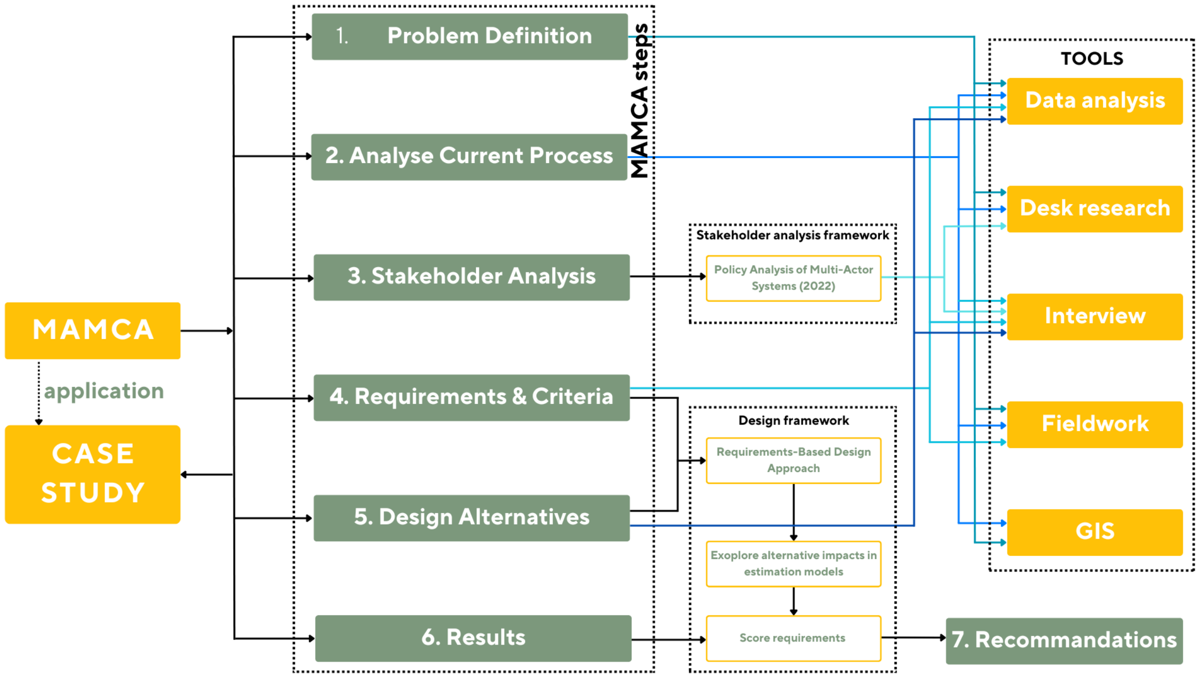


Figure 1.3: Overarching Research Approach

interests are systematically incorporated into the waste collection design for Dreven, Gaarden, and Zichten.

A traditional Multi-Criteria Decision Analysis (MCDA) could have been used to compare different waste collection techniques based on various criteria. However, this study opts for MAMCA because the literature review highlights that stakeholder collaboration is essential for a successful waste collection system. Unlike conventional MCDA, which primarily focuses on criteria evaluation, MAMCA explicitly integrates stakeholder perspectives throughout the decision-making process, ensuring a more inclusive and participatory approach [Macharis et al., 2010b].

Another alternative could have been a Cost-Benefit Analysis (CBA), which focuses primarily on financial aspects. However, relying solely on a cost-driven approach would overlook other critical factors [Macharis et al., 2010b]. The research area is highly densely populated, making space usage a crucial consideration. Additionally, the European Union has set ambitious sustainability targets to enhance waste reuse and circular economy initiatives. Therefore, it is important to include environmental and spatial efficiency criteria alongside economic factors.

By using MAMCA, this study ensures that all key stakeholders are actively involved in evaluating trade-offs between cost, space efficiency, sustainability, ease of use, and feasibility. This approach provides a balanced and structured decision-making framework, making it well-suited for complex, multi-stakeholder urban waste management challenges.

As outlined in Table 1.7, the research questions and corresponding project phases are listed, along with the tools used for each sub-question. These tools are based on approaches from prior studies discussed in the Literature Review (section 1.4).

1.5.2. Case Study: Dreven, Gaarden and Zichten

As outlined earlier, the primary research method used in this study is MAMCA (Multi-Actor Multi-Criteria Analysis). The objective is to assess whether MAMCA can improve waste management decision making for the Dreven, Gaarden, and Zichten neighborhoods, particularly in improving stakeholder collaboration. Given that MAMCA has not previously been applied to

Table 1.7: Research Questions, Project Phase, and Tools

Research Question	Project Phase	Methods
1. What is the current waste collection process, and what policies govern it?	Problem Definition, Analyze Current Process	Data Analysis, Desk Research, Fieldwork, GIS
2. Who are the key stakeholders in the decision-making process for the waste collection alternatives, and what are their objectives and criteria?	Stakeholder Analysis, Define Criteria & Requirements	Desk Research, Interview
3. What are the requirements and criteria for the future waste collection system?	Define Criteria & Requirements	Fieldwork, Interview, Data Analysis
4. Which innovative waste collection methods can be implemented?	Design Alternatives	Desk Research, Interview
5. How do proposed designs score on the identified criteria, and which design is most suitable for implementation?	Results, Recommendations	Data Analysis, Interview

the domain of waste management, this research serves as a case study to explore its potential effectiveness in this context. The selection of a waste collection alternative in these neighborhoods is the focal point to evaluate the applicability and success of MAMCA in such decision-making processes.

A case study in qualitative research is defined as an in-depth analysis of a phenomenon within its real-world context, aimed at understanding complex issues through detailed exploration [Hecker and Kalpokas, nd]. Unlike quantitative methods, which emphasize breadth, case studies favor depth and offer nuanced insights that may not emerge through other methods. This approach often relies on multiple sources of evidence, such as interviews, documents, and observations, to build a holistic understanding of the topic.

The Dreven, Gaarden, and Zichten research represents an exploratory case study, aimed at investigating a novel application of MAMCA in waste management [Hecker and Kalpokas, nd]. Exploratory case studies are particularly suited for examining phenomena that have not been extensively studied, allowing researchers to develop frameworks or theories for future research.

1.5.3. Stakeholder Analysis Framework

To conduct the stakeholder analysis, the methodology described in the book *Policy Analysis of Multi-Actor Systems* [Enserink et al., 2022] is applied. Several analytical tools were used as part of this process.

First, a formal chart is created to map the contractual relationships and obligations among all stakeholders. In addition, an overview of the goals of each stakeholder is developed to identify potential conflicts or contradictions. Lastly, a Power-Interest diagram is constructed to determine the most relevant stakeholders to include in the evaluation of criteria for the MAMCA.

1.5.4. Requirements-Based Design Approach

To design the waste collection alternatives, a comprehensive list of requirements is established. A distinction was made between constraints and objectives, as well as between functional and non-functional constraints and objectives [AltexSoft Software R&D Engineering, 2023]. Constraints represent mandatory requirements for the alternatives, while objectives reflect the goals of the alternatives. These requirements formed the foundation for designing the alternatives to ensure a fit within the established framework.

For example, the capacity of the waste collection system was defined as a constraint. This capacity was calculated, and all waste collection alternatives were required to meet this criterion. Additionally, the requirements and input from stakeholder interviews were used to define the criteria for evaluating and comparing the alternatives.

Once the requirements were determined, the designs for the collection alternatives were created. An estimation model in Excel was then developed to assess the impact of each alternative. Due to incomplete cost data and other key figures, a flexible Excel model was chosen, allowing parameters and assumptions to be easily adjusted. This ensured that the impact of these changes could be recalculated automatically.

The impact model was subsequently used to score the alternatives, enabling an assessment of how well each alternative performed against the criteria. Additionally, each alternative was evaluated to determine its compliance with the predefined requirements.

1.5.5. Tools

This section explains the tools utilized during each phase of the research. Tools refer to the resources and methods used to gather and analyze data throughout the study.

Desk Research

Desk research involved conducting secondary source research, mainly reviewing policy documents. Relevant documents, such as the Resource Plan (Grondstoffenplan Den Haag) and the Waste Attack Plan (Aanvalsplan Afval) [Gemeente Den Haag, 2021a, Gemeente Den Haag, 2023], were examined to gain valuable insights for stakeholder identification. These documents were supplemented with information retrieved from stakeholders' websites. The identification of various waste streams was based on the mentioned municipal policy plans, further supported by the scientific literature on household waste streams in urban areas. Furthermore, the literature reviewed in section 1.4 was used to identify innovative technologies for waste management and collection.

Fieldwork

The fieldwork involved visiting the research area to observe and gather first-hand insights. The case study focused on the neighborhoods of Dreven, Gaarden, and Zichten. These areas were visited multiple times to observe current waste collection processes. Visits also included Staedion offices in the neighborhood to discuss and review ongoing construction and demolition plans.

Additionally, fieldwork included accompanying a community coordinator to observe issues related to illegal waste dumping on the streets or inside Staedion-owned buildings. Participation in community meetings was also an integral part of the fieldwork. These meetings included one that focused on the development plans for Dreven and Gaarden and another for Zichten. These activities provided a deeper understanding of the current state of the neighborhood, its future development plans, and the concerns and opinions of residents regarding these plans.

Interview

The interviews were selected as a qualitative research method tool to uncover the complexities of decision-making within the waste management sector [Hecker and Kalpokas, nd]. This method is particularly relevant for this study as it provides in-depth insights into sector-specific dynamics and strategies, which are essential for gaining a detailed understanding of waste management in the Netherlands. The interviews served three main objectives. First, the aim was to gather background information on waste management and establish connections to facilitate further research. Second, in-depth interviews were conducted with relevant actors involved in the specific case study of Dreven, Gaarden, and Zichten. Finally, standardized interviews were employed to gather stakeholder preferences regarding criteria necessary for the results of the

MAMCA.

For the first objective, gathering background information and establishing relevant connections, online interviews were primarily conducted through platforms such as Microsoft Teams. This approach was chosen for its efficiency and ability to reach participants in different geographical locations. Online interviews are not only cost-effective, but also offer flexibility for researchers and participants [Hecker and Kalpokas, nd]. This made it possible to engage with key stakeholders, such as the Royal Dutch Association for Waste Management (NVRD). As a central authority in waste collection and sanitation, the NVRD provided valuable insights and advice, as well as access to relevant waste management conferences. These conferences created opportunities to network with other municipalities and gain insights into their waste collection strategies.

An interview with the Municipality of Tilburg, recommended by the NVRD, served as a unique case study due to their implementation of indoor waste collection systems in high-rise buildings. This interview provided critical insight into the challenges and successes of this approach. In addition, innovative companies such as Sidcon, a producer of underground compression containers, contributed technical perspectives on modern waste collection solutions.

Although these interviews were primarily conducted online due to geographical constraints, attendance at waste management conferences provided an additional opportunity to establish face-to-face connections with other municipalities and companies. These in-person interactions enriched the research by providing valuable information for further analysis.

For interviews with relevant stakeholders, semi-structured face-to-face interviews were chosen as the preferred method. This decision was made because traveling to The Hague, the location of the case study area, was geographically feasible. Face-to-face interviews are often regarded as the traditional form of qualitative interviewing, offering the advantage of direct interaction between the interviewer and the interviewee. This approach allows for comprehensive communication, including verbal and non-verbal cues such as body language, facial expressions, and tone of voice [Hecker and Kalpokas, nd]. These elements help foster rapport and trust between the interviewer and the interviewee, which can lead to richer and more nuanced data.

The semi-structured format provided a balance between flexibility and structure. Although the interviews were guided by a predetermined list of questions, the interviewer could ask additional open-ended questions or explore new topics that emerged during the conversation. This approach ensured that all essential topics were covered while allowing deeper insight into the unique perspectives of each stakeholder.

The primary goal of these interviews was to understand the goals, preferences, and priorities of all stakeholders involved in the waste collection system of Dreven, Gaarden, and Zichten. Furthermore, the interviews aimed to explore how stakeholders collaborated and communicated with each other, identify key issues within the system, and collect all information relevant to the case study. Using this method, the research was able to capture the complexity and depth of stakeholder dynamics in the context of waste management.

To determine the weights of the criteria for the MAMCA, structured interviews with all stakeholders were conducted. This approach, sometimes referred to as standardized interviews, involved asking the same set of predetermined questions in the same order to ensure consistency among participants [Hecker and Kalpokas, nd]. Structured interviews were particularly well suited for this purpose, as they helped keep responses focused on the research topic and allowed for direct comparison of responses between stakeholders.

In these interviews, stakeholders conducted pairwise comparisons of criteria using the Analytic Hierarchy Process (AHP) [VUB, 2024]. This systematic and quantitative method provided a structured way to capture stakeholder priorities, ensuring that their preferences were accurately reflected in the MAMCA analysis. The structured format used in the questionnaire can be found in Appendix C. How the questionnaires were processed and the criteria weights were calculated can be found in Weighting Criteria (item 3.1.2).

Data Analysis

The data analysis involved examining existing data to understand the current waste collection system in The Hague. Comparable cities were analyzed in terms of waste separation performance and the associated costs for residents, such as waste collection fees (afvalstoffenheffing). This analysis provided insights into how The Hague's system performs relative to similar municipalities.

An estimation of the future waste volume in the redesigned neighborhood was also conducted based on the available data. During the design phase, costs associated with various waste collection methods were estimated. Some of this data was obtained through stakeholder interviews. Additionally, a comprehensive analysis was performed to evaluate and compare the proposed designs against the established criteria. This approach ensured a thorough understanding of the current system and informed potential improvements.

Geographical Information System (GIS)

GIS was used to process and analyze additional data relevant to the research. It was employed to map the locations of the current underground containers in the neighborhood, providing a clear overview of the existing waste collection infrastructure. Additionally, GIS was utilized to incorporate background information about the case study, including the locations of housing corporation properties within the research area and demographic data such as population density. This comprehensive analysis contributed to a deeper understanding of the geographical and social context of the neighborhood.

2

Case Study Background

2.1. Problem Definition

As described in section 1.2, the neighborhoods of Dreven, Gaarden, and Zichten are undergoing redevelopment led by developer Heijmans, housing corporation Staedion, and the municipality of The Hague. The municipality aims to ensure that, in the future, waste collection for all new buildings will take place indoors. The municipality indicated in the interview that this shift is caused by the increasing density of The Hague (Figure 2.2), where more people live on limited land, leaving insufficient space for outdoor waste collection in public spaces. Nevertheless, significant doubts exist among stakeholders about the feasibility and practicality of indoor waste collection (section 2.3). These concerns stem from challenges related to implementation, costs, and the varying priorities of different actors.

Currently, waste collection is managed through underground waste containers, as detailed in section 2.2. Staedion has not yet determined how waste collection should be organized within their buildings. Figure 2.1 highlights Staedion-owned buildings, shown in pink, which is the main focus of the design of the waste collection system. Other active housing corporations in the area include Haag Wonen, Stichting DUWO, and Hof Wonen, as well as a few buildings that are not owned by housing corporations.

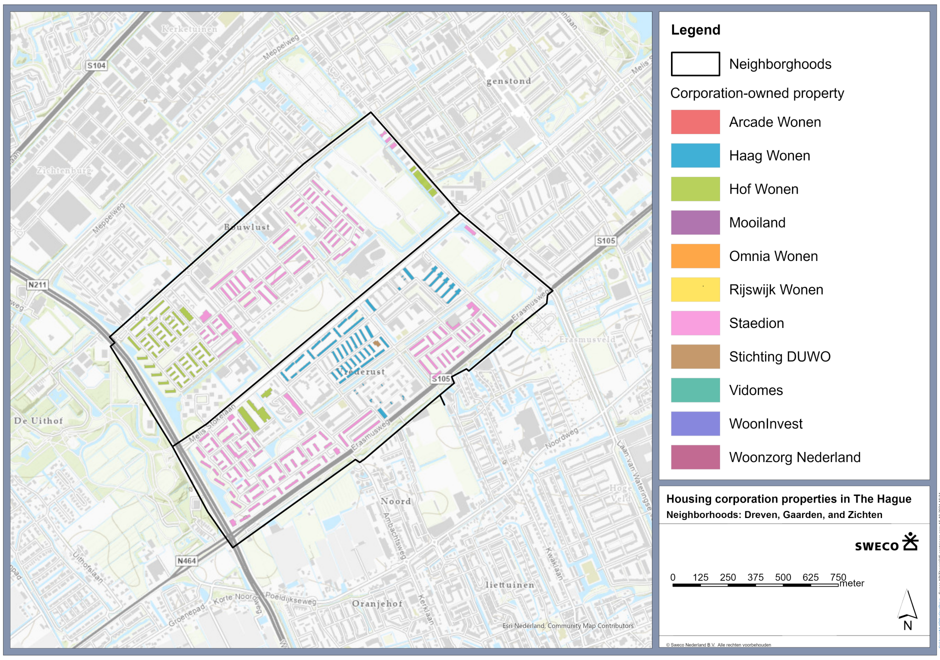


Figure 2.1: Housing Corporations

2.1.1. Staedion's Design Inquiry

There is a clear demand from Staedion for advice on how this system can best be designed. Additionally, the project holds significant societal relevance: improving waste collection in The Hague, as outlined in section 1.3, can reduce litter and enhance waste separation efforts. Furthermore, the MAMCA has not yet been applied in academic studies to a waste management system, despite the importance of stakeholder collaboration, as highlighted in the Literature Review in section 1.4, for a well-functioning waste management system.

2.1.2. Spatial and Demographic Overview of Dreven, Gaarden, and Zichten

For the spatial and demographic overview of the neighborhood, open-source data has been analyzed using ArcGIS Pro. Figure 2.2 illustrates the population density across the Netherlands. According to the municipality, The Hague faces the largest densification challenge in the country compared to other major cities. This is evident from the high number of residents per square kilometer [CBS, 2023]. Such significant urban densification increases pressure on public space, making efficient use of available space essential. Consequently, the municipality aims to implement an indoor waste collection system.

As shown in Figure 2.3, the population density within The Hague reveals that the neighborhoods in the research area are also densely populated. Dreven and Gaarden fall into the highest density category (red), while Zichten, Steden, and Zijden are in the second-highest category, with approximately 8,000 residents per square kilometer (orange) [CBS, 2016].

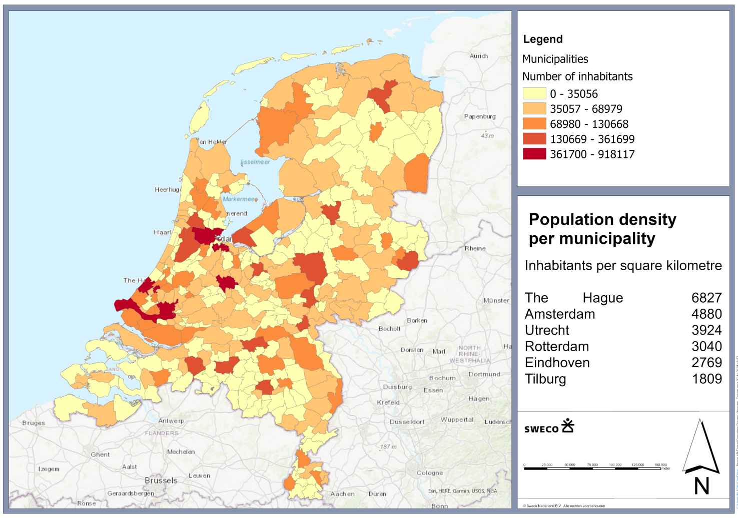


Figure 2.2: Population Density Netherlands

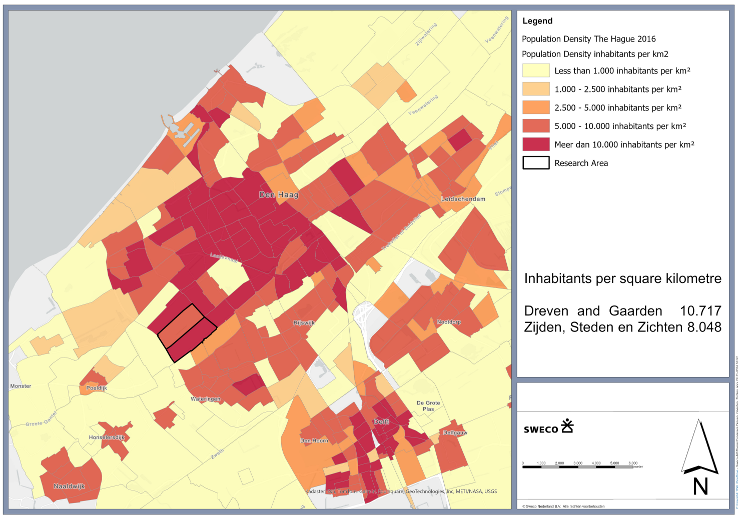
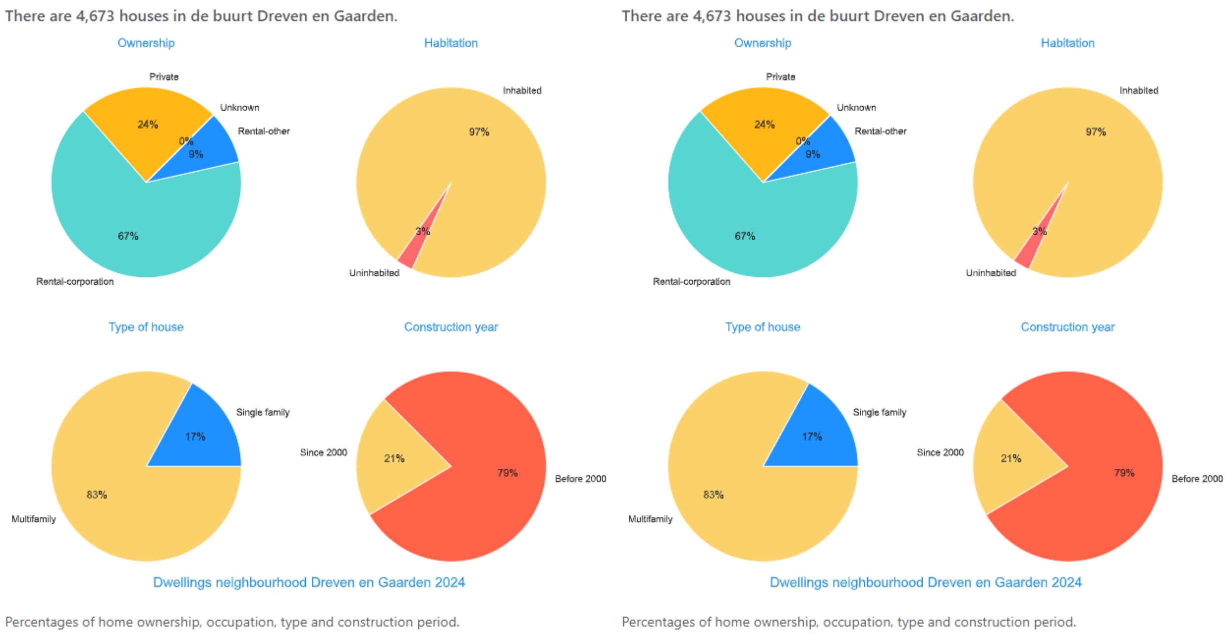


Figure 2.3: Population Density The Hague

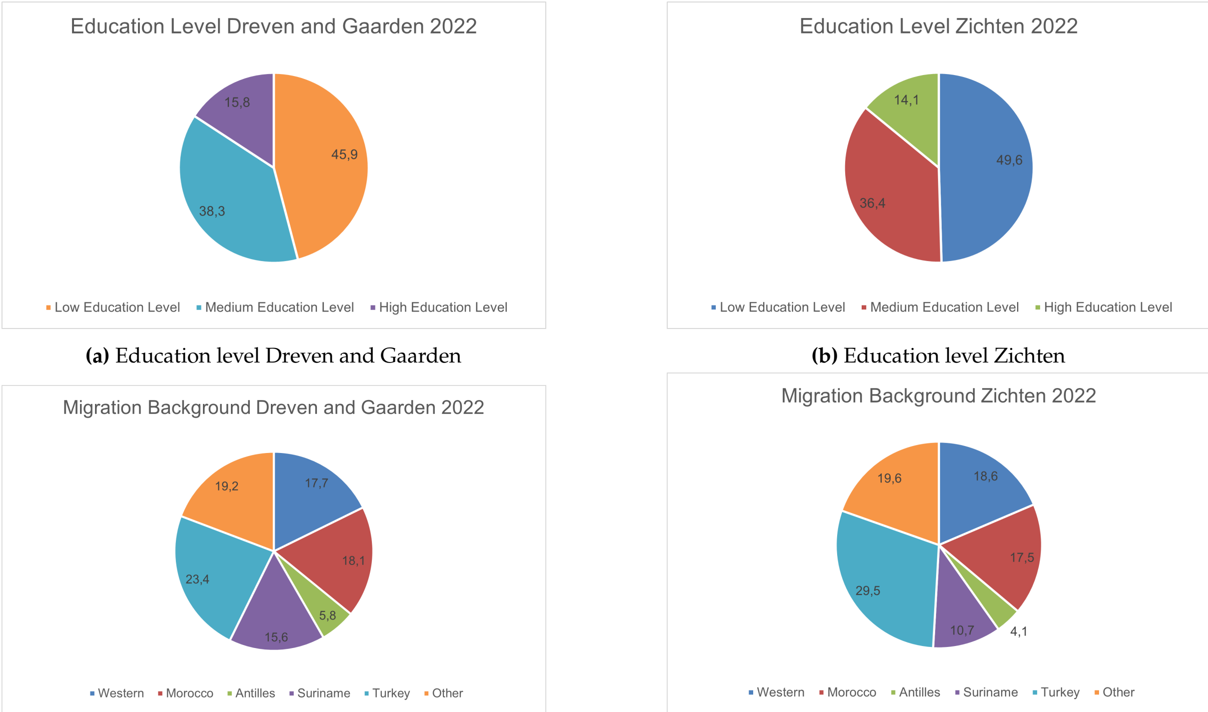
In Figure 2.4, data on the current situation in the neighborhoods is presented. Notably, the majority of homes in both neighborhoods are social housing units owned by a housing corporation. Most are multi-family households, reflecting the densely populated nature of the area. Additionally, the majority of homes were built before 2000 and are in a significantly outdated condition, which is one of the key reasons for the large-scale demolition and subsequent new construction planned for the neighborhoods [Gemeente Den Haag, nd].

In Figure 2.5, demographic data for the neighborhoods of Dreven, Gaarden, and Zichten is presented [AlleCijfers.nl, a, AlleCijfers.nl, b]. A minority of residents in both neighborhoods have a high level of education, and there is a diverse range of migration backgrounds. This provides a clearer picture of the neighborhoods and serves as background information for the case study.



(a) House characteristics Dreven and Gaarden **(b)** House characteristics Dreven and Gaarden

Figure 2.4: House characteristics



(a) Education level Dreven and Gaarden

(b) Education level Zichten

(c) Migration background Dreven and Gaarden

(d) Migration background Zichten

Figure 2.5: Demographics Dreven and Gaarden

2.2. Analyze Current Process

In step 2 of the project phases, the current state of the waste collection system in the case study neighborhoods of Dreven, Gaarden, and Zichten was analyzed, along with the overarching waste management policies of the Municipality of The Hague. The tools utilized for this step included desk research, data analysis, GIS, and fieldwork.

First, desk research was conducted, primarily focusing on two key policy documents from the Municipality of The Hague: the 2024 Resource Plan and the Waste Management Plan. Based on the foundational knowledge obtained from these policy documents, fieldwork was carried out to examine the specific waste collection instruments used in each neighborhood.

Additionally, various waste streams and associated costs were analyzed through data analysis and compared with those of other cities similar to The Hague to assess how the current system functions within the municipality.
This section answers the following research question:
What is the current waste collection process, and what policies govern it?

2.2.1. Current waste collection in Dreven, Gaarden, and Zichten

In general, the following waste collection methods are applied in The Hague [Gemeente Den Haag, 2023]:

- Underground residual waste containers (ORACs): ORACs are used for collecting household residual waste in many neighborhoods. There are approximately 7,000 ORACs for residual waste in The Hague. Residents can deposit their waste bags here.
- Door-to-door collection on a fixed day with mini-containers, roll containers, or bags: In some neighborhoods where there are no ORACs, household residual waste can also be placed on the street on a fixed day in roll containers or bags, which are then collected. The neighborhoods where bags are collected will be replaced with ORACs.
- Separated collection for specific waste streams: Separate containers are available for the collection of paper, glass, textiles, and Plastic, Metal packaging, and Drink cartons (PMD). In almost every neighborhood, there is at least one waste sorting street.
- Bulky waste collection by appointment: Bulky waste can be collected for free by appointment or taken to a waste disposal station.

In the neighborhoods of Dreven, Gaarden, and Zichten, the current underground waste containers can be seen in Figure 2.6. It is notable that there is a high concentration of residual waste containers, while only a few containers are designated for separated waste streams.

During the fieldwork, ORACs (Underground Refuse Containers) were predominantly observed, particularly those designated for residual waste. In Figure 2.7, the ORACs are shown in detail. Figure 2.7a highlights the ORACs specifically for residual waste, which are by far the most common type in the area. In a few locations, ORACs for separated waste streams were found, as illustrated in Figure 2.7b. In Figure 2.7c, the locations of the ORACs are displayed. This is a screenshot from the "MyCleanCity" app, where residents can view the placement of ORACs and report any issues, such as malfunctioning containers or illegal dumping. The app, which is called MyCleanCity, has a rating of 3.7 out of 5 based on 9 reviews [myc,]. The general impression of the app is that it operates slowly and occasionally freezes. However, it is useful for distinguishing between residual waste ORACs (as seen in the image) and those for separated waste streams.

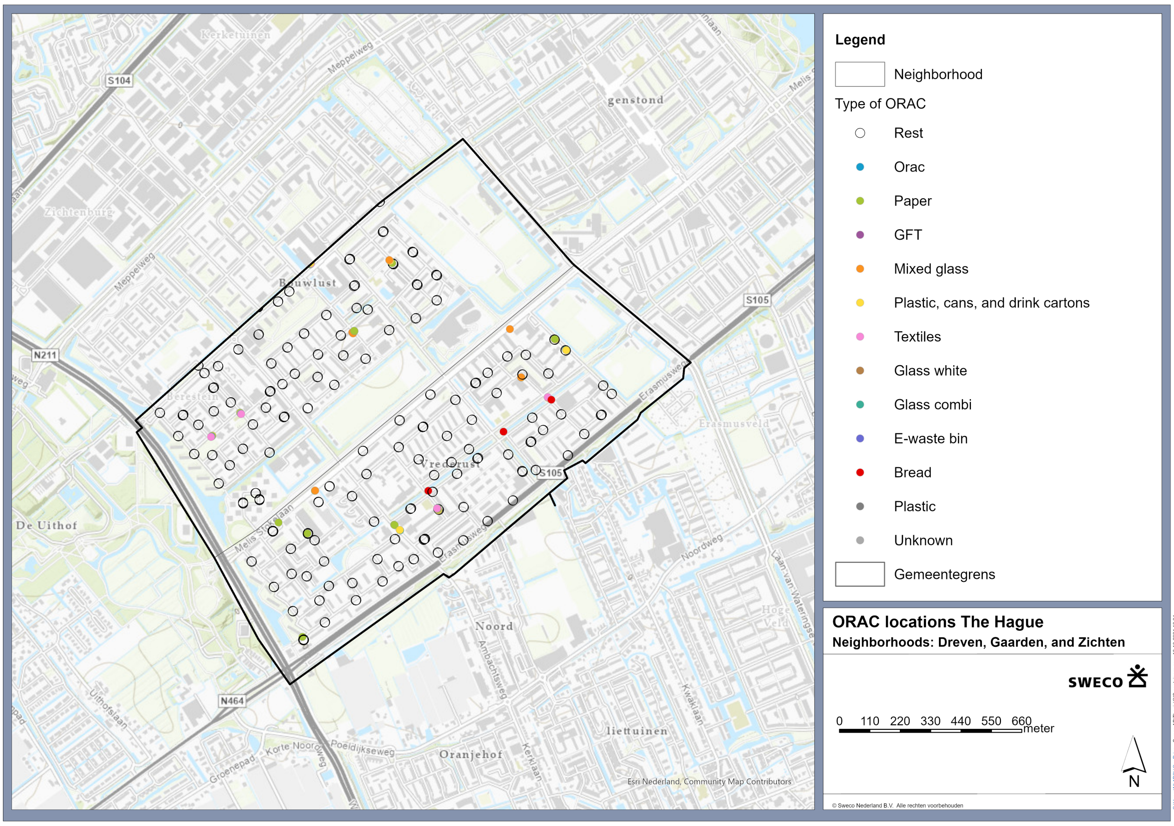


Figure 2.6: ORAC Locations in the research area

(a) ORAC residual waste **(b)** Sorting station ORACs **(c)** Location ORACs

Figure 2.7: Fieldwork for Waste Collection

Current issues regarding the waste collection

The waste collection policy in The Hague faces several significant challenges, as identified in the Waste Action Plan and the Resource Plan [Gemeente Den Haag, 2021a, Gemeente Den Haag, 2023]. A major issue is illegal dumping, where residents leave waste next to containers, creating an eyesore and attracting pests, such as rats and seagulls, which can spread disease and contribute to littering. The increase in single-use packaging has exacerbated littering, with waste often discarded in inappropriate locations, such as streets and parks. Additionally, the transition to a circular economy presents hurdles in terms of efficient waste collection and high-quality recycling. The city also grapples with the need for better communication and education to raise awareness of waste regulations among residents and businesses. Stricter enforcement of waste rules is necessary to ensure compliance and reduce nuisance. Overall, while The Hague is working towards enhancing waste management and reducing issues related to illegal dumping and pests, significant steps remain to fully address these challenges and facilitate a shift towards viewing waste as a valuable resource.

The findings from the fieldwork align with the waste management challenges and nuisances observed in the area. There is a significant amount of litter on the streets, as well as illegal dumping around the ORACs, as illustrated in Figure 2.8. These observations correspond closely with the issues outlined in the policy documents, indicating that the identified problems are consistent with the documented challenges in the area.

(a) Littering **(b)** Illegal Dumping

Figure 2.8: Fieldwork for Waste Issues

2.2.2. Overarching policy of municipality of The Hague

In 2021, the municipality of The Hague developed a Resource Plan outlining its objectives and ambitions regarding waste collection [Gemeente Den Haag, 2021a]. This ambitious Resource Plan aims to facilitate the transition from waste to resources. It serves as a response to both European and national sustainability objectives and is focused on increasing reuse while recognizing waste as a valuable resource. The municipality aspires to achieve a circular economy by 2050, wherein waste no longer exists and is entirely reused, either within the city or the surrounding region. The key themes and ambitions of the Resource Plan include:

Demand-Driven Collection: The municipality seeks to collect waste in such a manner that it can be processed as high-quality raw materials. This necessitates aligning waste collection with market needs. An example of this is the "Spullebak" initiative, a new collection method that allows for the scheduled home collection of resources, where residents can receive compensation for their waste.

Economic Value: The municipality aims to preserve and enhance economic value by promoting repair, sharing, and upcycling. This involves organizing the collection and processing of products and materials in a way that maintains or even increases their value.

Local Solutions Where Possible: There is a preference for collaboration within The Hague or the surrounding region to close resource loops as locally as possible. This entails involving local initiatives and entrepreneurs in the reuse of resources.

The Resource Plan focuses on eight specific resource streams: organic waste, PMD (plastic packaging, metal cans, drink cartons), bulky waste, textiles, electronic devices, paper and cardboard, commercial waste, and construction and demolition materials. Specific actions and measures have been planned for each of these streams to promote reuse and recycling.

Regarding source and post-separation, the municipality advocates for both methods. Source separation refers to residents and businesses separating their waste prior to collection, while post-separation involves sorting waste after collection at a processing facility. The municipality is exploring innovative solutions for post-separation and encourages source separation through communication campaigns and the provision of appropriate collection tools.

Furthermore, the Resource Plan emphasizes the need for supplementary actions, such as amending legislation to support circular ambitions and improving communication to engage residents and businesses in the resource transition.

In summary, the municipality of The Hague, through its Resource Plan, is committed to a future where waste is entirely transformed into resources, with a strong emphasis on demand-driven collection, preservation of economic value, and local processing, supported by appropriate legislation and communication strategies.

2.2.3. Data Analysis Current Process

To provide a comprehensive overview of the current process, a data analysis was conducted comparing The Hague with other major cities in the Netherlands. The analysis used CBS data [Centraal Bureau voor de Statistiek (CBS), 2024] to evaluate the effectiveness of The Hague's waste management system compared to similar cities. The analysis examined the total waste generated per person in each city, the separated waste streams, and the fees that municipalities charge their residents. This provided information on the budget required by each municipality for the management of household waste.

Total waste stream: All municipalities and national policies aim to reduce waste according to the waste hierarchy, where reduction is the first priority. In Figure 2.9, it can be observed that more kilograms of waste per capita were produced in 2001 than in 2023, a trend consistent across all municipalities. Amsterdam frequently ranks at the bottom of the chart, indicating that its residents produce less waste on average than those in other cities. While the focus of this research is not on waste reduction, it is a useful reference. Over recent years, The Hague has performed relatively average, but it is on the higher end compared to other municipalities. A general decline in waste generation per capita over the years is also noticeable for The Hague.

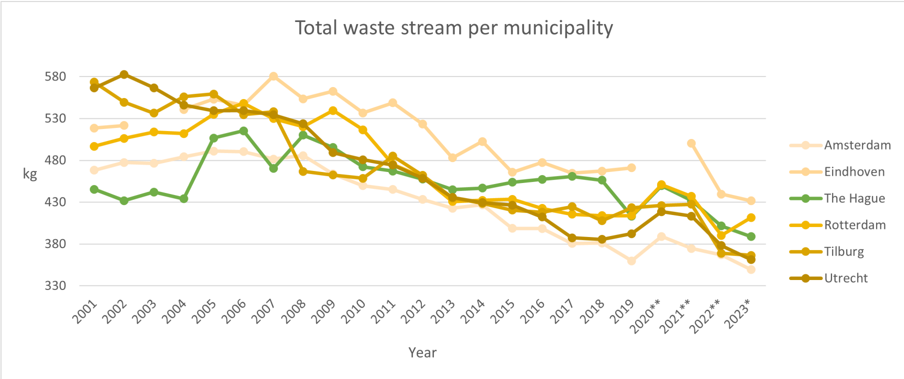


Figure 2.9: Total waste stream per municipality

Residual waste: The national goal is to reduce residual waste, partly to decrease the overall amount of household waste and partly to promote effective waste separation, leaving fewer kilograms of residual waste. In Figure 2.10, it is evident that trends vary significantly by municipality. The residual waste in The Hague (depicted in green) has remained relatively stable, with a slight increase in 2019, possibly due to the COVID-19 pandemic, which caused more people to stay home and generate waste domestically rather than at work. Tilburg stands out with the lowest kilograms of residual waste per capita and a significant decline. Utrecht also performs well, according to the graph. While Rotterdam has even more residual waste in 2023 than The Hague, its trend shows a stronger decline compared to The Hague.

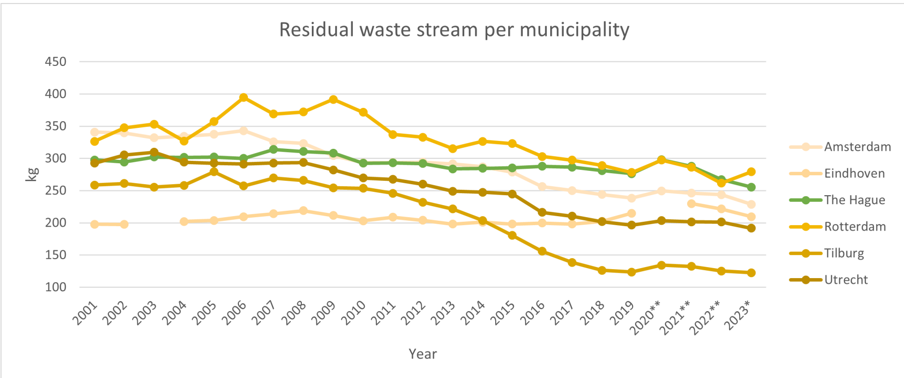


Figure 2.10: Residual waste stream per municipality

GFT (green) waste streams: Figure 2.11 shows the green (GFT) waste streams per municipality. This category is challenging to compare because municipalities with more gardens tend to have higher GFT waste volumes. However, separating food waste is also crucial. The national VANG program was launched to encourage municipalities to increase GFT collection, including organizing a GFT conference to share strategies for motivating residents to separate GFT waste. Since GFT waste is relatively heavy, separating it yields quicker benefits in terms of kilograms compared to lighter waste like PMD (plastic, metal, and drink cartons), which requires a higher volume to achieve similar weight reductions. Additionally, GFT is harder to separate post-collection compared to PMD, making effective source separation essential. GFT also contaminates the residual stream as it goes to incinerators, where its wet nature lowers the incineration temperature. Therefore, national goals focus on improving GFT separation. The graph shows that Tilburg has significantly increased its GFT waste collection, indicating improved separation. Eindhoven, which initially performed well, shows a decline but still outperforms other cities. Conversely, The Hague and Amsterdam lag significantly behind, with stable but low trends over the years. Rotterdam has shown improvement, supported by their presentation at the GFT conference, where they highlighted their strong policy shift towards GFT separation. They plan to implement GFT cocoons and underground GFT containers citywide, coupled with distributing 5-liter in-house containers to make separation easier for residents.

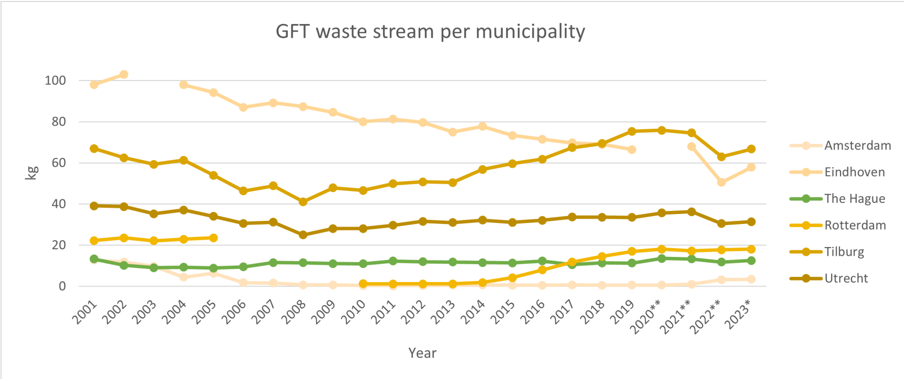


Figure 2.11: GFT (green) waste stream per municipality

Paper and cardboard waste streams: Figure 2.12 illustrates the paper and cardboard waste streams. The graph shows a slight decline overall. The Hague ranks low, indicating that less paper and cardboard are separated compared to other municipalities. Tilburg and Eindhoven perform best, achieving the highest kilograms per capita. Notably, Tilburg saw an increase from 2013 to 2017, followed by a slight decline, whereas Eindhoven has shown a consistent decline but still outperforms most other municipalities except Tilburg.

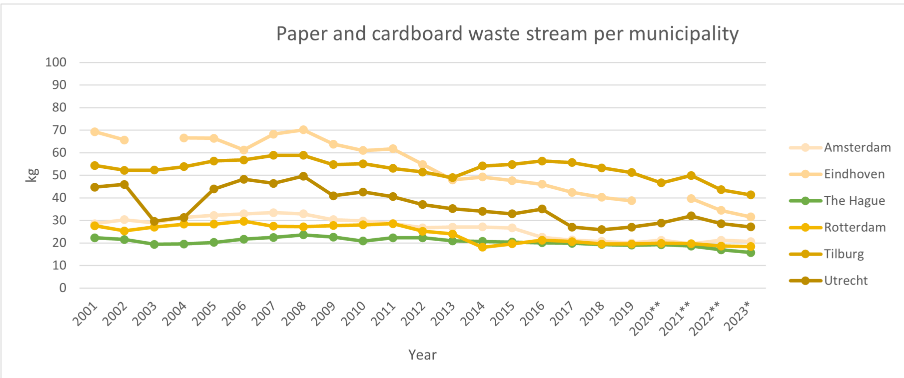


Figure 2.12: Paper and Cardboard waste stream per municipality

Glass waste streams: Figure 2.13 shows glass waste streams. Rotterdam performs the worst, with the lowest kilograms of glass per capita. The Hague performs slightly better than Rotterdam but still lags compared to Utrecht, Amsterdam, Tilburg, and Eindhoven, which lead in glass waste separation.

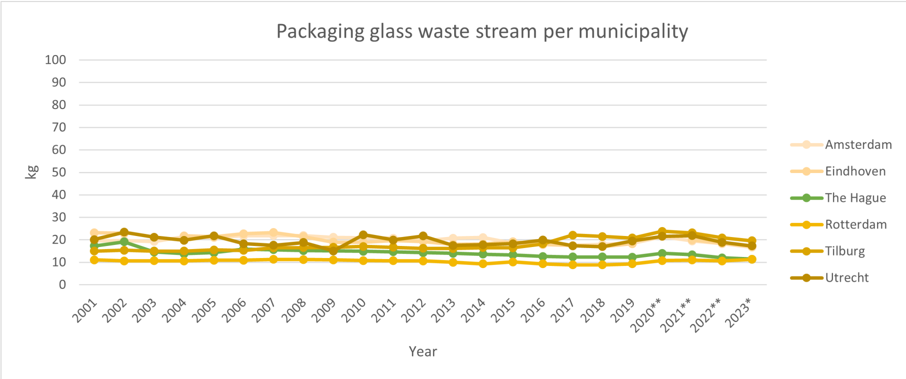


Figure 2.13: Packaging glass waste stream per municipality

All separated waste streams: All separated waste streams are shown on a scale of 0 to 100 kilograms. GFT dominates due to its relative weight and widespread use, including food scraps and garden waste. Paper and cardboard also account for a significant portion, as they are lighter materials than GFT and glass but are frequently used for packaging. Glass accounts for a smaller portion, which is surprising given its weight compared to paper. Plastic is excluded from this analysis due to data limitations, as many urban municipalities opt for post-separation, making the data less reliable and with many missing points.

Waste composition in The Hague: Figure 2.14 shows the waste composition in The Hague. The largest portion by far consists of residual waste, which is problematic as this waste is incinerated, with no reuse or recycling of materials. Bulky waste also makes up a significant portion, which is logical given its weight-based nature. To better visualize the other components, Figure 2.15 excludes residual and bulky waste, highlighting the proportions of paper and cardboard, glass, and organic (GFT) waste. GFT remains relatively low, indicating significant room for improvement in The Hague. It is noteworthy that the category other waste disappears after 2020, it was no longer tracked in CBS' data set after 2020.

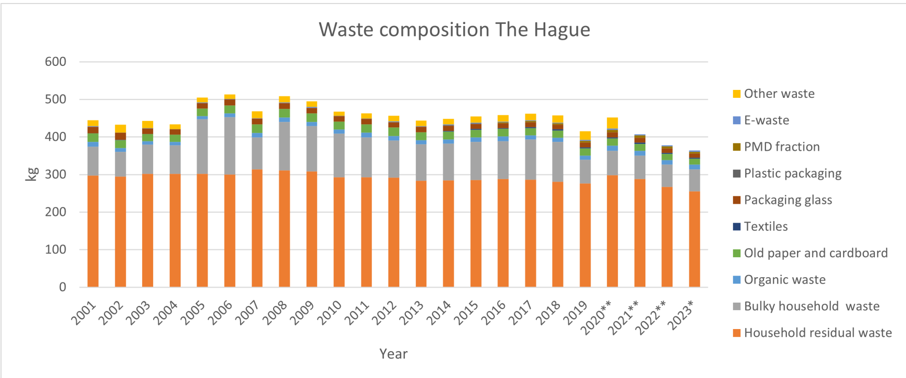


Figure 2.14: Waste composition The Hague

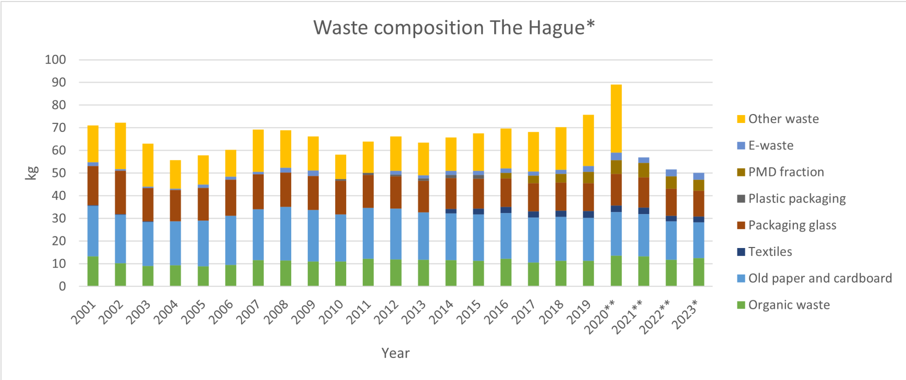


Figure 2.15: Waste composition The Hague without residual and bulky waste

Waste tax per municipality: Finally, Figure 2.16 illustrates the waste tax per municipality [Gemeente Den Haag, 2024b, Gemeente Amsterdam, 2024, Gemeente Rotterdam, 2024, Gemeente Eindhoven, 2024, Gemeente Tilburg, 2024, Gemeente Utrecht, 2024]. This tax is a fee households pay to municipalities for waste collection and processing, often based on the number of people in the household. It provides a good indicator of how much municipalities spend on waste management per household or person. The Hague consistently ranks among the highest in waste tax across all household categories. For single-person households, Amsterdam charges less than The Hague, while for two-person households, Amsterdam is slightly more expensive. However, The Hague surpasses Amsterdam again for households of three or more people. This is an interesting observation, as Amsterdam and The Hague do not perform well in waste separation compared to other municipalities. Their costs are higher, yet their results in waste separation are generally lower.

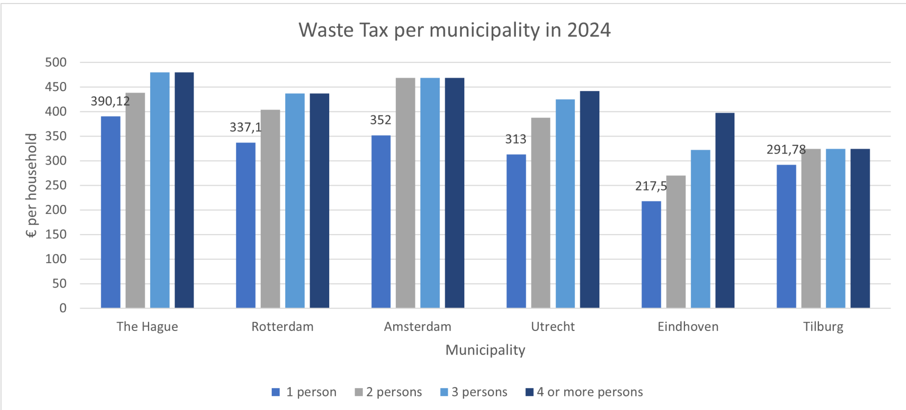


Figure 2.16: Waste Tax per municipality in 2024

This data analysis provides valuable insights into The Hague's current waste management process, highlighting key areas for improvement. Compared to other major cities, The Hague performs poorly in waste separation while charging households relatively high fees for waste processing. This indicates that The Hague has an expensive waste management system that does not necessarily yield better separation results. These findings are critical to consider when selecting an alternative waste collection method for the case study. Ideally, the chosen solution should improve waste separation while avoiding further increases in costs, given the already high expenses associated with the current system.

2.2.4. Conclusion research question 1

The current waste collection system in the neighborhoods relies primarily on underground residual waste containers (ORACs), with limited options for separated waste streams. Significant issues include illegal dumping and littering around these containers, impacting neighborhood cleanliness.

The overarching policy of the municipality of The Hague, as outlined in its Resource Plan, sets ambitious goals for improving waste separation, reducing litter, and transitioning towards a circular economy. Key strategies include demand-driven collection, enhancing economic value through reuse, and fostering local solutions for waste processing.

The data analysis highlights substantial variations in waste management performance across Dutch municipalities. While The Hague has made progress in reducing total waste generation per capita, it continues to lag in waste separation, with significant potential for improvement in organic (GFT) waste. Furthermore, The Hague has higher waste taxes compared to other cities, indicating high costs for household waste handling without achieving corresponding efficiencies in waste separation. These findings underscore the importance of aligning policy ambitions with actionable strategies to enhance waste separation and operational efficiency.

2.3. Stakeholder Analysis

In this section, the stakeholder analysis will be elaborated. First, all stakeholders will be discussed, and a power-interest grid will be created to determine which stakeholders are most relevant for the decisionmaking proces of the waste collection alternative. These stakeholders will be included in the MAMCA. This section answers research question 2:
Who are the key stakeholders in the decision-making process for the waste collection alternatives, and what are their objectives and criteria?

The stakeholder analysis is inspired by the framework provided in the book *Policy Analysis of Multi-Actor Systems*. This framework emphasizes a systematic approach to understanding the roles, interests, and relationships of all actors involved in a policy issue [Enserink et al., 2022]. To support this analysis, a formal chart has been developed to map the hierarchical and contractual relationships among stakeholders in the waste collection system for the neighborhoods of Dreven, Gaarden, and Zichten (DGZ). Additionally, an Overview Table of Actors' Problem Formulations has been created to summarize the interests, objectives, existing gaps, causes, and potential solutions for each stakeholder.

2.3.1. Identify Stakeholders

This subsection will provide an overview of all stakeholders through desk research. The websites and relevant documents of the stakeholders are consulted to gather information.

The Municipality of The Hague

The municipality is responsible for the collection of household waste, as outlined in the Environmental Management Act (Wet milieubeheer, [Wet, 2024]). Each municipality determines how to organize this, either through door-to-door collection or centralized collection points on the street. The municipality is a key stakeholder, as it supervises the waste collection process and decides how it will be implemented. The policies and objectives of the Municipality of The Hague are further described in Overarching policy of municipality of The Hague (subsection 2.2.2).

The Municipality of The Hague is a complex stakeholder, as it is composed of multiple hierarchical departments, as shown in Figure 2.17. At the top is the Municipal Council, consisting of 45 elected members representing various political parties. Currently, Hart voor Den Haag is the largest party, with 9 seats [Gemeente Den Haag, 2021c]. The Municipal Council is the highest governing body in the municipality. It sets policies, oversees the College of Mayor and Aldermen (B&W), and makes decisions on major policies and finances. While the council has significant influence, it does not execute policies; its role is to approve plans and monitor their implementation.

Below the Municipal Council is the College of Mayor and Aldermen (B&W), which comprises 9 aldermen, each responsible for a specific portfolio such as housing, mobility, waste management, or social affairs. The college is tasked with executing the policies established by the Municipal Council and is responsible for the day-to-day administration of the city. The mayor chairs the college and typically oversees public order, safety, and representation of the city. Aldermen are elected by the Municipal Council and are responsible for specific policy areas. For instance, Alderman Arjen Kapteijns oversees energy transition, mobility, and resources, including waste management [Gemeente Den Haag, 2021b].

Beneath the College of Mayor and Aldermen is the Municipal Secretary, who serves as the chief advisor to the College and as the general director of all civil servants within the municipality. The Municipal Secretary translates the political vision into actionable plans for the municipal staff to implement.

Under the Municipal Secretary are several departments responsible for policy implementation and the delivery of municipal services. The departments most relevant to waste management in the neighborhoods of Dreven, Gaarden, and Zichten are the following:

Public Space Management Department (Dienst Stadsbeheer, DSB): This department manages public spaces, including streets, parks, waste collection, and cleaning services. Two officials from this department were interviewed, and their insights will be discussed later. Urban Development Department (Dienst Stedelijke Ontwikkeling, DSO): This department is responsible for spatial planning, housing development, and economic growth. Its tasks include project development, issuing permits, and drafting zoning plans. This department is particularly relevant because the neighborhoods are undergoing extensive renovations, involving both demolition and new construction. Within these departments, there are further subdivisions. For example, within DSB, there is a specialized division dedicated to waste management.

Given the large number of departments and hierarchical relationships, the municipality is a complex stakeholder with potentially conflicting interests. One department may prioritize different goals than another. For instance, DSO might focus on future mobility plans for the neighborhood and advocate for more parking spaces, while DSB might prioritize using the same spaces for placing roll container collection points.

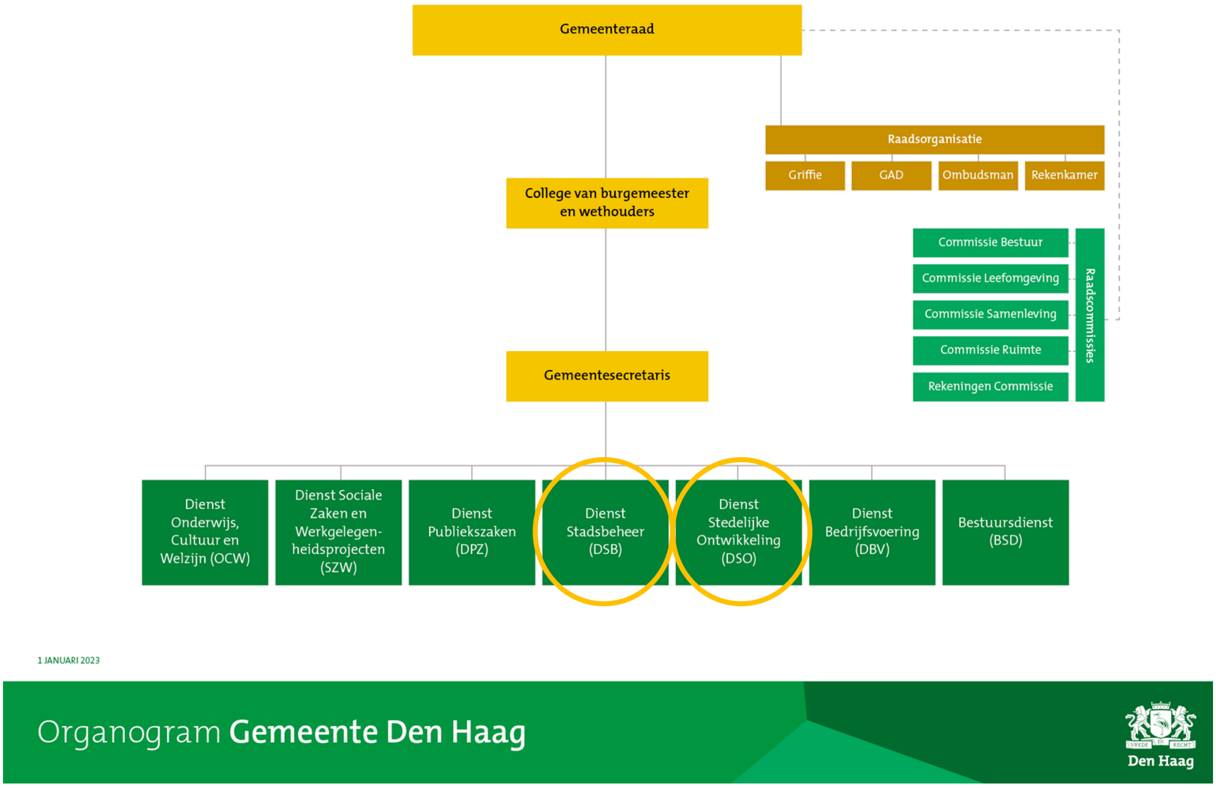


Figure 2.17: Organizational Chart of the Municipality of The Hague

Housing Corporation Staedion

Housing corporation Staedion owns the residential buildings that generate the waste. Staedion is responsible for the layout of these buildings. The municipality has decided that waste collection should be handled internally within the buildings, making Staedion accountable for organizing the most effective way to manage waste disposal within its properties. Currently, Staedion does not have a general policy for this approach, and it remains to be explored in this research. However, Staedion is actively working to reduce litter by informing residents about proper waste disposal and encouraging them to report street litter to the municipality if needed [Staedion, 2024].

Haagse Milieu Service (HMS)

Haagse Milieu Service (HMS) is responsible for collecting waste after it has been deposited, making it a key stakeholder in the waste management system. HMS operates within the municipality of The Hague and handles the collection of household waste, bulky waste, and a variety of recyclable materials, such as organic waste (GFT), paper and cardboard, glass, plastics, and hazardous waste.

HMS is fully owned by the municipality of The Hague and employs approximately 256 staff members with 87 vehicles, annually collecting over 162,000 tons of residual waste and around 48,000 tons of separated waste. The company focuses on sustainability, reducing its CO2 footprint, promoting recycling, and viewing waste as a resource. Additionally, HMS supports local communities and enhances employment opportunities for those facing challenges in the labor market [Haagse Milieu Service (HMS), 2024].

Currently, HMS is accustomed to emptying ORACs (underground containers) as the primary waste collection method, making it a crucial partner in improving waste management in the Dreven, Gaarden, and Zichten neighborhoods.

Heijmans

Heijmans, a project development company, is responsible for construction projects. In collaboration with Staedion and the municipality of The Hague, Heijmans is renovating the Dreven, Gaarden, and Zichten neighborhoods. Heijmans must consider waste collection in its architectural designs, especially when internal waste collection systems are required, as this will impact the design of the buildings [Heijmans, 2022].

Residents

The residents are crucial stakeholders, as they generate the household waste. They are responsible for discarding the waste, and the manner in which they do so is pivotal. Compliance with waste disposal policies and the motivation to separate waste are critical factors influencing the success of the system.

Other Housing Cooperatives

In addition to Staedion, other housing cooperatives such as DUWO, Hof Wonen, and Haag Wonen own properties in the neighborhoods of Dreven, Gaarden, and Zichten, as shown in Figure 2.1. Haag Wonen, like Staedion, actively combats littering by informing residents about proper waste disposal practices [Haag Wonen, 2024]. Similarly, Hof Wonen works to keep the area clean by removing litter or bulky waste and educating residents on maintaining cleanliness within the community [Hof Wonen, 2024].

AVR Post-Separation Center

AVR is a post-sorting facility located in The Hague and plays a crucial role in waste processing for the municipality. The method of waste collection significantly impacts AVR's operations, as better separation at the source affects the composition and volume of waste streams processed by the facility. AVR holds a contract with the municipality of The Hague to handle and transport approximately 153,000 tons of residual waste annually. This waste is compressed and transported via AVR's transfer station at Binckhorst to their main facility in Rozenburg. However, due to a recent fire at their Rozenburg location, AVR currently faces reduced capacity, impacting its ability to process waste at full scale, and is implementing temporary storage and alternative processing solutions [AVR, 2024].

Hart voor Den Haag

Hart voor Den Haag is the biggest local political party that prioritizes cleanliness and effective waste management in The Hague. They advocate for a zero-tolerance approach to littering, emphasizing strict enforcement and significant fines for repeat offenders, aiming to make The Hague the "Singapore of Europe." Their recent initiative includes a ten-point plan to combat persistent waste issues through increased fines, waste police, and reward systems for residents who actively help keep neighborhoods clean [Hart voor Den Haag, 2024, Hart voor Den Haag, 2023]. The party views this approach as essential to restoring and preserving a livable environment for all residents. Although Hart voor Den Haag has no operational role in the waste system, their policies and proposals could influence public perception and municipal waste management practices.

NVRD

The NVRD (Royal Dutch Association for Waste Services) is committed to a sustainable future where waste no longer exists, aiming for a fully circular economy by 2050. As a national association, the NVRD connects over 350 Dutch municipalities and public waste services, focusing on waste collection, sorting, and processing, as well as promoting waste prevention, repair, and high-quality reuse. NRVD also support the development of green public spaces that enhance biodiversity and climate adaptation. The NVRD serves as a vital link in the resource chain, driving the shift toward circularity through knowledge sharing and practical support.

The NVRD is a valuable stakeholder within the waste management sector, which led to an interview (section B.1) for this research. With its extensive network and expertise, the NVRD facilitates connections with other relevant stakeholders and provides useful background information. While the NVRD itself has no direct stake in the research area, their insights and network contribute meaningfully to the project's foundational knowledge and stakeholder engagement efforts.

2.3.2. Formal Chart

The formal chart presented in Figure 2.18 is inspired by the framework provided in *Policy Analysis of Multi-Actor Systems*. This chart visually maps the formal relationships and responsibilities of key stakeholders involved in the waste collection system for the neighborhoods of Dreven, Gaarden, and Zichten (DGZ). By depicting hierarchical and contractual relationships, it highlights the formal structure in which actors interact.

The chart illustrates that the Municipality of The Hague plays a central role, guided by the Environmental Management Act and supported by its departments, DSB (Public Space Management) and DSO (Urban Development). These departments are key in coordinating with stakeholders such as HMS, Staedion, and Heijmans. HMS, under a contractual agreement, collects and transports household waste to AVR for processing. Housing corporations like Staedion collaborate with Heijmans on redevelopment projects while managing waste responsibilities within their properties. This formal chart provides a structured understanding of the institutional landscape, laying the foundation for analyzing informal relations and identifying potential compromises among stakeholders.

2.3.3. Interests of Stakeholders

In Table 2.1, the interests of the stakeholders are presented in a single overview. Only stakeholders who are actively involved in the process from waste disposal to the moment the collection truck leaves the street have been included. This defines the scope of the study, so not all stakeholders mentioned previously are listed in the table. However, for contextual understanding, it is important to be aware of these other stakeholders, as the implementation of a specific waste collection alternative may still impact their operations and work processes. This table is based on the theory of Policy Analysis of Multi-Actor Systems, which emphasizes the importance of systematically comparing the problem formulations of all stakeholders involved in a policy issue.

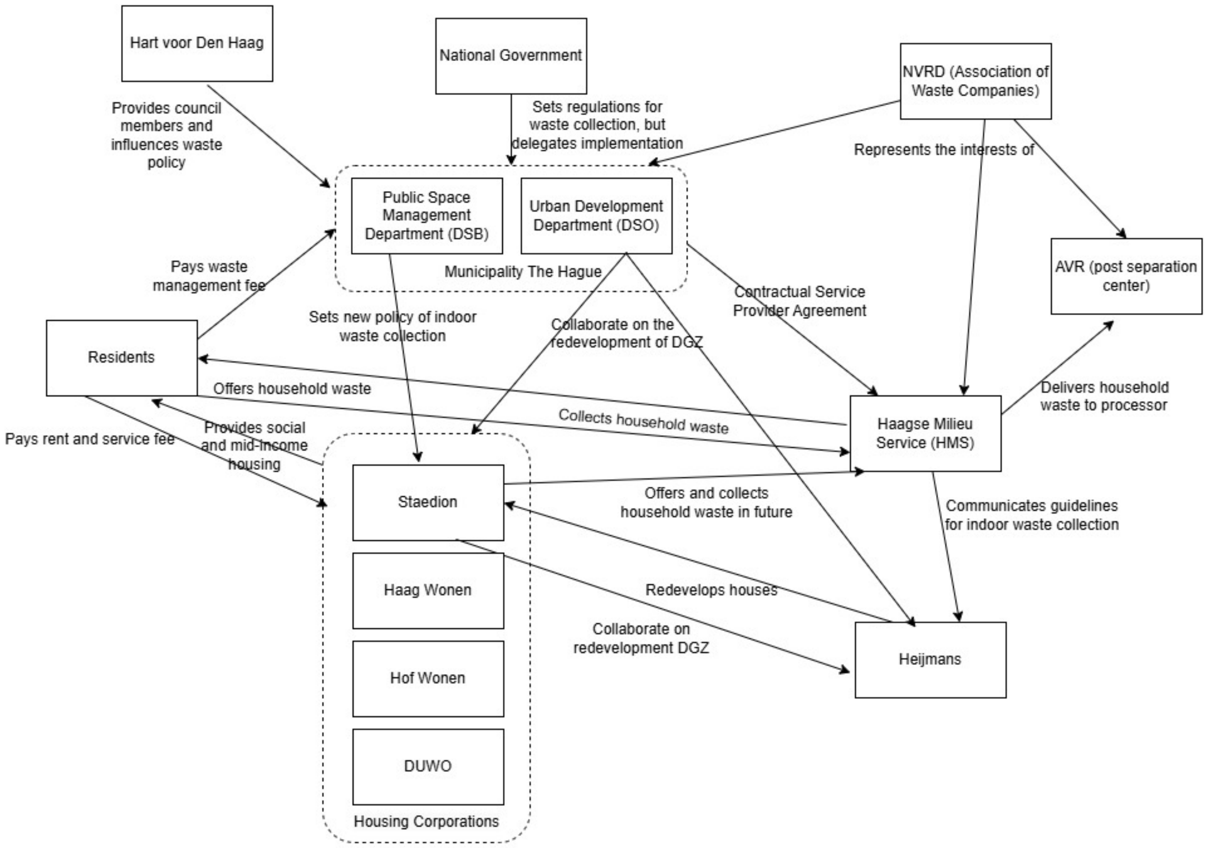


Figure 2.18: Formal Chart Stakeholders

By organizing the information in terms of interests, desired objectives, existing gaps, causes, and possible solutions, this table provides a clear overview of the perspectives and priorities of each actor [Enserink et al., 2022].

In this specific context, the table highlights a key tension: several stakeholders, including Staedion, HMS, and other housing corporations, prefer to maintain the ORAC system due to its efficiency, lower operational costs, and reduced physical strain on workers. However, the municipality's policy shifts towards an indoor waste collection system with roll containers, creating a significant gap between desired outcomes and proposed actions.

The insights gained from this table are crucial to identify common ground and shared objectives among the actors. They also highlight the need for improved collaboration between stakeholders who favor the ORAC system and the municipality, which advocates for a new approach. Exploring potential compromises, such as the integration of innovative waste collection solutions such as press containers, could bridge this gap. Ultimately, this systematic comparison supports a more informed and balanced decision-making process, ensuring the interests of all actors are considered.

Table 2.1: Overview table of actors' problem formulations

Actors	Interests	Desired Situation/Objectives	Existing or Expected Situation and Gap	Causes	Possible Solutions
Municipality of The Hague (DSB)	Maintain public spaces, manage waste collection, and reduce illegal dumping	Implement indoor waste systems to relieve public space pressure and prevent illegal dumping	ORAC system in use; resistance from stakeholders preferring ORACs	Limited collaboration, insufficient consultation, and lack of alternative suggestions	Collaborate with stakeholders to jointly explore effective waste solutions
Municipality of The Hague (DSO)	Integrate urban renewal, housing, and infrastructure with energy and climate goals	Ensure sufficient public space for infrastructure, green areas, and mobility needs	Indoor waste collection plans pressure public spaces due to required collection points, reducing space for other needs	Insufficient planning aligning waste policies with spatial requirements; lack of stakeholder collaboration	Work with stakeholders to minimize public space use and integrate waste systems with urban planning
Staedion	Provide quality housing and maintain clean environments for tenants	Retain ORAC system for efficient waste collection and reduced costs	Indoor systems increase costs, inefficiency, and illegal dumping	Poor collaboration and inadequate input from municipality on waste options	Continue with ORACs; collaborate to optimize collection systems
Haagse Milieu Services (HMS)	Ensure efficient collection, worker safety, and compliance with standards	Maintain ORACs for efficient and less labor-intensive waste collection	Indoor collection with roll containers increases inefficiency and labor demands	Policy disregards operational challenges and existing infrastructure	Improve collaboration to design efficient, future-proof systems
Heijmans (Construction Company)	Renovate and future-proof buildings within municipal guidelines	Optimize building space; prioritize ground floor for shops or bike storage instead of waste areas	Indoor waste policies require valuable ground floor space for container storage	Policies prioritize indoor systems without considering space-saving alternatives	Explore innovative waste systems to reduce ground floor space needs while meeting regulations
Other Housing Corporations	Ensure quality housing and cleanliness for tenants	Retain ORACs for waste collection where feasible in renovations	Indoor systems in new builds cause high costs and inefficiencies	Renovations allow ORAC use, but new builds must follow indoor waste policies	Work with municipality and HMS to address shared challenges
Residents	Desire clean neighborhoods and easy waste disposal	Convenient and efficient systems ensuring cleanliness	Indoor systems may burden residents, increase costs, and encourage illegal dumping	Lack of consultation with residents on usability and accessibility of systems	Consult residents; design user-friendly systems and maintain public cleanliness

2.3.4. Power and Interests Stakeholders

All stakeholders identified in Figure 2.19 and discussed in subsection 2.3.1 are relevant to the waste collection process. However, the key aspect is to determine which stakeholders play the most significant role in the decision-making process for the waste collection alternatives and should be included in the MAMCA.

Based on the Power-Interest Grid in Figure 2.19, the most relevant stakeholders for the decision-making process are those with both high power and interest: Staedion, the municipality, HMS, and Heijmans. The municipality holds the greatest power and interest as it sets the overarching policies and is legally responsible under the Environmental Management Act (Wet Milieubeheer). Staedion also has significant power and interest, as this research stems from their request, and Staedion owns the majority of buildings in the area compared to other housing corporations.

While other housing corporations are less powerful and less interested than Staedion, as they own fewer properties and were not the initiators of the research. These stakeholders will still be consulted for input but will not be included in the MAMCA. HMS and the Heijmans have lower power but high interest, making them key stakeholders for the MAMCA. HMS is partially dependent on the municipality's decisions, as its role is solely executive. However, it plays a significant role in determining the feasibility and efficiency of implementation. Heijmans, as a construction company, holds less power and interest than Staedion because its involvement is limited to the reconstruction phase, while long-term concerns fall under the responsibility of the housing corporations. However, Heijmans plays a significant role in decision-making during the redevelopment phase; therefore, it is included in the MAMCA.

Residents have a significant influence on the waste collection process through their behavior. However, this study focuses solely on determining which alternative is best for implementation, and in the decision-making process, residents have little power. AVR, as a waste sorting facility, will be affected by potential changes in waste separation, but has limited power and interest in the collection process. Hart voor Den Haag and the NVRD, while involved in broader waste management issues, do not have specific influence in this neighborhood and will be consulted for general insights but not included in the MAMCA.

In summary, the stakeholders included in the MAMCA will be the municipality, Staedion, HMS, and Heijmans. Other stakeholders will be kept satisfied, informed, and monitored.

2.3.5. Conclusion Research Question 2

This section answers Research question 2:
Who are the key stakeholders in the decision-making process for the waste collection alternatives, and what are their objectives and criteria?

The key stakeholders in the decision-making process for waste collection alternatives in Dreven, Gaarden, and Zichten are the municipality, Staedion, HMS, and Heijmans. These stakeholders will be included in the MAMCA.

Additionally, this section provides a clear overview of all involved stakeholders and those who may be affected by the final decision regarding a waste collection alternative. The analysis also reveals that there are conflicting interests among stakeholders.

Table 2.1 uncovered significant tension between the municipality's policy to implement an indoor waste collection system and the preferences of other stakeholders, such as Staedion and HMS, who favor the current ORAC system. This conflict arises from concerns about inefficiencies, increased costs, operational challenges, and the use of valuable public and ground-floor spaces for waste collection points.

In conclusion, the findings underscore the need for improved stakeholder collaboration to

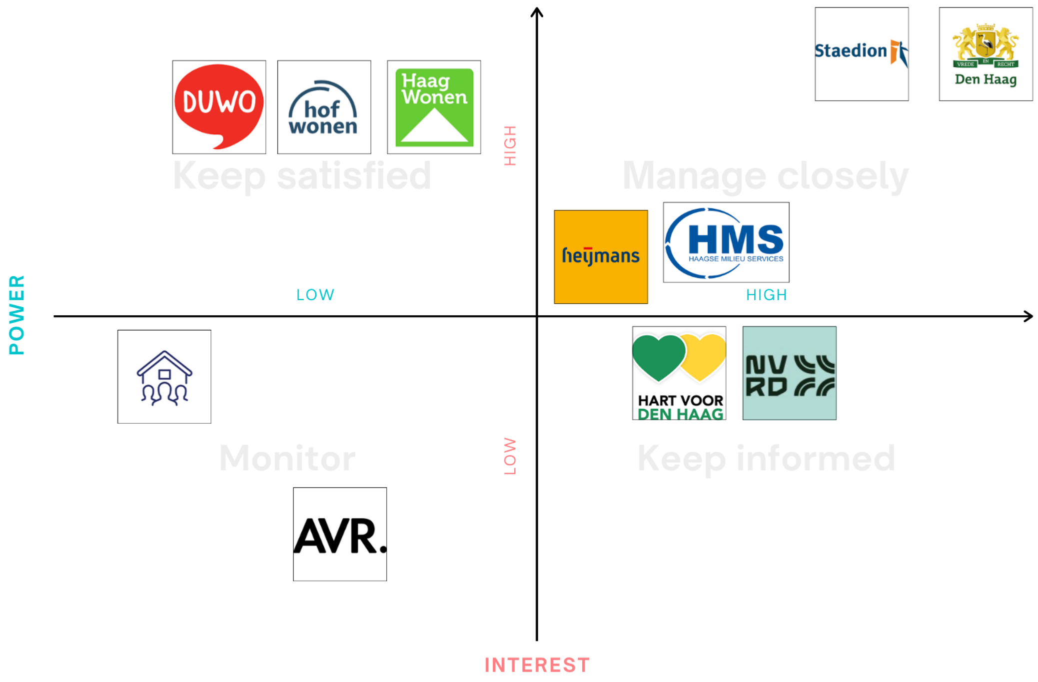


Figure 2.19: Power Interest Grid Stakeholders

develop a future-proof waste management system. The aforementioned stakeholders have all been interviewed and will be included in the MAMCA.

3
Design

This chapter first determine the requirements that the waste collection alternative designs must meet in section 3.1. In the same section, the criteria for evaluating these designs are defined, based on stakeholder preferences and key considerations in the redevelopment of the area and The Hague itself. The requirements also play a role in the criteria selection, as it helps assess how well each alternative meets the set conditions. Additionally, this section outlines the weightings assigned by each stakeholder for every criterion.

After defining the requirements, the alternative waste collection designs are developed, which are presented in section 3.2. Next, **??** explains how each alternative is evaluated based on the established criteria. For this, estimations were made in Excel, and some criteria values were rated on a scale from 1 to 10.

3.1. Define Requirements and Criteria

This section establishes the requirements for the new system. Subsequently, based on these requirements and stakeholder interviews, criteria are defined to compare and evaluate the different alternatives using the MAMCA method. This section answers sub-question 3:

What are the requirements and criteria for the future waste collection system?

3.1.1. Requirement Analysis

This section defines the requirements for the new system. It begins with an estimation of the required system capacity, followed by the formulation of broader requirements based on goals identified as relevant by stakeholders.

Capacity of the collection system

The primary and most straightforward requirement is the capacity of the system. This involves determining the amount of waste generated in the case study area and estimating how this will change with the addition of new housing. Stakeholders indicated that concrete data on this is currently unavailable. Since not all redevelopment plans are finalized, the exact number of new homes and residents per household remains uncertain. Therefore, an estimation was made using averages.

It is estimated that 3,500 additional homes will be constructed in the area [Gemeente Den Haag, nd]. While 5,000 new homes are planned, some existing homes will be demolished or renovated, resulting in a net increase of 3,500 homes.

In Figure 3.1, the current population numbers for the neighborhoods are presented. The weekly generation of household waste was calculated using the waste averages of the data analysis in subsection 2.2.3 for The Hague in 2023. Only standard household waste streams were considered, such as residual waste, organic waste, plastic, paper, cardboard, and glass. Bulky waste and other nonstandard waste streams were excluded because they are collected separately. This results in an estimated **300 kg per inhabitant per year** [Centraal Bureau voor de Statistiek (CBS), 2024],

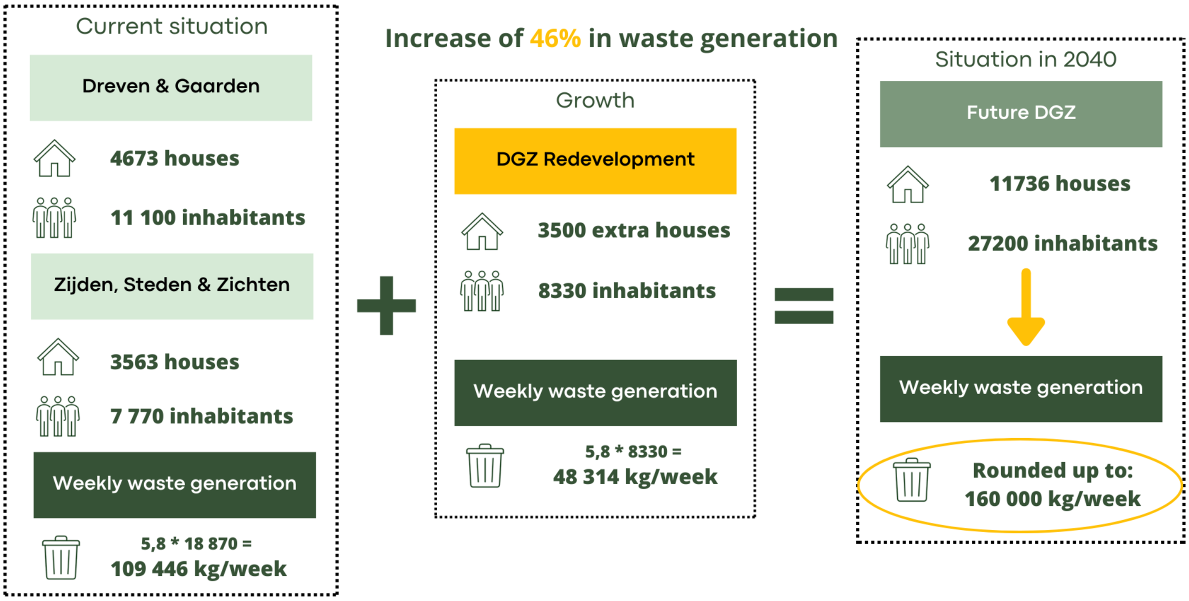


Figure 3.1: Capacity of the collection system

which, when divided by 52 weeks, equates to **5.8 kg per person per week**. This calculation underpins the value of **5.8 kg** shown in the figure.

The population increase was then estimated using the average number of residents per household in 2023 for the respective neighborhoods:

- **Dreven and Gaarden: 4,673 homes** (as of 2023) and **11,100 residents**, giving an average of **2.38 residents per household**.
- **Zijden, Steden, and Zichten: 3,563 homes** (as of 2023) and **7,770 residents**, with an average of **2.18 residents per household**.

An estimated 3,500 additional homes will be added to the area. Based on CBS data, the national average household size in the Netherlands is **2.11 residents per household**, which is slightly lower than the neighborhood averages [Centraal Bureau voor de Statistiek (CBS), 2023]. Therefore, a range was estimated:

- **Minimum estimate:** 3,500 × 2.11 = **7,385 new residents**.
- **Maximum estimate:** 3,500 × 2.38 = **8,330 new residents**.

Thus, the total population of the neighborhoods Dreven, Gaarden, and Zichten is expected to increase from the current **18,870 residents** to a maximum of **27,200 residents**.

Table 3.1: Housing and Population Data for Dreven, Gaarden, and Zichten (2023)

Data	Dreven and Gaarden	Zijden, Steden, and Zichten	Total
Houses	4,673	3,563	8,236
Residents	11,100	7,770	18,870
Average residents per house	2.38	2.18	2.11 (according to CBS)

It is important to note that the capacity calculation includes a safety margin, ensuring that the system can handle slight overestimations. Overestimating capacity is safer than underestimating it, as insufficient capacity could lead to waste accumulation and street littering, significantly affecting neighborhood livability.

Lastly, this estimated capacity will serve as the baseline for comparing various waste collection system designs. Each alternative will be evaluated based on its ability to meet this capacity, as well as other factors such as cost and space efficiency. The capacity calculations will also determine the required number of facilities, the total operational cost, and the spatial requirements of each alternative.

A challenging aspect of this project is that it spans multiple years, with new homes being added gradually. The final homes are expected to be completed by 2040. However, by 2040, the system will need to meet the calculated capacity of 160,000 kg of waste per week.

Estimated Budget for Waste Collection in DGZ

To establish a financial framework for waste collection in DGZ, an estimated budget is calculated based on the average waste tax per household. This tax includes both waste collection and processing (such as incineration and recycling), making it difficult to determine the exact portion allocated solely to collection services. However, by multiplying the average waste tax per household by the projected number of households in DGZ in 2040, a general budget estimate can be derived. This estimation serves as a reference point for evaluating the financial feasibility of different waste collection alternatives assessed in this study.

By 2040, the number of households in DGZ is expected to reach approximately 11,800 (rounded) (Figure 3.1). The average household size in these neighborhoods is estimated at two persons (rounded), based on previous calculations regarding system capacity. Therefore, the budget calculation uses the waste tax rate for a two-person household, which amounts to €438.48 per year [Gemeente Den Haag, 2024a]. Multiplying this rate by the projected number of households results in an estimated annual budget of approximately **€5.17 million**.

It is important to note that this estimate provides a general indication rather than an exact budget for waste collection alone. Since the waste tax also includes costs related to waste processing and treatment, the actual amount allocated to collection services will be lower. Nonetheless, this estimation offers a useful benchmark for assessing the relative costs of the proposed waste collection alternatives and understanding the potential financial impact of different systems.

Constraints and Objectives of the Collection System

In this subsection, the analysis extends beyond just the capacity of the system and also considers its various functionalities. The design requirements are categorized into two main groups: mandatory and preferred requirements. These are divided into constraints and objectives, providing a comprehensive framework for evaluating and implementing the system.

The constraints focus on defining the essential functionalities and characteristics the system must fulfill [AltexSoft Software R&D Engineering, 2023]. These are split into:

- **Functional Constraints:** Specify the core operations and capabilities required from the system.
- **Non-Functional Constraints:** Define the attributes or qualities the system should have to ensure efficiency, compliance, and integration with the surroundings.

The objectives describe the desired improvements or enhancements to the system. These are also divided into:

- **Functional Objectives:** Outline performance-related goals that directly improve the system's functionality.

- **Non-Functional Objectives:** Focus on broader goals like sustainability, cost-effectiveness, and user satisfaction.

Table 3.2 and Table 3.3 below present these categories in detail, with functional and non-functional aspects clearly delineated. These constraints were established based on key factors in the redevelopment process and stakeholder priorities, as identified in the interviews Appendix B. Additionally, relevant Dutch regulations and specific requirements set by the municipality of The Hague were considered.

FC1 was formulated to ensure the system meets the required capacity, as substantiated in Figure 3.1.

FC2 was established because an analysis of the current waste collection process revealed that The Hague lags behind other cities in terms of waste separation. The new system must support and enhance waste separation efforts rather than worsen them.

FC3 sets a maximum distance of 125 meters for waste collection points. Although this distance varies by municipality, The Hague has set this requirement at 125 meters [Gemeente Den Haag, 2024c].

FC4 was established in accordance with Dutch accessibility regulations. The Equal Treatment Act on Disability or Chronic Illness (WGBH/CZ) mandates that service providers, including municipalities, gradually improve accessibility for people with disabilities unless this imposes a disproportionate burden [College voor de Rechten van de Mens, 2024]. This requirement also applies to waste collection systems, which must be designed to ensure accessibility for all.

The non-functional constraints were also derived from stakeholder input and urban development factors. **NFC1** was formulated because the municipality emphasized the high pressure on public space, which is also the primary reason for their preference for indoor waste collection (section B.4). The Hague is the most densely populated city in the Netherlands, and Dreven, Gaarden, and Zichten are already among its most densely populated neighborhoods, as described in the Case Study Background (chapter 2). With 3,500 additional homes planned [Gemeente Den Haag, nd], the demand for space will increase further, leaving less room for waste collection facilities, making this a necessary non-functional constraint.

NFC2 concerns the integration of the waste collection system into the urban streetscape. The design must not obstruct driveways, limit green spaces, or compromise traffic safety, as established in the Guidelines for Waste Collection Facility Locations [Gemeente Den Haag, 2010].

NFC3 was established to ensure hygiene standards. Waste collection systems that are difficult to maintain or clean can attract pests, an ongoing issue in The Hague [Gemeente Den Haag, 2023]. These constraints ensure that the waste collection system is functional, accessible, space-efficient, and well-integrated into the urban environment while also addressing hygiene and operational efficiency.

#	Functional Constraints	#	Non-Functional Constraints
FC1	The system must accommodate the average weekly waste volume per household.	NFC1	The system must use a minimal footprint to avoid excessive space usage.
FC2	The system must support separate collection for paper, plastic, glass, and residual waste.	NFC2	The design must align with the visual identity of the neighborhood.
FC3	The containers must be accessible for residents within 125 meters of their residence.	NFC3	The system must allow for easy maintenance and cleaning.
FC4	The containers must meet safety and accessibility standards for people with disabilities.		

Table 3.2: (Non-)Functional Constraints.

FO1 aims to improve user convenience by minimizing the walking distance to waste collection points. While the strict requirement is a maximum of 125 meters (FC3), it is preferable for collection points to be as close as possible to residents.

FO2 was established because fill-level sensors contribute to sustainability by reducing waste collection-related transport movements by 20% to 30% [Supporter van Schoon, 2024]. Currently, almost all underground containers in The Hague are equipped with fill-level sensors, so the new waste collection system should ideally include this feature as well [Avalex, 2024].

FO3 aligns with FO2, as efficient routing based on fill-level sensors can further optimize collection operations, leading to the same 20% to 30% reduction in transport movements [Supporter van Schoon, 2024].

Among the non-functional objectives, **NFO1** takes sustainability even further by optimizing the spatial distribution of waste collection points. A system with fewer, well-located collection hubs requires fewer transport movements compared to a system with many dispersed collection points, thereby further reducing emissions.

NFO2 addresses the high waste collection fees that The Hague imposes on its residents, as identified in the analysis of the current process (section 2.2). The new system should ideally be cost-effective to implement, preventing further increases in waste collection fees, which are already relatively high in The Hague.

NFO3 also relates to the high waste collection fees but focuses on operational costs rather than implementation. Keeping operational costs as low as possible ensures that waste collection fees remain manageable and do not continue to rise.

#	Functional Objectives	#	Non-Functional Objectives
FO1	It would preferably minimize the distance residents have to walk to dispose of waste.	NFO1	It would preferably promote sustainability by reducing waste-related transport emissions.
FO2	It would preferably include smart sensors for monitoring container fill levels.	NFO2	It would preferably be cost-effective to install and operate, aiming to reduce overall waste management costs.
FO3	It would preferably support efficient routing for collection vehicles.	NFO3	It would preferably require minimal maintenance and operational costs.

Table 3.3: (Non-)Functional Objectives.

3.1.2. Criteria

After defining the requirements to be met by the system, it is important to translate these requirements into criteria so that different waste collection designs can be compared. First, the different criteria will be explained. Then, the process of weighting these criteria to arrive at a combined score will be discussed so that the different designs can be assessed against these criteria.

Different criteria

To establish a robust set of criteria, interviews were conducted with the key stakeholders identified in the stakeholder analysis in section 2.3: the Municipality of The Hague, Staedion (the housing corporation), Heijmans (the developer), and HMS (the waste collection service provider). During these interviews, discussions focused on the main challenges in the neighborhoods of Dreven, Gaarden, and Zichten, the implications of the ongoing redevelopment, and the factors that each stakeholder considers important for an effective waste collection system.

In addition to stakeholder input, the analysis of the current waste management process in section 2.2 in The Hague played a significant role in defining the criteria. The findings from this analysis revealed that The Hague has a relatively expensive waste management system with suboptimal waste separation results. Compared to other major cities, the city performs poorly in terms of waste separation while maintaining high operational costs. These inefficiencies underscored the importance of including cost efficiency and sustainability as key evaluation criteria.

From these combined insights, five primary criteria were identified, reflecting the key aspects that need to be considered for a well-functioning waste collection system. These criteria were presented to all stakeholders, allowing them to provide feedback and suggest additional criteria if necessary.

Costs

The first criterion is costs, which encompasses both the initial investment and ongoing operational expenses. This criterion was chosen as a primary factor because The Hague's current waste management system is relatively expensive compared to other major cities in the Netherlands. The city imposes the highest waste collection tax (subsection 2.2.3) on its residents, making cost efficiency a critical aspect of designing a new waste collection system that remains financially sustainable and fair. The financial burden of waste collection is not uniform across all stakeholders, as each group incurs different types of expenses. To ensure a comprehensive cost evaluation, the cost criterion has been divided into four subcategories:

1. **Investment Costs:** refer to the one-time expenses required to acquire and implement the waste collection system. This includes the purchase of waste collection infrastructure, such as underground refuse containers (ORACs), roll containers, or waste rooms within buildings. These costs have been aggregated across all stakeholders rather than being assigned to individual entities. This decision was made to enable a fair comparison between the alternatives without prematurely allocating specific financial responsibilities. Once the most effective waste collection system has been identified, a separate analysis can be conducted to determine how costs should be divided among stakeholders.

2. **Operational Costs:** refer to the recurring expenses necessary for maintaining and running the waste collection system. For example cleaning costs, waste collection and transportation costs, maintenance costs.

3. **Waste Collection Tax (Afvalstoffenheffing):** is a municipal-imposed charge on residents to fund municipal waste services. In The Hague, this tax is already the highest among major

Dutch cities, making it an important subcriterion to prevent further financial burdens on residents. Evaluating how different waste collection alternatives affect the waste collection tax ensures that the new system does not disproportionately increase costs for the public.

4. **Service Costs for Tenants (Staedion-specific):** the housing corporation, covers certain waste-related expenses that are ultimately passed on to tenants through service costs. This subcriterion was included at the request of Staedion, which expressed concerns about the financial impact of certain waste collection alternatives on its tenants. For example indoor waste collection systems would require maintenance of waste rooms and staffing costs to move waste bins outside for collection multiple times per week. These costs would be directly passed on to tenants in the form of higher service fees, making affordability an important factor for Staedion. By incorporating service costs as a distinct subcriterion, this analysis ensures that the financial implications for residents of social housing are explicitly considered in the decision-making process.

Space Usage

The second criterion is space usage, which is particularly important in densely populated areas. Space usage refers to the amount of physical space required for waste collection infrastructure, measured in square meters (m^2). This criterion considers aboveground space requirements, as facilities such as ORACs occupy underground space, while roll containers take up surface space. In order to assess the impact on public areas, the space required by each solution will be evaluated.

The importance of space usage is particularly relevant for The Hague, which is the most densely populated city in the Netherlands, as stated in the Problem Definition: Case Study Background (section 2.1). This high population density means that available public space is already limited, making it critical to compare different waste collection alternatives in terms of their spatial footprint. Ensuring that the selected system minimizes space usage is essential for preserving public areas and maintaining accessibility in these neighborhoods.

Moreover, the Municipality of The Hague has emphasized that urban densification is a major challenge for the city. The ongoing development pressure is expected to further reduce the availability of public space. As a result, the municipality strongly prefers indoor waste collection systems. By incorporating space usage as a key criterion, this research ensures that waste collection alternatives are evaluated with respect to their impact on the urban landscape, addressing the municipality's concerns about growing pressure on public space.

To provide a detailed comparison, this criterion is divided into two subcategories:

1. **Public space usage**, which refers to the amount of space occupied by waste collection facilities in streets, sidewalks, and other outdoor areas.

2. **Indoor space usage**, which assesses the space required within buildings, such as designated waste collection rooms in residential complexes.

This distinction allows for a more nuanced evaluation of how different waste collection alternatives impact both public and private spaces within the urban environment.

Ease of Use

The third criterion, ease of use, focuses on how easy the waste collection system is to operate for both residents and waste collection workers [College voor de Rechten van de Mens, 2024]. This includes factors such as the effort required to dispose of waste, the physical strain involved in using the system, and the overall intuitiveness of its operation. Key considerations include the weight and resistance of disposal mechanisms and the force needed to open or lift lids.

Each waste collection alternative is evaluated on a scale from 1 to 10, based on the level of physical effort and operational simplicity. A higher score indicates a system that requires minimal effort, is ergonomically designed, and is easy to use for all residents, including the elderly and people with disabilities, as well as for waste collection workers during the emptying process.

Sustainability
The fourth criterion is sustainability, which evaluates how well the waste collection system supports broader sustainability goals, such as increasing waste separation, and lowering carbon emissions. This criterion is divided into two subcategories: transport movements and waste separation.

1. **Transport Movements**, Alternatives are ranked on a scale from 0 to 10, where 10 indicates very few transport movements, resulting in lower emissions, and 0 represents the highest number of transport movements, leading to increased emissions.

2. **Waste Separation**, This category is more complex because each alternative is initially assessed based on residual waste only, for the sake of simplification. However, alternatives are also ranked based on how well a waste separation system could be integrated and how effectively it would encourage waste sorting. The ranking ranges from 0 to 10, where 0 indicates poor waste separation potential, and 10 represents optimal opportunities for effective waste separation.

Ease of Implementation
Finally, the fifth criterion is ease of implementation, which considers the logistical and infrastructural challenges associated with adopting a new waste collection system. This includes the need for infrastructure modifications and the extent of educational or awareness campaigns required for residents to adapt to the system. The ease of implementation is measured on a ranking scale from 0 to 10, where a score of 10 represents the zero alternative, meaning no changes are required for implementation, while a score of 0 indicates a challenging implementation that requires significant modifications and adjustments to infrastructure or operational processes.

In summary, these five criteria—costs, space usage, ease of use, sustainability, and ease of implementation—provide a comprehensive framework for evaluating the proposed waste collection solutions.

Weighting Criteria
To determine the weights of the criteria for each stakeholder, a survey was distributed to all stakeholders. The survey can be found in Appendix C. In this survey, stakeholders were asked to compare the criteria against each other to establish which aspects they considered most important. This was conducted using the Analytical Hierarchical Procedure (AHP). AHP is a structured decision-making process that organizes complex problems into a hierarchy of goals, criteria, and alternatives. Stakeholders make pairwise comparisons between criteria, indicating their relative importance, which allows the method to calculate weights for each criterion based on their preferences. AHP was chosen because it is well-suited for multi-criteria decision-making involving multiple stakeholders. It provides a clear and transparent structure for comparing criteria and ensures consistency in judgments. This makes it particularly valuable for evaluating designs in waste collection, where priorities such as cost, sustainability, and ease of use must be balanced. The method's flexibility and reliability ensure that stakeholder input is effectively incorporated into the decision-making process [VUB, 2024].

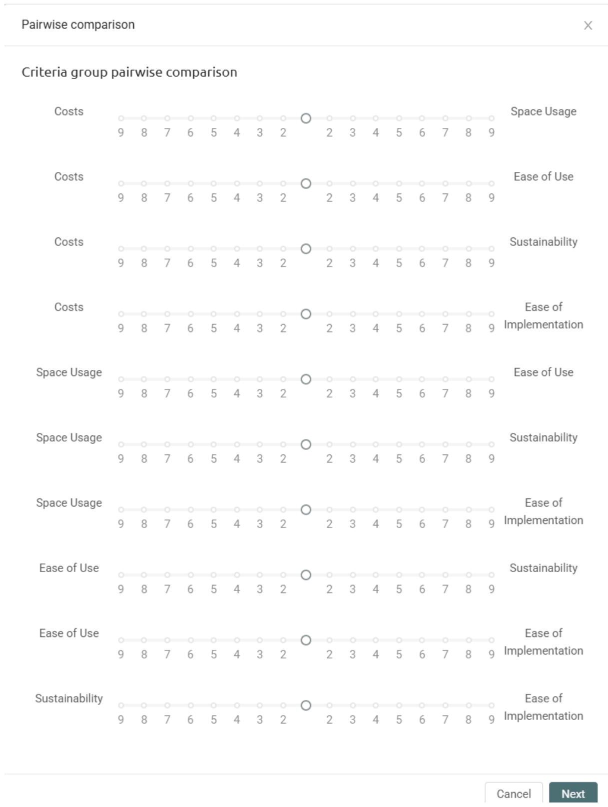


Figure 3.2: Input criteria preferences MAMCA software

After each stakeholder completed the form and indicated their preferences, the responses were processed to determine the final weights per stakeholder per criterion. This was done as follows: For example, if a stakeholder indicated that costs are absolutely the most important criterion compared to sustainability, the MAMCA software assigns a score of 9 for Costs vs. Sustainability. Conversely, Sustainability vs. Costs is assigned the reciprocal value 1/9. Figure 3.2 illustrates how this pairwise comparison works in the software.

After each criterion has been compared with all others, as shown in the example of Costs and Sustainability, a comparison matrix can be created for each stakeholder, containing the assigned scores. This matrix includes all criteria, with each criterion being compared against every other criterion. The rows and columns of the matrix represent the same set of criteria, ensuring that each criterion is systematically evaluated in relation to every other criterion. Each comparison matrix has the following properties:

- The diagonal always contains the value 1 (each criterion is equally important to itself).
- The values are reciprocal (if Criterion A compared to Criterion B = 3, then Criterion B compared to Criterion A = 1/3).

To calculate the final weights, the pairwise comparison matrix is normalized through the following steps:

1. Sum each column of the matrix to obtain the total for each criterion.
2. Divide each individual value in the matrix by the sum of the columns, converting it into a relative fraction of the total.

3. Calculate the average of each row, which results in the final weight for each criterion per stakeholder.

These weights indicate how important each criterion is according to each stakeholder. The same process is repeated for subcriteria, ensuring that their weights are proportionally assigned within their respective main criterion. For example, if Costs receives a weight of 0.5, then all subcriteria within Costs must sum up to 0.5.

In Figure 3.3, the different criterion weights assigned by each stakeholder are presented. Notably, these weights vary significantly between stakeholders, indicating that each party values different aspects of the alternatives. For instance, Heijmans and Staedion place a high emphasis on costs, whereas HMS and the Municipality of The Hague consider costs to be of lesser importance. This variation highlights the relevance of using the MAMCA method in this case study, as it is crucial to identify a waste collection alternative that is supported by all stakeholders. The MAMCA approach provides a structured way to map out and balance these differing priorities, ensuring that the final decision aligns with the collective interests of all involved parties.

(a) Municipality The Hague

(b) Staedion

(c) HMS

(d) Heijmans

Figure 3.3: Comparison of Weight of Criteria for the Four Stakeholders

3.1.3. Conclusion Research Question 3

This section answers the question: *What are the requirements and criteria for the future waste collection system?*

The requirements that the system must meet are outlined in Table 3.2 and Table 3.3. These requirements serve as the foundation for designing the waste collection system.

The key criteria used to evaluate the alternatives are: costs, space usage, ease of use, sustainability, and ease of implementation. These criteria ensure that the selected waste collection system aligns with stakeholder priorities and the long-term feasibility of waste management in the Dreven, Gaarden, and Zichten neighborhoods.

3.2. Design Alternatives

This chapter discusses the design alternatives for waste collection systems in the neighborhoods of Dreven, Gaarden, and Zichten. First, the alternatives are briefly described. Next, they are evaluated based on the predefined requirements that the system must meet. Finally, an explanation is provided on how each alternative has been incorporated into the estimation model in Excel.

3.2.1. Different Alternatives

In this section, a brief explanation of each alternative will be provided, accompanied by visual materials to give an impression of the different options. The alternatives have been designed with the requirements outlined in section 3.1 in mind. Each alternative will later be evaluated based on the defined criteria.

Baseline Alternative 0: Current ORAC System

As a baseline alternative, the current underground residual waste container (ORAC) system is included to enable a comprehensive comparison with other alternatives [MKBA Informatie, nd]. This system is described in detail in section 2.2. In Figure 2.7a, the design is illustrated: the gray section is located underground, while the container's opening is above ground. This design makes the alternative space-efficient. ORAC's have already been realized across the neighborhood and offer several advantages. Cost-effectiveness is a key benefit, as no additional capital investment is required for new infrastructure. Moreover, operational efficiency is ensured, given that waste collection is already structured around these containers, and HMS is fully equipped to manage their emptying. The ORACs are seamlessly integrated into existing collection routes, and fill-level sensors trigger emptying once the containers reach 80% capacity, allowing for optimized collection scheduling (section B.3). Additionally, their underground, enclosed design helps mitigate pest issues and odor, further contributing to their effectiveness.

Despite these advantages, future urban development is expected to lead to a growth in the number of residents, increasing the volume of household waste. This necessitates either more frequent collection or the installation of additional ORACs to accommodate the rising demand. However, the system conflicts with the municipality's policy direction, which prioritizes indoor waste collection as the preferred approach (section B.4). Another critical drawback is the persistent issue of fly-tipping (bijplaatsingen), where waste is frequently placed outside the designated containers, affecting both cleanliness and public space usability. Furthermore, ORACs occupy valuable public space permanently, which could otherwise be allocated for alternative urban purposes.

Alternative 1: Indoor Roll Containers

This alternative involves collecting waste in roll containers stored indoors within buildings, which are then placed outside twice a week by Staedion for collection by HMS. It is currently being implemented in the first building of the Dreven, Gaarden, and Zichten (DGZ) redevelopment project. While the initial costs of roll containers are relatively low due to their inexpensive plastic material, this system has raised significant concerns among stakeholders. Additionally, this alternative can be convenient for residents in situations where they have a shorter walking distance to an indoor roll container compared to a collective point like an ORAC outside the building.

The municipality does not view this as a suited long-term solution (section B.4). Staedion has expressed concerns about indoor waste management, such as overflowing roll containers, unsafe and non-fire-compliant storage conditions, and increased annual costs for waste removal within their buildings. As shown in Figure 3.5a, poorly managed indoor spaces can lead to excessive clutter and safety hazards. Staedion also anticipates higher service costs due to the

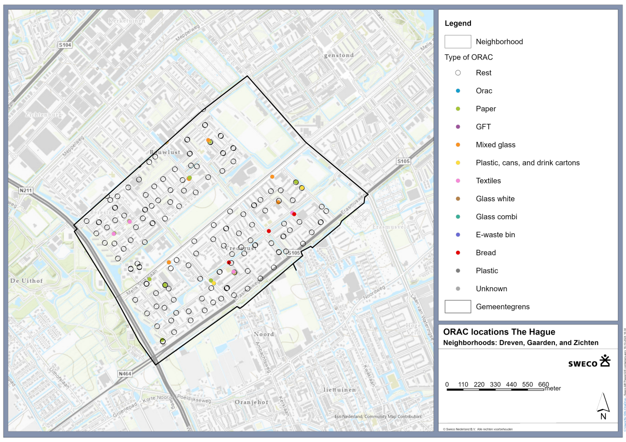



Figure 3.4: Design of ORAC (left, Source: [De Rooij Milieutechniek, nd]) and current locations in The Hague (right).

labor-intensive process of moving containers outside and back in twice a week, as well as increased cleaning and maintenance expenses for the storage spaces (section B.5).

HMS is similarly concerned about inefficiencies in waste collection, as emptying roll containers requires more staff, additional trucks, and increased physical effort compared to underground containers (section B.3). These inefficiencies result in more transport movements, higher collection costs, and potentially increased waste disposal fees for residents. Additionally, as highlighted in Figure 3.5c, designated street spaces for roll containers are required twice a week, reducing available public space for parking or greenery. This conflicts with the municipality's concerns about maintaining sufficient public space. Moreover, Figure 3.5b underscores the unattractive street view caused by roll containers being placed on the streets twice a week.

Further disadvantages include the lack of waste separation facilities, the absence of fill-level sensors, and the susceptibility to pest infestations. While the alternative offers low initial costs, it imposes significant long-term challenges for stakeholders and compromises public space management.

Alternative 2: Indoor Press Containers

This alternative replaces indoor roll containers with indoor press containers, which compress waste into a compact form. The press container, shown in Figure 3.6b, is designed to significantly reduce the volume of waste. The compressed waste is then collected by trucks specifically equipped for this system. These containers can either be moved outdoors using a mover, as shown in Figure 3.6a, for collection by a truck, or they can be placed inside the building with side access, allowing the truck to collect the waste directly, as illustrated in Figure 3.6c. By compressing the waste, these containers require less indoor space, as they can store a larger volume of waste in the same area, making them more space-efficient compared to roll containers.

One of the key advantages of this system is its space efficiency, as compressed waste significantly reduces the required storage area indoors. Additionally, the incorporation of fill-level sensors enables real-time monitoring and optimized collection schedules, which minimizes unnecessary trips and enhances operational efficiency. The use of press containers also reduces the number of transport movements, as more waste can be collected per trip. Furthermore, their closed design helps to prevent pest infestations, contributing to better hygiene and environmental control. Compared to roll containers, the process of emptying press containers is less labor-intensive, further improving overall efficiency.

Despite these benefits, this alternative comes with several disadvantages. The initial investment costs are substantial, as the press containers themselves, as well as the specialized

(a) Indoor Storage (Staedion)

(b) Street View of Roll Containers

(c) Collection Space on Street for Roll Containers

Figure 3.5: Overview of Roll Container Storage and Usage: (a) Indoor storage, (b) Street View, and (c) Street Collection Space.

trucks required for collection, represent a significant financial outlay. The system also requires dedicated space near buildings for trucks to access and load the containers, which permanently reduces the availability of public space. Another limitation is the lack of waste separation capabilities, as the system does not inherently support separation unless multiple press containers are implemented, which would further increase costs. Additionally, the system involves high service and maintenance costs, along with higher waste disposal fees due to HMS's need to adjust operations, including the use of new equipment and additional personnel.

Overall, while press containers offer increased efficiency and better space utilization, their high upfront costs, logistical complexities, and limited support for waste separation present significant challenges. This makes them a viable but complex alternative for urban waste management systems.

Alternative 3: Press ORACs (SIDCON)

This system features underground press containers, developed by SIDCON, which are designed to combine the functionality of traditional underground containers (ORACs) with the efficiency of press containers. These press ORACs compress waste within their underground structure, significantly increasing their capacity—up to 6 times (for residual waste) greater than traditional

(a) Mover system for transporting press containers to pick-up point.

(b) Press container with tilting installation.

(c) Truck collecting the press container.

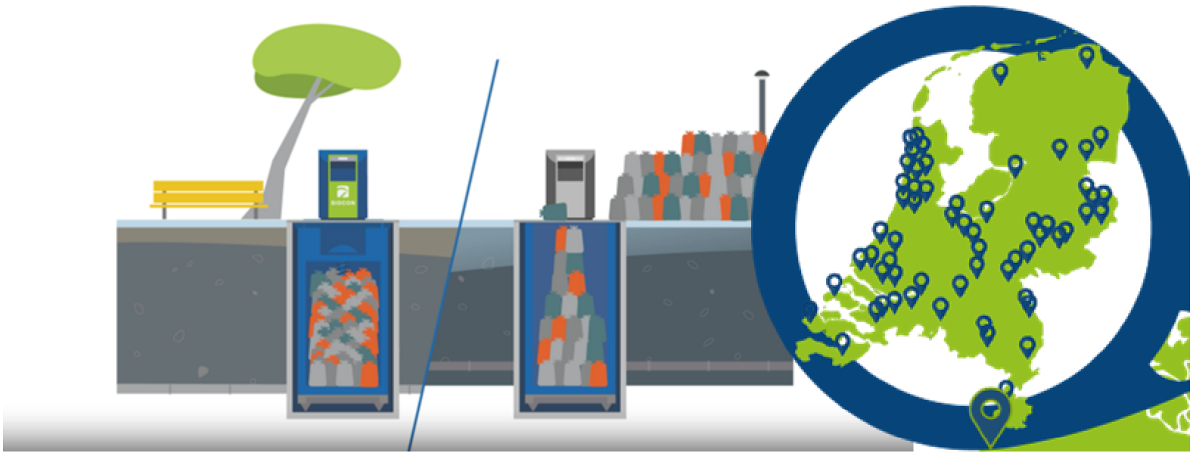
Figure 3.6: Overview of the press container system: (a) Mover system for transporting containers, (b) press container with tilting installation, and (c) truck collecting the press container.

ORACs. This makes them particularly suitable for densely populated areas or high-rise neighborhoods, where large volumes of waste need to be managed in a limited space. In this study, SIDCON, one of the manufacturers of these containers, was interviewed regarding their implementation (section B.6), although other manufacturers also provide similar solutions.

The press ORAC system offers the advantage of being space-efficient by reducing the number of containers required in public spaces, as compressed waste occupies far less volume. Furthermore, this system integrates seamlessly into the existing waste collection infrastructure. The current trucks used by HMS can empty these containers without requiring additional modifications, as the emptying process remains similar to traditional ORACs and is triggered by fill-level sensors. Figure 3.7 illustrates the design and operation of the press ORAC system: Figure 3.7a shows the SIDCON press ORAC, which accommodates significantly more waste bags than a traditional ORAC due to its compression mechanism, while Figure 3.7b highlights municipalities where this system is already in use.

One of the key advantages of the press ORAC system is its space efficiency. By utilizing the current ORAC locations (as shown in Figure 3.4), it minimizes the need for additional public space as it uses the already occupied spaces. The closed underground design prevents odors and pest issues, and the inclusion of fill-level sensors ensures optimized collection schedules, reducing unnecessary transport movements. Additionally, the emptying process is not labor-intensive and aligns with the existing equipment used by HMS. Another benefit is the potential for a phased rollout, as the redevelopment of buildings in the area will take place gradually until 2040. This allows for a data-driven replacement strategy, where traditional ORACs can be incrementally upgraded to press ORACs in locations where waste collection data indicates frequent emptying is required. By monitoring fill-level sensor data, areas with high waste production can be prioritized for early implementation, ensuring an efficient and demand-based transition to the new system. Furthermore, the press ORACs support waste separation, increasing their adaptability to future urban waste management needs.

However, the system does come with some drawbacks. The high initial investment costs for installation and equipment are a significant barrier. Additionally, convincing the municipality and other stakeholders to adopt this system may require substantial effort, as the upfront costs and the permanent use of public space could raise concerns. Nevertheless, the press ORAC system presents a promising solution for efficient and scalable waste management in urban environments.



(a) Press ORAC (SIDCON)

(b) Locations where underground press containers are used

Figure 3.7: Overview of underground press containers: (a) Example of a press ORAC by SIDCON, and (b) locations where these containers are implemented.

Alternative 4: Underground Waste Transport System

For this study, a technical manager from OAT Sluisbuurt at Sweco was interviewed to gather detailed insights into the implementation and operation of underground automated waste collection systems (OAT)(section B.7). An Underground Automated Waste Collection System (OAT) is a network of underground vacuum tubes that transport waste from disposal points to a central collection facility, where it is then picked up for processing. Instead of traditional waste bins or containers, waste is deposited into designated inlets located throughout the neighborhood. At scheduled times, the system uses suction to transport the waste through underground pipelines to a central collection point, reducing the need for visible waste containers in public spaces. This system is currently being implemented in Sluisbuurt, Amsterdam, by the Finnish company MariMatic, and it is already in use in Almere and Arnhem [van Zoelen, 2017, Gemeente Almere, nd, Centralned, nd]. Recently, it was announced that Schieveste, an area near Schiedam Station along the A20, will also implement an OAT system. This project, is now integrated into the development plans of Dura Vermeer, which is working with Envac to bring the system to Schieveste.

The main advantages of an underground waste transport system lie in its space efficiency and its ability to reduce transport movements. Since waste is transported directly to a central location, there is no need for traditional waste trucks to navigate through the neighborhood as frequently, leading to lower traffic congestion and emissions. The collection process itself is also less labor-intensive, as there is no need for manual bin emptying or container transportation. Additionally, the system allows for waste separation, enabling better recycling opportunities. Importantly, the municipality supports this solution (section B.4), as it aligns with long-term sustainability and urban planning goals.

However, the disadvantages of an OAT system are significant. High investment costs are one of the biggest challenges, as the system requires extensive underground infrastructure. This includes installing a network of waste transport pipelines throughout the entire neighborhood, which demands sufficient underground space—a factor that can be difficult in densely built environments. Additionally, maintenance costs can be substantial, with risks of blockages, system malfunctions, and early-stage technical issues that may require costly repairs. Another critical drawback is that the system does not utilize existing waste collection infrastructure, meaning a complete transition is required, rather than a gradual upgrade of current systems.

Despite these challenges, the underground waste transport system represents a high-tech, space-efficient, and modern approach to waste collection, with significant potential for urban areas prioritizing sustainability and reduced waste-related transport movements.

Figure 3.8: Underground Waste Transport System (OAT) [Sweco Nederland, nd]

3.2.2. Score alternatives on requirements

In section 3.1, requirements were defined based on the objectives of all stakeholders and the considerations involved in the redevelopment of the Dreven, Gaarden, and Zichten neighborhoods. In Table 3.4, each requirement is evaluated for each alternative. A "+" indicates that the alternative performs positively, meaning it meets or exceeds the requirement, while a "-" signifies that the alternative performs less effectively in meeting the requirement.

Figure 3.9: Underground Waste Transport System (OAT) Inlet [MariMatic Group, 2020]

Unlike the stakeholder weightings used in the MAMCA analysis, this scoring was not assigned by stakeholders themselves. Instead, the researcher conducted the evaluation based on desk research, expert interviews, and qualitative analysis of each alternative's characteristics. The scores reflect an objective comparison derived from available data and stakeholder insights rather than direct stakeholder input. However, the reasoning behind each score is based on the previously outlined descriptions of each alternative, which can be referred to for a detailed justification of the evaluations.

The alternatives are scored relative to the baseline alternative, which is the current ORAC system. For this reason, all scores in the first column (baseline) are marked as +/- with a yellow background, indicating the current situation. The remaining columns show whether the alternatives perform better or worse compared to the baseline alternative for each requirement.

Table 3.4: Evaluation of Alternatives Against Requirements

Requirement	**A.0. Underground Containers (ORAC)**	**A.1. Roll Containers in Indoor Storage**	**A.2. Indoor Press Containers**	**A.3. Press Underground Containers (ORAC)**	**A.4. Underground Waste Transport System**
Functional Constraints					
FC1: Capacity meets weekly waste volume	+/-	- -	+ +	+ + +	+ + +
FC2: Supports separate collection	+/-	- - -	- -	++	+ + +
FC3: Accessible within 50m of residence	+/-	+ + +	+ + +	+/-	+ +
FC4: Meets safety and accessibility standards	+/-	- -	- - -	+/-	+ + +
Non-Functional Constraints					
NFC1: Minimal footprint	+/-	- - -	- -	+ +	+ +
NFC2: Matches neighborhood aesthetics	+/-	- - -	- -	+/-	+ + +
NFC3: Easy maintenance	+/-	- -	- -	-	- - -
Functional Objectives					
FO1: Minimizes walking distance	+/-	+ + +	+ + +	+/-	+ +
FO2: Includes smart monitoring	+/-	- - -	+	+ +	+ + +
FO3: Efficient routing for collection	+/-	- - -	- -	+ +	+ + +
Non-Functional Objectives					
NFO1: Reduces emissions	+/-	- - -	- -	+ +	+ + +
NFO2: Cost-effective in implementation	+/-	- -	+	+ + +	- - -
NFO3: Low maintenance and operational costs	+/-	- - -	- -	+	- - -

3.3. Implementation of Alternatives in the Estimation Model

After designing the different waste collection alternatives, it is essential to evaluate how each alternative performs against the predefined criteria in section 3.1. To achieve this, a detailed estimation was conducted for investment costs, operational costs, and space usage (both indoor and public space). These factors were selected because it could be reliably estimated based on stakeholder interviews, expert input, and available data. Given the time constraints of this study, it was not feasible to conduct detailed estimations for every criterion. Instead, the focus was placed on the most relevant and measurable aspects, ensuring a balance between data availability and research feasibility.

In subsection 3.3.1 and its subsections, the methodology for estimating investment costs, operational costs, and space usage (both indoor and public) for each alternative is elaborated. These sections include screenshots from the Excel model where calculations were performed. All estimations were verified by stakeholders with relevant expertise; however, in some cases, stakeholders were unable or unwilling to provide verification. Estimated parameters are highlighted in yellow, while the remaining calculations were automatically processed in Excel.

For other criteria, such as waste tax for households, residents' service fees (Staedion), ease of use, transport movement, waste separation score, and ease of implementation, a relative ranking from 1 to 10 was applied. This approach was chosen because the primary goal is to compare the differences between alternatives rather than obtain exact values. Additionally, these criteria are inherently more qualitative and difficult to measure precisely, making a ranking system more appropriate for evaluation.

Moreover, the absolute values of the criteria are not required for the MAMCA input. The MAMCA focuses on the relative comparison of alternatives rather than their absolute performance. Therefore, all criteria values were normalized on a 0 to 1 scale to ensure a clear and consistent comparison between alternatives, as further explained in section 4.1.

3.3.1. Estimation Calculations in Excel Overview

Figure 3.10 provides an overview of the key parameters, each alternative, and the calculated results. The general assumptions are also listed. The yellow cells can be adjusted, and any changes will directly influence the outcomes.

The most important assumptions that apply to all alternatives include that all data is estimated. The model only considers residual waste to simplify the calculations. Including multiple waste streams would have made the model too complex, and there was insufficient data to make precise estimates per waste stream. Although CBS data is available to estimate total waste per stream, there was a lack of specific data on the collection process, such as frequency and operational details per waste type. Therefore, this simplification was necessary.

Additionally, illegal waste dumping (bijplaatsingen) is assumed to be equal across all alternatives, meaning that any associated costs are not factored into the calculations. Estimating these costs is highly uncertain, as it depends on behavioral aspects that this study does not address. Similarly, pest control costs are excluded, as stakeholders indicated that these costs are difficult to estimate in advance due to resident behavior, such as the cleanliness of waste storage areas.

Furthermore, cost aggregation was applied, meaning that all costs are combined in the outcome. This approach was chosen because later recommendations will address cost distribution. Since a collective decision on the waste collection alternative requires assessing total costs rather than just individual costs per stakeholder, this method was preferred.

Figure 3.10 also provides a clear overview of the key parameters. Some parameters are constant across all alternatives, such as the total amount of waste generated per week. This was calculated based on the capacity requirement explained in section 3.1. Other parameters vary, such as emptying costs. HMS was asked for verification, but since this could not be provided, these costs were estimated based on labor and fuel expenses.

The capacity of each alternative was estimated with more certainty, as these values are often standardized. For example, the dimensions of a mini press container were provided by Heijmans, as shown in Figure 3.15. Sidcon provided capacity estimates for both a standard ORAC and a press ORAC, noting that the press mechanism reduces the capacity by approximately 1 m^3. The capacity of press alternatives is further increased by the compaction factor, which is explained per alternative later in this chapter.

Appendix: Waste Collection Alternatives

In Dreven, Gaarden and Zichten

Alternatives	
A0	Baseline Alternative: current ORACs
A2	Indoor Roll Containers
A3	Indoor Press Containers
A4	Press ORACs
A5	Underground Waste Transport System (OAT)

Note

data is estimated

Uniform waste type – No distinction is made between waste streams; all calculations assume residual waste.

Illegal dumping – Assumed equal across scenarios and excluded from the study as a behavioral issue.

Pest control – Not considered; potential extra costs in roll container scenarios are omitted for simplicity.

Cost aggregation – All costs are shown as totals; cost distribution among stakeholders can be determined later.

Key Figures:			
Waste per person	**300**	kg/pp/year	CBS data 2023
Waste per person per week	5,8	kg/pp/week	
Number of people in 2040	27200	persons	
Waste per week	160.000	kg/week	
Density of residual waste	135	kg/m3	
Waste volume per week	1.185	m3/week	
ORAC emptying	50	€/ container	
Rol container emptying	20	€/container	
Press container emptying	100	€/container	
Press ORAC emptying	50	€/container	
OAT emptying	100	€/emptying	
ORAC capacity	5	m3	
Rol container capacity	0,66	m3	
Press container capacity	25	m3	
Press ORAC capacity	4	m3	*1m3 less because of pressmechanism
OAT capacity	-	m3	

OUTCOME

Alternatives		Investment Costs		Operational Costs		Total Costs	1000000
A0	Baseline Alternative: current ORACs		0	€	1,63	€	1,63 miljoen
A2	Indoor Roll Containers	€	7,88	€	2,04	€	9,92 miljoen
A3	Indoor Press Containers	€	2,84	€	0,26	€	3,11 miljoen
A4	Press ORACs	€	1,36	€	0,25	€	1,60 miljoen
A5	Underground Waste Transport System (OAT)	€	24,07	€	0,99	€	25,06 miljoen

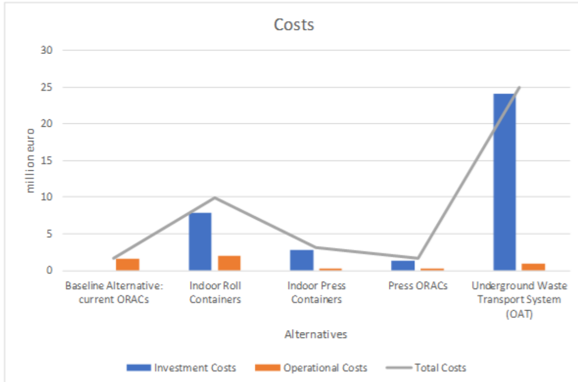


Figure 3.10: Overview page with different alternatives, key figures, and outcomes

Estimation Calculations A0: Current ORACs

In Figure 3.12, the assumptions specific to this alternative are presented. The first assumption is that an ORAC is emptied on average 1.3 times per week, as indicated by HMS during the interview (section B.3).

Maintenance costs are estimated at €600 per ORAC per year. HMS could not verify this amount, but it was assumed to be half the maintenance cost of a press ORAC (which was verified by Sidcon), as standard ORACs do not require maintenance for a compaction mechanism.

The calculation indicates that 237 ORACs would be needed. However, there are also ORACs for glass, paper, and other recyclables, as shown in Figure 2.6. Therefore, the 315 ORACs currently present in the neighborhood, based on GIS data, are retained in this scenario. These 315 ORACs will be emptied 46% more frequently, as waste production is projected to increase by 46%, as calculated in the requirement analysis (subsection 3.1.1). The number of collections per year is determined by taking the current weekly average of 1.3 collections per ORAC, increasing it by 46%, and multiplying by 52 weeks per year.

ORAC dimensions can vary, but for this estimation, an average above-ground footprint of 3 m^2 was used, based on dimensions presented in Figure 3.11. This value is multiplied by the number of ORACs in the neighborhood to determine the total occupied surface area in public space.

There are no investment costs for this alternative, as the existing ORACs remain in place and no indoor waste collection rooms are required. The only operational costs are related to maintenance and emptying costs.

Figure 3.11: Dimensions ORAC

Estimation Calculations A1: Indoor Roll Containers

The key assumptions for this alternative are that the roll containers are collected twice per week, as agreed upon by HMS, Staedion, and Heijmans for the first buildings to be completed. The capacity per roll container is 0.66 m^3, as shown in Figure 3.14, where a roll container is listed as 660 liters, which converts to 0.66 m^3. This capacity is multiplied by two since the roll containers are emptied twice per week.

The roll containers must be transported from the indoor waste storage area to the street, where it is placed at designated collection points for HMS to collect them. Figure 3.5c illustrates these collection areas, which resemble parking spaces but are specifically designated for roll

A0 Baseline Alternative: current ORACs

SWECO

Assumptions and extra explanation:

1. ORACs are emptied an average of 1.3 times per week according to the HMS.
2. ORAC maintenance costs are estimated at €600 per year, half the cost of a press ORAC.
3. According to calculations, 237 ORACs are needed, but 315 exist due to separate waste streams.
4. The existing 315 ORACs will be maintained.
5. Current ORACs will be emptied 46% more frequently due to increased waste generation in 2040.
6. The number of emptyings is based on the average of 1.3 per ORAC per week plus a 46% increase.
7. An ORAC has an average surface area of 3 m² above ground.
8. The total surface area in public space is 945 m² above ground.

Key Figures:

Waste per week	160000	kg/week	
Density of residual waste	135	kg/m3	
Waste volume per week	1.185	m3/week	
ORAC emptying	50	€/ container	
ORAC capacity	5	m3	
Average emptying	1,3	ORAC/week	
ORAC maintenance costs	600	€/ORAC/year	
Number of ORACs needed	237		
Number of ORACs in DGZ	315	aantal	GIS ORAC location map
Extra emptyings	46%		
Number of emptyings per week	554,40	emptyings/week	
Number of emptyings per year	28828,8	emptyings/jaar	
ORAC surface area	3,0	m2/orac	
Total surface area	945	m2	

Cost Item	Description	Unit	Unit Price	Quantity	Total amount	Total Cost (euro)
	Investment Costs					
1	*Staedion*					
1.1	Investment in indoor waste storage room		€ -	0	0	
1.2	Investment in containers		€ -	0	€ -	
1.3			€ -	0	€ -	
	sum (rounded)					€ -
2	*HMS*					
2.1	Investment material		€ -		€ -	
2.2			€ -		€ -	
2.3			€ -		€ -	
2.4			€ -		€ -	
	sum (rounded)					€ -
3	*Municipality of The Hague*					
3.1						
3.2						
3.3						
	Operational Costs					
4	*Staedion*					
4.1	Waste disposal on the street					
4.2	Cleaning of waste storage rooms					
4.3	Cleaning of containers		€ -		€ -	
5	*HMS*					
5.1	Emptying costs	€/emptying	€ 50	28.829	€ 1.441.440	
5.2						
	sum (rounded)					€ 1.441.440
6	*Municipality of The Hague*					
6.1	Maintenance costs	€/container	€ 600	315	€ 189.000	
	sum (rounded)					€ 189.000
	Investement costs total					0
	Operational costs total					€ 1.630.440
	Total Costs					**€ 1.630.440**

Figure 3.12: Baseline Alternative Estimation: current ORACs

containers. Staedion is required to hire personnel to perform this task twice per week per building. These costs were estimated at €161 per container per year, based on Staedion's calculations for the first completed building. Additionally, Staedion calculated the cleaning costs, which amount to approximately €7 per m² per year for the waste storage area and €13 per container per year for cleaning the containers themselves.

For the investment costs, Staedion determined that the cost of constructing an indoor waste storage area is €3,700 per m², based on the first completed buildings where such spaces were implemented. The storage area must meet specific requirements, including sufficient maneuvering space for roll containers. HMS provided a list of requirements to Heijmans and Staedion, which served as the basis for designing the first waste storage area. The total square meters of this storage area were divided by the number of roll containers it accommodates, resulting in an estimated 2 m² per container. Using this requirement, the total required indoor and public space usage was calculated by multiplying the required m² per container by the total number of containers.

Since the roll containers must be placed on the street twice per week, the total indoor space required equals the total public space usage, meaning these containers permanently occupy designated areas in the public space, as shown in Figure 3.5c.

The total number of collections per year was determined by multiplying the number of containers by 2 (for twice-weekly collection) and by 52 weeks. In addition to the costs associated with indoor waste storage, new roll containers were also considered, with prices based on an online search indicating a cost of €200 per unit [Kruizinga,]. Moreover, HMS stated in their interview that their current fleet cannot accommodate roll container collection if this system is implemented in all new buildings (section B.3), as the required trucks differ from those used for ORAC emptying. Therefore, it was estimated that three additional trucks would be necessary, with an average cost ranging from €150,000 to €200,000, depending on the required specifications [Beequip, nd]. HMS also indicated that additional personnel would be needed; however, an estimate could not be provided, so these costs are excluded from the calculations due to a lack of reliable data.

The operational costs consist of the placement of containers on the street by Staedion, cleaning costs, and emptying costs.

A1 Indoor Roll Containers

SWECO

Assumptions and extra explanation:

1. The roll containers will be collected twice a week, hence the capacity is multiplied by two.
2. Staedion provided the costs for placing containers on the street, and cleaning both containers and waste storage rooms.
3. The roll container surface area was provided by Staedion, based on HMS guidelines for required space and maneuverability.
4. Investment costs per m² for indoor waste collection were based on Staedion's first building project.
5. Total surface is calculated as the number of needed containers multiplied by the surface area required per container.
6. The public space surface area equals the indoor surface area as the same space is needed for container collection.
7. The number of emptyings per year is calculated as the number of containers × 2 × 52 weeks.
8. The average purchase price of a plastic roll container is €200 (source: internet).
9. A truck costs approximately €150,000 (source: internet). It is estimated that three extra truck is needed for the district.
10. No additional personnel costs for HMS were considered for this alternative, as HMS could not provide this data.

Key Figures:

Waste per week	160.000,00	kg/week
Density of residual waste	135,00	kg/m3
Waste volume per week	1.185,19	m3/week
Roll container emptying	€ 20,00	€/container
Roll container capacity	0,66	m3
With two-weekly emptying	1,32	m3
Placing containers on the street	€ 161,15	€/container/year
Cleaning of waste storage rooms	€ 7,02	€/m2/year
Cleaning of containers	€ 12,74	€/container/year for cleaning 6x/year
Surface area per roll container	2,19	m2/container
Purchase of waste storage room	€ 3.686,99	€/m2
Total indoor surface area	1.966	m2
Number of containers emptied biweekly	898	containers
Number of emptyings per year	93.378	emptyings/year

Cost Item	Description 0	Unit	Unit Price	Quantity	Total amount	Total Cost (euro)
	Investment Costs					
1	*Staedion*					
1.1	Investment in indoor waste storage room	m2	€ 3.686,99	1.966	€ 7.249.839	
1.2	Investment in containers	€/container	€ 200,00	898	€ 179.574	
1.3			€ -		€ -	
	sum (rounded)					**€ 7.429.412**
2	*HMS*					
2.1	Investment material				€ -	
2.2	Investment extra trucks for collection waste	€/truck	€ 150.000	3	€ 450.000	
2.3		0	€ -		€ -	
2.4		0	€ -		€ -	
	sum (rounded)					**€ 450.000**
3	*Municipality of The Hague*					
3.1						
3.2						
3.3						
	Operational Costs					
4	*Staedion*					
4.1	Waste disposal on the street	€/year/container	€ 161,15	898	€ 144.691	
4.2	Cleaning of waste storage rooms	€/m2/year	€ 7,02	1.966	€ 13.798	
4.3	Cleaning of containers	€/year/container	€ 12,74	898	€ 11.439	
0	**sum (rounded)**					€ 169.928
5	*HMS*					
5.1	Emptying costs	€/per emptying	€ 20	93.378	€ 1.867.565	
5.2					€ -	
0	**sum (rounded)**					€ 1.867.565
6	*Municipality of The Hague*				€ -	
6.1	Maintenance costs	€/container	€ -		€ -	
	Investement costs total					€ 7.879.412,44
	Operational costs total					**€ 2.037.492,94**
	Total Costs					**€ 9.916.905**

Figure 3.13: A1: Indoor Roll Containers Estimation

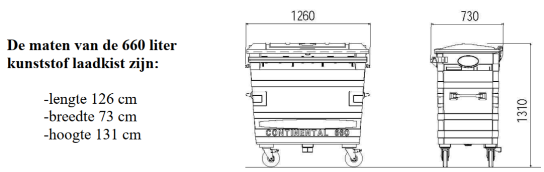


Figure 3.14: Dimensions Roll Container

Estimation Calculations A2: Indoor Press Containers

There are various types and sizes of press containers. The press container used in this estimation is a mini press container, with its dimensions shown in Figure 3.15. The compaction ratio for residual waste is 1:5, meaning the capacity is calculated as five times larger than its actual volume [Recycling Nederland, nd].

The press containers must be transported outside to be placed on the street for collection by HMS. The cost for this process is estimated to be 25% higher than for roll containers, as it requires the use of a mover (Figure 3.6a), which slows down the process compared to a single roll container. Apart from this, many costs remain the same as in the indoor roll container alternative, as verified by Staedion. The number of required press containers was determined by calculating the total weekly waste production and dividing it by the compacted capacity, assuming that press containers are emptied once per week.

The public space usage is calculated by taking the total surface area of all press containers and multiplying it by two, as the truck collecting the press containers must be able to position itself in front of the container. This requires an accessible, hardened road surface free of parked vehicles or other obstructions. The collection process is illustrated in Figure 3.6b.

The total number of collections per year is determined by multiplying the number of press containers by 52, as it is emptied once a week.

The purchase price of a press container is estimated at €30,000, based on a requested quotation [Recycling Nederland, nd]. A new collection truck is also required. Since this truck must be equipped with additional features, such as a lifting arm to pull the press container onto the vehicle, the cost is estimated at €200,000, compared to €150,000 for the roll container collection truck. It is estimated that only one truck will be needed, compared to the three required for roll containers, due to the significantly lower number of press containers required.

The maintenance costs for the press containers are assumed to be the same as those for underground press containers (section B.6).

The investment costs consist of the construction of indoor waste storage areas per m², the purchase of press containers, and the acquisition of a truck for press container collection.

The operational costs include the transportation of press containers to the street, cleaning costs for the waste storage areas, collection costs, and maintenance costs for the containers.

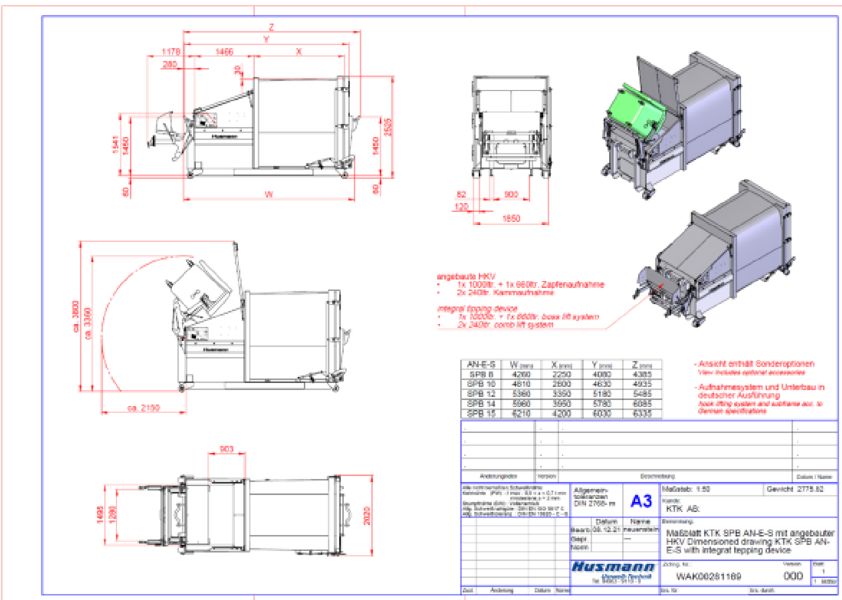


Figure 3.15: Dimensions Mini Press Container (provided by Heijmans)

A2 Indoor Press Containers

Assumptions and extra explanation:

1. A specific type of press container was used, namely a mini press container.
2. The compaction factor is 1:5 for residual waste, increasing the capacity accordingly.
3. It is assumed that placing a press container on the street is 25% more expensive than a roll container.
4. Many cost values match those of the roll containers provided by Staedion.
5. The required number of press containers is based on capacity, compaction factor, and weekly emptying.
6. Public space must be twice as large to allow truck access for press container collection.
7. The number of containers multiplied by 52 gives the total number of emptyings per year.
8. A price quote was requested to determine the purchase price of a press container.
9. A specialized truck is required, estimated to cost €150,000–€200,000 (source: internet).
10. Maintenance costs are estimated to be the same as for an underground press container: €1,200 per year.

Key Figures:

Waste per week	160.000	kg/week	
Density of residual waste	135	kg/m3	
Waste volume per week	1.185	m3/week	
Press container emptying	100	€/ container	
Press container capacity	6	m3	
Compaction factor	5	1 on 5	
Capacity of waste press container	30	m3	
Placing press container on the street	€ 201		
% more expensive than roll cont. placement	25%	*takes more time, mover needed	
Cleaning of waste storage rooms	€ 7	€/m2/year	
Surface area per press container	10	m2	
Purchase of waste storage room	€ 3.687	€/m2	
Total indoor surface area	395	m2	
Public space surface area	790	m2	*doubled
Number of press containers	40	containers	
Number of emptyings per year	2054	emptyings/year	

Cost Item	Description 0	Unit	Unit Price	Quantity	Total amount	Total Cost (euro)
	Investment Costs					
1	*Staedion*					
1.1	Investment in indoor waste storage room	m2	€ 3.687	395	€ 1.456.589	
1.2	Investment in containers	€/container	€ 30.000	40	€ 1.185.185	
1.3				1		
	sum (rounded)					**€ 2.641.774**
2	*HMS*					
2.1	Investment material	0			€ -	
2.2	Investment extra trucks for collection waste	€/truck	€ 200.000	1	€ 200.000	
2.3		0			€ -	
2.4		0			€ -	
	sum (rounded)					**€ 200.000**
3	*Municipality of The Hague*					
3.1						
3.2						
3.3						
	Operational Costs					
4	*Staedion*					
4.1	Waste disposal on the street	€/year/container	€ 201	40	€ 7.958	
4.2	Cleaning of waste storage rooms	€/m2/year	€ 7	395	€ 2.772	
4.3	Cleaning of containers	€/year/container				
0	**sum (rounded)**					**€ 10.730**
5	*HMS*					
5.1	Emptying costs	€/per emptying	€ 100	2.054	€ 205.432	
5.2						
	sum (rounded)					€ 205.432
6	*Municipality of The Hague*					
6.1	Maintenance costs	€/container	€ 1.200	40	€ 47.407	
						€ 47.407
	Investement costs total					€ 2.841.773,83
	Operational costs total					**€ 263.570**
	Total Costs					**€ 3.105.344**

Figure 3.16: A2: Indoor Press Containers Estimation

Estimation Calculations A3: Press Underground Containers

In this alternative, the collection process remains the same as with the current ORACs, meaning collection costs are identical. The capacity of a press ORAC is reduced by 1 m^3 due to the compaction mechanism. However, the compaction ratio of 1:6 for residual waste compensates for this reduction, effectively increasing the container's capacity (Interview Sidcon, section B.6).

The above-ground footprint remains the same as a regular ORAC, as shown in Figure 3.11. The required number of press ORACs is determined based on their capacity and the total weekly waste production. The total public space usage is calculated by multiplying the above-ground footprint by the number of required press ORACs. Since the press ORACs are entirely located in public space, the required indoor space is zero, as no indoor waste storage rooms are needed.

The total number of collections per year is determined by multiplying the number of press ORACs by 52, assuming each container is emptied once per week.

The investment cost per press ORAC is approximately €27,500, based on a quote requested from Sidcon. The maintenance cost is €1,200 per year per press ORAC (Interview Sidcon, section B.6).

The investment costs consist solely of the purchase of press ORACs. The operational costs include collection costs and maintenance costs.

A3 Press Underground Containers

Assumptions and extra explanation:

1. Emptying costs are the same as regular ORACs since they are emptied the same way.
2. Capacity is reduced by 1 m³ due to the press mechanism.
3. The compaction factor is 1:6 for residual waste, increasing ORAC capacity.
4. Above-ground surface area remains 3 m², same as a regular ORAC.
5. The required number of ORACs is calculated based on capacity and weekly waste volume.
6. Indoor surface is 0, as ORACs are only placed in public space.
7. Total emptyings per year = number of press ORACs × 52 weeks.
8. A press ORAC costs approximately €27,500 (Sidcon quote).
9. Maintenance costs for a press ORAC are €1,200 per year (Sidcon)

SWECO

Key Figures:

Waste per week	160000	kg/week	
Density of residual waste	135	kg/m3	
Waste volume per week	1185	m3/week	
Press ORAC emptying	50	€/container	
Press ORAC capacity	4	m3	
Compaction factor	6	1 on 6	
Capacity waste press ORAC	24	m3	
Surface ORAC	3,0	m2	
Number of Press ORACs	49	Press ORACs	*weekly emptying
Indoor surface area	0	m2	
Public space surface area	148	m2	
Number of emptyings per year	2568	emptyings/year	

Cost Item	Description	Unit	Unit Price	Quantity	Total amount	Total Cost (euro)
	Investeringskosten					
1	*Staedion*					
1.1	Investment in indoor waste storage room		€ -	0	0	
1.2	Investment in containers		€ -	0	€ -	
1.3	**sum (rounded)**		€ -	0	€ -	€ -
2	*HMS*					
2.1	Investment material		€ -	1	€ -	
2.2	Investment extra trucks for collection waste		€ -	1	€ -	
2.3	x		€ -	1	€ -	
2.4	x		€ -	1	€ -	
	sum (rounded)					€ -
3	*Gemeente*					
3.1		€/container	27500	49	1.358.025	
3.2						
3.3	**sum (rounded)**					**€ 1.358.024,69**
	Operationele kosten					
4	*Staedion*					
4.1	Waste disposal on the street		€ -		€ -	
4.2	Cleaning of waste storage rooms		€ -		€ -	
4.3	Cleaning of containers		€ -		€ -	
						€ -
5	*HMS*					
5.1	Emptying costs	€/emptying	€ 50	2.568	€ 128.395	
5.2						
	sum (rounded)					**€ 187.654**
6	*Gemeente*					
6.1	Maintenance costs	€/container	€ 1.200	49	€ 59.259	
	sum (rounded)					**€ 59.259**
	Investement costs total					€ 1.358.024,69
	Operational costs total					**€ 246.914**
	Total Costs					**€ 1.604.938**

Figure 3.17: A3: Press Underground Containers Estimation

Estimation Calculations A4: Underground Waste Transport System (OAT)

For the estimation of the Underground Waste Transport System (OAT) alternative, an interview was conducted with Hans de Vrij, technical manager of the OAT system being implemented in Sluisbuurt (section B.7). Several assumptions were made regarding the total pipeline length (8 km), the number of inlets where residents deposit their waste, and the number of terminals required for waste collection. These assumptions were verified and adjusted based on expert input from Hans de Vrij, who also provided cost estimates for the system components. It was assumed that the waste inlets would be located inside buildings, requiring the construction of indoor waste storage rooms. The costs per square meter for these waste rooms were taken to be the same as those used for indoor roll and press containers, with cleaning costs provided by Staedion.

According to the technical manager, two waste terminals are required in the district, each equipped with a vacuum suction installation to transport waste through the underground pipelines. These installations incur separate costs for implementation. The terminals are situated in public space, meaning they contribute to public space usage, while the inlets are considered part of indoor space usage. It is assumed that each terminal is emptied once per week. Since this system is not yet operational in The Hague, HMS does not currently have compatible collection trucks, necessitating the purchase of a specialized vehicle. The estimated cost of this truck is €200,000, similar to the cost of a press container truck [Beequip, nd].

The investment costs for this alternative include the construction of indoor waste rooms, installation of inlets for the underground pipeline system, procurement of a specialized collection truck, installation of the underground pipeline network, construction of waste terminals, and the setup of vacuum suction systems. The operational costs consist of cleaning expenses for the indoor waste rooms, maintenance of the inlets, operational costs for the pipelines, terminals, and suction systems, and the costs associated with emptying the terminals.

A4: Underground Waste Transport System

SWECO

Assumptions and extra explanation:

1. Quantity estimates (pipes, inlets, terminals) were verified by the OAT system's technical manager in Sluisbuurt.
2. All costs were also verified by the technical manager.
3. Waste inlets inside buildings are assumed, accounting for indoor space usage.
4. Indoor waste room costs match other indoor alternatives, as provided by Staedion per m².
5. Cleaning costs for these spaces are also included.
6. There are two terminals located in public space.
7. It is assumed that each terminal is emptied once per week.
8. One truck, purchased by HMS, is assumed sufficient, with costs similar to the press container truck.

Key Figures:

Waste per week	160000	kg/week
Density of residual waste	135	kg/m3
Waste volume per week	1185	m3/week
OAT emptying	100	€/emptying
OAT capacity	-	m3
Pipe system	8	km
Collection points	85	points
OAT terminals	2	terminals
Purchase of waste storage r	3.687	€/m2
OAT collection area	5	m2
OAT terminal area	500	m2
Total indoor surface area	425	m2
Total public surface area	1000	m2
Number of emptyings	312	emptyings/year

Cost Item	Description 0	Unit	Unit Price	Quantity	Total amount	Total Cost (euro)
	Investeringskosten					
1	*Staedion*					
1.1	Investment in indoor waste storage room		€ 3.687	425	€ 1.566.971	
1.2	Investment inlets		€ 100.000,00	85	€ 8.500.000,00	
1.3						
	sum (rounded)					**€ 10.066.971**
2	*HMS*					
2.1						
2.2	Investment truck for emptying OAT		€ 200.000	1	€ 200.000	
2.3						
2.4						
	sum (rounded)					**€ 200.000**
3	Gemeente					
3.1	Investment pipe system	€/km	€ 1.000.000,00	€ 8	8.000.000	
3.2	Investment terminal	€/terminal	€ 2.000.000	2	€ 4.000.000	
3.3	Investment installation in terminal **sum (rounded)**	€ / 2 installations	€ 1.800.000		€ 1.800.000	13.800.000
	Operationele kosten					
4	*Staedion*					
4.1	Waste disposal on the street					
4.2	Cleaning of waste storage rooms		€ 7	425	€ 2.982	
4.3	Maintenance inlet		€ 4.000	85	€ 340.000	
	sum (rounded)					€ 342.982
5	*HMS*					
5.1	Exploitation pipe system	€/km	€ 40.000	8	€ 320.000	
5.2	Exploitation OAT terminal	€/terminal	€ 25.000	2	€ 50.000	
	Exploitation OAT terminal installation	€/ installation	€ 125.000	2	€ 250.000	
	Emptying costs	€/emptying	€ 100,00	312	31200	
	sum (rounded)					€ 651.200
6	*Gemeente*					
6.1						
						€ -
	Investement costs total					€ 24.066.970,75
	Operational costs total					**€ 994.182**
	Total Costs					**€ 25.061.153**

Figure 3.18: A4: Underground Waste Transport System (OAT) Estimation

3.3.2. Implementation of Alternatives Using Scaled Criteria (1–10)

The scores for the remaining criteria (rated on a scale from 1 to 10) were assigned based on insights from interviews and additional desk research, when available. Each criterion or sub-criterion will be explained in detail in the following sections.

Ease of Use

The ease of use criterion assesses how user-friendly the waste collection system is for both residents and waste collection workers. This includes factors such as the physical effort required to open the system, the height at which waste must be lifted to reach the opening, and the overall accessibility for different demographic groups. Additionally, the criterion considers the labor intensity for waste collection workers during the emptying process. Table 3.5 presents the scores assigned to each alternative, including references and justifications.

For the current system (A0) with underground waste containers (ORACs) and underground press containers (A3), a score of 7/10 was assigned. Both systems function similarly in terms of ease of use for residents and waste collection workers. The system is easy to use since residents do not need to lift their waste, and the container opening slides open rather than requiring forceful lifting. This makes it accessible to all age groups. A study conducted by the municipality of Nijmegen on the usability of underground containers found that 68% of respondents were satisfied with the ease of use of ORACs [Manders, 2023]. Furthermore, the emptying process for workers is fully mechanized and does not impose a physical burden, as confirmed by HMS during the interview (section B.3).

For indoor roll containers (A1), a score of 3/10 was assigned. Residents must lift their waste to deposit it into the container, which can be challenging for certain groups, such as elderly and vulnerable individuals. A waste collection system should be accessible to all demographic groups, as emphasized in the requirements [College voor de Rechten van de Mens, 2024]. Moreover, the emptying process for workers is highly labor-intensive and ergonomically problematic, causing significant physical strain on collection workers [Gemeente Rotterdam, 2023]. Therefore, this alternative receives the lowest score, as it poses difficulties for both residents and waste collection workers.

The indoor press container (A2) receives a score of 5/10. Similar to the roll container, residents must lift their waste to dispose of it. However, the roll container inside the press container is emptied mechanically, and the press container itself is also emptied mechanically by the waste collection service, as shown in Figure 3.6b. This eliminates the physical strain on collection workers, justifying a higher score than standard roll containers.

For the underground waste transport system (A4), a score of 9/10 was assigned. Residents do not need to lift their waste and can easily deposit it into the inlets. The emptying process is fully automated, minimizing physical effort for waste collection workers. As this system requires the least manual labor and provides high accessibility as the inlets are indoor on short walking distance. Therefore, it receives the highest ease-of-use rating among the alternatives.

Costs: Waste Tax for Households and Resident Service Fees for Staedion

The cost criterion is divided into four subcategories: investment costs, operational costs—both of which are estimated in detail in subsection 3.3.1—and waste tax for households and resident service fees for Staedion. The last two are assessed on a scale from 0 to 10. This scoring method is used to compare how different alternatives might increase or decrease these costs rather than calculating exact values, as waste tax consists of multiple components beyond just collection costs, including processing and disposal expenses [Gemeente Den Haag, 2024a]. This study focuses solely on collection, but because collection costs contribute to the overall waste tax, a significant rise in collection expenses is expected to increase waste tax accordingly. The waste tax score primarily reflects the expected cost increases for the municipality and HMS, while the resident service fee score considers additional investment and maintenance costs for Staedion's waste storage facilities in each alternative.

The waste tax scores are largely based on insights from the HMS interview (section B.3). Additionally, logical reasoning was applied: alternatives with higher investment and operational

Table 3.5: Ease of Use Criterion Score

Ease of Use	Score	Explanation and Reference
A0: Current ORAC	7/10	Residents do not need to lift waste; container opening slides open; fully mechanized emptying process for workers [Manders, 2023].
A1: Indoor Roll Containers	3/10	Residents must lift waste and open a heavy lid; emptying is labor-intensive and ergonomically problematic for workers [Gemeente Rotterdam, 2023, College voor de Rechten van de Mens, 2024].
A2: Indoor Press Containers	5/10	Waste must be lifted into the roll container [College voor de Rechten van de Mens, 2024], but emptying is fully mechanized, reducing physical strain on workers.
A3: Underground Press Containers	7/10	Identical usability to standard ORACs: no lifting required, and emptying is mechanized [Manders, 2023].
A4: Underground Waste Transport System	9/10	No lifting required for residents; waste disposal is easy, and the system is fully automated with minimal manual labor required (Figures 3.8 and 3.9).

costs are more likely to cause an increase in waste tax. Therefore, alternatives with higher estimated costs in subsection 3.3.1 receive higher scores. In Table 3.6, the assigned values for household waste tax are presented, while Table 3.6 shows the assigned values for resident service fees for Staedion.

The baseline alternative, A0 (Current ORAC), receives a score of 0/10 because no major changes are made to the existing system. Although more frequent collections will be required, the increase in operational costs is assumed to be negligible. A1 (Indoor Roll Containers) receives a high score of 9/10, as HMS indicated that this alternative would lead to higher waste tax due to an inefficient process, including labor-intensive and slow collections, the absence of fill-level sensors, and the need for additional personnel and trucks. These increased costs would ultimately be passed on to residents via waste tax (section B.3). Furthermore, this alternative was among the most expensive in subsection 3.3.1.

A2 (Indoor Press Containers) receives a score of 7/10 because it is more efficient than roll containers. Compacted waste reduces collection frequency, and fill-level sensors can optimize emptying schedules. Additionally, mechanical emptying reduces the physical burden on workers, as shown in Figure 3.6b (section B.3). However, investment is required in specialized trucks with lifting mechanisms. A3 (Underground Press Containers) receives a score of 2/10 because it requires an investment of approximately €27,500 per press ORAC section B.6, but operational costs remain similar to A0. Additionally, fewer collections are needed due to waste compaction, further reducing costs.

A4 (Underground Waste Transport System) receives the highest score of 10/10. This alternative requires a completely new infrastructure, including underground pipelines, terminals, and suction systems. The collection process differs significantly from existing systems, requiring investment in new specialized trucks. As the most expensive alternative according to the cost estimates in subsection 3.3.1, it is assigned the highest score.

The assessment of resident service fees for Staedion focuses on whether each alternative

Table 3.6: Waste Tax for Households Criterion Score

Waste Tax for Households	Score	Explanation and Reference
A0: Current ORAC	0/10	No significant changes; slight cost increase due to higher collection frequency.
A1: Indoor Roll Containers	9/10	High labor and operational costs; inefficient collection method; requires additional trucks and personnel [Gemeente Den Haag, 2024a], (section B.3).
A2: Indoor Press Containers	7/10	More efficient due to waste compaction and sensor-based collection; requires investment in specialized trucks (section B.3).
A3: Underground Press Containers	2/10	Investment cost per unit €27,500 (section B.6); operational costs remain similar to A0, with reduced collections.
A4: Underground Waste Transport System	10/10	Highest investment cost; requires new infrastructure, terminals, and specialized trucks (subsection 3.3.1).

leads to higher costs for Staedion and whether these costs would be passed on to tenants. Staedion provided several cost estimates used in the financial assessment of each alternative (subsection 3.3.1). Additionally, logical reasoning was applied: alternatives with high investment or operational costs for Staedion—such as indoor space investment per m^2, container purchase, cleaning expenses, and the cost of moving waste containers to the street—receive a high score, while alternatives with lower costs receive a lower score.

A0 receives a score of 0/10, as no additional investments are required, and the current system remains unchanged. Staedion does not need to invest in indoor waste storage facilities, nor does it incur operational costs for setting waste outside or maintaining indoor waste rooms.

A1 receives a score of 9/10, as it entails high investment costs due to the significant amount of indoor space required for roll containers. This leads to high upfront investment costs, as shown in Figure 3.13. Additionally, Staedion must maintain these spaces, hire personnel to move the containers outside twice per week, and cover container cleaning costs. These expenses result in high investment and operational costs for Staedion, which the corporation has indicated will be passed on to tenants, many of whom are social housing residents (section B.5).

A2 receives a score of 7/10 because, although it still requires indoor waste storage, compacting the waste reduces the number of containers needed, significantly lowering the required space and investment costs. Furthermore, waste only needs to be placed on the street once per week, reducing operational costs compared to A1. While Staedion would still face increased costs compared to the baseline alternative A0, they would be lower than those associated with A1.

A3 receives a score of 0/10, as it maintains the current process and does not impose additional costs on Staedion for indoor waste storage or operational expenses such as moving waste to the street. Although co-financing underground press containers could be recommended in this alternative, potentially increasing costs, this aspect will be discussed in the recommendations.

A4 receives the highest score of 10/10, as the installation of inlets within buildings requires significant investment, making it the most expensive alternative for Staedion, as shown in Figure 3.18. Additionally, maintaining the inlets is costly, and Staedion expects these expenses to be passed on to residents through increased service fees.

Table 3.7: Resident Service Fees for Staedion Criterion Score

Resident Service Fees for Staedion	**Score**	**Explanation and Reference**
A0: Current ORAC	0/10	No investment or operational costs for Staedion; waste is collected in public space.
A1: Indoor Roll Containers	9/10	High investment costs for indoor waste rooms, cleaning, and container transport; costs passed to tenants (Figure 3.13).
A2: Indoor Press Containers	7/10	Lower investment than A1 due to waste compaction; fewer containers and lower operational costs (Figure 3.16).
A3: Underground Press Containers	0/10	No additional costs for Staedion; waste collection remains in public space.
A4: Underground Waste Transport System	10/10	Highest investment costs for inlets inside buildings and high maintenance costs (Figure 3.18).

Sustainability: Transport Movement and Waste Separation Goals

The sustainability criterion is divided into two subcategories: transport movement and waste separation goals. Transport movement assesses whether an alternative generates more collection trips, resulting in a lower sustainability score due to higher emissions. Alternatives that utilize fill-level sensors reduce unnecessary trips, as collection is only performed when containers are sufficiently full [Supporter van Schoon, 2024]. Additionally, alternatives with waste compaction require fewer trips as more waste can be collected per trip, improving efficiency. Waste separation goals evaluate the potential of each alternative to facilitate waste sorting. First, the transport movement scores are explained in Table 3.8, followed by the waste separation goal scores in Table 3.9.

A0 receives a score of 6/10 as collection is based on fill-level sensors, preventing unnecessary trips for empty containers [Supporter van Schoon, 2024]. However, waste is not compacted, limiting further efficiency gains.

A1 receives a score of 2/10 since collection is not based on fill-level sensors, and waste is not compacted, leading to inefficient transport operations.

A2 receives a score of 7/10 as waste can be collected based on fill-level sensors and is compacted, reducing collection frequency [Supporter van Schoon, 2024, Milieu Service Nederland, nd]. However, the efficiency of the fill-level sensors depends on how press containers are implemented. ORACs are automatically scheduled for collection when they reach 80% capacity and are always available for emptying, whereas indoor press containers require additional handling. They must first be moved outside using a mover before a truck can collect them, as shown in Figure 3.6a. This logistical challenge results in a slightly lower score compared to underground press containers.

A3 receives a score of 8/10 because waste is compacted and scheduled efficiently for collection once containers reach 80% capacity, optimizing transport movements [Supporter van Schoon, 2024, Milieu Service Nederland, nd].

A4 receives a score of 10/10 as this alternative requires trucks to visit only two central collection points, which can significantly reduce local emissions in urban areas [Miller and Spertus, 2013]. Additionally, waste can be compacted at these terminals, further decreasing the number of collection trips required [Milieu Service Nederland, nd].

Table 3.8: Transport Movement Criterion Score

Transport Movement	Score	Explanation and Reference
A0: Current ORAC	6/10	Collection based on fill-level sensors, preventing unnecessary trips, but no waste compaction [Supporter van Schoon, 2024].
A1: Indoor Roll Containers	2/10	No fill-level sensor usage, no compaction, leading to inefficient transport.
A2: Indoor Press Containers	7/10	Uses fill-level sensors and compacts waste, reducing trips, but requires additional handling for collection (Figure 3.6a) [Supporter van Schoon, 2024, Milieu Service Nederland, nd].
A3: Underground Press Containers	8/10	Compacted waste, efficiently scheduled for collection at 80% capacity [Supporter van Schoon, 2024, Milieu Service Nederland, nd].
A4: Underground Waste Transport System	10/10	Only two collection points for trucks, with waste compacted at terminals, minimizing transport movements [Miller and Spertus, 2013, Milieu Service Nederland, nd].

For the scoring of waste separation goals across the different alternatives, the focus was on their potential rather than actual separation rates, as waste separation heavily depends on resident behavior, which is beyond the scope of this study. Instead, this evaluation assesses whether each waste collection system could be expanded to facilitate waste separation. Literature suggests that source separation yields the best results for effective waste sorting (section 1.4), and analysis of the current waste management process in The Hague has shown that the city performs poorly in comparison to other municipalities regarding waste separation (section 2.2). Therefore, assessing the potential for improved waste separation is essential for addressing this issue.

A0 receives a score of 6/10 as it represents the current system. As seen in Figure 2.6, most ORACs in the area are designated for residual waste, with only a limited number assigned for paper, glass, and a few for PMD. Since residual waste containers are the majority, they do not actively encourage source separation.

A1 receives a score of 2/10 since the initial plans for the newly constructed buildings include only residual waste containers. This decision is driven by space constraints, as roll containers already require more storage area, and developers Staedion and Heijmans aim to minimize the footprint of indoor waste storage. Accommodating additional containers for separate waste streams would increase space requirements. Moreover, since the containers are placed on the street twice per week, separate collection trucks would be needed for each waste stream, leading to inefficient collection routes. Source separation in this alternative would require more containers, additional storage space, and higher operational costs, resulting in a low score.

A2 also scores 2/10 because multiple press containers per building would be required to facilitate waste separation. However, most buildings are only expected to need one press container for residual waste, meaning that adding additional press containers for separate waste streams would unnecessarily increase space usage and investment costs.

A3 receives a score of 7/10 as it provides better potential for waste separation. Since waste is compacted, fewer underground containers are required overall, allowing existing residual waste ORACs to be replaced with containers for separate streams. An additional advantage is that materials such as plastic have an even higher compaction factor (section B.6). Furthermore, collection trucks for separated streams operate dedicated routes, meaning that all PMD containers are emptied on one route, while other waste streams are collected separately, improving efficiency.

A4 is assigned the highest score of 10/10 because this alternative is inherently designed for waste separation. The system already includes three separate waste streams, each with its own dedicated pipeline leading to a central terminal for collection. Glass and paper, which are less suitable for pneumatic waste transport, can still be collected through underground containers, while residual waste, plastic, and organic waste are transported via the pipeline system.

Table 3.9: Waste Separation Criterion Score

Waste Separation Goals	Score	Explanation and Reference
A0: Current ORAC	6/10	Majority of containers are for residual waste, limiting source separation potential (Figure 2.6)
A1: Indoor Roll Containers	2/10	Only residual waste containers planned; adding separate waste streams would require more space and inefficient collection routes.
A2: Indoor Press Containers	2/10	Requires additional press containers per building for separate streams, increasing space use and costs.
A3: Underground Press Containers	7/10	Allows existing residual waste ORACs to be replaced with source-separated containers; plastic compaction further improves efficiency (section B.6)
A4: Underground Waste Transport System	10/10	System is designed for three separate streams, enabling highly efficient waste separation.

Ease of Implementation

The ease of implementation criterion evaluates how easily each alternative can be introduced. Key factors include the extent of infrastructure modifications, whether users need to adapt to new waste disposal practices, and the level of operational adjustments required for the waste collection service.

A0 is assigned a score of 10/10, representing the easiest implementation, as no changes are needed. Residents are already accustomed to this system, and HMS is fully equipped to handle it with the existing infrastructure.

A1 receives a score of 5/10 since it does not utilize the current infrastructure, which is designed for underground containers. Investments are required for roll containers and indoor waste storage rooms. Additionally, HMS must modify its operations by acquiring new collection trucks and hiring additional personnel to manage the increased workload (section B.3).

A2 is assigned a score of 6/10 because, like A1, it does not rely on the existing infrastructure. Investments are needed for indoor waste storage areas and press containers. HMS must also purchase a specialized truck to collect the press containers. However, this alternative requires fewer trucks and personnel than A1, and it demands less space for indoor waste storage, leading to a slightly higher score.

A3 receives a score of 8/10 as it partially utilizes the existing infrastructure. The current HMS trucks are compatible with underground press containers. While new press ORACs must be installed, the concrete pits of the existing ORACs can be reused, minimizing the need for major infrastructural changes.

A4 is assigned the lowest score of 1/10 due to its extensive infrastructure overhaul. This alternative requires the installation of underground waste transport pipes, terminals, and suction systems. Inlets must be integrated into buildings, necessitating significant investments in indoor waste storage areas. Additionally, HMS would have to acquire an entirely new fleet of collection vehicles. Given the scale of these modifications, A4 is the most challenging to implement.

Table 3.10: Ease of Implementation Criterion Score

Ease of Implementation	**Score**	**Explanation and Reference**
A0: Current ORAC	10/10	No changes required; existing system and infrastructure remain unchanged.
A1: Indoor Roll Containers	5/10	Requires new infrastructure, roll containers, and indoor waste storage; HMS needs additional trucks and personnel section B.3.
A2: Indoor Press Containers	6/10	Requires investment in indoor storage and press containers; fewer trucks and personnel needed compared to A1.
A3: Underground Press Containers	8/10	Partially utilizes existing infrastructure; current trucks are compatible, and existing concrete pits can be reused.
A4: Underground Waste Transport System	1/10	Requires a complete infrastructure overhaul, including underground pipes, terminals, and new collection trucks.

3.3.3. Conclusion Research Question 4

This section answers the research question:
Which innovative waste collection methods can be implemented?

The designed alternatives include: indoor roll containers, indoor press containers, underground press containers, an underground waste transport system (OAT), and the current underground container system (ORACs) as the baseline alternative. These alternatives offer various advantages and challenges, with differences in cost, sustainability, space usage, ease of implementation, and operational efficiency.

Each alternative presents trade-offs between cost, efficiency, and sustainability, and stakeholder feasibility. The underground waste transport system (A4), for example, scores high on sustainability by reducing transport movements and enabling effective waste separation. However, it has the highest investment cost and is the most difficult to implement, requiring extensive infrastructural modifications such as underground pipes, terminals, and specialized trucks. The underground press containers (A3) offer a balance between operational efficiency and sustainability, as it reduces transport movements through waste compaction while utilizing the existing waste collection infrastructure.

In contrast, indoor roll containers (A1), which are being implemented in the first phases of the redevelopment, score poorly across multiple criteria. This alternative increases labor-intensive handling for both residents and waste collection workers. It also results in inefficient transport movements due to the lack of fill-level sensors. Additionally, it has high operational and maintenance costs. Indoor press containers (A2) offer improvements over A1 by incorporating waste compaction. This reduces the frequency of collection and lowers long-term operational costs. However, it still requires significant investments in indoor waste storage and specialized collection vehicles.

The choice of an optimal waste collection system depends on the prioritization of criteria by stakeholders. In the results chapter, all criteria scores will be normalized to allow a direct comparison of the alternatives. Furthermore, the MAMCA will determine how each alternative is perceived by different stakeholders. Each stakeholder group has assigned weightings to the criteria based on their priorities, allowing an assessment of which alternative aligns best with their interests.

4 Outcome

4.1. Final Results

This section presents the results of the criteria estimation models and scoring. First, an explanation of the normalization process will be provided, as it is necessary to enable a comparison between the criteria. Subsequently, the final results of the MAMCA will be presented.

4.1.1. Normalization of the Results

Since the values of the criteria are expressed in different units—such as euros, square meters, or scores—all criteria are normalized to allow for comparison. The min-max normalization method has been chosen, as it is a straightforward technique that scales all data between 0 and 1. Two formulas are used, depending on whether a higher value is considered favorable or unfavorable.

In this method, the minimum value of a criterion is assigned a score of 0, while the maximum value is assigned a score of 1 [Ciaburro et al., 2018]. This rule applies to criteria where higher values are considered favorable. For criteria where high values are better (Ease of Use, Transport Movements, Waste Separation Goals, Ease of Implementation), the following formula is applied:

$$X_{\text{scaled}} = \frac{X - X_{\text{min}}}{X_{\text{max}} - X_{\text{min}}} \tag{4.1}$$

For criteria where low values are better (Investment Costs, Operational Costs, Waste Tax for Households, Resident Service Fees for Staedion, Indoor Space Usage, and Collection Space Usage), the following formula is applied:

$$X_{\text{scaled}} = \frac{X_{\text{max}} - X}{X_{\text{max}} - X_{\text{min}}} \tag{4.2}$$

By applying these formulas, all criteria are scaled between 0 (least favorable) and 1 (most favorable), ensuring comparability across different types of data.

In Figure 4.1, the normalized values for each criterion across the alternatives are shown. If an alternative has a score of 0 for a criterion, it will not appear in the diagram, as the value is zero. This visualization provides a clear overview of how the alternatives perform across the criteria. A score of 1 indicates that the alternative performs the best for that specific criterion.

4.1.2. Results of the MAMCA

The results of the MAMCA are presented in Figure 4.2, showing how each alternative is evaluated by different stakeholders. These evaluations are based on the predefined criteria and the weight each stakeholder has assigned to them (subsection 3.1.2). A clear trend in the results is that alternatives requiring indoor waste storage tend to score lower across all stakeholders. This is due to the additional investment needed for indoor facilities, as well as the operational complexity of

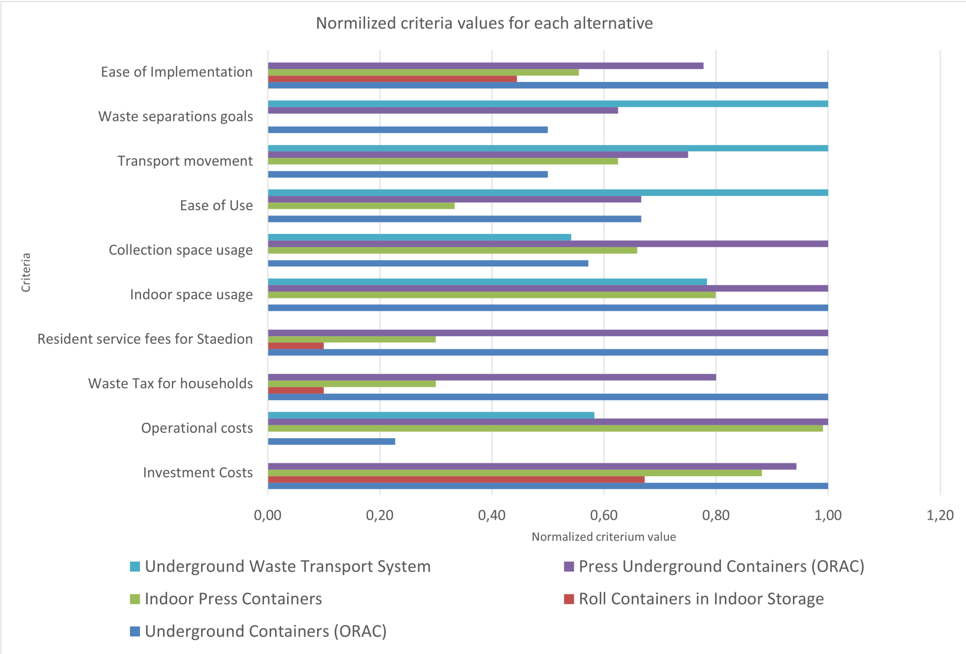


Figure 4.1: Normalized criteria values

moving waste from indoor storage to the street. This results in higher costs and increased space requirements, both indoors and in public areas.

The Indoor Roll Containers alternative receives the lowest overall score from all stakeholders. This alternative performs poorly on nearly all criteria, including high operational costs due to frequent collection and cleaning, high space requirements, and increased service costs as the containers need to be placed on the street multiple times per week. Moreover, it is not sustainable, difficult to implement, and not user-friendly, particularly for workers responsible for emptying the containers. Additionally, it takes up a significant amount of space both indoors and in public areas. Furthermore, it requires high investment costs for indoor waste collection spaces. This is remarkable, as roll containers are still being implemented in the first building to be completed, despite the fact that this alternative is poorly received by all stakeholders.

The Indoor Press Containers alternative scores slightly better but still ranks low. While compaction reduces the frequency of collection and makes it more sustainable due to fewer transport movements, the need for indoor storage and specialized collection equipment still results in high investment and operational costs. Additionally, there is limited potential for waste separation, making it less sustainable.

The Press Underground Containers (ORACs) alternative ranks the highest overall, except for the Municipality of The Hague, where it is the second-best option. This alternative benefits from efficient use of space, as fewer containers are needed due to compaction, and lower operational costs due to reduced transport movements. Additionally, it offers opportunities for enhanced waste separation at the source, as residual ORACs can be replaced by separate waste streams, given that compaction ensures fewer ORACs are required.

The Underground Waste Transport System (OAT) scores the highest for the Municipality of The Hague but ranks lower for other stakeholders. This is primarily due to the high investment costs associated with installing underground pipelines and centralized collection terminals. However, the system offers significant long-term efficiency by minimizing transport movements and supporting extensive waste separation.

A general observation is that compaction-based alternatives tend to score better than noncompaction alternatives. By reducing the number of containers needed and decreasing collection frequency, these alternatives result in fewer transport movements and lower operational costs, making them more favorable in the evaluation. Overall, the results highlight the trade-offs between investment, operational costs, efficiency, and spatial impact, demonstrating how different stakeholders prioritize these factors differently.

4.1.3. Conclusion Research Question 5

This section answers the question *How do proposed designs score on the identified criteria, and which design is most suitable for implementation?*

Figure 4.1 illustrates how each design performs based on the identified criteria. Figure 4.2 shows which alternative is most supported by all stakeholders, which is the underground press containers.

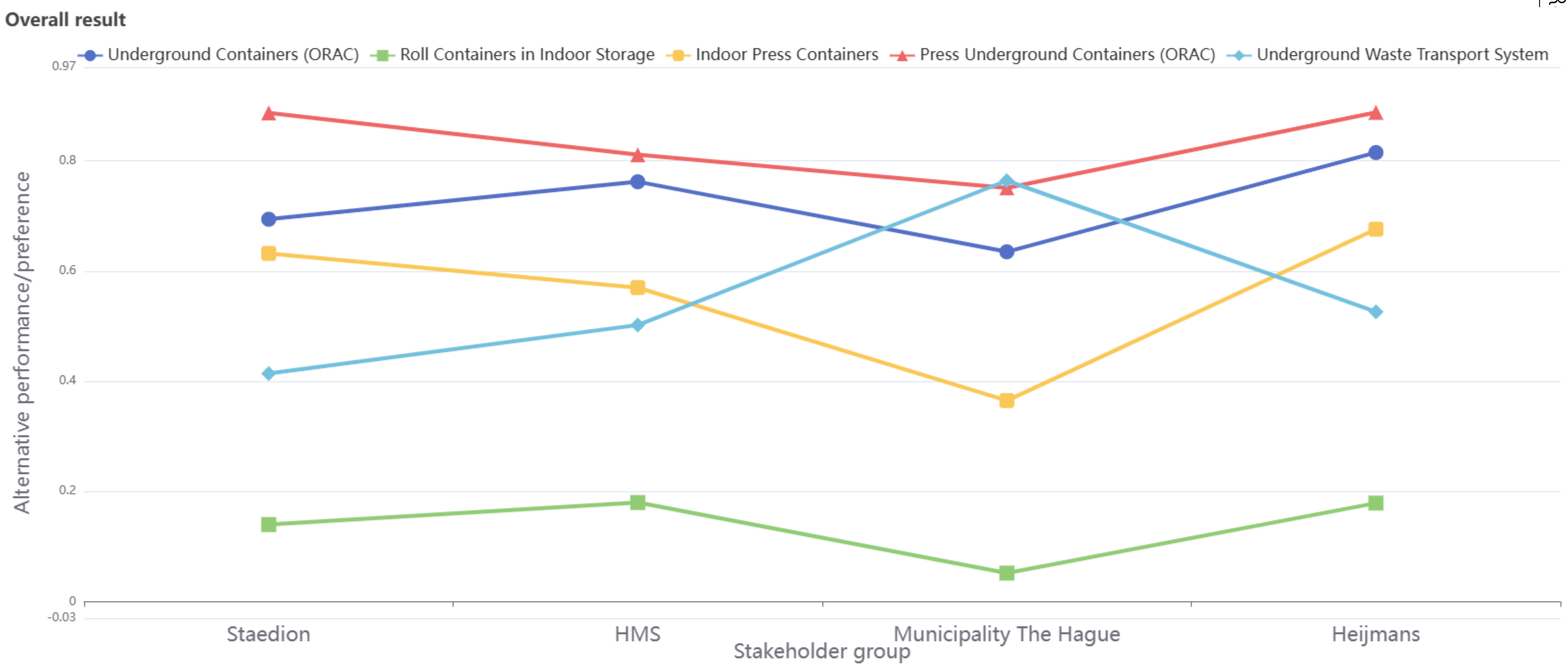


Figure 4.2: MAMCA results

4.2. Discussion and Future Research Recommendations

This study primarily focused on an exploratory assessment of different waste collection alternatives and how stakeholders perceive them. The Multi-Actor Multi-Criteria Analysis (MAMCA) was chosen as the primary evaluation method due to its ability to incorporate diverse stakeholder perspectives in decision-making processes, particularly when conflicting objectives are present. This study has demonstrated that MAMCA is an effective tool for structuring complex decision-making problems in waste collection. However, like any methodology, MAMCA has inherent strengths and limitations that impact the findings and their broader applicability.

4.2.1. Strengths of the Study and the MAMCA Approach

One of the key strengths of this study is its ability to integrate multiple stakeholder perspectives into the evaluation process. Waste collection decisions are inherently multi-faceted, involving various actors with differing priorities, including municipalities, waste collection companies, and housing corporations. The MAMCA provided a structured framework for assessing these divergent views, ensuring that the decision-making process accounted for multiple criteria beyond just financial costs.

Furthermore, the study confirmed that individual stakeholder decision-making may lead to suboptimal outcomes compared to collective decision-making. While individual decision-making often favors roll containers, the collective MAMCA results revealed that this option performed the worst, reinforcing the importance of a holistic approach in policy-making.

Another strength of this study lies in its practical implications. The results provide a strong foundation for policymakers and urban planners to make more informed decisions regarding waste collection infrastructure. By applying MAMCA, stakeholders can visualize trade-offs between different criteria and better understand the long-term implications of their choices. This study also demonstrates that MAMCA is a flexible tool that can be applied to various urban settings, making it a valuable decision-support method for municipalities.

4.2.2. Limitations of the Study and the MAMCA Approach

Despite its strengths, this study has several limitations, primarily related to the subjectivity of MAMCA. One of the key challenges was the estimation of criteria input values, which required multiple assumptions due to the lack of precise cost and operational data. While every effort was made to verify these assumptions with stakeholders, not all stakeholders were able or willing to provide accurate estimates. This introduces a degree of uncertainty into the model, making it difficult to ensure that all evaluations fully reflect real-world conditions. Future research could address this by conducting a more detailed cost-benefit analysis of each alternative, incorporating comprehensive financial and operational data to refine the decision-making process.

Another limitation of the MAMCA is its reliance on stakeholder-assigned weightings, which are inherently subjective. The weight assigned to each criterion can significantly influence the ranking of alternatives. For instance, the Municipality of The Hague assigned a low value to cost as a criterion. However, if another department within the municipality had been consulted, a higher weighting might have been given to cost, potentially leading to a different ranking of alternatives.

Additionally, this study deliberately excluded residents from the stakeholder analysis. The primary reason for this was that residents do not have an active role in the formal decision-making process. Moreover, engaging with residents proved challenging, as waste collection was not a key topic of discussion during community meetings organized by Staedion. The housing corporation preferred not to raise concerns that might generate resistance to planned changes in waste collection. However, resident behavior plays a crucial role in the success of any waste management system, as highlighted in existing literature. Future research should focus on incorporating resident perspectives, particularly their willingness to separate waste and how design choices influence participation rates. Behavioral interventions such as gamification, incentives, and nudging strategies could be explored to improve waste separation and reduce illegal dumping.

4.2.3. Generalization of the Findings

The results of this study are not fully generalizable, as waste management policies vary significantly between municipalities. Each city has its own municipal council, waste collection companies, and housing corporations, all of which influence decision-making processes. As a result, the weightings assigned to different criteria and even the relevance of certain criteria may differ across municipalities. Some cities prioritize sustainability, while others focus more on cost efficiency. This was evident from participation in waste management conferences and discussions with municipal representatives, where diverse waste collection approaches were observed. Political dynamics further shape these preferences, meaning that the rankings of waste collection alternatives will likely differ based on local priorities and policies.

Despite these variations, the MAMCA itself is highly generalizable and remains a valuable tool for structuring complex decision-making processes. The study demonstrated that applying MAMCA leads to a more holistic evaluation of waste collection alternatives, ensuring that stakeholder perspectives are systematically considered. The methodology has proven effective in bringing together conflicting interests, leading to a more informed and transparent decision-making process. Future applications of MAMCA in different municipalities are recommended, as it can facilitate discussions among stakeholders and highlight trade-offs between different criteria. While the specific outcomes may vary depending on local circumstances, the structured approach of MAMCA ensures that decisions are based on a comprehensive stakeholder analysis rather than isolated preferences.

4.2.4. Opportunities for Future Research

While this study provided a high-level overview of different waste collection alternatives, future research should explore specific alternatives in greater depth. For example, a focused study on underground waste transport systems could investigate optimal network design, including the placement of terminals, pipe length constraints, and inlet configurations. Similarly, optimizing the placement and collection routes for Press Underground Containers (ORACs) through vehicle routing problems could improve operational efficiency.

Beyond technical optimization, further research could explore policy measures that support sustainable waste management, such as cost-sharing models where developers contribute to waste infrastructure investments. Additionally, emerging technologies such as real-time waste monitoring, dynamic collection scheduling, and AI-driven route optimization could be investigated to enhance efficiency and sustainability.

Overall, this study highlights the value of MAMCA as a decision-support tool in waste collection planning, providing a comprehensive overview of stakeholder preferences and trade-offs. While the method effectively captures diverse perspectives, its reliance on subjective weightings and estimated data presents challenges that future research should address. Despite these limitations, MAMCA remains a valuable framework for structuring complex decision-making processes and serves as a strong foundation for future studies in waste management and urban sustainability.

4.3. Conclusion

The research question guiding this study was as follows:
How can the waste collection for household waste in the neighborhoods of Dreven, Gaarden, and Zichten be best organized and implemented, taking into account all stakeholders involved?

The findings of this study indicate that press underground containers (ORACs) are the most supported alternative by all stakeholders. This is primarily due to several advantages: no investment costs for indoor waste storage spaces, lower operational costs as there are no service fees for placing waste on the street, and no additional costs for HMS for extra equipment or personnel. Additionally, the compacted waste allows for fewer ORACs, creating room for separate collection streams (e.g., organic waste, plastic, paper, glass) by replacing some residual waste ORACs. Transport movements are reduced due to fill-level sensors and the compacted waste requiring fewer trips. Implementation is straightforward since the existing infrastructure and HMS operations are already adapted to the ORAC system. These characteristics result in favorable criteria values, making it the most supported option by all stakeholders.

For the implementation and organization of waste collection, a data-driven and phased implementation of press containers is recommended. Given that the redevelopment of the neighborhoods will be completed gradually by 2040, press containers can be strategically installed based on actual demand. This can be determined by analyzing the weekly number of collections required for existing ORACs. Additionally, older ORACs that are reaching the end of their lifespan can be replaced with press ORACs as the old ones are phased out. In such cases, only the additional cost of the press system needs to be considered, rather than the full investment cost of a completely new installation.

To optimize the organization of the implementation, a co-financing model is advised, allowing Staedion and Heijmans to contribute financially to the underground press containers. The capital these stakeholders are currently investing in indoor waste storage facilities for roll containers would be more effectively allocated to press containers. By redirecting these funds, it can actively participate in financing the implementation of underground press containers, ensuring a more efficient and sustainable waste collection system.

4.3.1. Conclusion: MAMCA in Waste Collection Decision-Making

The existing literature on waste collection lacks a method to systematically map stakeholder perspectives, despite emphasizing that effective collaboration is crucial for a well-functioning waste collection system. This study was the first to apply MAMCA in the waste management domain, integrating stakeholder perspectives into a joint decision-making process, which led to valuable insights.

In the coming years, until 2040, buildings will be gradually completed in Dreven, Gaarden, and Zichten. The first completed buildings will use roll containers, requiring investment in indoor waste storage spaces and designated streetside collection areas. This comes at the expense of parking spaces and green areas.

Roll containers emerged as the least favorable alternative in the MAMCA analysis, but were chosen for the initial developments. This raises the question: why was this decision made? In this study, the costs and impacts of the alternatives were evaluated as a whole rather than per stakeholder. When all costs are aggregated, roll containers are a costly option due to high investment costs for indoor waste spaces and high operational costs for collection and placement on the street. In addition, it is not user-friendly, poses ergonomic challenges for waste collection workers, does not promote sustainability, and generates excessive transport movements. When considering the combined impact among all stakeholders, MAMCA indicates that press containers would be the preferred choice. This highlights the added value of MAMCA:

joint decision-making yields different results compared to decisions made individually.

For example, the decision by the municipality to prioritize indoor waste collection to make sure that the pressure on public space should not increase has significant implications for housing corporations like Staedion and developers such as Heijmans. Similarly, Staedion and Heijmans' decision to implement roll containers heavily impacts HMS, the waste collection service, which must invest in additional equipment and personnel. This study has provided valuable insights into how stakeholders' decisions affect one another. MAMCA leads to better decision making by selecting alternatives that benefit all stakeholders and are future proof.

A broader conclusion about the application of the MAMCA in the decision making in waste collection is positive. It proves to be a valuable tool that forces stakeholders to carefully consider and weigh criteria. The method effectively highlights trade-offs, demonstrating that prioritizing one criterion often comes at the expense of another. Moreover, MAMCA fosters constructive dialogue among stakeholders, enabling to understand each other's perspectives and incorporate these into a more holistic decision-making process. This encourages reflection on the long-term implications of specific choices.

However, determining the input values for the criteria remains a challenge, often requiring numerous assumptions. Although this may be considered a limitation, it is not unique to this study or the waste collection domain; similar challenges arise when applying MAMCA to transport and mobility-related decision-making processes.

In addition to its benefits, MAMCA's ability to create transparency and structured stakeholder engagement makes it suitable for broader use in complex decision-making processes. Nevertheless, future applications could benefit from refining criteria definitions and ensuring better data availability to minimize reliance on assumptions and improve accuracy. Despite these challenges, the MAMCA remains a robust framework for aligning diverse stakeholder objectives and fostering well-informed, sustainable decisions.

4.4. Recommendations

The stakeholder analysis revealed that the different stakeholders— the municipality, HMS, Staedion, and Heijmans—do not share the same vision regarding the future waste collection policy in Dreven, Gaarden, and Zichten after redevelopment. During the interviews, it became apparent that there is minimal communication between the stakeholders. The MAMCA output could serve as an excellent starting point to promote mutual understanding of each stakeholder's objectives and priorities. It is also crucial for all stakeholders to adopt a long-term perspective on waste collection. Currently, roll containers are being implemented for the first buildings in the redevelopment, with substantial investments being made. However, this is the least preferred alternative by all stakeholders. Stakeholders need to collaborate to develop a more efficient and sustainable waste collection system.

This research has also attempted to provide an overview of the costs associated with each alternative. It is essential to evaluate total investment and operational costs comprehensively. The current decision-making process places too much emphasis on short-term costs and initial investments. However, in the long term, roll containers are rated as the least favorable by all stakeholders, as evidenced by the MAMCA results. A key conclusion is that the decision-making process must shift towards long-term, future-proof solutions. Cost-sharing among stakeholders should also be considered. For instance, the municipality of Tilburg has implemented a system where developers contribute a fixed amount per household towards waste collection infrastructure. Similarly, it would be more effective for developers and housing corporations to contribute to the costs of underground press containers. The capital Staedion and Heijmans currently allocate to creating indoor waste storage spaces for roll containers, as well as the associated operational costs, could instead be invested in co-financing underground press containers. This would result in a more sustainable and cost-effective system that benefits all stakeholders in the long run.

4.4.1. Recommendation for Staedion

A key recommendation for Staedion is to initiate discussions with the Municipality of The Hague and propose the implementation of underground press containers. This study can be used as a justification against indoor waste storage facilities. Staedion should emphasize the municipality's responsibility for collecting and processing household waste and argue that this responsibility cannot simply be transferred to a housing corporation. To foster collaboration and contribute to a future-proof system, Staedion could offer to co-finance a portion of the underground press containers, reallocating part of the capital initially reserved for indoor waste storage spaces.

It is also advised that Staedion involves multiple housing corporations, as all housing corporations are subject to the municipality's new requirement for indoor waste collection. By forming a collective, housing corporations can jointly advocate for a more effective solution. However, Staedion should be cautious not to adopt an overly confrontational stance, as the objective is to improve communication and cooperation between stakeholders. A constructive approach, considering alternative solutions, is crucial. Additionally, emphasizing sustainability will be a key argument in this discussion.

4.4.2. Recommendation for Sweco

The recommendation for Sweco is to assume a mediating role in this specific case study. As an advisory firm and an independent party, Sweco can bring all stakeholders together and present the MAMCA findings. It is recommended that Sweco develops a project dedicated to the implementation and realization of waste collection in Dreven, Gaarden, and Zichten, assigning a long-term coordinator to facilitate stakeholder collaboration and implementation.

Furthermore, Sweco is encouraged to engage in more waste collection projects. Attending waste management conferences has highlighted the significant variations in municipal policies across different cities. As indicated in both existing literature and the findings of this study, effective collaboration among all stakeholders in the waste management process is essential. Sweco could play a significant role as a project leader in similar initiatives throughout the Netherlands.

Thus, the recommendation for Sweco is twofold: first, to dedicate a long-term coordinator to facilitate cooperation for this case study in Dreven, Gaarden, and Zichten; and second, to explore opportunities for similar projects nationwide, as there is substantial potential for expanding these initiatives.

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A
Scientific Paper

The following appendix contains the scientific paper titled "Application of the Multi-Actor Multi-Criteria Analysis in the Waste Collection Decision Process: A Case Study on the Neighborhoods Dreven, Gaarden, and Zichten in The Hague." This paper examines the application of the MAMCA in waste management, focusing on optimizing waste collection systems for these neighborhoods.

Application of the Multi Actor Multi Criteria Analysis in the Waste Collection Decision Process

A case study on the neighborhoods Dreven, Gaarden and Zichten in The Hague for future waste collection alternatives using the MAMCA in the decision making process

Pien Biersteker[a]

[a]*Delft University of Technology, The Netherlands*

Abstract

Effective waste management is critical for urban sustainability, yet decision-making in this domain is often divided due to diverse stakeholder interests. This study applies the Multi-Actor Multi-Criteria Analysis (MAMCA) to evaluate waste collection alternatives for the redevelopment of the Dreven, Gaarden, and Zichten neighborhoods in The Hague. Stakeholders—including the Municipality of The Hague, Staedion (housing corporation), Haagse Milieu Service (waste collection service), and Heijmans (developer)—were engaged to define key evaluation criteria: cost, space usage, ease of use, sustainability, and implementation feasibility. Five alternatives were assessed: (1) the existing Underground Residual Waste Containers (ORACs) as a baseline, (2) Indoor Roll Containers, (3) Indoor Press Containers, (4) Press Underground Containers (ORACs with compaction), and (5) an Underground Waste Transport System (OAT). The results indicate that press underground containers (ORACs) are the most supported alternative across stakeholders, offering a balance between cost efficiency, operational feasibility, and sustainability. In contrast, indoor roll containers received the lowest evaluation due to high operational costs and inefficiencies. Despite this, indoor roll containers are currently being implemented in the first newly constructed buildings in the redevelopment area. This underscores the necessity of using MAMCA in waste management decision-making, as it enables a structured, multi-stakeholder approach that can lead to more broadly supported and efficient solutions. The study demonstrates MAMCA's potential as a decision-support tool, integrating stakeholder preferences and structuring complex multi-criteria evaluations. The findings provide a foundation for the data-driven, phased implementation of press underground containers and emphasize the importance of stakeholder collaboration in waste management decision-making.

Keywords: Waste Collection Systems, Multi-Actor Multi-Criteria Analysis (MAMCA), Stakeholder Decision-Making, Press Underground Containers, Municipal Solid Waste (MSW), Compaction-Based Waste Collection, Underground Waste Transport System (OAT)

1. Introduction

Waste management plays a crucial role in achieving circular economy goals, where waste is increasingly perceived as a resource rather than an end product (European Commission, 2023). Despite efforts to minimize waste generation, the need for efficient waste collection systems remains, especially in urban areas. European Union (EU) regulations mandate increasing recycling targets—55% by 2025, 60% by 2030, and 65% by 2035—making effective waste management strategies essential (European Union, 2022). In this context, waste collection systems must be designed to optimize efficiency, sustainability, and stakeholder acceptance.

The Hague faces significant challenges in household waste collection, particularly in high-density urban areas. With only 34% of household waste being separated and an annual residual waste generation of 256 kg per capita (Centraal Bureau voor de Statistiek (CBS), 2024), the city lags behind other Dutch municipalities. The neighborhoods of Dreven, Gaarden, and Zichten, currently undergoing redevelopment with 3,500 additional housing units planned (Gemeente Den Haag, nd), provide an ideal case study to explore innovative waste collection approaches. Disagreements among stakeholders about the most suitable system highlight the need for a structured decision-making framework.

The Multi-Actor Multi-Criteria Analysis (MAMCA) offers a systematic approach to evaluate waste collection alternatives by integrating stakeholder preferences. Unlike conventional decision-making methods, MAMCA explicitly incorporates the perspectives of diverse actors, such as municipalities, waste collection services, housing corporations, and developers. This approach is particularly relevant in waste management, where stakeholder involvement is critical to the success and acceptance of new systems (Kurniawan et al., 2024; Suryawan and Lee, 2023; Hao et al., 2024; Chowdhury et al., 2023; Jiang et al., 2023).

This study applies the MAMCA to assess different waste collection alternatives for Dreven, Gaarden, and Zichten. By systematically evaluating stakeholder preferences, this research aims to bridge the gap between policy objectives and practical implementation. The findings contribute to the broader research on waste management by demonstrating the effectiveness of structured multi-criteria multi-actor decision making in optimizing urban waste collection systems.

2. Literature Review

Effective waste management plays a critical role in the transition to a circular economy, with increasing attention on waste collection efficiency and sustainability (European Commission, 2023). Literature highlights that successful waste collection systems rely not only on technological and infrastructural solutions but also on strong stakeholder collaboration (Kurniawan et al., 2024; Suryawan and Lee, 2023; Hao et al., 2024). Cooperation between municipalities, waste collection services, housing corporations, and residents is essential to ensure the effectiveness and acceptance of waste separation systems (Chowdhury et al., 2023; Jiang et al., 2023). However, despite the recognized importance of stakeholder involvement, existing research lacks a structured methodology to systematically incorporate diverse stakeholder preferences into waste collection decision-making.

Previous studies have explored various waste management approaches, emphasizing the importance of source separation over post-collection sorting (Jin and Li, 2023; Anuardo et al., 2022; Zaman, 2022). Innovations such as AI-based sorting systems, Smart bins with fill-level sensors, and blockchain waste tracking have been proposed to optimize waste collection (Kurniawan et al., 2024; Hao et al., 2024; Popova and Sproge, 2021). Additionally, policy measures, such as economic incentives and regulatory enforcement, have been identified as key drivers in promoting sustainable waste management practices (Kurniawan et al., 2021; Gardiner and Hajek, 2020). However, while these strategies address technical and policy dimensions, they often overlook the role of multi-stakeholder decision-making, which is crucial for ensuring the successful adoption and long-term viability of waste collection systems (Kurniawan et al., 2024; Suryawan and Lee, 2023; Hao et al., 2024; Chowdhury et al., 2023; Jiang et al., 2023).

A significant gap in the literature exists regarding the systematic integration of stakeholder perspectives in waste collection planning. Although stakeholder collaboration is frequently mentioned as a key factor for success, no widely adopted method has been established to structure and evaluate stakeholder preferences in the decision-making process. The Multi-Actor Multi-Criteria Analysis (MAMCA) offers a structured approach for incorporating stakeholder perspectives, yet its application has been primarily limited to transportation and mobility studies rather than waste management (Macharis et al., 2010). To date, MAMCA has not been systematically applied in urban waste collection planning.

This research aims to fill this gap by applying the MAMCA to assess waste collection alternatives in Dreven, Gaarden, and Zichten. By integrating stakeholder preferences into the decision-making process, this study contributes to both academic literature and practical waste management applications, demonstrating the potential of MAMCA as a decision-support tool for sustainable and collaborative waste collection planning.

3. Methodology

This study applies the Multi-Actor Multi-Criteria Analysis (MAMCA) to assess different waste collection alternatives by integrating stakeholder preferences into the decision-making process (Macharis et al., 2010). As identified in the literature review (section 2), stakeholder collaboration is a key success factor in waste management, yet no structured method currently exists to systematically evaluate stakeholder preferences in this domain. The MAMCA framework provides a structured multi-criteria decision-making approach that explicitly incorporates diverse stakeholder perspectives, making it well-suited for evaluating waste collection alternatives.

The research followed a structured process consisting of several key steps: (1) problem definition, (2) analysis of the current process, (3) stakeholder analysis, (4) definition of requirements and criteria, (5) design of alternatives, and (6) results: evaluation of criteria scores for each alternative. This approach enables a systematic assessment of competing waste collection strategies, ensuring that stakeholder preferences are quantified and integrated into the final decision.

To test the applicability of MAMCA in waste management, this research applies the method to a case study in the Dreven, Gaarden, and Zichten neighborhoods in The Hague. These areas are undergoing significant redevelopment and present a complex stakeholder environment with diverging preferences regarding future waste collection systems (Gemeente Den Haag, nd). A structured stakeholder analysis (Enserink et al., 2022) was conducted to map actors, contractual relationships, and power dynamics. Additionally, requirements-based design principles (AltexSoft Software R&D Engineering, 2023) were used to develop feasible waste collection alternatives that align with both stakeholder priorities and technical constraints.

To gather data, this research employs desk research, interviews, fieldwork, and GIS-based spatial analysis. Stakeholders were interviewed to determine their waste collection preferences and decision criteria, which were then weighted using Analytic Hierarchy Process (AHP) (VUB, 2024). The final MAMCA evaluation provides insights into the most suitable waste collection system, balancing economic, environmental, and social criteria.

4. Criteria Analysis

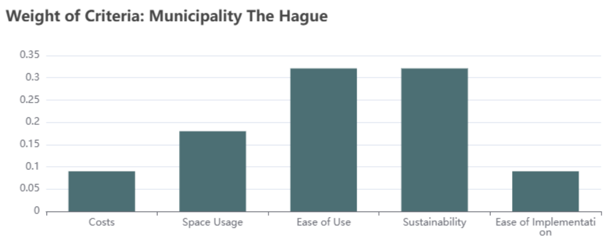
The criteria for evaluating waste collection alternatives were defined based on stakeholder input and analysis of the current waste management process in The Hague. Interviews were conducted with key stakeholders—the Municipality of The Hague, Staedion (housing corporation), Haagse Milieu Service (HMS, waste collection service), and Heijmans (developer)—to identify their priorities and concerns regarding waste collection in Dreven, Gaarden, and Zichten. Each stakeholder participated in the Analytic Hierarchy Process (AHP), using pairwise comparisons to assign relative weights to the criteria (VUB, 2024). This structured approach ensures that the evaluation reflects stakeholder-specific priorities.

4.1. *Stakeholder analysis*

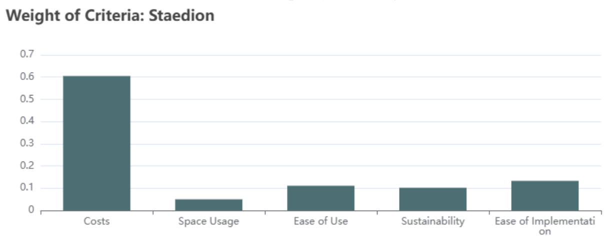
Stakeholder selection for the MAMCA process was conducted using the Policy Analysis of Multi-Actor Systems framework (Enserink et al., 2022). A Power-Interest Grid analysis identified the Municipality of The Hague, Staedion (housing corporation), Haagse Milieu Service (HMS), and Heijmans as the most influential stakeholders in the waste collection decision-making process for Dreven, Gaarden, and Zichten (DGZ). These stakeholders have the highest level of power and interest in shaping waste collection policies, as the municipality determines regulatory frameworks (Wet, 2024), Staedion owns most residential buildings (Staedion, 2024), HMS operates waste collection services (Haagse Milieu Service (HMS), 2024), and Heijmans is the developer of the redevelopment (Heijmans, 2022). Consequently, these four stakeholders were included in the criteria weighting phase of the MAMCA.

4.2. *Criteria*

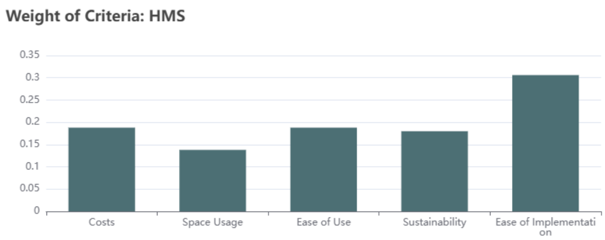
Five key criteria were selected to assess the waste collection alternatives. (1) Costs were included as The Hague currently has one of the highest waste collection fees in comparison with other large cities in the Netherlands, making cost efficiency a critical factor (Amsterdam, 2024; Rotterdam, 2024; Utrecht, 2024; Tilburg, 2024; Eindhoven, 2024). (2) Space usage is particularly relevant given The Hague's high urban density, necessitating a minimal footprint for waste collection infrastructure to preserve public space (CBS, 2023). (3) Ease of use means the system is designed to be user-friendly for both residents and waste collection workers, requiring minimal physical effort and featuring intuitive, ergonomic mechanisms. (College voor de Rechten van de Mens, 2024). (4) Sustainability was selected to assess both the environmental impact of transport movements and the system's ability to support efficient waste separation, aligning with municipal sustainability goals. This is particularly relevant as The Hague has a low waste separation rate of only 34%, lagging behind other cities (Centraal Bureau voor de Statistiek (CBS), 2024). Finally, (5) ease of implementation considers the feasibility of adopting a new system, taking into account infrastructure modifications, which are crucial for long-term success. In Figure 1, the criteria weights for each stakeholder are shown. Notably, there are significant differences in priority among stakeholders, highlighting the necessity of the MAMCA to systematically capture and balance these diverse preferences. This ensures that the selected waste collection alternative aligns with the priorities of all involved parties.



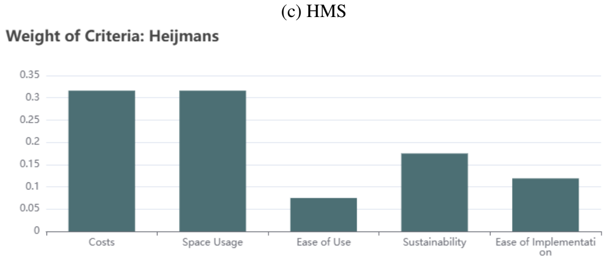
(a) Municipality The Hague



(b) Staedion



(c) HMS



(d) Heijmans

Figure 1: Weighting of criteria for the four stakeholders using the AHP method. (a) Municipality The Hague, (b) Staedion, (c) HMS, (d) Heijmans.

5. Alternatives

To evaluate the future waste collection system in Dreven, Gaarden, and Zichten, five alternatives were considered based on stakeholder input and predefined requirements.

5.1. *(A.0) Baseline Alternative: Current ORAC System*

The existing Underground Residual Waste Containers (ORACs) serve as the baseline. This system is cost-effective as it is already implemented, and HMS is fully equipped for its collection. However, increasing waste volumes may require additional ORACs or more frequent collections. Challenges include fly-tipping (bijplaatsingen) and the municipality's preference for indoor waste collection.

5.2. (A.1) Indoor Roll Containers

This alternative places roll containers inside buildings, which are moved outside twice weekly for collection. While potentially more convenient for residents, concerns arise regarding increased operational costs, safety hazards, and space requirements. HMS faces inefficiencies due to labor-intensive collection, and the municipality does not see this as a long-term solution.

5.3. (A.2) Indoor Press Containers

Press containers inside buildings compress waste, reducing collection frequency. It requires less storage space than roll containers and allow for optimized collection with fill-level sensors. However, high investment costs, logistical constraints, and limited support for waste separation pose challenges.

5.4. (A.3) Underground Press ORACs (SIDCON)

This system upgrades traditional ORACs by integrating waste compression technology, increasing capacity while maintaining underground storage. Fewer collections are needed, reducing transport movements and costs. It utilizes existing infrastructure but requires a higher initial investment.

5.5. (A.4) Underground Waste Transport System (OAT)

This automated vacuum waste system transports waste via underground pipes to a central collection facility, minimizing transport movements and maximizing space efficiency. Despite strong municipal support, the system demands extensive infrastructure investments and full system replacement, making implementation highly complex.

6. Results

Alternatives are systematically evaluated based on costs, space usage, ease of use, sustainability, and implementation feasibility. To estimate space usage, investment, and operational costs, Excel-based estimation models were developed. These models project the generation of household waste in 2040 and calculate the number of units required for each alternative, along with the annual collection frequency. In addition, the models determine the requirements for indoor and public spaces (m²) for each alternative. The remaining criteria were ranked on a scale from 1 to 10 based on their relative performance. Cost estimates were made in consultation with stakeholders, who were asked to verify the values. However, not all stakeholders were able or willing to provide verification, leading to some estimations remaining unconfirmed.

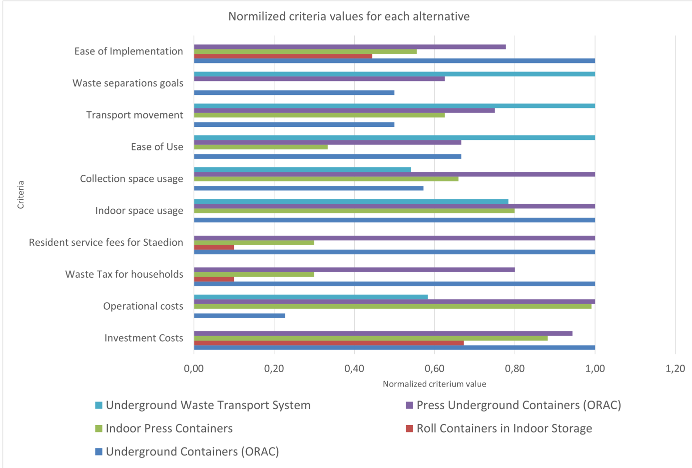


Figure 2: Normalized Criteria Values

6.1. Criteria Normalization

To ensure comparability across criteria with different units (e.g., euros, square meters, or scores), min-max normalization is applied, scaling all values between 0 (least favorable) and 1 (most favorable) (Ciaburro et al., 2018). Two formulas are used depending on whether a higher or lower value is preferred:

For criteria where higher values are better (Ease of Use, Transport Movements, Waste Separation Goals, Ease of Implementation):

$$X_{\text{scaled}} = \frac{X - X_{\min}}{X_{\max} - X_{\min}} \tag{1}$$

For criteria where lower values are better (Investment Costs, Operational Costs, Waste Tax, Resident Service Fees, Indoor and Collection Space Usage):

$$X_{\text{scaled}} = \frac{X_{\max} - X}{X_{\max} - X_{\min}} \tag{2}$$

This ensures that all criteria are expressed on a uniform scale, allowing for direct comparison between alternatives. Figure 2 visualizes the normalized values, where a score of 1 indicates the best-performing alternative for a given criterion.

6.2. MAMCA Results

The results of the Multi-Actor Multi-Criteria Analysis (MAMCA) in Figure 3 show clear differences in how stakeholders evaluate the waste collection alternatives. Press underground containers (ORACs) emerge as the most favorable option, receiving strong support from all stakeholders except the Municipality of The Hague, which ranks the Underground Waste Transport System (OAT) higher. This is because the municipality places less emphasis on cost compared to other stakeholders, despite OAT being the most expensive alternative.

Indoor storage-based alternatives, such as roll containers and press containers, consistently score lower due to high operational and investment costs, space constraints, and labor-intensive waste collection processes. The roll container system, currently being implemented, is the least preferred by all stakeholders due to high maintenance costs and inefficiencies.

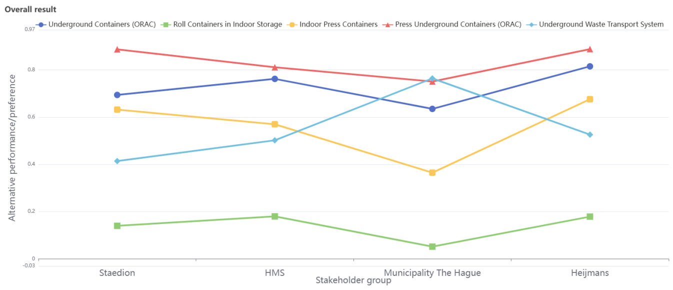


Figure 3: Results MAMCA

A key insight from the MAMCA results is that waste compaction significantly enhances feasibility. Press underground containers require fewer collection trips, reducing transport movements, emissions, and operational costs. Additionally, it integrates seamlessly with the existing ORAC infrastructure, making implementation straightforward. This alternative also allows for a gradual, data-driven roll out, replacing conventional ORACs when exceeding the average emptying frequency of 1.3 times per week. Over time, fewer ORACs would be needed, enabling the replacement of some residual waste ORACs with containers for separated waste streams, further improving sustainability.

7. Conclusion

The application of the MAMCA in this study demonstrates its effectiveness in structuring complex decision-making processes in urban waste collection. By systematically incorporating stakeholder preferences and weighting different criteria, the method provides a transparent and structured approach to selecting an optimal waste collection system.

One of the key advantages of the MAMCA is its ability to integrate diverse stakeholder perspectives into a single framework. Waste collection involves multiple actors—municipalities, housing corporations, waste collection companies, and urban developers—each with different priorities. The structured weighting process ensures that all voices are considered, making it easier to identify solutions with broad support.

Furthermore, MAMCA is particularly suited for evaluating infrastructure-heavy decisions that involve trade-offs between costs, sustainability, and operational efficiency.

The result of a joint decision-making process for waste collection in Dreven, Gaarden, and Zichten leads to underground press containers as the best alternative, whereas individual choices currently result in indoor rolling containers implemented in the initial buildings. This demonstrates the importance of MAMCA in this research area and highlights the added value of making better decisions collectively rather than individually.

The findings of this study can serve as a valuable basis for stakeholders to engage in discussions and foster collaboration. The results highlight differing priorities and trade-offs, offering a structured framework for dialogue and decision-making. This reinforces the value of the MAMCA in the waste management domain, as the literature review already established that stakeholder collaboration is essential for an effective waste management system.

8. Discussion

Despite its advantages, the MAMCA has certain limitations. Its accuracy heavily depends on the quality of input data, which in this study required multiple assumptions due to the lack of precise cost and operational figures. Additionally, the ranking and weighting process is inherently subjective, as it relies on stakeholder perceptions that may not always reflect objective or long-term considerations. However, this is a general limitation of the method rather than a waste management-specific issue, as similar challenges arise in transport and mobility decision-making processes, where estimating costs and impacts also involves uncertainties.

Future research could focus on obtaining more reliable data for the input values of the criteria. The goal of this study was not to provide an exact cost estimation but rather to clearly map out the different stakeholder perspectives and priorities. Further studies could refine the estimation models, incorporate empirical data, and explore additional factors influencing the feasibility of waste collection alternatives.

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B Stakeholder Interviews

B.1. Interview NVRD

Interview with: Interviewee 1
Date of Interview: 29/10/2024
Subject: The interview with Interviewee 1 from the NVRD covered various aspects of waste management, particularly for high-density urban settings such as high-rise buildings. The discussion highlighted current waste collection practices, recent legislative changes, and innovative methods implemented in Dutch municipalities.

Waste Streams and Collection Methods
Interviewee 1 detailed the typical waste streams—residual waste, PMD (plastic, metal, and drink cartons), GFT (organic waste), and paper. For low-rise areas, waste collection is often conducted door-to-door, while high-rise neighborhoods typically offer nearby collection points or communal facilities. In Tilburg, approximately 80% of waste in high-rise buildings is collected internally, with the collection service responsible for transporting containers with building access keys. Interviewee 1 noted that this method has been particularly effective and will provide contact information for a local contact person in Tilburg. In Amsterdam, food waste grinders are being piloted in high-rise buildings, inspired by U.S. practices, as a means to manage organic waste directly at the source.

Innovative Collection Systems
Interviewee 1 discussed the OAT (Underground Waste Terminal) system, an advanced collection technology applied in Arnhem, Almere, and Schiedam. This innovative solution allows for efficient, underground waste transport, preserving urban space while simplifying waste logistics. Additionally, for GFT collection, some areas use refrigerated compactors, particularly useful given the European Waste Framework Directive (2018/851/EU), which mandates source-separated GFT collection in high-rise areas from January 2024.

Challenges of GFT Separation in High-Rise Buildings
Interviewee 1 emphasized the importance of GFT separation, noting that municipalities face increased responsibility to collect GFT separately, especially in high-density and high-rise zones. Despite legislative advances, many high-rise projects struggle with GFT separation due to space limitations and logistical challenges. Interviewee 1 suggested looking into the VANG research on waste separation in high-rise areas, particularly the "triad model," which is specifically tailored to improve source separation in these environments.

Benchmarking and Monitoring
The NVRD offers tools for benchmarking household waste data across municipalities, with a new report expected for 2023. Interviewee 1 noted that these tools can be valuable for analyzing

how municipalities compare in waste management efficiency. Further, he highlighted that waste monitoring—using AI and sensor-equipped cameras—has become increasingly essential for identifying and addressing issues in waste separation. These systems can notify individuals if their waste is miscategorized, providing an opportunity for direct feedback and education on proper sorting methods.

Public Involvement and Behavioral Influence
Interviewee 1 pointed out a growing shift in waste management, where logistics are complemented by a focus on social behavior and community influence. He recommended exploring "citizens' councils" as they offer insights into public attitudes on waste management policy. Such councils exist in cities like Amsterdam, Rotterdam, and Arnhem, providing valuable feedback for policymaking.

Key themes emerged during the interview:
GFT Separation: While much focus is on PMD, Interviewee 1 stressed that GFT, by weight, contributes significantly to contamination if improperly separated.

Cost, Service, and Environmental Impact: Municipalities often weigh these three factors when determining waste management solutions.

Quality over Quantity: Not only is the volume of separated waste important, but also the quality—highly contaminated waste has limited value in the recycling process.

Importance of Early Planning: Interviewee 1 stressed that waste collection should be integrated early in project planning, particularly in densely populated areas where green spaces are often prioritized.

Interviewee 1 also recommended reaching out to Interviewee 6 from the municipality of The Hague for further insights on high-rise waste management.

Key Innovations
Cooled compactors for GFT waste. AI and sensor-equipped cameras to monitor and track waste separation efficiency. Benchmarking tools for comparing waste management performance across municipalities.

Key Takeaways for Stakeholder Analysis of the NVRD
The NVRD plays a central role in advising and benchmarking waste management strategies across Dutch municipalities. Key insights from this interview for this research include:

Internal Collection in High-Rise Buildings: Tilburg's internal collection approach for high-rise buildings, where containers are moved by the waste collection service, is a promising model for effective waste management in similar urban settings.

GFT Collection Mandate: Recent legislative changes make source separation of GFT mandatory for municipalities, highlighting the importance of innovating within high-rise GFT collection systems.

Innovative Technologies: Interviewee 1 pointed out several innovations that could enhance waste management, such as the Underground Waste Terminal (OAT) system, refrigerated compactors for GFT, and AI-equipped cameras for monitoring separation quality.

Behavioral Influence: There is an increasing emphasis on behavioral aspects of waste management, with municipalities now using citizens' councils to gather input on waste policy and employing behavioral feedback via AI systems.

Importance of Early Planning: Integrating waste collection solutions early in urban planning is crucial to accommodate space and logistical needs, particularly for high-density areas.

These insights from the NVRD underscore the importance of a well-rounded approach to waste management, combining logistics, innovative technology, and community engagement.

B.2. Interview Municipality Tilburg

Interview with: Interviewee 2 (Policy Advisor for Waste Management at the Municipality of Tilburg)
Date of Interview: 31/10/2024
Subject: The purpose of the interview was to understand the experience of the Municipality of Tilburg with indoor waste collection in high-rise buildings.

On the recommendation of Interviewee 1 from the NVRD, a meeting was arranged with the Municipality of Tilburg, as the city has extensive experience with in-building waste collection in high-rise buildings. The interview was conducted with Interviewee 2, Policy Advisor for Waste Management at the Municipality of Tilburg.

Of the 700 high-rise buildings in Tilburg, 600 use an in-building waste collection system. This system operates according to certain requirements for collection rooms, such as the room being located on the ground floor and a specified distance from the street. When these requirements are met, waste is collected by the Brabant Afval Team, which has a key to access the waste collection room. They roll out the containers, empty them, and return them to the room. The building owner is responsible for the maintenance and cleanliness of the collection room and for clearing any additional waste left outside the containers.

The necessary size of a collection room is calculated based on the estimated waste volume per unit. For example, an average of 60 liters of residual waste per household is used, along with a specified volume for separated waste streams. Using this data, the municipality determines the number of containers required and calculates the square meter area they will occupy. These calculations are also available on the municipality's website.

For low-rise buildings, Tilburg provides dual-compartment bins, which are collected door-to-door. These bins are divided by an internal partition, allowing different waste streams to be separated within the same container.

Throughout the city, many ORACs (underground containers) are also in use. Illegal dumping near ORACs is an issue, and the municipality clears these areas seven days a week. However, if the ORACs are not located on municipal land, the municipality is not responsible for managing dumped waste around them.

Overall, the current system is functioning well, and the municipality is satisfied. However, under the new policy, for newly built complexes with 75 or more units, ORACs are installed instead of in-building collection. This is partly because it is physically more demanding to empty rolling containers than ORACs, and rolling containers are less desirable due to health and safety regulations. An important point of debate concerning ORACs is their location. If ORACs are installed on municipal land, the municipality is responsible for managing any illegal dumping around them. If they are on private land, this responsibility falls to the developer. Therefore, the municipality aims to place ORACs on developers' land where possible, though this is not always feasible in practice.

Many developers of buildings with in-building collection systems are interested in switching to ORACs. One major reason is that the collection room must be on the ground floor, and developers prefer to use this valuable space for other purposes, such as bike or mobility scooter storage. A scheme exists that allows developers to contribute financially per unit to transition to ORACs. The price per unit decreases as the number of households increases.

Finally, source separation is very successful in Tilburg. The municipality does not employ downstream sorting because the quality of the separated waste streams is high, and downstream sorting is not financially advantageous. Typically, Tilburg uses a combination of four ORACs:

one each for residual waste, paper, glass, and PMG (plastic, metals, and cartons). GFT (organic waste) is also a focus area, and for this purpose, Tilburg uses containers with biofilter lids to reduce odor.

In densely populated areas, Tilburg also uses compacting ORACs, supplied by SIDCON. A standard ORAC can handle waste from approximately 75 households, whereas a compacting ORAC can accommodate waste from around 400 households.

B.3. Interview with Haagse Milieu Service (HMS)

Interview with: Interviewee 3 (responsible for ORACs) and Interviewee 4 (Manager Operations at HMS)
Date of Interview: 11/11/2024
Subject: Current challenges and future plans for waste collection in The Hague, specifically in the districts of Dreven, Gaarden, and Zichten.

Current ORAC Challenges and Management
Placement and Maintenance: Interviewee 3 indicated that HMS has not yet received definitive guidelines from the municipality on which ORACs (underground containers) will be retained, relocated, or removed within the districts. This uncertainty hinders maintenance and replacement plans, as there is a risk that recently replaced ORACs might later need to be removed. Each ORAC location is carefully determined, considering walking distances and the number of households served. Modifying these locations requires approval from the city council due to the Waste Management Ordinance.

Future Plans and Municipal Collaboration: There is ambiguity regarding the progress of waste collection plans for the neighborhood. Although a recent meeting was scheduled to discuss this, HMS has not received further information.

Implementation of Load Bins and Operational Challenges
Efficiency and Costs: The transition to load bins poses significant operational challenges. The physically demanding task of emptying load bins reduces efficiency, potentially requiring HMS to hire additional personnel and deploy more vehicles. This would likely result in higher waste collection fees for residents.

CO_2 Emissions and Public Space Impact: Load bins increase waste collection frequency (twice per week, compared to the usual 1.3 times for ORACs). This raises the burden on public spaces and increases CO_2 emissions.

Research on Compactors and Safety Concerns
Pilots and Limitations for Compactors: HMS is researching the use of compactors for household waste. Currently, they use compactors only for paper, as the municipality has safety concerns for residual waste compactors. Two incidents of children entering ORACs have led to a decision to delay compactor use for residual waste.

Pass System for ORACs: A pass system could limit ORAC access, thereby increasing safety. However, this system would add costs and carry the risk of technical issues, which could result in waste buildup next to the containers.

Waste Collection in New Developments and Roll Container Challenges
In-building Collection in Binckhorst: In the new development area of Binckhorst, in-building collection with roll containers is utilized. This system incurs high personnel costs, as an employee can empty only a limited number of roll containers per day.

Issue of Illegal Dumping
Behavior Dependency and Monitoring of Bulk Waste: The problem of illegal dumping varies greatly by area. HMS monitors bulk waste, while the municipality is responsible for enforcement and removing trash bags and boxes.

Limitations of ORAC Vehicles: ORAC vehicles cannot easily collect illegal dumping, as their top-loading design is unsuitable for loading loose items left outside the containers.

Exploration of Mini-compactors
Advantages and Disadvantages of Mini-compactors: HMS is considering mini-compactors, although they are primarily used in the commercial sector. These require specific setup locations and space for collection trucks. This system has the advantage of being emptied mechanically, which is less physically taxing on staff.

Electrification and Fleet Challenges
Transition to Electric Vehicles: HMS aims to transition to a fully electric fleet by 2030, but faces delays in receiving electric ORAC-compatible trucks. Existing trucks would need to be replaced early, leading to higher costs.

Innovation and Spatial Constraints
Underground Waste Terminals (OATs): While OATs have been successfully implemented in cities such as Almere, they are considered impractical in The Hague due to existing infrastructure.

Long-term ORAC Maintenance: The current ORACs in Dreven, Gaarden, and Zichten are, on average, 15 years old. Maintenance and cleaning occur twice a year, and HMS outsources these tasks to contracted suppliers.

Waste Separation and Facilities by District
Waste Separation Options: Each district has different separation options, including sorting stations, curbside collection, and waste drop-off points. Narrower collection vehicles are used in the city center, but the limited demand for electric versions of these vehicles remains a challenge.

Conclusion
The interview with HMS provided valuable insights into the operational and strategic challenges of waste collection in The Hague. The current uncertainty regarding ORAC plans, the additional costs of load bins, and the difficulty of transitioning to an electric fleet pose significant obstacles. HMS is exploring alternative solutions, such as mini-compactors, but faces physical and infrastructural limitations. This information is crucial for mapping out the operational limitations and opportunities for waste collection in the districts of Dreven, Gaarden, and Zichten.

B.4. Interview Municipality of The Hague

Interview with: Interviewee 5 (Policy Officer at the Municipality of The Hague), and Interviewee 6 (Policy Advisor for Waste Management and Circular Economy). They are part of the same team within the *City Management Department (Dienst Stadsbeheer)*
Date of Interview: 21/11/2024
Subject: Current challenges and future plans for waste collection in The Hague, specifically in the districts of Dreven, Gaarden, and Zichten.

Interviewee 5 is a Policy Officer at the Municipality of The Hague, and **Interviewee 6** is a Policy Advisor for Waste Management and Circular Economy. They are part of the same team within the *City Management Department (Dienst Stadsbeheer)*, which is responsible for various aspects of waste collection in The Hague. The team operates on a policy level and manages a clear separation (a "Chinese Wall") between household waste and commercial waste. HMS acts as the waste collection service provider, with the municipality as the client and HMS as the contractor.

Formal Policy for Indoor Waste Collection: The policy is outlined in the Kadernota Openbare Ruimte, which mandates indoor waste collection. Additionally, it is referenced in the document Eyeline Skyline.

Rationale Behind Indoor Waste Collection: The Hague faces a significant densification challenge, being surrounded by other municipalities and lacking expansion space. Consequently, new housing developments are concentrated within the city, often in high-rise buildings. This creates pressure on public spaces, making street-level waste collection unfeasible. Indoor waste collection is therefore considered the most effective solution.

Future of Waste Management in The Hague: The municipality envisions a waste management system that prioritizes separation at the source, supported by automated, data-driven collection processes. Innovations such as food waste disposers for organic waste in apartments, combined with local anaerobic digestion facilities, are part of this vision. Research on food waste disposers is currently being conducted by the Amstel Institute in Amsterdam. While organic waste is already collected door-to-door in low-rise housing, high-rise buildings lack such a system. The municipality is experimenting with underground containers for organic waste in areas like Ypenburg and is testing new systems such as Freshstations developed by Sidcon.

Evaluation of Alternative Waste Collection Systems: The municipality has considered underground waste pipe systems but found them impractical due to high costs and limited support from developers. Implementation of such systems would require approximately ten years.

Waste Separation Goals and Current Practices: The municipality aims to enhance waste separation, focusing on organic waste at the source and plastic waste through post-separation methods. Currently, organic waste is collected door-to-door in low-rise areas, while glass, paper, and plastics are collected through ORACs and sorting stations. Plastics are primarily processed through post-separation by AVR.

Potential Expansion of Organic Waste Separation in High-Rise Buildings: While organic waste separation is established in low-rise housing, no concrete plans exist to extend this to high-rise buildings.

Consideration of Alternatives for Indoor Waste Collection: Options such as indoor compactors and underground waste systems have been explored. Rolling bins are currently offered but are not considered a sustainable long-term solution.

Safety Concerns Related to Compactors: The municipality does not perceive compactors as a safety risk and remains open to their implementation.

Future Waste Management Infrastructure Changes: Approximately one-third of the ORACs are expected to remain operational, though precise calculations have not been made. ORACs will continue to be used for existing buildings, while indoor waste collection will become mandatory for all new developments.

Uncertainty About ORAC Retention and Relocation: HMS has expressed concerns about uncertainty regarding ORAC retention, relocation, or removal within neighborhoods. The municipality has not yet provided definitive answers on this matter.

Projected Number of ORACs in the Neighborhood: The municipality has not determined the exact number of ORACs that will remain. Placement decisions are made by the municipal council based on household numbers and maximum walking distances for residents.

Vision for Waste Collection in the Neighborhood: Rolling bins are seen as a temporary solution, often chosen by developers due to convenience. However, the municipality does not consider them a long-term sustainable option. Instead, indoor compactors that can be moved outside for collection are preferred over fully underground systems.

Stakeholder Coordination and Future Meetings: A lack of coordination among stakeholders was noted. While no formal meetings are currently planned, the municipality is open to facilitating discussions among relevant parties.

B.5. Interview Staedion

During the research, there was intensive contact with the housing corporation Staedion. Various people within the organization were spoken to and semi-interviewed. Not every interaction was a formal interview; some involved attending meetings, participating in resident evenings, or visiting Staedion's local offices in the neighborhood where they engage with residents. The goal was to gather insights through multiple interactions rather than conducting strictly structured interviews.

A brief overview of these engagements is provided below. As these interactions were spread across several meetings and took different forms, not every conversation follows a formal interview format but instead reflects a broader process of knowledge gathering

Interview with: Interviewee 7 - Staedion
Date of Interview: 5-11-2024
Subject: Bulky Waste Management and Costs in Staedion Buildings

Staedion, like other housing corporations, faces significant difficulties in ensuring that bulky waste is collected efficiently while keeping costs manageable. Ideally, bulky waste should be collected by the municipality and funded through the waste disposal tax. However, when bulky waste is left inside Staedion buildings or on its property, Staedion becomes responsible for its immediate removal. The costs associated with this are substantial, and Interviewee 7 from Staedion actively tracks these expenses. During our discussion, he provided valuable insights into the financial burden and operational challenges related to bulky waste management.

According to Interviewee 7, other housing corporations face similar issues, but they do not have a clear understanding of the exact costs involved. Unlike Staedion, which systematically monitors and records waste management expenses, many other corporations lack a structured tracking system, making it difficult for them to quantify the financial impact of bulky waste removal.

One of the key issues is the current process for bulky waste collection. Ideally, residents would call the municipality directly to arrange for collection, but the system in place is not user-friendly, making it difficult for tenants to submit requests effectively. As a result, bulky waste is frequently dumped in unauthorized locations, such as entrance halls and communal areas, which creates safety and logistical issues for Staedion. The municipality has established a working group to address waste collection concerns, but challenges remain in ensuring seamless cooperation between all stakeholders.

In areas such as Binckhorst, there have been notable inefficiencies in waste collection planning. At the De Blox residential complex, for example, waste storage was designed to accommodate 36 containers for 360 apartments. However, due to miscalculations, the system was poorly integrated, leading to an increased need for collection—sometimes twice as often as expected. Additionally, the space was only designated for residual waste, failing to account for other waste streams, further complicating the collection process.

Staedion actively engages with the municipality to improve bulky waste collection policies. Currently, requests for collection must be submitted online in a resident's name, and different types of waste must be categorized separately, creating additional administrative burdens. Given the fire safety risks posed by bulky waste accumulation, there is a need for a more immediate response system to ensure prompt removal. Other housing corporations report similar complaints but often lack the structured tracking system Staedion has implemented.

A significant cost-saving measure would be if Staedion could utilize the municipality's waste collection service (HMS) free of charge, as this would alleviate a large portion of the financial burden. However, the municipality does not currently allow this, meaning that bulky waste from Staedion properties is classified as commercial waste, leading to higher disposal fees per kilogram compared to household waste.

To manage the bulky waste, Staedion contracts private waste collection companies such as Van der Toorn Dienstverlening and EscaSoranje, which remove bulky waste for a fixed fee. These companies provide Staedion with detailed lists of collected waste, allowing the organization to maintain records and monitor problem areas more effectively.

Some locations require additional investment in waste management. For instance, in the Transvaal neighborhood, Staedion initially faced high costs managing waste at the Roze Flat student complex, where a full-time caretaker was assigned to handle waste issues. While costs were eventually reduced from €14,000 to €248 per month, having a full-time caretaker remains an expensive necessity in some cases.

Despite all residents paying a waste disposal tax, which in theory should cover bulky waste collection, many tenants still discard items improperly, forcing Staedion to cover additional cleanup costs. Rent payments include service fees, a portion of which is allocated to bulky waste removal. However, the existing financial structure does not fully account for the extent of the problem.

To combat excessive waste dumping, Staedion has introduced measures to raise awareness among tenants. New residents receive flyers containing municipal contact information for bulky waste collection. Additionally, when tenants terminate their lease, they are actively informed about proper disposal methods, ensuring they are aware of the available collection services.

Staedion also has a duty of care to maintain fire safety and cleanliness within its properties. This means that bulky waste cannot be left in entrance halls or stairwells due to fire hazards. To enforce this, Staedion conducts regular inspections to identify and address problem areas before they escalate.

Financially, bulky waste management represents a significant expense. Staedion spends approximately €127,000 per year on waste removal. The major cost components include:

- Collection and transportation fees.
- Disposal fees at commercial waste processing facilities.
- Contracts with private waste processors, such as Kleineburg, instead of using municipal services.

Data collection plays a crucial role in tracking waste trends. Van der Toorn Dienstverlening documents all collections through photographs, providing visual proof of collected items, which range from mattresses and sofas to large cabinets. This data helps Staedion monitor waste trends and identify problematic areas.

There are also seasonal variations in waste disposal patterns. For example, during the COVID-19 pandemic, municipal cleaning services experienced delays, and residents carried out more home renovations, leading to a clear increase in bulky waste volumes. Additionally, waste disposal tends to spike during tenant relocation periods.

Between 2021 and May 2024, Staedion incurred €127,056.27 in bulky waste removal costs for buildings in Dreven and Gaarden, and €61,898.42 for Zijden, Steden, and Zichten. Dreven and Gaarden rank 2nd and Zijden, Steden, and Zichten 7th among the 70 monitored neighborhoods in The Hague with the highest bulky waste costs for Staedion. This highlights the already significant financial burden in these areas. Staedion expects these costs to increase further with the planned indoor waste storage rooms in the new buildings under redevelopment. Higher bulky waste costs would ultimately be passed on to residents through service charges, despite them already paying waste disposal taxes, which should, in principle, cover bulky waste collection.

In summary, bulky waste management remains a complex and costly issue for Staedion. The organization continues to explore potential improvements, such as negotiating cost-sharing agreements with the municipality, implementing better resident education programs, and leveraging data-driven solutions to optimize waste collection efforts.

Interview with: Interviewee 8 (Neighborhood Manager of Dreven, Gaarden, and Zichten - Staedion)
Date of Interview: 6-11-2024
Subject: Waste Management and Challenges in Staedion Buildings

A walk-along with district coordinator Interviewee 8 was conducted. Interviewee 8 provided an in-depth tour of the neighborhood, highlighting which buildings are scheduled for demolition. The group passed by the demolition sites and the first newly constructed building, which is nearing completion and is expected to be delivered in February 2025. This provided a comprehensive understanding of the neighborhood.

Additionally, Interviewee 8 explained that when new residents move into Staedion buildings, they have an introductory meeting with him, during which he informs them about the local waste management policies. He also pointed out locations within Staedion buildings where bulky waste is frequently dumped. In these cases, Interviewee 8 is responsible for contacting a waste collection company to remove the bulky waste and transport it to a commercial waste facility. The bulky waste is categorized as business waste, meaning it is subject to a higher disposal fee per kilogram than household waste, even though it originates from residential buildings.

Staedion collaborates with companies such as Van der Toorn Dienstverlening and EscaSoranje, which handle the collection and transportation of bulky waste. Staedion pays both for the service and the waste disposal fees incurred at the commercial waste facility. Interviewee 8 expects that the introduction of indoor waste collection areas will lead to an increase in the amount of bulky waste being dumped inside Staedion buildings.

Interviewee 8 expressed significant concerns regarding indoor waste collection areas. He noted that in buildings where Staedion has already implemented such spaces, there have been numerous problems. These include pest infestations, as rodents and insects can enter containers through small openings at the bottom. The containers emit strong odors, and cleaning them is challenging because washing them in the streets is not permitted due to wastewater regulations. Consequently, both the containers and the waste rooms become increasingly difficult to maintain. Additionally, the containers are prone to tipping over in strong winds.

Interviewee 8 demonstrated where the containers are currently positioned: in parking spaces that have been repurposed for waste storage. This reduces the already scarce availability of parking and green spaces in the neighborhood. This issue is visually represented in Figure B.1a. Furthermore, the ongoing demolition of buildings in the district is illustrated in Figure B.1b.

Another major concern is the handling of bulky waste inside Staedion buildings, as seen in Figure B.1c. Bulky waste must be removed as quickly as possible due to safety and fire hazards. Interviewee 8 frequently photographs such cases and sends them to the waste collection company to ensure immediate removal. During the walk-along, multiple instances of improperly disposed bulky waste were observed, indicating the scale of this ongoing issue.

Interviewee 8 also showed several buildings where indoor waste rooms with roll containers are currently in use. These spaces had a persistent foul smell. Figure B.1d reveals that residual waste often remains in the bottom of the containers even after they have been emptied. These waste residues begin to rot, exacerbating the odor problem. Cleaning the containers is difficult, as they cannot be rinsed outside the building due to wastewater regulations. As a result, maintaining hygiene in these waste collection areas remains a major challenge.

(a) Roll Container Collection Space

(b) Demolition in the Neighborhood

(c) Bulky Waste in a Staedion Building

(d) Residual Waste in Emptied Roll Container

Figure B.1: Observations from the Walk-Along with District Coordinator Interviewee 8

B.6. Interview SIDCON

Interview with: Interviewee 9, Account Manager at Sidcon Environmental Technology
Date of Interview: 11-11-2024
Subject: Underground Press Containers and Implementation in The Hague

Company Background
Sidcon has been developing underground press containers for waste management for approximately 15–16 years. The company was founded by Reinier Siederius and initially worked with the municipality of Arnhem. Over time, the company has expanded significantly, currently supplying over 2,000 press containers across 125 municipalities in the Netherlands, including The Hague. Sidcon has also expanded internationally, operating in countries such as Sweden, Denmark, Norway, Germany, Switzerland, and France.

Application of Underground Press Containers
Sidcon initially focused on PMD (plastic, metal, and drink cartons) press containers before expanding to residual waste, paper, and cardboard. These containers are particularly effective in high-density urban areas, where space constraints are a challenge. Instead of placing five standard underground containers, a single press container can be used, reducing spatial impact and freeing up land for green spaces. Sidcon typically recommends press containers for buildings with at least 100 residential connections or areas where regular containers require emptying two to three times per week. According to Sidcon, transitioning from regular ORACs to press containers becomes economically beneficial after approximately 10 years.

Technical and Safety Considerations
One of the primary concerns regarding underground press containers is safety, particularly the risk of children falling into the system. Sidcon has implemented a safety funnel design, which prevents children from accidentally entering the container. Additionally, press containers comply with CE safety regulations. In traditional ORACs, accidents often occur when side doors remain open, allowing entry. Sidcon's design minimizes this risk.

Sidcon's press containers also include welded "teeth" inside the drum, which prevent people from climbing inside. These measures were tested at childcare centers, where children showed no interest in entering the drum unless sharp objects were inside. This design makes press containers safer than traditional ORACs, which lack such safeguards.

Implementation in The Hague
Sidcon has delivered several press containers in The Hague, including two for paper and five additional units currently on order. Specific locations include:

- Willem de Zwijgerlaan 80
- Van Imhoffplein 15
- Hotspot locations designated for HMS as part of a pilot project

The types of waste processed in Sidcon press containers include:

- Paper and cardboard (compacted at a ratio of 1:5)
- Residual waste (compacted at a ratio of 1:6)
- PMD (compacted at a ratio of 1:10)

Sidcon estimates that the average investment cost for a press container is between €25,000 and €30,000, depending on its specifications. These containers can be installed in existing 5m^3 concrete pits, making them ideal for cities that initially used standard ORACs and now face capacity challenges.

Maintenance and Operational Insights
Sidcon's press containers are designed for high-intensity use, capable of handling 5,000 drum movements per week. They are equipped with fill-level sensors that transmit data to a web portal, allowing municipalities to monitor waste levels in real time. This portal can be easily integrated with The Hague's existing waste management systems. In terms of maintenance, Sidcon provides preventive and collective servicing, with an annual maintenance contract costing approximately €1,200 per container.

Challenges and Lessons from Previous Installations
Sidcon previously collaborated with Staedion in The Hague. However, these containers were later removed due to poor operational management. The key issue was that the designated caretaker was responsible for placing the containers outside for collection. Uncertainty over whether HMS would arrive to empty them led to operational failures, prompting their removal. The responsibility for proper waste collection management remains a challenge, and future implementations require clear agreements between waste collection services and housing corporations.

Cost and Efficiency Considerations
The price of a press ORAC is approximately 2.5 to 3 times that of a traditional ORAC. However, the long-term financial benefits include reduced emptying frequency and higher capacity per collection, making them a cost-effective solution over time. A fully equipped press container typically costs €27,500.

Additionally, a press ORAC has a higher waste density, allowing a single truck to collect significantly more waste per trip:

- Residual waste: 1,200–1,300 kg per press ORAC
- PMD: 500–800 kg per press ORAC

Despite the increased weight of compacted waste, the same collection trucks can be used as with standard ORACs. Some municipalities, such as Amsterdam, implement access control systems to improve waste stream quality, while others, including The Hague and Delft, do not.

Future Innovations and Integration
Sidcon continues to refine its press container technology. The company employs five product engineers who work on improving the durability and efficiency of their containers. The technology behind the press containers has been continuously developed since 2008/2009, with early models now reaching the end of their economic lifespan after 10–12 years. The company also maintains a web-based monitoring system that tracks the performance of all 2,000 installed press containers daily. This system helps detect anomalies such as power failures or blockages, allowing technical teams to respond proactively.

Conclusion
Sidcon's underground press containers offer a high-capacity, space-saving alternative to traditional ORACs. The company has extensive experience in both domestic and international markets, with The Hague already implementing several press containers in key locations. The technology ensures higher efficiency, reduced collection frequency, and increased safety measures. However, previous challenges with implementation in The Hague highlight the importance of proper management and coordination between municipal waste collection services and housing corporations.

Sidcon continues to expand its reach, working with major cities such as Amsterdam (400 units), Utrecht (350 units), Leiden (80 units), and Delft (30 units). Their press containers are designed for long-term cost efficiency and can be seamlessly integrated into existing infrastructure, making them an attractive solution for municipalities facing space and capacity challenges.

B.7. Interview Sweco

Interview with: Interviewee 10, Technical Manager OAT Sluisbuurt (Sweco)
Date of Interview: 23-01-2025
Subject: Information gathering on the Underground Waste Transport System (OAT)

The interview aimed to gather more information about the OAT system. Additionally, Interviewee 10 assisted in estimating the costs of the OAT system for DGZ.

Interviewee 10 is the Technical Manager (IPM) responsible for the preparation, tendering, and realization of the underground waste transport system (OAT) in the Sluisbuurt district in Amsterdam. This solution for the separate collection of household waste in this new residential area operates at the intersection of architecture and civil engineering and integrates implementation and operation.

In Sluisbuurt, three waste streams will be collected via the OAT system: residual waste, PMD (plastic, metal, and drink cartons), and organic waste (GFT).

Almere also has an OAT system for household waste, which initially faced many technical failures and teething problems. However, these were mainly due to user behavior. Smaller waste bags are required, and residents must adapt to this. Using oversized waste bags leads to blockages, as the standard 80-liter bags are unsuitable. Additionally, issues arose with paper and cardboard shredders.

Arnhem also has an OAT system, but it is primarily used for commercial waste.

A critical discussion in implementing an OAT system revolves around cost distribution. This can be compared to investments in tram and bus lines, as significant costs are involved. In Sluisbuurt, the municipality is responsible for the terminals and pipelines up to the building. Within the building, the property owner is responsible for both the cost of inlets and their maintenance. The system's operation should be funded through waste disposal fees, but the initial investment costs are not covered by these fees.

The system is less suitable for paper and cardboard due to clogging and blockages. It is preferable to retain underground containers for glass, paper, and cardboard while using the OAT system exclusively for residual waste.

An interesting aspect of such a redevelopment is the possibility of preparing residents for the system within their homes. Instead of 80-liter bins, multiple smaller waste bins should be provided, as large waste bags are unsuitable for the system. The design of kitchen units can already take this into account.

In Sluisbuurt, the system includes approximately 4 km of pipelines, 40 collection points, serving 6,000 residences and 150,000 m^2 of commercial space. The design accounts for a 25% overcapacity.

A Finnish supplier, MariMatic (SF), is used for the Sluisbuurt OAT system. This supplier is more expensive but provides higher-quality systems. Another crucial aspect of implementation is determining the optimal location for waste terminals, which serve as collection hubs. The OAT system in Sluisbuurt is scheduled for completion in 2026.

Email Correspondence on OAT Cost Verification

In addition to the interview, further verification of cost estimates for the OAT system in DGZ was conducted through email correspondence with Interviewee 10. The relevant emails have been translated and added in the following text. These communications provide additional

insights into cost breakdowns and considerations for implementing the OAT system in DGZ.
Email Correspondence with Interviewee 10
Email from: Interviewee 10 (Sweco, Advisor on Building and Safety)
Sent: January 31, 2025
To: Pien Biersteker
Subject: RE: Additional Questions on OAT

The determination of the size and scope of an OAT system is an iterative process:

1. Where can/may a terminal be built (accessibility for collection trucks)?
2. What is the maximum pipeline length (to ensure sufficient suction power)?
3. How many collection points are required in the neighborhood (i.e., walking distance from residential buildings)?

Practical Considerations:

- When estimating costs, consider the initial investment (construction), maintenance, and operational costs.
- Given the scale of the system, approximately two OAT installations are needed (mainly due to pipeline length and the number of containers that need to be filled).
  - This is rounded from an estimated 1.5 systems.
  - The installations can either be housed in two separate terminal buildings or combined into one dual-terminal (the latter being more cost-effective).
- The estimated pipeline length matches my expectations for these neighborhoods.
- For these neighborhoods, I recommend using external inlets.
- Pricing varies slightly and can differ between manufacturers and suppliers.

Cost Distinction Between Investment (Construction) and Operation:
Investment Costs (Construction):

Component	Cost (€)	Details
OAT Pipeline (per meter)	1,000	Minimum of 2 main branches
OAT Collection Points (per unit)	100,000	Assuming 4 inlets per collection point
OAT Terminal (Building)	2,000,000	Assuming one building with a dual installation
OAT Installation (Terminal)	1,200,000	Dual installation at one location

Table B.1: Estimated Investment Costs for OAT System

Maintenance and Operational Costs:
Waste Collection Frequency from the OAT Terminal:
On an average week, around **15-16 trucks** will collect waste from the OAT terminal (with a dual installation). This is similar to traditional collection methods using roll containers or underground containers, except for occasional Saturday collections.
Reference Videos on Similar Systems:

- MariMatic (SF): `https://www.youtube.com/watch?v=gHmt1GTVlnM`

Component	Annual Cost (€)	Details
OAT Pipeline	40	Per meter per year
OAT Collection Points	4,000	Per collection point per year
OAT Terminal (Building)	25,000	Per terminal per year
OAT Installation (Terminal)	125,000	Per installation per year

Table B.2: Estimated Maintenance and Operational Costs

Waste Type	Pickups Per Week	Details
Residual Waste	10	Every 2 days, 3 containers of 20m^3 each
Organic Waste (GFE)	3	3 containers of 20m^3 per week
Paper Waste (excluding cardboard)	3	3 containers of 20m^3 per week

Table B.3: Expected Waste Collection Frequency from the OAT Terminal

- Envac (S): `https://www.youtube.com/watch?v=0aP4sUNZdeA` (Envac is distributed in the Netherlands via Dura Vermeer)
- More solutions from MariMatic: `https://www.youtube.com/watch?v=Izxj10sjrRk`

It is now confirmed that an OAT system will also be installed in Schieveste (near Schiedam Station, along the A20). This will be an Envac system, implemented via the developer Dura Vermeer after a somewhat complex procurement process. Initially, it was planned as an independent tender but has now been integrated into the overall project development, meaning the system is being procured by the developer.
Best regards,
Interviewee 10
Advisor on Building and Safety
Sweco Nederland B.V.

Cost and Space Estimation for OAT System
Correspondence with: Interviewee 10 (Sweco, Advisor on Building and Safety)
Date: January 31, 2025
Subject: Estimations for the Implementation of an Underground Waste Transport System (OAT) in The Hague

During the discussion on OAT system implementation for the neighborhoods of Dreven, Gaarden, and Zichten, several key estimations were reviewed. Below is an overview of the initial estimates along with expert feedback from Interviewee 10:
Estimated Infrastructure Requirements:

- 8 km of pipelines: **This estimate is fairly accurate.**
- 65 collection points: **This number may be slightly overestimated (it depends on walking distances). Assume that one collection point with four inlets serves 100-140 residences (depending on the number of residents per household; for The Hague, an average of 2 residents per household is expected).**
- 9 terminals: **No more than 2 terminals are needed for these two adjacent neighborhoods; the required number is determined by the total waste volume (number of households) and the maximum pipeline length (considerations related to kinetic energy).**

Cost Estimates:

- €100,000 per collection point: **This is highly dependent on the number of inlets per point (residual waste, organic waste, and plastics). For 3 inlets: €100,000; for 4-5 inlets: €150,000. Keep this in mind.**
- €200,000 per terminal: **Add another zero to this estimate.**
- **A terminal where containers are collected outside (as in the Almere OAT system) would cost approximately €2 million for both the terminal and its installations.**
- €2 million per km of pipeline: **Assume around €1,000 per meter of pipeline.**
- €4,000 per year for terminal maintenance: **Consider this as the base cost for maintenance and operational expenses.**
- €2,000 per year for collection point maintenance: **This should be adjusted to €3,000 per year.**
- €100 per terminal emptying: Are these emptied weekly? What is the expected frequency?

Space Requirements:

- 5 m^2 per collection point: **Yes, for the outdoor solution (indoor setups may vary).**
- 500 m^2 per terminal: **Yes.**

C
Criteria Weights (AHP)

In Figure C.1, a screenshot of the Microsoft digital form is shown, displaying the criteria comparison table. The screenshots are in Dutch because the form was designed in Dutch, as all involved stakeholders were Dutch. Each stakeholder completed this form by comparing each criterion against the others.

In the comparison table, the middle point represents an equal level of importance between the two criteria. The left side indicates that the first-mentioned criterion is more important than the second, while the right side indicates that the second criterion is more important than the first.

After comparing the main criteria, stakeholders were asked to compare the subcriteria within each main criterion. For instance, in Figure C.2, the subcriteria for costs are compared. Similarly, Figure C.3 presents the questionnaire for the space usage and sustainability criteria.

1. Welke criterium vindt u belangrijker en in welke mate? Let op u kunt opzij scrollen.

Voorbeeld bij Kosten vs. Ruimte gebruik: Als u Kosten absoluut belangrijker vindt dan ruimtegebruik: klik dan links "Absoluut belangrijkst" aan. Vindt u Ruimte gebruik absoluut belangrijker dan Kosten klik dan rechts "Absoluut belangrijkst" aan. Vindt u beide criteria even belangrijk klik dan "Even belangrijk" aan. *

	Absoluut belangrijkst	Duidelijk belangrijker	Iets belangrijker	Even belangrijk	Iets belangrijker	Duidelijk belangrijker	Absoluut belangrijkst
Kosten vs Ruimte gebruik	○	○	○	○	○	○	○
Kosten vs. Gebruiksgemak	○	○	○	○	○	○	○
Kosten vs. Duurzaamheid	○	○	○	○	○	○	○
Kosten vs. Implementatie gemak	○	○	○	○	○	○	○
Ruimte gebruik vs. Gebruiksgemak	○	○	○	○	○	○	○
Ruimte gebruik vs. Duurzaamheid	○	○	○	○	○	○	○
Ruimte gebruik vs. Implementatiegemak	○	○	○	○	○	○	○
Gebruiksgemak vs. Duurzaamheid	○	○	○	○	○	○	○
Gebruiksgemak vs. Implementatiegemak	○	○	○	○	○	○	○
Duurzaamheid vs. Implementatiegemak	○	○	○	○	○	○	○

Figure C.1: AHP Questionnaire: Criteria Comparison

2. Welk sub criterium vindt u het belangrijkst in het criterium: **Kosten**? Let op u kunt opzij scrollen.

   Uitleg: welke kosten vindt u het belangrijkste ten opzichte van elkaar. Hieronder nogmaals de uitleg van de verschillende soorten kosten:

   - Investeringskosten: Kosten voor containers of container-ruimtes.
   - Operationele kosten: Dagelijkse kosten, zoals schoonmaak, afval buiten zetten, en ophalen.
   - Servicekosten: Kosten die u als bewoner betaalt aan Staedion voor onderhoud van inpandige afvalruimtes.
   - Afvalstoffenheffing: Belasting die u als bewoner betaalt aan de gemeente voor afvalinzameling en verwerking.

   Voorbeeld bij Investeringskosten vs. Operationele kosten: Als u Investeringskosten absoluut belangrijker vindt dan Operationele kosten: klik dan links "Absoluut belangrijkst" aan. Vindt u Operationele kosten absoluut belangrijker dan Investeringskosten klik dan rechts "Absoluut belangrijkst" aan. Vindt u beide criteria even belangrijk klik dan "Even belangrijk" aan. *

	Absoluut belangrijkst	Duidelijk belangrijker	Iets belangrijker	Even belangrijk	Iets belangrijker	Duidelijk belangrijker	Absoluut belangrijkst
Investeringskosten vs. operationele kosten	○	○	○	○	○	○	○
Investeringskosten vs. afvalstoffenheffing	○	○	○	○	○	○	○
Investeringskosten vs. service kosten op de huur	○	○	○	○	○	○	○
Operationele kosten vs. Afvalstoffenheffing	○	○	○	○	○	○	○
Afvalstoffenheffing vs. service kosten op de huur	○	○	○	○	○	○	○

Figure C.2: AHP Questionnaire: Subcriteria Comparison for Costs

3. Welk sub criterium vindt u het belangrijkst in het criterium: **Ruimte gebruik**?

Uitleg: Ruimtegebruik verwijst naar het aantal vierkante meters dat afvalinzameling inneemt. Dit kan zowel:

- Openbare ruimte zijn, zoals straatruimte op gemeentelijke grond.
- Inpandige ruimte, zoals afvalruimtes binnen uw gebouw voor rolcontainers.

Voorbeeld bij Inpandig ruimtegebruik vs. Openbare ruimte gebruik: Als u Inpandig ruimtegebruik absoluut belangrijker vindt dan Openbare ruimtegebruik: klik dan links "Absoluut belangrijkst" aan. Vindt u Openbare ruimtegebruik absoluut belangrijker dan Inpandig ruimtegebruik klik dan rechts "Absoluut belangrijkst" aan. Vindt u beide criteria even belangrijk klik dan "Even belangrijk" aan. *

	Absoluut belangrijkst	Duidelijk belangrijker	Iets belangrijker	Even belangrijk	Iets belangrijker	Duidelijk belangrijker	Absoluut belangrijkst
Inpandig ruimtegebruik vs. openbare ruimtegebruik							

4. Welk sub criterium vindt u het belangrijkst in het sub criterium: **Duurzaamheid**?

Duurzaamheid meet hoe milieuvriendelijk een alternatief is en bestaat uit twee aspecten:

- Vervoersbewegingen: Hoeveel transport nodig is voor afvalinzameling en de uitstoot die hierbij vrijkomt.
- Afvalscheiding: In hoeverre elk alternatief afvalscheiding ondersteunt.
  In sectie 1 geeft u aan hoe belangrijk duurzaamheid in zijn algemeenheid is.

Voorbeeld bij Vervoersbewegingen vs. Afvalscheiding gebruik: Als u Vervoersbewegingen absoluut belangrijker vindt dan Afvalscheiding: klik dan links "Absoluut belangrijkst" aan. Vindt u Afvalscheiding absoluut belangrijker dan Vervoersbewegingen klik dan rechts "Absoluut belangrijkst" aan. Vindt u beide criteria even belangrijk klik dan "Even belangrijk" aan. *

	Absoluut belangrijkst	Duidelijk belangrijker	Iets belangrijker	Even belangrijk	Iets belangrijker	Duidelijk belangrijker	Absoluut belangrijkst
Vervoersbewegingen vs. afvalscheiding							

Figure C.3: AHP Questionnaire: Subcriteria Comparison for Space Usage and Sustainability

D

Detailed Criteria Values Overview

In Figure D.1, an overview of all criteria values is presented. The investment costs and operational costs are shown in millions. The green table displays the actual scores, while the blue table represents the normalized scores.

Alternative	Investment Costs	Operational costs	Waste Tax for households	Resident service fees for Staedion	Indoor space usage	Collection space usage	Ease of Use	Transport movement	Waste separations goals	Ease of Implementation
Underground Containers (ORAC)	0,000	1,630	0	0	0	945	7	6	6	10
Roll Containers in Indoor Storage	7,879	2,037	9	9	1966	1966	3	2	2	5
Indoor Press Containers	2,842	0,264	7	7	395	790	5	7	2	6
Press Underground Containers (ORAC)	1,358	0,247	2	0	0	182	7	8	7	8
Underground Waste Transport System	24,067	0,994	10	10	425	1000	9	10	10	1

NORMALIZED

Alternative	Investment Costs	Operational costs	Waste Tax for households	Resident service fees for Staedion	Indoor space usage	Collection space usage	Ease of Use	Transport movement	Waste separations goals	Ease of Implementation
Underground Containers (ORAC)	1,00	0,23	1,00	1,00	1,00	0,57	0,67	0,50	0,50	1,00
Roll Containers in Indoor Storage	0,67	0,00	0,10	0,10	0,00	0,00	0,00	0,00	0,00	0,44
Indoor Press Containers	0,88	0,99	0,30	0,30	0,80	0,66	0,33	0,63	0,00	0,56
Press Underground Containers (ORAC)	0,94	1,00	0,80	1,00	1,00	1,00	0,67	0,75	0,63	0,78
Underground Waste Transport System	0,00	0,58	0,00	0,00	0,78	0,54	1,00	1,00	1,00	0,00

Figure D.1: Criteria Values Overview