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Light into the Urban Black Box – A Comprehensive Urban Metabolism Approach for Strategic Policy Making

A Case Study of Household Waste Management in Amsterdam

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A Comprehensive Urban Metabolism Approach for Strategic Policy Making

A Case study of Household Waste Management in Amsterdam

By

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Elias Vetter
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Executive Summary

The limitation of natural resources forces humanity to rethink its current way of resource use. Urgency for improvement is elevated by the fast-growing world population and development of big economies as India, China and Brazil. To decrease the need for natural resource, but above all ensure that no resources are wasted, new strategies have to be embraced to change resource use efficiency. Circular Economy (CE) is one of these rising strategies. By “closing the loop” CE aims at increasing the time materials are used before their final disposal. Reusing, repairing and remanufacturing products, taking materials back to be reinserted into production and the recycling of material to be used for new products are actions of CE. However, the current efforts do not live up to their goals yet. Urbanization, often seen as a big societal challenge itself, can play an important role in this process, due to high resource use in a relatively small area. Understanding the current material flows and the system they flow through might generate knew knowledge of material use dynamics. This knowledge can help policy makers to stimulate resource use efficiency. To generate the necessary knowledge this research takes an Urban Metabolism (UM) approach. Therefore, the following main research question was posed:

“How can an Urban Metabolism approach facilitate a comprehensive and actor-centred analysis of urban material flows, generating knowledge of material flow dynamics and enabling policy makers to formulate strategies for sustainability increasement of urban material flows?”

In contrast to established material flow focused and analytical aggregated UM approaches, this research proposes a more comprehensive approach. Defining the UM not only as material flows and processes, but giving more weight to the Social, Economic, and Institutional system aspects as well as the role of actors. On top of the different system perspective the metabolism analysis is conducted on different time and spatial levels. Months instead of years and neighbourhoods instead of cities. The addition of disaggregated analytical levels enables the use of statistical analysis to discover material use patterns over time and identification of actor group related material-use behaviour. The statistical methods used are Time Series, Correlation and Geospatial Analysis in addition to the common Material Flow Analysis and a Life Cycle Assessment. The proposed UM approach is applied to the case of household waste management in Amsterdam. Its analysis focuses on the current situation of material recovery and prevention for plastic and GFT waste and potential future improvements of these waste supply chains. The aim of the case study is to explore the potential of the approach and generation of insights for policy making and theory. The specifications and choices of the approach design can be found in chapter 2, metabolism analysis definition in chapter 5 and results in chapter 8.

The findings of this research are discussed in three stages. First is the theoretical findings are presented. Second is the policy advice formulated. Finally, the most important conclusions from the application of the comprehensive UM approach are drawn.

The theoretical findings of this research are related to the waste generation and separation behaviour of citizens. Previous research clearly distinguished between generation and separation of waste behaviour. Separation mostly being related to the ability to separate and the complexity of the task itself. Generation of waste is much more complex being more related to personal values and environmental awareness.

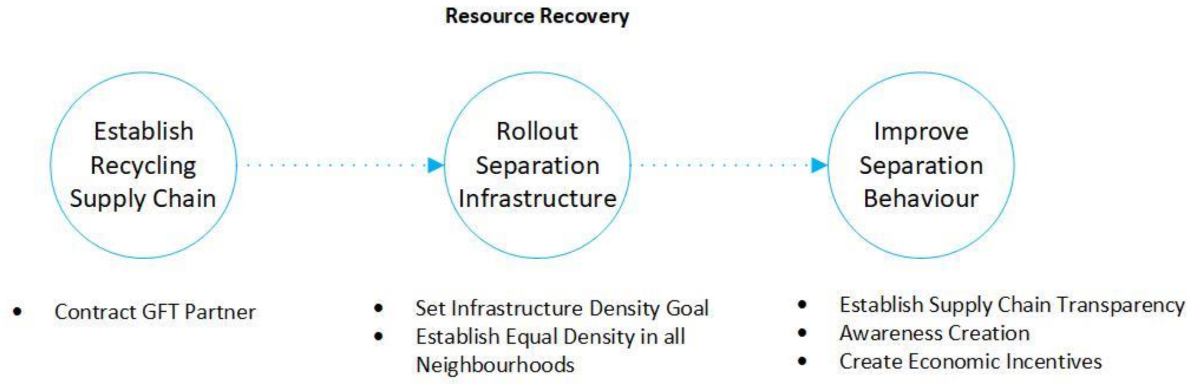
The development of separated and non-separated waste overtime showed different overall behaviour. While separated waste appeared to be more fluctuating, non-separated waste showed a rather stationary behaviour. Changing attitudes towards separation might be a reason behind the

fluctuating behaviour shown by the separated waste data. Lows in the non-separated waste data could be explained by vacation periods.

The separation behaviour tested on a neighbourhood level for plastic waste showed no significant relationship between density of separation infrastructure and the separated plastic waste quantities. Neighbourhoods with low infrastructure density showed relatively high separation quantities and the other way around. Also, no significant relationship between housing type or citizens density and separated plastic waste quantities were found. A significant relationship was found between separated waste quantities and education level as well as origin of citizens. This does not mean that low, medium or high educated people intentionally separate less or more waste. However, this behaviour might indicate systematic imperfections as the complexity of the separation task and the related information provided.

The theoretically well-established relationship between income and waste generation could not be proven by this case study. No significant relationship between the total plastic waste generated and the average income level of citizens on a neighbourhood level was found.

Based on the system demarcation in chapter 4 and the results of the metabolism analysis in chapter 5 policy advice for sustainability increasement of the GFT and Plastic household waste supply chains was formulated. Most of the waste in Amsterdam is still incinerated regardless of the circularity and separation goals set. To move towards the a more circular system a lot has to change in the different supply chains. Not only within the city of Amsterdam, but on national and European level as well. Since the scope of this research is the jurisdictional area of the municipality of Amsterdam, the policy advice only addresses the issues within this area. To improve resource recovery of the GFT and plastic supply chain the steps shown in the figure below should be taken. The complete policy advice can be found in chapter 9.



Finally, it can be concluded that the designed Comprehensive Urban Metabolism approach can enable comprehensive understanding of urban material flows and the actors shaping them to provide evidence supporting policy making for sustainability increase. It accomplishes this by first demarcating the system to understand its complexity and define objectives for the analysis. Second, is the metabolism analysis combining technical and social analysis of material flows and related actor behaviour, to create evidence for better understanding of the system behaviour. In the last step this evidence is used to formulate policy advice for improving the systems sustainability. Taking a more systematic perspective and combining material and behaviour analysis makes the difference in comparison to established approaches. Even though, not all aspects of the approach were analysed and addressed in depth due to data and time constraints, this research proved that the approach can be of great value for progressive development in the field of UM studies.

Table of Contents

Table of Figures

Table of Tables

List of Abbreviations

Application Programming Interface (API)
Circular Economy (CE)
European Commission (EC)
Geospatial Information System (GIS)
Industrial Ecology (IE)
Life-Cycle-Assessment (LCA)
Material Flow Analysis (MFA)
Municipal Solid Waste (MSW)
Municipal Solid Waste Management (MSWM)
Pay-as-you-throw (PAYT)
Urban Metabolism (UM)
Smart Urban Metabolism (SUM)
Waste Prevention Behaviour (WPB)
Waste Prevention Plans (WPP)

Definitions

Data Granularity

Detail level of the data. Often related to spatial area or time. High granularity refers to data with a high level of detail. Example of this data could be the energy or waste production of an individual household.

Underlying Material Flow Dynamics

Material flows are moving through the urban environment in different time periods. The dynamics influencing the speed and manner with which this flows behaviour are the underlying material flow dynamics.

Rural to Urban Migration

The phenomenon of rural to urban migration describes the shift in population proportions living in rural and urban areas. In the last decennia people more and more moved from rural to urban areas due to job opportunities and other liveability related issues.

Source-Separation

Waste can be separated in different stages of the waste supply chain. Source-Separation describes the process of citizens separating different waste fractions in their homes and placing them in specific containers.

Waste Fraction

A waste fraction is a single waste stream containing a single or a collection of specified materials. The most common household waste fractions are residual, plastic, paper, glass, gft and bulky waste.

Virgin Material

Material directly produced from natural resources and not recycled products

1. Introduction & Research Definition

The limitation of natural resources forces humanity to rethink its current habits of material use. Plastic product packaging, fossil fuels for transportation and energy generation are just a few examples of highly resource intensive processes in modern society. Urgency of this matter increases due to the fast-growing world population and big economies as India, China and Brazil. In 2015 the world population reached the 7.3 billion mark. Until 2050 the United Nations estimate an increase up to 11.2 billion (United Nations, 2015). Satisfying the resource need of such a big population will not be possible in the way natural resources are currently exploited. To decrease the amount of resources needed, but above all ensure that no materials are wasted, new strategies have to be embraced to optimize resource use (United Nations, 2018).

Cities can play an important role in this optimization process, due to their high population density and use of materials (Girardet, 2017). Just as the population, cities worldwide have grown tremendously in the last decades (Hoornweg & Pope, 2017). In 2007 the tipping point was reached: more people were living in cities than in rural areas. Rural-to-urban migration and the continuous growth of cities themselves are fuelling this urbanization process (Duijsens, 2018). This phenomenon is often associated with a lot of problems such as safety, congestion and air quality. National, but mostly municipal governments are struggling to keep up with these issues. However, the agglomeration and networks of cities offer a lot of opportunities to find sustainable solutions for resource use on a local level (Nijkamp & Kourtit, 2012).

Amsterdam is one of these fast-growing cities. From 2000 to 2014 its population increased by 73.000 citizens, mainly due to migration and good job opportunities in the region. The problems Amsterdam is facing, due to this growth, are diverse as for example a decrease in air quality, scarcity of housing, and urban social segmentation (Nabielek, 2016). This development also offers opportunities. High population density can increase sustainability of last mile goods transportation, waste management or energy use. The number of strategies for efficient material use and their ambition is high. Circular Economy (CE) being the most prominent one. By “closing the loop” this strategy tries to increase the lifespan of materials. The closing actions are the reuse, reparation and remanufacturing of products, taking goods back to be reinserted into production and the recycling of goods to be used for new products. CE approaches are diverse and still need behavioural change of governments, businesses and citizens to be successful.

To make this happen, information support to local governments and citizens is essential. The current state of the system has to be understood. With a better understanding of the in-, out-, and internal-flows of resources in cities, opportunities to improve those flows can be identified, aiming to improve resource use efficiency, and creating a more sustainable and liveable city.

1.1 Research Problem

Improving resource efficiency in urban areas consist of two main tasks: Understanding and Reshaping. Understanding the current system and its resource flows enabled by urban system analysis and evaluation. Reshaping the current system to change flows enabling increase of resource efficiency. In this chapter theories for resources flow assessment are discussed and analysed in a literature review. Knowledge, stating the necessity of this research.

1.1.1 Urban Metabolism

Urban Metabolism (UM) is a metaphor conceptualizing a city as an organism, or ecosystem, which consumes, transforms, and emits resources. Different methods and approaches are used to analyse this UM. Wolman was the first to analyse the resource supply of a hypothetical city in 1965, and can therefore be seen as one of the theories founding fathers (Wolman, 1965). The advantages of this theory are the possibility to explore the current resource flows and processes, evaluate their efficiency and propose changes to improve system performance.

Over the years, the conceptualization of the city as an organism developed to a more systematic concept of a city as an ecosystem. The main difference lies in the fact that an ecosystem approach widens the scope from a pure biological black-box to inclusion of actor and sub-system relations. The organism represents the current linear inefficient perspective of a city. Whereas a ecosystem stands for efficiencies and closing the loop between outputs and their potential of being new input. A good definition of the current UM concept is:

"the collection of complex sociotechnical and socio-economical processes by which flows, material, energy, people, and information shape city, service, the needs of its populace, and impact the surrounding hinterland" (Currie & Musango, 2016, p. 4).

1.1.2 Research Gaps

The number of UM resource flow assessment methods has increased in the last two decades. Their focus shifted from a simple accounting of material and energy flows to identifying changes and determining environmental impact of UM. According to Musango, J.K., Currie, P. & Robinson (2017) the well-established methods can be categorized into accounting, input-output analysis, ecological footprint analysis, and life cycle assessment. All those methods help to understand the urban ecosystem and its resource flows.

Accounting is mostly focused on determining the material balance by executing a **Material Flow Analysis** (MFA), mapping all material flows entering and leaving a system. One of the numerous examples of this approach is the UM analysis of Paris, executed by Barles (2009). It gives a high-level picture of the resource throughput of Paris and its hinterland. Comparing the results to the national average and identifying material flows within the city, enabled the researchers to place the current situation in Paris into perspective (Barles, 2009). However, it strictly focused on highly aggregated structures and processes. Solely discussing abstract material flows without an analysis of the underling processes.

Input-Output analysis studies the material flows between sectors, and their productivities (Giljum & Hubacek, 2009). Usually, this is done on a macro level. In the application of this method to UM, Zhang, Yang, & Yu, (2009) they used input-output analysis in multiple case studies in the form of ecological network analysis in big Chinese cities. Similar to accounting, Input-Output analysis focuses on aggregated values. Sector specific resource flow analysis is neither taking into account the processing, and transportation of resources, nor the socio-economic dynamics. However, it opens op the "black-box" a little by the identification of sector specific resource flows.

Rees & Wackernagel (1996) define **Ecological Footprint** analysis as the area of productive land needed to sustain a defined population undefinedly. It is a simplification of resource flow analysis down to one variable: land use. It enables comparison, but only considers environmental aspects.

Life Cycle Assessment (LCA) is a popular tool to determine the environmental impact of a product, or a service (Ferrão & Nhambiu, 2009). LCA enables the comparison of those products, and services.

Goldstein et al. (2013) combined LCA with UM to create a better picture of the resource flow up-, and downstream of UM. They analysed the resources and their condition before they entered and after they left the city. LCAs empower policy makers to get a comprehensive picture of the resource supply chain in their city (Goldstein, Birkved, Quitzau, & Hauschild, 2013). Nonetheless, LCA by itself only look at the environmental impact of a product or services and not at financial or other aspects of the products or service use.

The concept of Urban Metabolism must evolve, in order to effectively improve the resource flow efficiency in cities. Musango, Currie & Robinson (2017) argue that these approaches are not comprehensive enough to successfully improve sustainability of cities. Even though, the conceptualization change from organism to ecosystem indicates a more holistic approach, a comprehensive and implementation-oriented framework has yet to be developed. Pincetl, Bunje, & Holmes (2012) argue for the development of a more comprehensive framework for the analysis of physical material and energy flows as well as social, institutional and economic aspects, which all structure and govern the urban metabolic system. Expanding UM analysis variables with social, financial and other aspect could be of great value for decision makers in charge of urban sustainability.

To enable a more comprehensive analysis, deeper analysis of material flows and their surroundings is necessary. An increase of temporal and spatial data detail can help UM studies to connect waste streams to specific citizens or groups, their activities and surroundings. New approaches as Smart Urban Metabolism (SUM) show the potential a more detailed analysis can have. SUM is a concept proposed by Shahrokni, Lazarevic, & Brandt (2015). The study suggests to use SMART city features, like real-time and high-resolution data generation, to create real-time information systems of UM (Shahrokni, Lazarevic, & Brandt, 2015). In 2015, a study of a first successful SUM system implementation in a part of the port of Stockholm was published. This research mainly focused on visualising the energy flows and greenhouse gas emission (Shahrokni, Årman, Lazarevic, Nilsson, & Brandt, 2015). It shows the need for a continuous and more detailed analysis of UM. Shahrokni, Arman, Lazarevic, & Brandt (2015) as well as Pincetl et al. (2012) advocate for a higher spatial and temporal detail of resource flow analysis, in order to successfully increase sustainability of urban resource flows.

The literature review identified different shortcomings of the established UM analysis approaches. Their snapshot of resource flows on a very aggregated level only can give a brief, static impression of the resource flows. Further, do they not analyse dynamics and characteristics of their surrounding system nor are they able to identify areas of improvement, and suggest solutions. These two knowledge gaps have to be further investigated. The research aims to develop a new analytical approach of UM. Combining sustainability analysis of urban resource flows and patterns in resource use driven by key actors and their environment.

1.2 Research Definition

The knowledge gaps define the theoretical focus of this research. In the research definition this focus is translated in to a concrete research strategy. The research definition elaborates and explains the research objectives, approach, flow and scientific contributions.

1.2.1 Research Question

The knowledge gaps identified are diverse and the opportunities for research are significant. This research is aiming to extend the commonly established approaches of UM from a purely material cantered analysis to a more comprehensive and actor-centred approach. Comprehensive, meaning a complete system analysis and interpretation of results with relation to policy strategies and measures to realize system change. Actor-centred refers to a deeper analysis of key actor groups specific resource use. Key actor specific characteristics as well as their living space are considered. Aiming to not only facilitate evidence for policy making, but generate new knowledge of urban material flows underling dynamics.

To gather the knowledge needed the following main research question needs to be answered:

"How can an Urban Metabolism approach facilitate a comprehensive and actor-centred analysis of urban material flows, generating knowledge of material flow dynamics and enabling policy makers to formulate strategies for sustainability increasement of urban material flows?"

Corresponding sub questions are:

Sub Q1: *What system aspect have to be considered to create a comprehensive UM approach?*

To fully understand the UM material flows and the urban environment a comprehensive perspective has to be taken. Different system aspects must be considered and contextual information has to be gathered to formulate goal oriented analytical objectives. Aspects as the multi actor setting and system governance can help to understand its complexity. Translating this understanding into analytical objectives increases the potential of the results to generate relevant knowledge and support the policy making process. The first sub question, therefore, aims to determine what system aspects have to be considered to improve system understanding and determine better analytical objectives.

Sub Q2: *How and why should the actor role be incorporated into a comprehensive UM approach?*

Humans shape their environment and use it to their advantage. Either as individuals or groups, they create wanted and unwanted system behaviour. A comprehensive understanding of the UM can only be achieved, if the actors and their behaviour is incorporated in the UM approach. The second sub question addresses the how and for what advantage actors are integrated in the comprehensive UM approach.

Sub Q3: What analytical levels and methods should be applied to enable analysis of underlying material flow dynamics?

To generate a deeper understanding of underlying material flow dynamics different level of analysis and new methods than the common assessment methods are necessary. Sub question three tries to determine the right analytical levels and the methods to create new evidence of not only material flows, but insights of material use patterns and behaviour.

Sub Q4: *What theoretical insights of resource flow dynamics can a comprehensive UM approach generate?*

Comprehensive system demarcation and goal-oriented analysis of its material flows generates knowledge of the flow dynamics. It possibly enables the validation of existing theoretical knowledge and creation of new evidence. Thus, sub question four aims to determine what theoretical knowledge the comprehensive UM approach is capable of generating.

Sub Q5: *What analytical insights does a comprehensive approach create for policy makers?*

The evidence generated not only creates new theoretical evidence, but facilitates information for the policy making process. Its usefulness has to be further investigated. Determining what insights, the new way of analysing the UM has generated for policy makers. Sub question five tries to determine what the potential of the comprehensive UM approach is for policy making.

The geographical scope of this research is the municipality of Amsterdam and the thematic focus is the solid household waste management. Household waste has been chosen, because of data availability, its position on the political agenda on a regional, national and on European level and its importance for environmental issues.

1.2.2 Research Approach

To be able to answer the main research question a case study approach is applied. A case study is suited to test a new approach of UM and gives the opportunity to generate new theoretical knowledge. Due to the nature of the data used in this research, validation and testing of past findings is possible. The case study is conducted in three steps. First, a new UM approach must derive from existing approaches to address the shortcomings of the knowledge gaps. Second, this approach has to be applied to a case to determine its analytical added value and generate new knowledge of household waste dynamics. Third, the approach has to be evaluated.

1.2.3 Case Introduction

An important part of efficient resource use is the minimization or recycling of waste. In the last decades, the issue of waste management has moved up on the European, as well as the Dutch national and regional agendas. The European Commission started to develop a prevention and recycling of waste strategy in 2005 and published it in 2011 (European Commission, 2011). The municipality of Amsterdam translated these guidelines into regional policy with the introduction of “Agenda Duurzaam Amsterdam” in 2015, including a goal for waste separation of 65% by 2020 (Gemeente Amsterdam, 2015). In June 2016 the city council published an implementation plan to achieve the goals set in 2015. Important parts of this plan are the creation of awareness and facilitating information to citizens as well as policies for waste prevention (Gemeente Amsterdam, 2016).

Currently, the transparency of the waste treatment chain is low. After placing their waste into a trash container people never see it again nor do they hear about it. The information provided about the amount, effects and treatment of waste to citizens is minimal. However, it is essential to inform citizens about this to simulate responsible environmental behaviour. According to Barr (2003) recycling behaviour is also related to this. On top of information, Barr (2003) identified environmental values, situational factors and psychological variables as main drivers of responsible environmental behaviour. Increasing awareness by creating transparency through the accessibility of information is therefore essential for Amsterdam to reach their goals. The channels of communication and information to be provide are so far not clearly determined in the policy plans of the municipality.

Another important aspect is the minimization or prevention of waste. Amsterdam considers the implementation of a weight-based tax for residual waste to stimulated waste separation, as well as minimization. This so called “Gedifferentieerde Tarieven” (DIFTAR) or Pay-as-you-throw (PAYT) system was introduced in the Netherlands in the mid-90s. Since then, the implementation of this system has increased, however, mostly in smaller villages or towns located in rural arears. Currently, 43 percent of the Dutch municipalities make use of a DIFTAR system (PBL, 2017). However, research by Linderhof, Kooreman, Allers, & Wiersma, (2001) showed the positive influence of this policy on the total waste generation and amount of waste separated. The main reasons why it has not been implemented everywhere, despite the proven positive effects, are the following. First, the quality of separated waste, as glass or plastic, decreased (CPB, 2017). Verhoef, van Houwelingen, Dijkema, & Reuter (2006) concluded that a DIFTAR system increases the amount of separated waste, but lowers the quality due to the increase of non-recyclable materials in the separated waste. Second, is the issue of illegal waste disposal in neighbouring municipalities with no DIFTAR system or in public trash containers. This strategic behaviour of citizens demands an evaluation of the DIFTAR system, to enable the benefits without the issues caused by this behaviour.

The waste management system of Amsterdam is an important part of the cities metabolism. The waste produced shows the efficiency with which resources are used. Different aspects as, citizen behaviour, technical challenges, regulations and financial aspects make the improvement of this management process a complex and challenging task.

1.2.4 Thesis Outline

The thesis outline is shown in figure 1. Chapter one introduces the topic and defines the objectives of the research. The research questions defined are answered and used for evaluation of the research in chapter ten. The knowledge gaps identified are used in the research approach design in chapter two. The approach design chapter elaborates what to include in the new approach and what possible advantages this can offer. Chapter three explores the complexity of waste management to determine important aspects of successful waste management practices. These aspects are used to give structure to the research analysis. Chapter four is the execution of the first research step, the system demarcation. Describing and analysing the actors involved and the social, institutional and economical aspects of the Amsterdam waste management system. The results from the system demarcation determine the focus of the methodology defined in chapter five. It formulates analysis objectives, methods and tools used. The following two chapters, six and seven, describe the two stages of the analysis. Chapter eight shows and describes the results of the analysis. These results are discussed and translated into recommendation in chapter nine. Finally, chapter ten draws conclusions and answers the research questions.

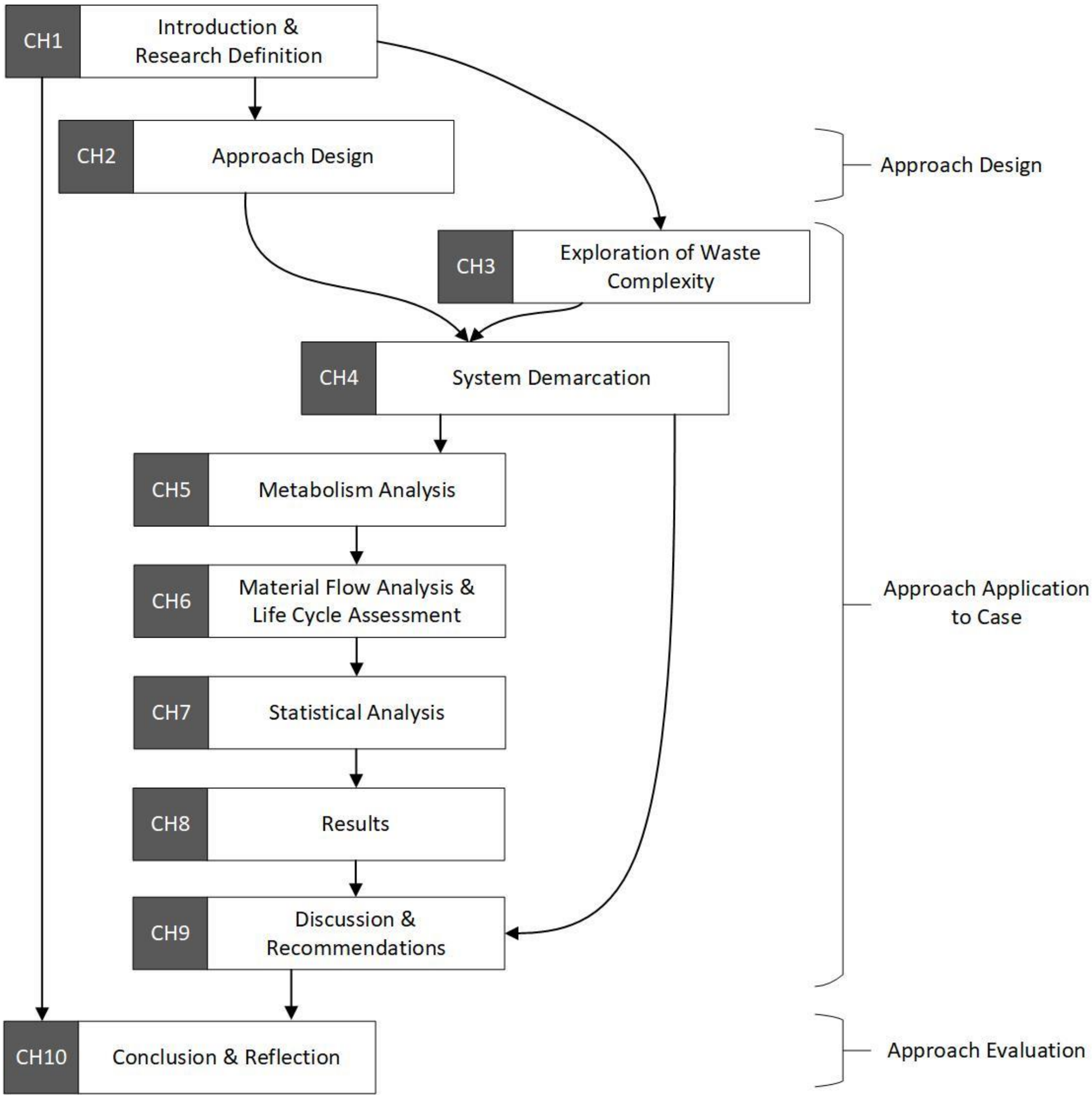


Figure 1 Thesis outline: Approach Design, Application & Evaluation

Chapter Summary

Natural resource scarcity is a global problem, challenging humanity to evaluate and change the way its society works. Urban areas play an important role in this process due to their population density, which leads to high material use in small areas. Creating circular use of materials to minimize needs of virgin material and generation of waste is one of the top priorities on political agendas. Despite its importance, successful changes are yet to be made. A deeper understanding of material flows and their underlying system is needed. This research tries to combine the so far scattered UM approaches into one comprehensive UM approach and give it a more detailed level of analysis. Not only focusing purely on material flows, but considering contextual and especially actor behaviour. Applying this approach to the case of household waste in Amsterdam, enables this study to evaluate the approach, generate new insights of material use related behaviour and help the municipality of Amsterdam in defining a new waste management strategy.

2. Approach Design

Chapter one pointed out the need for a new comprehensive approach of UM. The fundamental issues lie in the technical focus of established UM approaches withholding them from truly creating resource efficiency in urban environments. Chapter 2 further elaborates on the aspect for improvement. Based on this information the research proposes a new comprehensive UM approach to be applied in the following chapters.

2.1 Design Objectives

Increasing comprehensiveness of UM approaches by combining existing approaches and extending them with deeper analysis is the first step of this research. The theoretical grounds and a set of system dimensions are determined first. After which the key extensions of the proposed approach are explained. Focus on local and more detailed analysis, system change over time, data granularity, and statistical analysis are going to be these key extensions. Then existing literature is evaluated based on its system dimensions considered and level of analysis conducted.

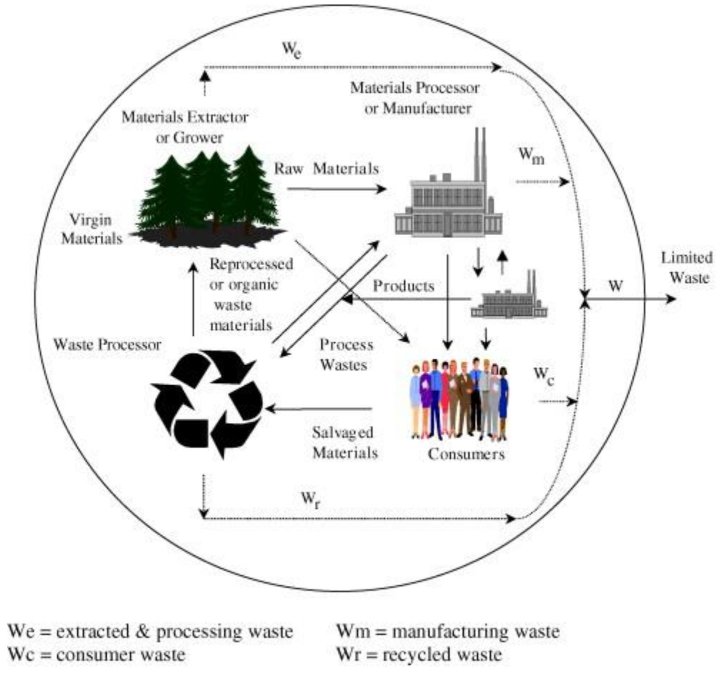


Figure 2 Industrial Ecological System View (Graedel, 1996)

The conceptual approach of this research is grounded in the field of Industrial Ecology (IE). Research in this field is concerned with the minimization of waste and re-use of by-products in industrial processes (Roberts, 2004). Deriving from the thought that industrial activities and systems can be looked at in the same way as a biological ecosystem. It conveys the notion that a system in balance strives towards integration of activities and cyclization of resources (Graedel, 1996). Figure 2 shows a simplified conceptualization of the IE system view. Analysis of every stage of the cycle enables IE to quantify inefficiencies in the system and make suggestions for potential sustainability improvement.

The rather technical approach of IE, narrowing systems down to industrial processes and activities, might be too limited to fully grasp the complexity of the urban system and its potential for sustainability improvement. Even though, approaches in the field of IE become more and more multi-disciplinary, this research advocates the inclusion of social science and policy analysis aspects to increase the weight of actors in IE systems. This requires the extension of the system dimensions considered.

2.1.1 Comprehensive Approach Dimensions

The typical system dimensions of UM research are the material and energy flows of a city metabolism. This research tries to extend these dimensions in a holistic manner. Earlier efforts of improving the completeness of UM studies exist. Pincetl et al. (2012) argues for a socio-economic, policy and extra quantitative analysis of UM to understand its material flows and political, economic and ecological system context. They suggest a material and biophysical analysis of resource flows on one hand and human, social, policy, economic and governance related context on the other to comprehensively analyse the UM of a city. Mostafavi, Farzinmoghadam, Hoque, & Weil (2014) emphasize the importance of social, economic and physical factors on the environmental metabolism effects by applying simulation techniques. Even though, efforts have been made, non-have achieved the goal of effectively analysing material flows and contextual settings and use this as input for advice for decision makers. The dimensions of a holistic UM analysis can, however, be summarized as material and energy flows and their contextual factors of economic, environmental, social, technical and institutional nature.

2.1.2 Evidence for Policy Making

Comprehensive understanding of a city’s metabolism has the goal of increasing its sustainability. This means that resource use is efficiently minimized, material flows are circular rather than linear, costs are minimized, and life quality of all citizens is maximized. This more holistic view on sustainable cities is different from the commonly formulated goal of material use efficiency. Pure efficiency might, however, not lead to resource use minimization and thus not to true sustainability. Spacious houses of wealthier citizens might be better insulated, therefore energy efficient in comparison to social housing flats. However, the total energy use of energy efficient houses might still be higher due to their size. These kinds of insights are valuable knowledge for policy makers in their decision-making process. So far, most UM studies access the material flows from a certain perspective without taking the extra step from analysis to re-design possibilities for cities sustainability increasement (Musango, J.K., Currie, P. & Robinson, 2017). The approach of this research tries to take this extra step by analysing context and metabolism of a city itself and evaluating possible changes to the system with a scenario analysis. Based on the results of the different scenarios, reshaping options for material flows can be selected and actions to not only change the material flows, but identify the necessary contextual changes to truly increase sustainability of the urban system. The evidence necessary to holistically change the system ask for deeper analysis.

2.1.3 Extension Assessment Methods

In the research problem definition of chapter 1.1, the main assessment methods of the UM field are summarized in Input-Output Analysis, Material Flow Analysis, Life Circle Assessment and Ecological Footprint. In past studies, multiple ways of applying those methods are illustrated. To enable deeper understanding of the material flows within a region and the actors generating or influencing them, this research proposes to add statistical analysis to the group of methods. After assessing material flows, this statistical analysis can help to understand underlying dynamics of the material flows. Based on their material use behaviour areas can be selected for further investigation of different characteristics as for example, the socio-economics, infrastructure or housing type. This offers the opportunity to identify relation between individual or group behaviour and contextual setting. After identification of relationships the goal should be to understand them. Discovering the reason behind the behaviour is essential for understanding and influencing it. Generation of this deeper analytical insights different level of analysis are necessary.

2.1.4 Deeper Understanding of Local Scale

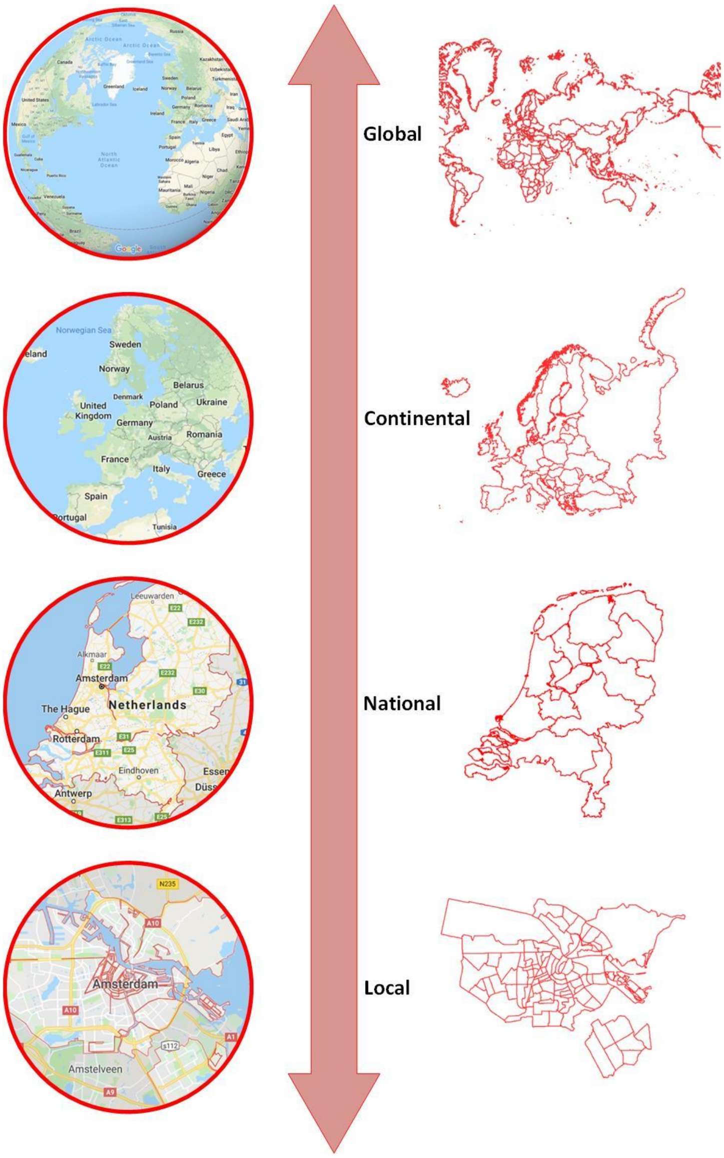


Figure 3 Levels of Analysis

The ecosystem of a city is part of a bigger whole. Different geographical scales can be distinguished in global, continental, national and local level. Cities can be seen as the local level and are of great importance. Concentration of human population and therefore activity, processing immense amounts of resources, increase cities potential for sustainable resource use development. This makes geographic specificity important and a better understanding of local ecosystem characteristics is at the heart of it. Global trends suggest Rural-Urban migration, but each urban system has its own characteristics as well as place in contextual global network (Pincetl et al., 2012). This means that the UM studies should have a local level of analysis. However, the results and contextual analysis should always consider the other levels of national, continental and global scale for comparison and interconnectivity reasons.

Nonetheless, should the local analysis not limit itself to only look at a region or city as a whole. Rather should the smaller components, suburbs, districts and neighbourhoods, be analysed in depth. The overarching local perspective should be accumulated from these smaller components. This implicates the availability of bottom-up data. Data with a high spatial granularity.

2.1.5 Bottom-up data for Disaggregated Urban Metabolism Analysis

UM studies are data intensive and their quality is closely connected with the availability and quality of the necessary data. Often data has a low granularity or is derived from highly aggregated and estimated average values called top-down data. This not only reduces the quality of results, but limits the possibilities for deeper analysis of disaggregated material flow analysis. Pincetl et al. (2012) also argues for a more disaggregated metabolism analysis to be able to analyse "*who*-is-using-*what*-flows-*where*-to-do-*what*". Availability of data is the main cause of this issue. Kennedy & Hoornweg (2012) argue for more cities to collect UM data to increase the potential of the field and for cities to improve their resource use. Pincetl, Graham, Murphy, & Sivaraman (2016) state that high-resolution data and its analysis is obligatory to identify hotspots of material use and develop priorities in sustainable development efforts.

2.1.6 Multiple Time Dimensions

Similar to the disaggregation of data on a spatial level, the analysis of material flows over time have high potential for improvement of UM studies. The common snapshot of material flows at one point in time, often annually, does not offer the analysis of material flow development over time. By extending the analysis time level form only years to month, weeks or even days and looking at multiple and not only one timestep will enrich the research quality and possibilities of analysis.

Figure 4 Time scales

2.1.7 State of the Art Holistic Urban Metabolism Research

The proposed changes or extensions to UM approaches are not all new to the field. Some have been part of past studies. Barriers for not applied extensions could be data scarcity, especially data with high granularity. This data is either not openly available or is just not being collected yet. To support the argumentation for the necessary combinations and extensions and overview of state-of-the-art UM studies has been made. For this review not all UM where considered, but the once with a holistic perspective. To generate an overview of the state-of-the-art UM studies with the aim of creating a comprehensive picture, a literature review was conducted. Table 1 shows a list of 10 studies of the last decade. The search engines used are Google Scholar and Scopus. Time limitations were set to the time period 2009-2019. A selection was made based on relevance and the key objectives listed below.

Scopus search terms:

urban AND metabolism AND holistic

urban AND metabolism AND comprehensive

Key Objectives:

- Methods
- Time Level
- Time Dimension
- Geographical Level
- Analytical Dimensions: Economic, Environmental, Social, Technical, Institutional

Table 1 shows that most of the studies only look at material flows and their environmental impact. The level of analysis if often aggregated and static. This proves the necessity of a more comprehensive approach.

Title	Key Objectives	Methods	Time Level	Time Dimension	Geographical Level	Dimensions	Source
Environmental and economic assessment of urban water systems and evolution towards a sustainable model. Case study of La Vall de Boí	Sustainability assessment of local water management system with a holistic approach	MFA, LCA	Year	Static	Local	(Social) - Economic Technical Institutional	(Muñoz Liesa, 2016)
Evaluation of the Urban Hydrologic Metabolism of the Greater Moncton Region, New Brunswick	Evaluation of Regions Water Metabolism	I-O	Year	Dynamic	Local	-	(Thériault & Laroche, 2009)
A holistic framework for the integrated assessment of urban waste management systems	Asses different performance indicators of Urban Municipal Waste System	Network Analysis	Year	Static	Local + National	Environmental	(Chifari, Lo Piano, Bukkens, & Giampietro, 2018)
Dynamic metabolism modellin g of urban water services - Demonstrating effectiveness as a decision-support tool for Oslo, Norway	Asses environmental impact of urban water and wastewater systems	LCA, Scenario-Analysis	Year	Dynamic	Local	Environmental Economic, Technical	(Venkatesh, Sægrov, & Brattebø, 2014)
Research on Comprehensive Evaluation of Urban Material Metabolism Based on MFA —a Case Study of Chengyang District in Qingdao	Evaluation of Urban Metabolism	MFA	Year	Dynamic	Local	-	(Zhou, 2010)
Enhanced Performance of the Eurostat Method for Comprehensive Assessment of Urban Metabolism: A Material Flow Analysis of Amsterdam	Modify Eurostat MFA method and create deeper and more comprehensive understanding of	MFA	Year	Static	Local	-	(Voskamp et al., 2017)

	Amsterdam Urban Metabolism						
Efficiency estimation of urban metabolism via Emergy, DEA of time-series	Reflect on relation between urban metabolism, environment and economy by combining Emergy synthesis, PCA, DEA of time-series	ES, PCA, DEA	Year	Dynamic	Local	Environmental Economic	(Wu et al., 2018)
A water-energy nexus review from the perspective of urban metabolism	Less independence and eco-environment impact improvements of water supply alternatives assessment	LCA	Year	Static	Local + National	Environmental Social	(Fan, Kong, Wang, & Zhang, 2019)
A Mathematical Description of Urban Metabolism	Development of mathematical model for dynamic material flow analysis of cities as well as their interrelationships	MFA	Year	Dynamic	-	-	(Kennedy, 2012)
Metabolism-modelling approaches to long-term sustainability assessment of urban water services	Quantification of urban water systems with the application of different modelling techniques	MFA, LCA	Year, Month, Day	Dynamic	Local	Environmental Economic Institutional	(Venkatesh, Brattebø, Sægrov, Behzadian, & Kapelan, 2017)

Table 1 Systematic literature review holistic urban metabolism studies

2.2 Comprehensive Urban Metabolism Approach

Derived from existing approaches and extended with the mentioned aspect is the comprehensive UM approach shown in figure 5. The approach aspects are defined by Environment, System, Metabolism and Scenario's. The environment defines the natural surroundings of the system. Its characteristics influence the system via the metabolism of the system, materials and energy are extracted as input for the metabolism and emitted as output of the metabolism. The metabolism is the connection between the urban system and its natural environment. The system characteristics determine the contextual aspects of the metabolism and therefore the relation with the environment. The system consists of the three main actor groups businesses, government and citizens, which interact and shape the system with their actions. The three dimension of the system, Economic, Institutional and Social, further define the characteristics of the system. The system influences the metabolism thus changes in the system are changing the metabolism. The application of this comprehensive approach consists of three stages.

The first step of the comprehensive UM approach is the **System Demarcation**. By conducting desk research and support this knowledge with interviews of key actors, the different system aspects are identified. Actor roles and capabilities are defined and the three-pillar economic, institutional and social aspects in the relation to material or energy flows are described. The system demarcation identifies important factors and determines the focus for the metabolism analysis.

Stage two, the **Metabolism Analysis**, takes the contextual analysis of the system demarcation as an input and determines its analytical focus base on it. Methods to conduct this analysis are determined to evaluate the metabolism. Development of current and future metabolism scenarios enables the exploration of changes in the material supply chains. In addition, potential relationships of material use and user groups are tested. The analysis of the metabolism as well as the deeper understanding of potential material use behaviour of specific actor groups is used to formulate policies for system change in the last stage of the approach.

The third and last stag of the research defined the **Policy Advice**. The results of the metabolism analysis are used as an input. Desirable improvements as well as the necessary system changes are identified. The current institutional setting explored in the system demarcation is used as starting point. Policy strategies to make this change to come about are formulated and presented finally.

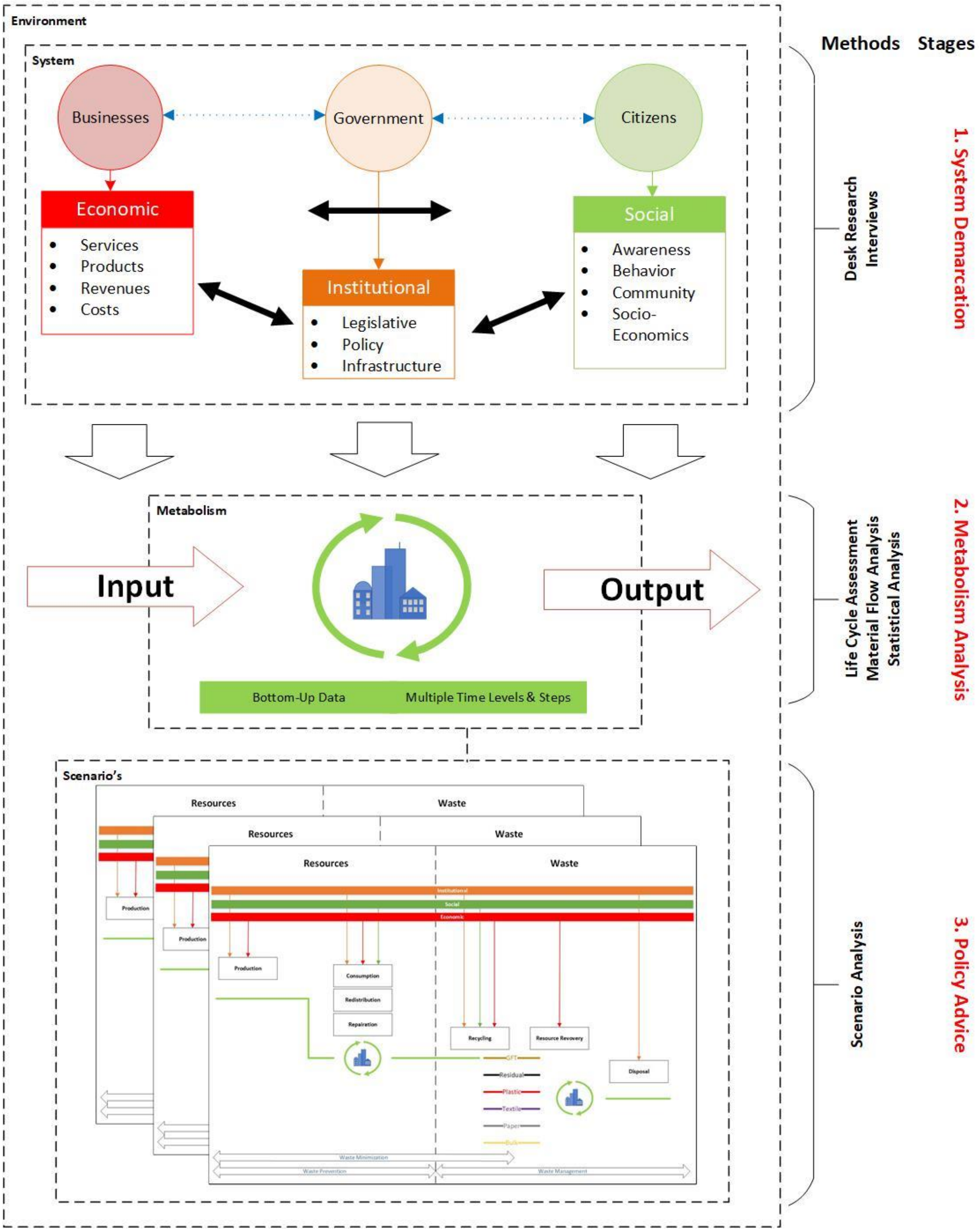


Figure 5 Comprehensive Urban Metabolism Approach: The system influences and shapes a city metabolism. The metabolism describes the material and energy exchange between a city and its environment. The system demarcation describes and analysis the system setting of the waste management case. The metabolism analysis is conducted with the knowledge of the system demarcation and usage of bottom-up data as well as multiple time and geographical analysis steps and levels. The results are used to formulate policy advice.

Chapter Summary

The typical UM approaches in the field of IE, analysing material flow on a city level, form the base for the comprehensive UM approach designed. As comprehensive suggest, this research extends the established approaches to create a more holistic system perspective and enable true sustainability increasement. The metabolism analysis of material flows entering and leaving the urban environment is extended with a system layer. This layer defines the actors influencing and economic, institutional and social aspects shaping the metabolism. Demarcating this system, before diving into the material flows of its metabolism, increases system understanding and the focus of the analysis. The improved focus is used for not only analysing the material flow itself, but the behaviour related to it. By extending the methods with statistical analysis and multiple time and spatial scales, relations between materials use behaviour and the surroundings can be determined. Surroundings as system characteristics and actor groups. The ability to explore potential relations between material flows and system aspects creates better opportunities for designing policy for sustainability improvements of the urban system.

This comprehensive UM approach is applied to the case of Amsterdam household waste management to test the concept and generate new insight into waste related behaviour. The system demarcation is executed in chapter 4, the urban metabolism analysis is defined and executed in chapter 5 till 8 and the policy advise elaborated in chapter 10. To better understand the complexity of waste and give direction to this research the complexity of waste is explored next.

3. Exploration of Waste Complexity

The comprehensive UM approach is applied to the complex case of household waste in Amsterdam. Before the first step of the UM approach is executed, further information related the management of waste is gathered. This chapter touches upon complexity of waste management, importance, driving forces and their development over the years as well as sustainable waste management approaches and strategies to realize true sustainability.

3.1 Waste Generation

Waste is the result of human activity and thrives due to urbanization, economic development and population growth. All those phenomena grow, and so does the amount of waste. The world bank estimated global waste production in 2012 around 1.3 billion tons per year (Hoornweg & Bhada-Tata, 2012). In 2016 it already reached 2.01 billion tones. Most of the waste is produced by high- and middle-income countries (Kaza, Yao, Bhada-Tata, & Van Woerden, 2018). Despite this trend, citizens in first-world countries cannot really tell where all the waste is going. Not to mention what is done with it.

This ignorance can probably be ascribed to the “well” developed waste management systems. “Well” in this context means it is ensured that the waste is taken out of side. Solid Waste Management, or more precisely Municipal Solid Waste Management (MSWM), is one, if not the most important service a municipality provides its citizens with. Different cases in Italy have shown the dramatic effects a malfunction of a waste management system can have. The importance of managing Municipal Solid Waste (MSW) is only surpassed by its complexity. Waste streams have to be collected transported, processed and disposed in the most economical, social and environmental acceptable manner (Hoornweg & Bhada-Tata, 2012). The different waste streams can be categorized into residential, commercial, industrial and agricultural waste. Over time, waste management practices developed due to different reasons.

3.2 Driving Forces of Waste Management

The development of waste management within the last millennium and the forces it was driven by varied quite a lot. Wilson (2007) identified six key drivers of this development. He distinguishes between developing and developed countries. The drivers in developed countries historically developed as follows. Public health, which was mainly an issue in the 19th and beginning of the 20th century in de developed countries, is taken for granted nowadays. Resource value of waste, started to gain importance in the beginning of the 19th century as a base for building materials. It was only in the 70th of the 20th century that environmental protection got more attention and was put on the political agenda. Until that point, waste was mainly disposed in landfill. In the 90th of the 20th and the beginning of the 21th century the realization came through, that a decrease of the environmental impact of waste might only be possible with a more integrated approach. As a result, other driving forces emerged, fostering a more holistic and intergraded approach to waste management: Closing the loop, minimizing and preventing waste by recovering resources from the waste streams, institutional and responsibility issues, assigning the duty of collection to municipalities, and public awareness, creating acceptance and awareness within society for successful implementation of new strategies. The importance of environmental protection initiated the development of sustainable waste management approaches.

3.3 Sustainable Waste Management Approaches

Different approaches have been developed over the years. All with their own focus and strategy to improve their goals. Some of the most common and influential approaches are described to identify the essential aspects of sustainable waste management.

Increasing the sustainability of MSW, or the acknowledgement of its importance, truly started to develop in the beginning of the 90s of the 20th century, fed by the exponential growth of the industrialized economies and their ever-growing waste pile (Choe & Fraser, 1998). However, the understanding of sustainability in regards to MSW differed. Whether it meant sustainable management of a landfill, safeguarding health of citizens and environment or the participation of all stakeholders depends on ones focus (Desmond, 2006). Morrissey & Browne (2004, p. 298) gave the following, more comprehensive definition:

"For a waste management system to be sustainable, it needs to be environmentally effective, economical affordable and socially acceptable…"

3.3.1 Integrated solid waste management

Tchobanoglous, Theisen, Vigil, & Alaniz (1993) summarize and address the importance of an integrated approach to solid waste management. They are the first to place waste management into the framework of resource management, treating waste as a resource rather than to be disposed goods. Waste production and its management cannot be successful by only looking at a selection of factors. Even though, the main target was not to increase environmental impact, this approach can be seen as the starting point sustainable waste management approaches are built on due to its systematic structure.

3.3.2 Integrated Sustainable Waste Management

Integrated and Sustainable (solid) Waste Management (ISWM) is a concept advocating a comprehensive approach to sustainable waste management by focusing on three main dimensions: physical and technological, sustainability, and stakeholder aspects. The goal of this approach is to enable municipalities in developing countries to achieve sustainable waste management within their communities. Wilson, Rodić, Stretz, & Scheinberg (2013) transformed this framework into a method to benchmark cities municipal waste management system. This enables the evaluation and comparability of cities waste management sustainable performance. The framework is easy to apply and uses mostly stakeholder insights to address the issues of missing data. This strength is also its weakness. The aggregated analysis only gives a high-level picture and makes it difficult to understand the underlying system dynamics. Even though an easy to use possibility to asses a system and enable evaluation and comparison of progress is positive, to really reshape and change system behaviour a more sophisticate approach is needed.

3.3.3 Zero Waste

Another sustainability approach is the concept of zero waste. Zaman & Lehmann (2013, p. 124) define it as:

" … designing and managing products and processes systematically to avoid an eliminate waste, and to recover all resources from the waste stream."

In comparison to the widely integrated approach to waste management, zero waste also focus on avoidance and reduction. Another important part is the conversion from linear to circular city metabolism. The main drivers for the zero-waste concept are summarized in figure 6.

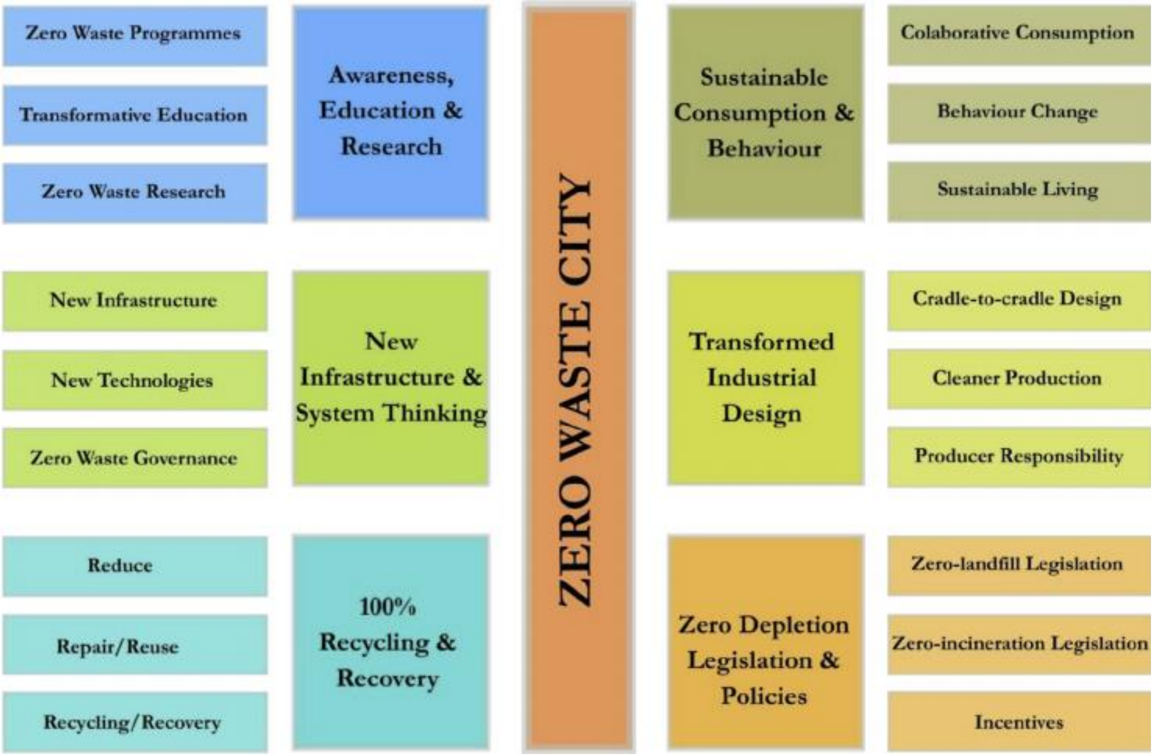


Figure 6: Drivers for Zero Waste Cities (Zaman & Lehmann, 2013)

The development of solid waste management from simply disposing waste to the ambiguous goal of zero waste changed the way waste is looked upon. Waste itself is an inefficiency of the system, while resources are of value and should be used in an efficient manner. Truly sustainable systems are the ones in which waste is minimized and resources are recovered from waste streams. Different approaches try to facilitate guidance to countries and municipalities by the development of frameworks and strategies. The emphasize always lays on the creation of a holistic approach containing environmental, economic and social aspects.

3.4 Prevention and Recycling

Different strategies for was management can have a different magnitude of environmental impact. An important role is the differentiation between prevention and recycling of waste is summarized in the waste hierarchy. It was introduced by European Union framework directive in 1975 (European Union, 2016). Nowadays, the strategic focus of waste management systems is always to prevent resources from becoming waste. In cases where this is not possible, as much resources should be recovered from these waste streams. The waste management hierarchy describes the different steps in waste minimization from favourable to less favourable. In figure 7 the waste prevention pyramid is shown.

Although recycling seems to be effective due to the environmental impact of waste, possibilities for recycling are quite limited. Especially plastic waste, with a big environmental impact, is not easily recyclable. Collection and separation are time and cost intensive, the actual recycling processes of the different materials consume high amounts of energy and the polymeric materials generated are often of a low quality (Garcia & Robertson, 2017). Another downside of recycling is its minor consequence on the environmental profile of waste management systems. However, the increasing prevention of waste, also reduces the amount of waste to be recycled. This significantly improves the environmental impact of waste management (Gentil, Gallo, & Christensen, 2011).

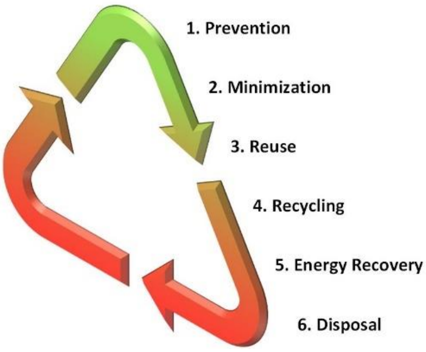


Figure 7: Waste Hierarchy Pyramid

3.5 Importance of Monitoring

The goals set for a potentially sustainable waste management system are high. An essential part in the improvement of waste management sustainability is the assessment of the current situation and the evaluation of interventions by monitoring. Similar to UM research, the assessment of waste streams in cities is often done in an aggregated and static manner. Yearly, or less frequent evaluation reports give a glimpse and an idea of the current system state. Zorpas & Lasaridi (2013) emphasize the importance of monitoring and evaluation to ensure effectiveness and stimulation of behavioural change by prevention initiatives of policy makers. They evaluate different monitoring methods and list both advantages and disadvantages. On top of that, they conclude that new disaggregated methods have to be developed. Data availability creates a barrier for this development. The World Bank Group (2018) supports this by advising municipalities in their roadmap for policy makers to included extensive monitoring in their MSWM. To realize the ambiguous goals of circular and sustainable waste management a clear picture of the current situation is necessary.

Chapter Summery

Waste and its management are of complex nature. Over the years it developed from only disposal of waste to the complex process of recovering materials and energy from waste. Ambitious goals of sustainable waste management combining financial, social, environmental aspects are formulated. Existing strategies emphasize on the importance of an integral and holistic approach to waste management, in order to prevent a disbalance between the three dimensions. To create circularity and increase material use efficiency, prevention and recycling are the way to go. However, both have barriers of their own. On top of that understanding of the current waste flows is low. To reach a desired future situation the current situation has to be understood well. Better understanding of the current waste flows, a holistic waste management strategy and moving towards recycling and prevention of waste are the goals aimed for in the case study. The first step is taken in chapter 4 demarcating the current system of the household waste management system in Amsterdam.

4.

System Demarcation

The municipality of Amsterdam has ambitious waste management goals. Improvement of waste collection, increase of separated fractions and more resource recovery, all for less operational costs. Specific policies and solutions to achieve that are yet to be determined. This research argues that the lack of true system understanding forms a barrier to successful and significant improvements and realization of the ambitious goals. This chapter describes the current system of the household waste management in Amsterdam. This is part of the first step of the in chapter two defined metabolism approach. The system demarcation will help to identify possible areas of improvement by describing actors and their capabilities, and the system aspects institutions, economics and social. The conclusion drawn from this demarcation are translated into analytical objectives for the metabolism analysis in chapter 5.

4.1 Actor Analysis

The three main stakeholder groups, businesses, governments and citizens, are all influencing and therefore shaping the waste management system of a city. This elevates all of them to great importance for improving sustainability of its waste management system.

Governments on different levels formulate strategies, influencing other stakeholder to change their behaviour, in order to protect public health and increase life quality of its citizens. This is done with waste management strategies and regulations in the form of different policies.

the different governmental actors have different interests and impacts on the waste management system in Amsterdam. The **European Commission,** on the supranational level, develops strategies, formulates guidelines and gives subsidies to stimulate European member states to work towards the waste related goals set. Their role is a facilitating and regulatory role with the main interest of increasing of resource use efficiency and reduction of C02 emission to fight climate change. On a national level the Dutch government, **Ministry of Infrastructure and Waterstate,** has to translate the European directives into national regulations to ensure their compliance with the directives. The **Municipality of Amsterdam** is in charge of collecting the waste on a regional level and can determine its own operational system as long as it complies with national and supranational regulations. Their main interest is to increase life quality and minimize negative effects on public health on one hand and on the other hand minimize costs of waste management.

Citizens consume products and dispose them at the end of their life cycle. Consumer needs lead to the development of certain product and their consumption behaviour results in waste generation. Awareness and other aspects influence citizen behaviour, which drives waste generation.

To get a better picture of waste related issues for citizens the municipality organized two evening events for citizens in 2015. The top five conclusions were related to information, education, user friendliness, cleanliness and local initiatives. The importance of **information** about separation of waste. Citizens would like to know more about the effect of recycling, how to do it properly and where are containers located. An example of unawareness is the fact that citizens often do not know that wine glasses are supposed to be disposed in residual, not glass, containers. This information is often not easily available to citizens and should be communicate better by the municipality.

Another important role in terms of knowledge is **education** of citizens. Implementing waste into education of children in schools can have short- and long-term effects on the waste prevention and recycling behaviour of citizens. Not as effective, but also important, is the education of adults.

The **user friendliness** of waste disposal system is important to stimulate WPP and recycling behaviour of citizens (Bortoleto, Kurisu, & Hanaki, 2012). Citizens of Amsterdam supported this finding by complaining about the distance between recycling containers and their homes. On top of that, is the **cleanliness** of the containers an issue. Often, containers are full which is why citizens place their waste next to the containers. Waste make the sites and the action of recycling unattractive.

Local initiatives can influence the sustainability of waste streams quite significantly. It enables waste prevention and recycling awareness. In Amsterdam multiple local initiatives are active. Examples are composting of bio waste individually or with neighbours, usage of coffee to grow vegetables, collection of plastic and repair cafes. Citizens would like these initiatives to be supported by the municipality of Amsterdam more actively.

Businesses can have different roles in the relation to household waste. Waste disposal businesses are in charge of separation and recovering resources from waste streams. Start-ups, local businesses or non-profit organization can facilitate repair services or other ways to creatively reuse materials or products. Retail businesses are responsible for the way products are sold and delivered to the citizens. Product origin, energy efficient transportation and use of materials for packaging, can be changed by retail businesses. Producers of products are in charge of the design and production process of products. They determine the life expectancy, repairability and reusability of products. Businesses of importance for household waste management in Amsterdam can be categorized into waste disposal companies, reuse businesses, retailers and producers.

4.2 The Institutional Situation

The institutional pillar of the system contains legislative, policy and infrastructure aspects. They are mainly determined by the different governmental layers on supranational, national and regional level. The design and nature of the different aspects shape the rest of the system. Legislatives set the rules of the game. It can force actors to rethink and change their behaviour. Policy are tools to achieve set goals. They can stimulate or prevent certain system behaviour. Infrastructure enables and facilitates society to function in a certain way. For MSWM, the following elements are of importance.

4.2.1 Regulations

The EC published the directive 2008/98/EC on waste in 2008, which includes a waste framework directive. It contains information regarding waste management related definitions, waste management principles, policy guidelines and recycling/recovery targets. They aim to achieve 50% re-use and recycle of household waste by 2020. Also, the emphasize lays on prevention above recycling and recovering of waste, only targets for recycling and recovery are set. In terms of prevention no targets are set, but member states are required to develop WPP (European Union, 2008).

On a national level the Dutch ministry for infrastructure and environment translated the European directive in the “Landelijk Afvalbeheerplan 3 (LAP3)”, which is grounded in the national environmental law, article 10. LAP3 defines recycling targets of 75% for household waste and not more than 100 kg residual waste per person in the year 2020. The Dutch national WPP, VANG, was released in 2013 and proposes the following three forms of actions as main focus:

- Better Design: Less material usage, less harmful substances, more recycled material, long life
- Less waste in the production phase: Less material usage/loss, less harmful substances, closed material cycles
- Conscious Consuming: Increase awareness of prevention by informing consumers and encouraging careful choices, less waste and more reuse

Municipalities have to put those national regulations into practice. The LAP3 gives the municipalities, however, some room to make their own decision on how to realize the set goals. This room for action is defined in four specifications within the national environmental law. Municipalities are allowed to except small areas within their jurisdiction form separated collection, the waste collection frequencies within a municipality may differ from the one stated in the environmental law, collection systems are allowed to be changed from house-by-house systems to centralized collection, and more fractions than stated in the environmental law may be collected.

The municipality of Amsterdam published the report “Afvalketen in Beeld – Grondstoffen uit Amsterdam” in October 2015. It describes its waste management system and goals to be achieved. Their goal is to increase their separated fractions up to 65% until the year 2020, which is 10% percent lower than the national goal and 15% higher than European regulations. In 2014 the separation percentage reached a level of 27% and the total amount of waste per citizens was at 370kg. According to LAP3 this is slightly below national average. This research defines separation percentage as the fraction of a waste stream which is used for new purposes other than burning after first and/or second separation. This is in line with the definition of Amsterdam. Even though the municipality tries to follow the circular economy principles and bases its strategy on European directives, its focus still lies on recycling rather than prevention of waste.

According to Peter de Boer, project manager, strategic, logistics and innovation advisor of the waste supply chain in Amsterdam, the municipality currently focuses on the operational optimization. Dynamic waste collection and technological innovations are of great importance. Improving the infrastructure and operations in the short run and new strategic approaches in the long run will change and the improve sustainability of the waste supply chain.

4.2.2 Common Waste Policies

To truly create a sustainable waste management system the goal has to be the prevention of waste, rather than recovery resources from it. According to Gentil et al. (2011) waste prevention policies can have significant impact on the environmental impact of waste management. Different policy instruments to increase waste prevention are analysed and discussed in the literature. The European Commission (EC) published guidelines for Waste Prevention Plans (WPP) in 2012. They differentiate between three different prevention measure types shown in table 2.

Promotional	Information	Regulation
➢ Support for voluntary agreement	➢ Public awareness campaigns	➢ Targets
➢ Promotion eco-design	➢ Information on waste prevention technique	➢ Eco-design futures
➢ Development and promotion of environmental management system	➢ Training programs for competent authorities	➢ Extended Producer responsibility
➢ Support for reuse and repair infrastructure	➢ Ecolabeling	➢ Waste taxes and quotas
➢ Clean consumption incentives	➢ Waste prevention information on products	➢ Green public procurement
➢ Promotion of research and development for developing less wasteful products and technologies		

Table 2 Waste Prevention Measures (EC, 2012)

These plans try to achieve waste prevention goals set on a European level by rethinking product design, change in consumption behaviour and facilitate necessary infrastructure. All kind of policies trying to achieve this are analysed on their effectiveness in scientific literature.

The different policies can be categorized into soft and hard measures. Examples of soft measures are awareness creation campaigns or development of guidelines. They are mainly focused on awareness creation, improving transparency and improving operational practice without direct consequences for the target group, if not complied with. Examples of hard measures are taxes, agreements or laws. These measures oblige the target group to behave in a certain way or take the risk of negative consequences in case one does not comply with them. Johansson & Corvellec (2018) argue that European waste policies are too soft and voluntary, rather than hard and obligatory, which makes them not capable of significantly improving waste prevention. They advocate an increase of taxes and bans in addition to the commonly applied information campaigns. Kirakozian (2016) supports this by also suggestion the use of taxes in the form of environmental taxation in addition to informative regulation to effectively change individual behaviour. Economical tools seem to be necessary to effectively reverse the trend of increasing waste.

An important economical regulatory tool for waste prevention is a Pay-as-you-throw (PAYT) system. The design of this “producer pays” approach is conceptualized by Morlok et al. (2017) as shown in figure 8. In comparison to a conventional equal waste fee system, the total waste fee per person or household in a PAYT system varies based on the waste collected to stimulated waste prevention and recovery. Building forth on this idea, different designs of a PAYT systems can be applied. The simple conceptual structure is, however, deceiving. The complexity of solid household waste management contextual structure is increasing significantly with the introduction of a PAYT system. Social acceptance, operational costs and technological challenges are the main issues. Elia, Gnoni, & Tornese (2015) therefore introduced a holistic framework to ensure a successful PAYT designing process. Their three main steps in the adaption of a PAYT system are defining the unit pricing model, identifying the MSWM service users and measuring of the waste quantity. These framework enables the analysis of organizational as well as technological issues to define a transparent, reliable and cost effective PAYT system.

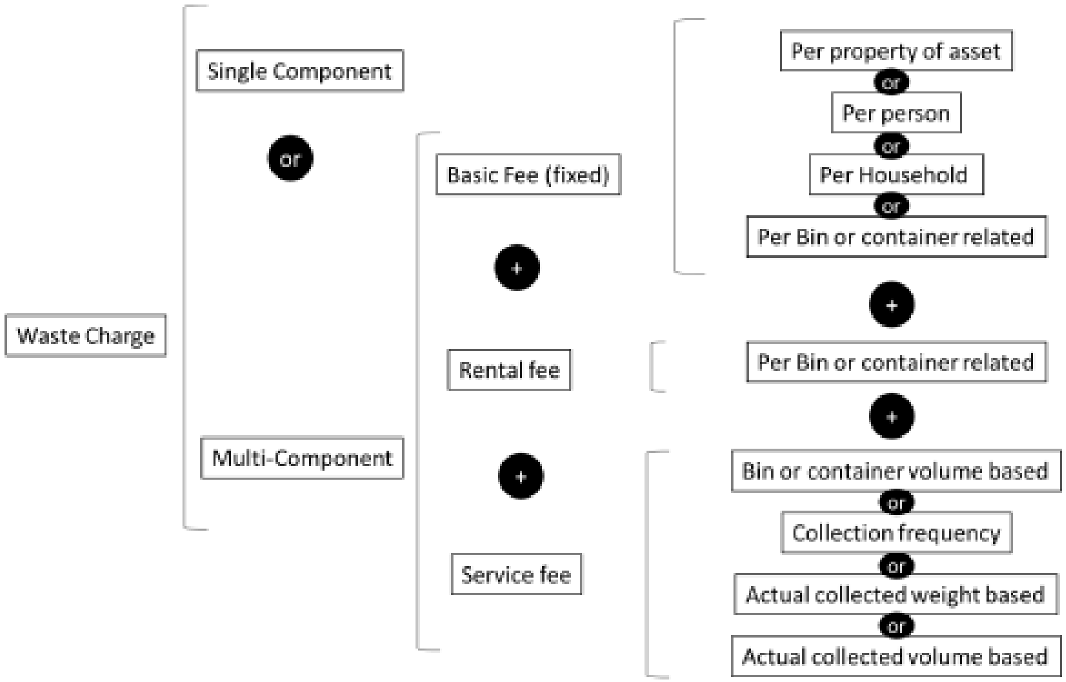


Figure 8 PAYT System Design Options (Elia et al., 2015)

The effectiveness of PAYT regarding the reduction of household waste production was proven by multiple studies around the globe (Carattini, Baranzini, & Lalive, 2018; Elia et al., 2015; Kirakozian, 2016; Lee, Jung, Lee, & Jung, 2017; Morlok et al., 2017). They concluded that PAYT systems in different geographical locations and different designs all resulted in the reduction of total waste produced and increase of recycled fractions. A specific effectiveness relation or rule could not be developed. The variations in effectiveness was mostly explained by contextual factors and the possibilities to reduce waste production. Reduction rates differed quite significantly between the cases. Some reduce their waste production up to 75% percent in the first years. In the long-run, the reduction of waste production was minimal. People might feel the urge to improve and reduce in the beginning, their dedication, nonetheless, is dependent on their possibilities to reduce. A PAYT system needs compulsory measures facilitating waste prevention options in order to maximize effectiveness. These measures can either be regional/national regulatory measures or bottom-up initiatives as reuse initiatives, second hand market and repair cafes.

The need of compulsory policies to increase and ensure long-term success for PAYT systems is not the only issue connected to PAYT systems. Other pros and cons are shown in table 3. Regardless on which side of the table they are placed, contradictory evidence can be found in the literature to support or weaken their position.

Issues regarding the technical complexity of measuring and monitoring of waste production are mainly reliability, accuracy and financial. What type of system can facilitate accurate measures, is reliable and affordable? Elia et al. (2015) suggest the importance of Internet of Things (IoT) solutions to reduce technical issues. The possibilities to measure waste production with sensors real-time could improve complexity of technical issues. The technological challenges could be solved in the near future depend on technology development.

Waste tourism is a commonly used term for the illegal dumping of waste in either neighbouring municipalities without PAYT, public containers or in nature and is an urgent issue of MSWM. Since PAYT systems increase the incentives for such behaviour, concerns are that the PAYT waste reduction effects can be explained by these illegal activities. Multiple studies indoctrinate this possibility, none of them can prove the connection what so ever (Kirakozian, 2016). Dijkgraaf & Gradus (2004) did not detected an increase of illegal dumping in their case studies in different Dutch municipalities. A common strategy to address the issues, non the less, is the prosecution and enaction of fines to reduce economic benefits of dumping waste.

Another aspect of PAYT is its fairness. Since its effectiveness is mostly determined by the acceptance and participation of citizens, the fairness plays an important role in terms of social acceptance. Batllevell & Hanf (2008) analysed the fairness aspect and came up with guidelines for decision-makers to take into consideration, while developing a PAYT system. They advise to take into account economical capacity, education level and age of citizens into account, while designing and implementing a PAYT system to increase fairness and therefore acceptance.

Advantage	**Disadvantage**
➢ Reduce amount of waste produced	➢ Technical challenges
➢ Increase of recycling rates	➢ Illegal dumping
➢ Less garden waste in household bins	➢ Increase of administration
➢ Fair allocation of costs	➢ Increased costs
➢ Transparency of Waste Management	➢ Increases contamination recyclables
➢ Increase awareness	

Table 3: Pros and Cons of PAYT systems

Regardless of PAYT systems proven effectiveness and the need of economical hard policy, the implementation of such a system without a proper system analysis might not result in significant long-term waste reduction. A proper analysis could generate different alternative PAYT system options and help to determine complementary policies to guarantee and maximize its effectiveness.

The waste management infrastructure in Amsterdam is extended in the last couple of years. The installation of roughly 13.000 under- and aboveground containers makes it the municipality with the largest container infrastructure in the Netherlands. The goal is that all fractions, residual, plastic, textile, glass, paper and GFT, are collected separately with containers in all neighbourhoods. However, the different characteristics of the city's districts challenge the implementation of infrastructure and make it necessary to find waste management solutions suited to the district needs.

Figure 9 Underground container side (1018, 2018)

4.3 The Social Aspect: Waste Behaviour

Behaviour related to the prevention or recycling of waste can be explained by different factors. The lack of information and awareness of waste related issues can be tackled with different communication strategies. But other more complex motives have to be analysed to understand the driving forces behind sustainable behaviour.

Barr (2003) identified the following three aspects, environmental values, situational characteristics and psychological variables, to explain responsible environmental behaviour. They conclude that environmental action on a household level is affected or determined by a great range of factors within those three aspects. The researched also showed differences between recycling and waste minimization behaviour. Recycling can be seen as normative behaviour and is well adapted if given the means as information and recycling facilities. Waste minimization on the other hand is a much complex phenomena which is based on different values and demographic variables. A reason for this could be the higher complexity of waste reduction tasks. Another aspect could be the fact that people tend to think of recycling as the solution to waste problems. Recyclers therefore do not tent to be the ones to minimize their waste production. Barr (2003) also identified age cohorts, gender and environmental values to minimizing behaviour.

Bortoleto, Kurisu, & Hanaki (2012) tried to develop a waste prevention behaviour model to help decision-makers create more effective waste prevention policies. Similar to Barr, they made a distinction between waste prevention behaviour (WPB) and recycling behaviour. Both studies could not definitely identify determents for this differentiation. Divergence in behavioural predictors, underdeveloped normative structure of WPB or other essential differences might explain the different behavioural structure of the prevention and recycling. Nevertheless, attitude and awareness towards environmental issues seems to be important in for WPB. Creating both should be realized by first communicating environmental issues in general before addressing WPB. Combining those two could overwhelm citizens. Policies for waste prevention should address moral obligation and individual responsibility as well as pointing out prevention opportunities one’s daily routine.

Johnstone & Labonne (2004) used the OECD database to also determine correlation between different demographic variables and waste generation. They created dummy variables on a national level for their analysis. Income and population density showed a significant positive correlation with waste generation. The household size could negatively be correlated to waste generation. However, they state that a municipality level analysis would be a better fit then their highly aggregated analysis on national level.

Past research agrees on the complexity of sustainable behaviour leading to waste recycling or prevention behaviour. Predictors or factors to predict or explain this behaviour are difficult to identify. Definite is the difference between recycling and prevention behaviour. While recycling seems to be closely related to awareness and usability of collection infrastructure, prevention behaviour is much more complex due to task complexity and ideological values related to it. Different Socio-economic factors have been tested as well and could be weakly linked to recycling behaviour. Examples are income and population density. The insights on recycling and prevention behaviour are used as base for determining research focus in Chapter 5.1.

Chapter Summery

The system demarcation has shown the complexity of the household waste streams in Amsterdam. Actors and their roles and capabilities have been identified and different system aspects have been described. Figure 10 summarizes the key flow aspects and their connection with the three contextual factors. Two key points in the waste supply chain can be identified to improve resource flows through the system and increase circularity. These two points are the prevention of waste and resource recovery, and are indicated in figure 10. Even though, prevention of waste should be the priority it also might be the more challenging task to achieve. On top of it can be stated that waste can be reduced to a minimum, but never diminished fully. This is way prevention as well as recovery of resources are the focus of the metabolism analysis. Current flows will be assets, different changes of supply chain shape will be explored and focus areas with high improvement potential will be identified and described.

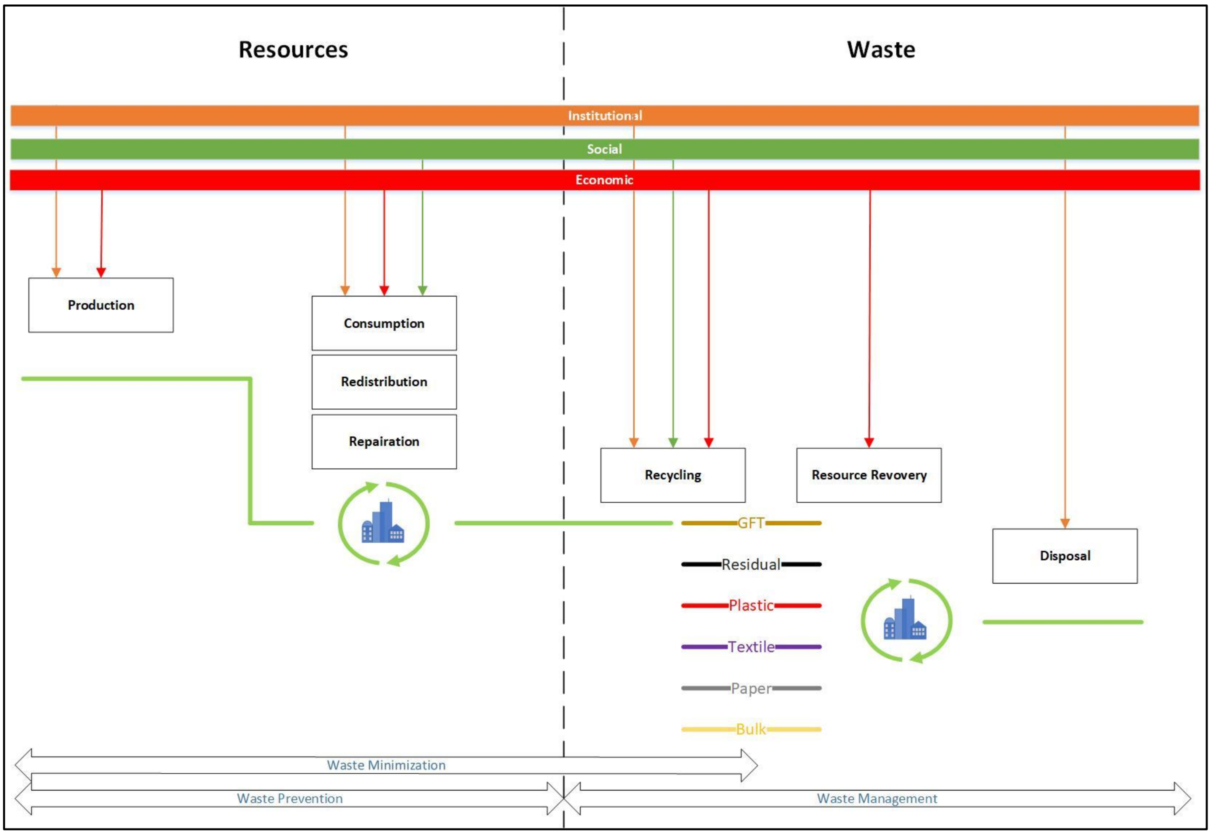


Figure 10 Amsterdam Household Waste Supply Chain Demarcation Overview

The different actor groups, governments, citizens, and businesses, can directly and indirectly influence the household waste supply chain shown in figure 10. Direct influence is enforced by businesses and citizens. Businesses products, their services and processes influence the amount of waste and reproduction opportunities as well as the efficiency of their processes and technologies used. Citizens influence the waste supply chain by their behaviour. Consumption, use and disposal behaviour directly shape the household waste flows.

Governments can mostly influence the waste supply chains indirectly with policies and regulations. Creating awareness, regulating material use, or installing infrastructure are three examples of theses indirect influence. These measures are rather soft. A harder option is the use of an economic incentive in the form of a PAYT system. Let citizens pay for the amount of waste might be necessary, since research argues the soft measures are not truly changing the behaviour and help to achieve the goals set. However, a PAYT system is complex. Different design options, costs, waste tourism and acceptability ask for a good understanding of the current state and behaviour of the waste system.

Direct influence of businesses and citizens are further investigated in the next step of the research to determine its methodology and focus. The different system aspect to make change come about and increase system performance are the focus of the analysis. The results of the analysis will help to determine a set of action the governments in general and the municipality of Amsterdam in specific can take to indirectly influence the system. This policy options and strategies are determined in chapter 9 of the research.

5.

Metabolism Analysis

Chapter five is defining the metabolism analysis of the comprehensive metabolism approach developed in chapter two. The focus does not only lie on technical aspects or pure quantities of material flows, but is extended with analysis of social aspects in the form of the actor or human factor. The different ways businesses and citizens are directly influencing the performance of the supply chain, as determined in chapter 4.6, are further investigated with the analytical extension. First the methodology explains the analysis scope, objectives and flow. The methods to fulfil the objectives, justification and steps of their use in the analysis, are explained next. The last step is the determination of data collection, structure and cleaning, and the description of different software tools used.

5.1 Methodology

The goal of the analysis is the better understanding of household waste flows in Amsterdam and their underlying dynamics. The focus lies in the recovery of materials and prevention of waste. These can come about by the influence and action of businesses and citizens. From product design of producers, over consumption and lifestyle of citizens, to the process optimization of waste processors. The result should create a better understanding of current system behaviour and give direction to potential improvement.

5.1.1 Scope & Analysis Objectives

The metabolism of city can be analysed on different aggregation levels. These levels know different dimensions as Time, Space and Quality. Time can be everything from multiple years to days or even hours. Difference in time aggregation levels enable the analysis of different patterns and routines. Space can be everything from global to household level. It either shows the bigger picture or enables the analysis of consumption or behavioural aspects of individuals or groups in a specific geographical area. Quality is related to the quality of material flows. It can be a combination of different materials in a flow or pure as a natural element. Purity or quality of materials increases their potential for reshaping their flow in the city. Mixed or low-quality materials make the reshaping difficult and might need processing to make reshaping possible. The direction of different scopes of material flows through the city are determined by the shape of the supply chains they are part of. The UM approach developed in chapter two emphasizes on the importance diverse and disaggregated analysis. Therefore, this research choses to analyse the case of Amsterdam household waste on different spatial, time and quality levels to generate deeper understanding of its material flows over time and space.

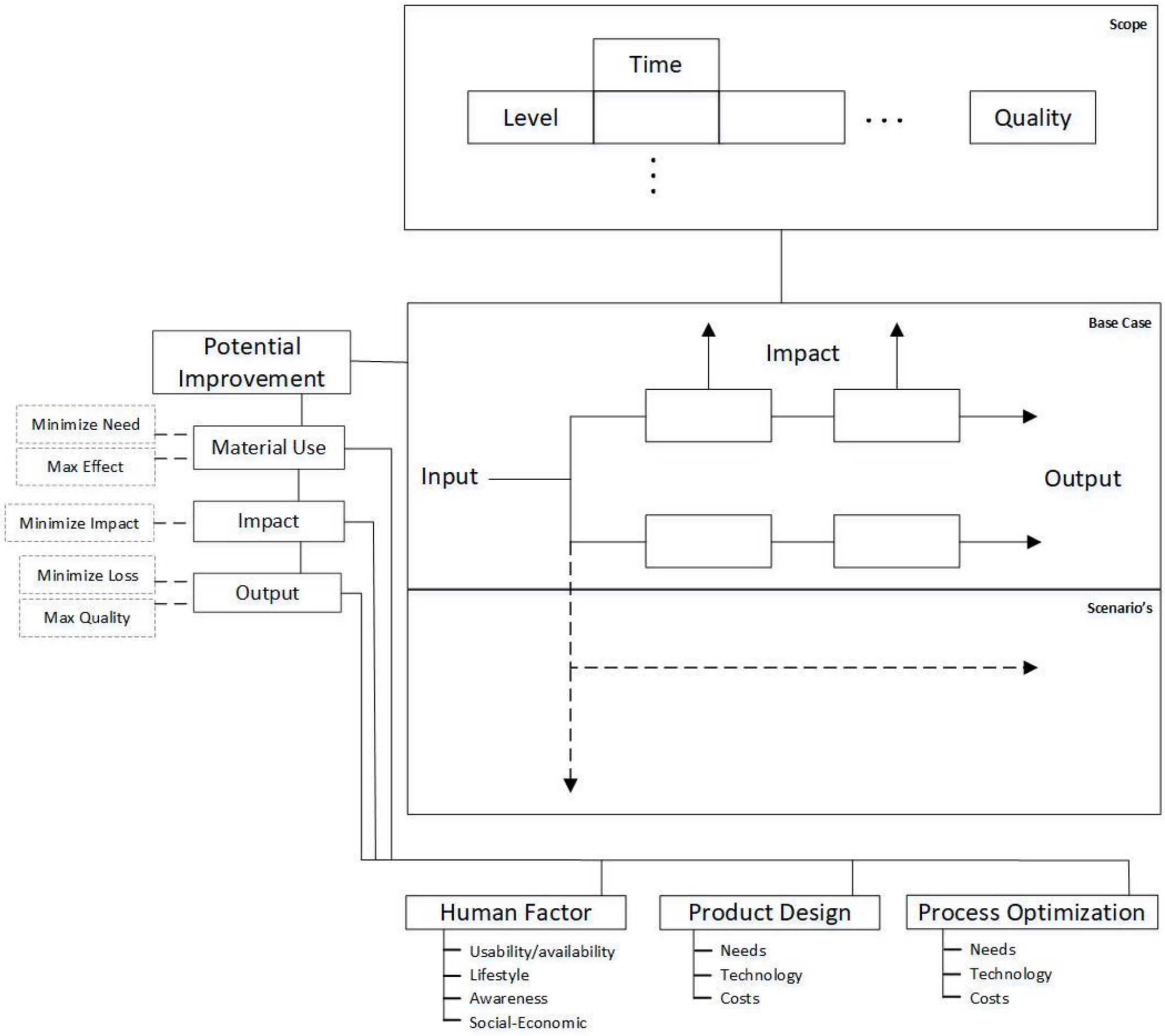


Figure 11 Analysis Scope and Objectives Diagram: Different geographical levels, time dimensions and material quality levels determine the scope of the metabolism analysis. The current supply chains are judged based on their input, impact and output. Improving those measures can be achieved by addressing their material use, impact and output. Minimizing material need, loss and impact as well as maximizing the value creating and quality of material output. Waste supply chain improvement can be accomplished by analysing and influencing the human factor, product design and process optimization

5.1.2 Supply Chain Analysis

The supply chain network of material flows is a combination of process with input, output and a certain impact. The base case determines the current state of the supply chains. Scenario's describe changes to the base case and their effect on input, output and impact. To support policy makers with information and suggest policies, critical aspects of the current system and potential changes have to be investigated. This research analyses the current supply chains of household waste management, identifies areas of improvement, suggest changes and evaluates their potential improvement.

Potential improvements of material flows are related to output, impact and input of the supply chains as show in figure 12. Outputs of individual processes or a supply chain as a whole are evaluated based on their loss and the quality of output material. By minimizing loss and maximizing quality, the output flows can be improved. Losses of material are often related to increase of process impact. Since this research considers the law of conservation of material, decrease of mass is impossible and loss only can mean transformation of material, or material to energy or vice versa. Some might be transferred to heat, others to gas emissions. While heat has no negative impact on the environment and is captured to increase process efficiency, gas emissions as CO2 harm the environment and increase the negative impact of a process. Input of flows are determined by the need for material to keep processes going and create value for citizens. Minimizing need and improving the value created per unit of input material improves the input flows.

Moving towards the desired improvement of output, impact and input of cities material flows, can come about by deeper understanding of the three system aspects human factor, product design and process optimization. Citizens behaviour influences the material flows of a city's metabolism. The household waste being an input of the waste supply chain is determined by the consumption behaviour of citizens. The number, selection, use and disposal of products all determine the amount and type of waste a citizen produces. The design of the products consumed determine their lifespan, potential for reuse and reparation, amount of waste due to consumption and possibilities for resource recovery. Vulnerability of products, replacement of parts, packaging and purity materials used are examples of factors determining the waste produced and efficiency of resource use. Processes in the waste supply chain determine impacts on the environment and material loss. Optimization of these processes can reduce loss and impact.

This research focuses on the analysis of the current household waste supply chains and the factors they are influenced by. The path of the analysis moves from output to input of the supply chain as shown in figure 12. For household waste this entails an analysis from resource recovery to prevention of waste and from process optimization to product design. First the recovery systems and the material flows going through them are analysed. Process optimization is related to the impact of the different resource recovery steps and the loss of materials during process of the supply chain. Central for resource recovery is the quality and amount of separated waste streams. Separation of waste into different fractions is necessary to recover waste streams. This can either be done at the source, the household, or mechanical in separation facilities. If waste streams are only separated mechanically and not at the source, contamination of combined fractions might be so significant that separation or high-quality resource recovery is not possible. This is one of the quality related issues of waste recovery. Other are the purity of product materials and the possibility of separate combinations of different materials. This is necessary to be able to feed materials back into production lines. The amount of waste separated at the source and the quality of these fractions is determined mainly by the human factor and product design. Human factor related to the separation behaviour of citizens and the product design to the purity of materials used.

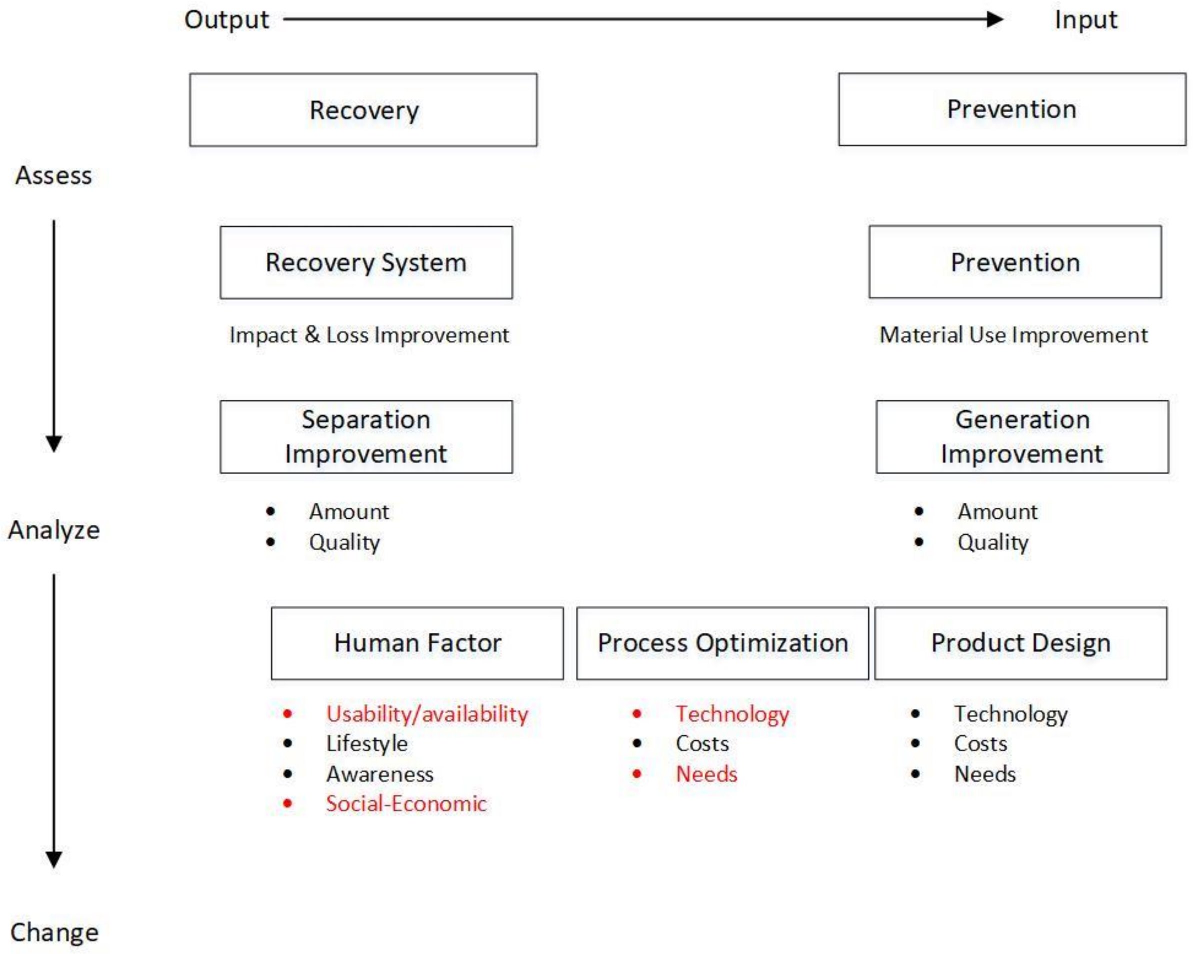


Figure 12 Analysis Objective Diagram: The red coloured aspects are considered in the metabolism analysis

5.1.3 The Human Factor

The Human factor is defined by the aspect's usability/availability, lifestyle, awareness and socio-economics. These were selected from the literature and explained in Chapter 4.3. **Usability** or **availability** addresses the product or service usability and availability for citizens. This Comfort of use and effort to be undertaken play an important role for citizens and their waste separation or prevention behaviour. Chapter 4.3 elaborates the relationship between availability of separation containers and embeddedness of the separation actions close relation to the amount of waste separate. This waste container infrastructure therefore plays an important role in the increase of waste separation. Different housing types are also related to this usability issues. Single party houses have the space for different waste containers or their walking distance to containers in the street might not be long. Multiple party housing blocks are often less spacious and do not offer the possibility to vacate separation containers. The distance a citizen has to walk to a street side separation container might also be significantly bigger. The relation between usability and separation behaviour is the one of the two proven significantly in the literature. Also, separation is important, it might have a negative effect on prevention behaviour on the contrary. People might feel they can produce more waste, if they only separated it at the end. Separation infrastructure availability in relation to separation behaviour and the relation between separation behaviour and the total amount of waste is explored for potential improvement of resource recovery and waste prevention.

The **lifestyle** of citizens also effects the separation behaviour. Environmentalist or people valuing the environment more might tent to separate more than people who feel less connected with the environment. In Chapter 4.3 the relation of values, political ideology and other situational factors are explained. The lifestyle factor is however not taken into consideration in this research due to time and data constraints.

Information to create **awareness** of citizens plays a crucial rule in the increase of separation quantity and quality. Citizens who do not know about the impact of their consumption behaviour, the importance and effects of separation, how and where to separate will never live up to the goals of separation target as well as quality of separated waste. Chapter 4.3 provides prove of the importance of information in relation to awareness for improving waste separation and prevention behaviour. It the second significantly proven relationship in the literature. Due to time and data constraints awareness is not going to be investigated in this research. The outcomes are aiming to identify high potential areas of improvement where further awareness determination and creation campaigns could be executed goal oriented and efficiently.

Different **socio-economic** factors have impact on waste separation behaviour. Education might be one of them as well as the income of citizens and population density. So far only weak links between recycling behaviour and those factors could be identified as explained in chapter 4.3. This research, therefore, further explores the potential relationship between different socio-economic factors and waste recycling and prevention behaviour.

5.1.4 Product Design

Product design can be narrowed down to the aspect's technology, costs and needs. **Technology** is increasing possibilities for new products and what products are made of. Improving lifespan, reducing resource needs and improving product abilities are a couple of aspects technology empowers product design in relation to waste. **Costs** address the fact that all products have to be economical sustainable to create a business case for a company or organization. This is closely connected to the **needs**. What is the aim and the task a product is fulfilling and who is paying what for it? The combination of these aspect offers opportunities for improvement of resource recovery and prevention of waste. However, the focus of this research is the case of household waste in Amsterdam. The municipalities ability to improve product design is rather small and could be addressed more effectively on a national or continental level. Due to this misfit and time constraint. this research does not further address the product design aspects.

5.1.5 Process Optimization

Similar to product design, process optimization can be analysed with the three aspects technology, costs and needs. **Technologies** improve the different efficiency aspects as quality, energy use and speed of its service or task. The level of technological advancement determines the level of improvement. However, this technological development has a price to it. Executing a task with a tool, way too expensive to what are considered reasonable **costs** for the service, might not generate acceptance of consumers or operators. The **needs** and willingness to pay for the satisfaction of these needs determines the room for technical innovation in an industry. Another side to the needs is the task to be fulfilled by a process. What level of service is enough and what is the minimal level creating acceptability? This research is looking into the technological and needs aspects of waste recovery treatment process optimization. The needs of the waste management system defined by municipality and citizens as well as technological improvements to reduce environmental impact and material loss. Costs are an important factor in this process and will be addressed in the next steps section of this research. However, a deeper analysis of the costs of certain changes to the waste supply chains in not executed due to the lack of data and time constraints of this research.

5.1.6 Flow of Analysis

After defining and elaborated the focus of this research the flow of the analysis and its case specific objectives are discussed. The three different stages are the material flow analysis, the life cycle assessment and the statistical analysis.

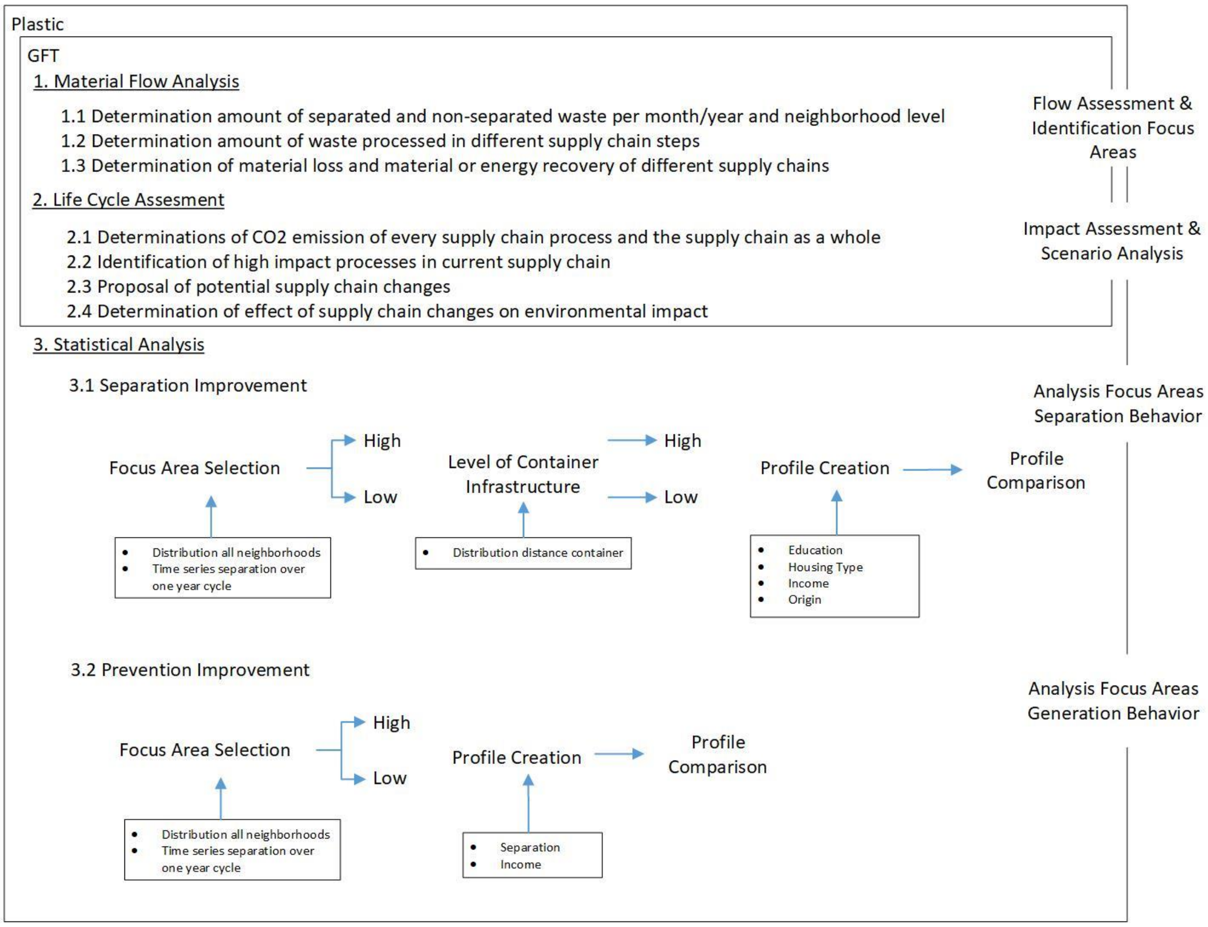


Figure 13 Analysis Flow Diagram

The material flow analysis will help to assess the current waste flows in the city and its different neighbourhoods. Focus areas can be selected based on their waste generation and separation quantities. A focus area is a neighbourhood with a significantly high or low separated waste quantity. To understand the quantities, they will be investigated further in the statistical analysis. The analysis of different supply chain steps will enable the life cycle assessment to assess the current environmental impact. Potential process optimization to improve the impact and material loss are suggested and analysed in different scenarios. Moving from the supply chain forward to the different high potential focus areas of waste generation and separation statistical analysis is used to create deeper understanding of the area’s characteristics. In the first step the focus areas with high and low separation percentages are analysed. Is their separation percentage related to their level of separation infrastructure? If separation is (not) related to infrastructure, what characteristics of their citizens enhances this behaviour even more? Generation behaviour is analysed in the second step. The goal is to explore if high income and high separation neighbourhoods generate more waste. Income is often linked to more consumption and therefore more waste. This traditional paradigm is aimed to be changed by initiatives as Zero Waste, but is it successful already or is Amsterdam just at the start of its separation of wealth and waste. Also, People tent to believe one good action justifies a couple of bad ones. High separation of waste might therefore imply that people produce more waste in total.

The results of this quantitative part are the base for policy advise for the municipality of Amsterdam formulated in chapter 9. Understanding current waste flows, changing their direction and treatment, understanding complexity of waste separation and generation, and goal-oriented awareness creation and education of citizens are the aimed for goals. The methods used are discussed next.

5.2 Methods

To generate the knowledge needed within each analysis step, different methods will be applied. The methods used are material flow analysis, life cycle assessment and statistical analysis. In the field of UM material flow analysis and life cycle assessment are commonly applied methods. In this research they are combined and their extend is reduced. This simplification is made due to time and data constraints and the aim to show the potential of using complementary methods. The complementary methods are the three statistical methods time series, geospatial and correlation analysis. This set of methods creates a clear picture of relevant material throughput and emissions, and enables the possibility to further investigate actor related flow dynamics. In this section methods specific choices are explained.

5.2.1 Material Flow Analysis & Life Cycle Assessment

The material flow analysis and life cycle assessment are the first two methods applied. They are typical to studies in the field of UM. In this research they are combined and their extensiveness is reduced. The choice for these two methods is due to the goal of the analytical objectives to determine input, output and impact of the household waste supply chains. Their systematic approach and the ability to calculated missing empirical information based on assumptions makes those two methods are used.

Material Flow Analysis (MFA) is one of the most common UM analysis techniques, as pointed out by Musango, J.K., Currie, P. & Robinson (2017). MFA systematically assesses all material flows and stocks on a spatial and time level (P. Brunner & Rechberger, 2016). Usually, all flows are taken into consideration, yet, this research will only consider solid household streams due to time and data constrains. On top of that, this research tries to give more weight to the contextual aspects of the streams, rather than the flows itself. Following considerations and choices have been made regarding the temporal, spatial, material and system modelling scope.

1. **Temporal**

The time span of the MFA is one year and the time steps used are monthly. Even though, a trend analysis of the flow development over time might not be possible, it is enough for the purpose of the study. The crucial factor of data availability and format is the most important reason for these choices.

2. **Spatial**

The spatial or geographical scope and boundaries of the MFA is the jurisdictive area of the municipality of Amsterdam. This area will be divided into smaller focus areas on a scale of neighbourhoods. This enables the comparison and differentiation of demographic characteristics of focus areas. The issue of materials leaving this boundaries and relations with surrounding areas are minimal, since most of the household waste is generated, collected and treated within the municipal boundaries.

3. **Material**

The level of material analysis will be on waste materials, rather than the more common approach of elementary or substance level analysis. The level of analysis should fit the goal of the research. Since this research aims to generate more insights into the household waste generate and therefore the behaviour and contextual setting related to it. A substance detail level is to detailed.

4. **System Modelling**

The common black-box approach of MFA studies only considering the in- and outflows of a system obstructs a better system understanding. This research tries to break open this box by analytical focus on contextual factors as the demographic characteristics of citizens. The goal is to create a more comprehensive picture of the system and develop more efficient and suited policies. Brining light into the urban Blackbox.

The **Life Cycle Assessment** (LCA) is conducted in combination with the material flow analysis and is based on the GHG Protocol for Cities published by Green House Gas Protocol (GPC) coming forth from a cooperation between the World Resource Institute and the World Business Council for Sustainable Development. The purpose of the GPC is to enable cities to create a robust and comprehensive inventory of greenhouse gas emissions to take action, development of reduction targets based on yearly base case emissions, create consistent and transparent accounting of emissions and emphasize the importance of cities in climate change actions. The GPC defines Accounting and Reporting, Inventory Boundary and Calculation of GHG Emissions principles to ensure consistent and comprehensive emissions reporting (Fong et al., 2014).

To be able to compare different waste supply chains and not cities, the sector specific emissions of waste defined by GPC are used. For the waste sector emissions of scope one and two are calculated. Scope one and two include emissions from waste treatment and transportation in and outside city boundaries (Fong et al., 2014).

The combined MFA & LCA contains five steps. First, the determination of the material scope of different waste fractions. Second, is the analysis of the material supply chain. The production, purchase, use, disposal and treatment of the different waste streams will be described. Third, a geographical focus area will be determined based on data availability and suitability. Fourth, the case specific supply chain will be described and analysed. Fifth, is the modelling of the mass flows.

5.2.2 Statistical Analysis

The second part of the methods are statistical data analysis methods helping to investigate patterns is waste generation and separation on a time and geographical level as well as exploring relations with actor groups with certain socio-economic characteristics. The three methods used are time series, geospatial and correlation analysis.

The **Time Series** analysis describes the analysis of empirical data observed on different points in time (Shumway & Stoffer, 2017). This method enables the discovery of patterns and trends in the data. Patterns describe a repetitive behaviour in a short to mid-size time period, while trends indicate striving into a specific value direction, increasing or decreasing, over a longer time period. Time series analysis was applied to waste generation behaviour earlier by for example Chang & Lin (1997). However, the issues of data availability limited the potential of the analysis often only having data sample sizes of 200 to 500 N. This research exploratory analysis of time series tries to determine typical behavioural patterns in waste separation or generation behaviour between different geographical regions in the city of Amsterdam. The high granularity data used in this research enables deeper and extensive analysis of different geographical areas.

The **Geospatial Analysis** is concerned with what happens where and tries to connect phenomena and variables to geographical locations (Michael John De Smith, Goodchild, & Longley, 2007). This research makes use of exploratory spatial data analysis, linking waste separation and generation quantities as well as demographic data to the geographical level of neighbourhoods. Point sets and distance statistics help to determine the infrastructure density of these neighbourhoods as well. Geospatial analysis is chosen due to its potential of making complex relationships understandable by visualizing it in a geographical context.

The last methods used is correlation analysis. This enables to establish numerical relationships between different variables. **Correlation Analysis** tries to identify possible causal relationships, however, does not indicate causation (de Smith, 2018). The goal is to investigate a potential correlation between the waste separation behaviour and different demographic variables. The chosen method is **Spearman Rank Order** correlation analysis. It is used for the identification, strength and direction determination of a relation between two variables of at least ordinal scale. This requirement is one of the two pre requirements of the methods. The other being and existing monotonic relationship. In comparison to other correlation methods, as for example Pearson correlation analysis, Spearman Rank Order correlation analysis does not require the investigated variables to be normally distributed. This is not the case for the waste data and the reason for selecting this method. The steps taken and choices made for each method are further discussed in chapter 7.

5.3 Software and Tools

This research makes use of different software and tools to execute each of its steps. Python is used for data preparation and cleaning, the execution of material flow and impact calculations, statistical analysis, and visualization of results. The most important libraries used are Pandas, Numpy, Request, Shapely, Plotly, Geopandas and Geolocator. Geolocator is making use of the GoogleV3 geolocator running on the Google Cloud platform. ArcGis is used for spatial analysis and visualization. All notebooks and data used are available on the Github.

5.4 Data Sources and Cleaning

Data is an essential part of this research. In every step of the analysis data is used to create a picture of the real world. Data quality and level of detail determine the quality of this picture. Different data sources are used. Cleaning the data by identifying different types of flaws in it and erasing them is of great importance to ensure better research outcomes or define limitations.

The data used for this research is household waste generation data, demographic data and spatial data. The source of this data is the Amsterdam open data portal.

Since 2012 the municipality of Amsterdam started to weight the under- and aboveground waste containers during the waste collection process. By weighing them two times, full and empty, the net amount of waste collected is determined. Also, the type of waste, rest, paper, glass, textile, gft and plastic, is recorded. In the beginning this data was only collected in a couple of districts and for a select group of containers. Since 2018 all containers are weight. The weight data is available via the 'kilogram' API, supplied and maintained by the third party Welvaarts. Data about containers sites, different containers and their location is available via an API supplied by the municipality. The format of the data collected from the different API's is shown in figure 14.

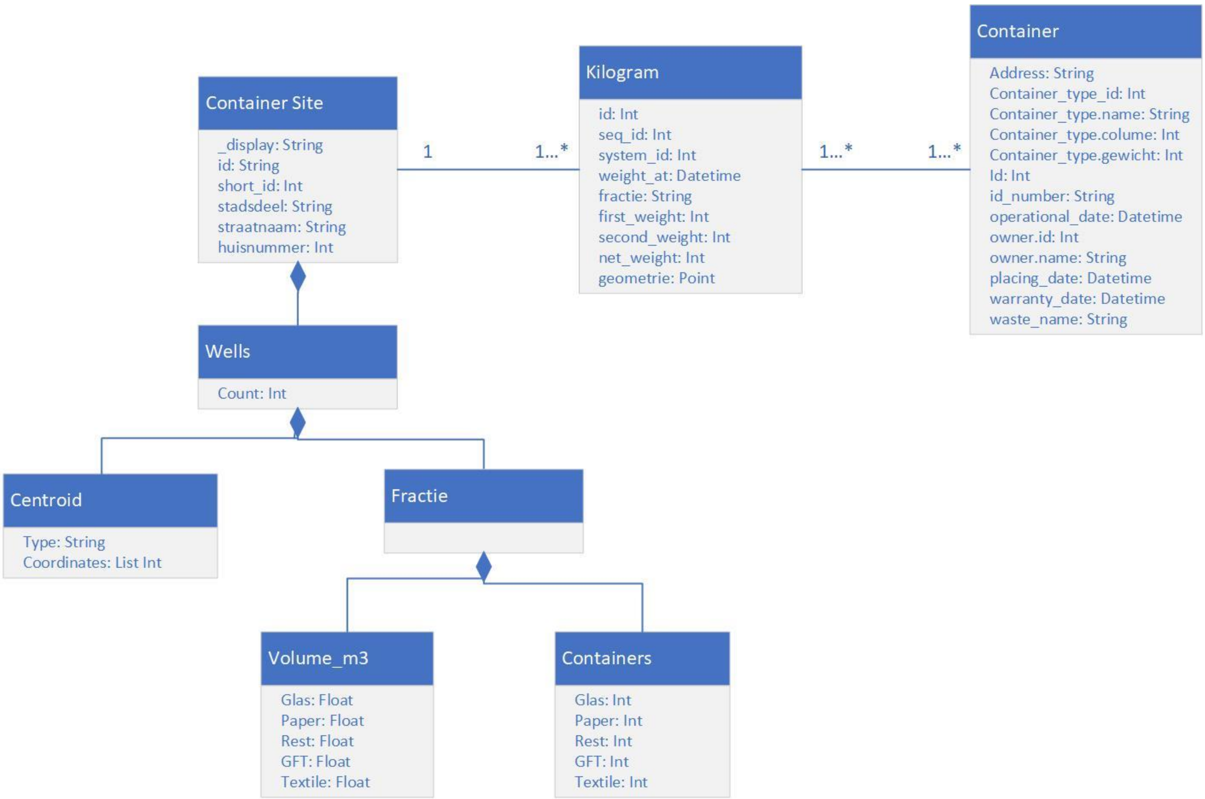


Figure 14 Container Data Diagram

The demographic data and its meta data are shown in table 4. The data was collected on a "wijk" or neighbourhood level from the open data portal of the city of Amsterdam.

Variables	**Unit**	**Explanation**
Education		**Highest finished education**
Low	Percentage (%)	Basis, HAVO, Mbo1
Medium		HAVO, VWO, Mbo2-4
High		WO and HBO
Average Income	Euro (€)	**Average income household**
Citizens	Number (#)	**Number of citizens**
Households	Number (#)	**Number of Households**
Origin		**Country of Origin**
West	Percentage (%)	Europe, North-America, Oceania
Non-West		Others
Single House	Number (#)	**Number of single party houses**
Multiple Party	Number (#)	**Number of multiple party apartments**

Table 4 Demographic data descriptive table

Price & Shanks (2016) distinguish three different categories of data quality criterions: **Syntactics**, **Semantics** and **Pragmatics**. The syntactic criterion category describes the level data is in line with its metadata. Metadata describes the structure and syntax of data. Simplified it can be defined as data describing data. The semantic criterion category describes to what degree data represents the real-world system it originates from. The pragmatic criterion category is related to the usefulness of data for a certain purpose. Huang (2013) summarized criterions for each category from literature. Syntactic criterions are divided into accuracy and consistency. An example of syntactic data quality issues could be inconsistent use of datatypes as is string and int for ids. Semantic criterions are **accuracy**, **completeness** and mapping **consistency**. Examples of semantic data quality issues are missing values or a high divergence of data value and real-world value of a specific observation. Pragmatic criterions are completeness, **timeliness**, **presentations suitability**, **precision** and **type-sufficiency**.

The waste data collected appears to be of good quality, especially its pragmatic quality is remarkable. High timely and spatial resolution represent a high level of pragmatic timeliness and completeness. The main data quality issues of the data used in this research are related to semantic accuracy, mapping consistency and completeness. An extensive description of data cleaning actions taken can be found in Appendix B.

Chapter Summary

Chapter five defined the methodology of this research. The analytical objectives are to determine current output, input and impact of the household waste supply chains and to investigate underlying material flow dynamics. The current material flows are analysed with a combination of the methods MFA and LCA. Different geographical level and time dimensions are used to enable a more dynamic and deeper analysis of the material flows with the use of statistical analysis. A full description of the analysis is described in chapter 6. The statistical analysis is used to explore waste separation and generation behaviour over time and its potential relation to availability of infrastructure and demographic characteristics of citizens. The statistical methods used are time series, geo spatial analysis and correlation analysis. The statistical analysis is further defined in chapter 7.

6. Material Flow Analysis & Life Cycle Assessment

Chapter 6 will be dedicated to the MFA and LCA. The method defined in chapter 5 are used to analyse the organizational structure of the waste supply chain and the materials or streams flowing through it as well as their environmental impacts. The analysis has five steps: Determination of Material Scope, Analysis of Material Supply Chain, Determination of Geographical Scope, Description Case Specific Supply Chain and Modelling of Mass Flows.

6.1 Determination Material Scope

The determination of the material scope is related to different aspects. Data availability as one of the biggest has significant influence on the material scope. The data of household waste, forming the core of this analysis, is of high quality in terms of type, time and space level. Information of waste quality and detailed product composition is not as detailed, but describes average values for residual waste composition in Amsterdam. The focus of the research will lay on plastic and organic waste collected separately or within the residual waste streams. The selection of these two fractions has several reasons. Time and scope constraints of this research being the clearest. The importance and potential for improvement are two arguments of these two fractions.

Plastic waste can be divided into the two parts separated and non-separated. The separated part is source-separated and collected from special plastic waste containers. The separated part is fully determined by the data collected from the open API of container weight. The non-separated part is determined based on the residual fraction waste data of the API and a percentage of plastic waste in residual waste analysed by CREM in 2016 (CREM, 2017). The GFT waste is not separated yet why only non-separated GFT waste is considered. Similar to the Plastic non-separated plastic waste, it is calculated based on the residual waste and a percentage from the CREM research.

6.2 Analysis Material Supply Chains

The waste material supply chain of household waste can be separated into two parts: Resources and Waste. As shown in figure 14, the Resource part on the left site is related to Production, Consumption, Redistribution and Reparation. Within this process the products are still resources and no waste yet. Preventing them from becoming waste is essential and can be done in all processes of this part of the supply chain.

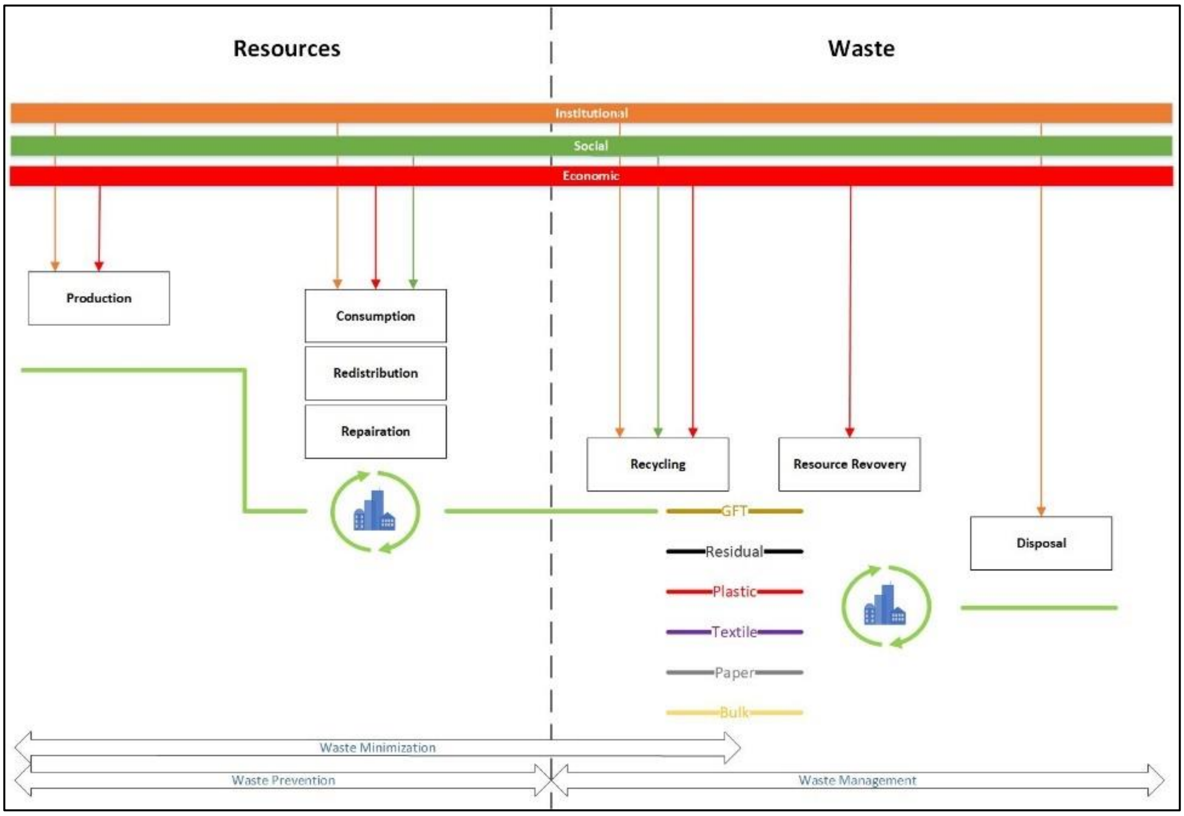


Figure 15 Conceptual Waste Supply Chain Amsterdam

After products are discarded, they become waste. To ensure waste is not ending up in landfills, they are first separated into different "pure" waste stream. The most common streams are GFT, Residual, Plastic, Textile, Paper and Bulk waste. Since this research is focusing on plastic and GFT waste, the current supply chains of this waste types are described in detail.

6.2.1 Potential of GFT

Organic or "Groente, Fruit & Tuin" (GFT) makes up a big fraction of household waste. So far it is only collected separately in a few small neighbourhoods for pilot purposes. In general, GFT is collected in the residual waste fraction. It makes up 37% of the total weight of household waste, but only 15% of its volume (CREM, 2017). This density offers high potential for the reduction of total residual waste weight, improve resource recovery and reduce environmental impact. Another aspect is the fact that the often wet GFT waste is contaminating the other part of the residual waste. Smell and wetness reduce the quality of residual waste significantly and makes second separation of residual waste unattractive. Resulting in the fact that all residual waste is currently incinerated in Amsterdam. Keeping GFT waste out of residual waste should have priority to increase residual waste quality on one hand and efficient reuse of GFT on the other hand.

Reuse options are diverse. Separated GFT can be collected and processed in different fermentation processes to generate electricity, heat and compost. Another alternative is the so-called worm hotel. It enables citizens to compost their GFT waste close to their homes and generate high quality compost for reuse. Since the hotel is placed in public space on the street site, households without a garden are able to make use of this service as well. Household with a garden have the option of home composting. Central fermentation has potentially the highest efficiency of these option. However, needs structural changes to the waste supply chain. This research will explore the potential, effects and option for GFT supply chain improvement and its implications for the municipality.

6.2.2 Complexity of Plastic

Nearly all of the plastic fraction of household waste is packaging of food or other products. Their goal is to protect the product or conserve it in order to maximize consumer experience and life-span of the product. Most of the plastic packaging is made out of either Polytene (PE), Polypropeen (PP) or Polyethyleentereftalaat (PET), or a combination of either one of those three. Yearly 475 kton overall and 28kg per person of plastic packaging is used in the Netherlands, of which two thirds end up in the household waste. The other third is collected via a return system. Household plastic waste is collected separately from the residual fraction since 2008. Source separated plastic is separated mechanically for a second time and afterwards used for reproduction purposes. Plastic waste ending up in the residual fraction is burned in an waste incineration facility for the purpose of energy recovery (Kennisinstituut Duurzaam Verpakken, 2017).

The complexity of plastic waste in comparison to paper or glass can be explained by the following factors. Combinations of different plastic and packaging types make reproduction and separation difficult. A lot of different parties are involved in the production, distribution, consumption, waste collection and reproduction of plastic. From an economic perspective reproduced plastic and the virgin material market are closely related. Virgin material itself is closely related to the oil price determined not only by the pure resource price, but the price of oil as well (Kennisinstituut Duurzaam Verpakken, 2017). This makes the plastic supply chain even more complex than other waste types.

Even though, separation and reproduction of plastic under any conditions is better than incineration of plastic waste, a lot of issues need to be solved to create true circularity of the plastic supply chain. Currently recycled plastic cannot compete with virgin material. According to Partners for Innovation & Rebel (2018) reasons for this can be categorized into technical, economical, regulatory and organizational issues. From a **technical** perspective the recycled material does not conform with the standards of potential users. Food packaging has to fulfill high standards, which recycled plastic material is not reaching at the moment. Another technical aspect is contamination of recycled material. This can create quality problems or result in esthetical issues of mismatching color or smell of the recycled material. Also, production lines of producers are often not able to process recycled material. Last is the fact that a lot of packaging is made of a complex polymer combination unable to be separated. This means that currently around 60% of all reproduced plastic is mixed material (DKR 350) being the lowest quality level only able to be downcycled to for example park banks or infrastructure as streets. From an **economical** perspective recycled material cannot compete with virgin material. Recycled material has still a lower quality, however, often comes with higher or the same costs as virgin material. On top of that the recycled material supply chain is not transparent, causing uncertainties for producers concerning future supply development. Strict **regulatory** for products prevent the use of recycled material and forces producers to use virgin material. **Organizational** issues are related to the structure and organization of the current plastic waste supply chain and recycled material market. The different stages of the plastic supply chain ask for action to improve circular flow of plastic material.

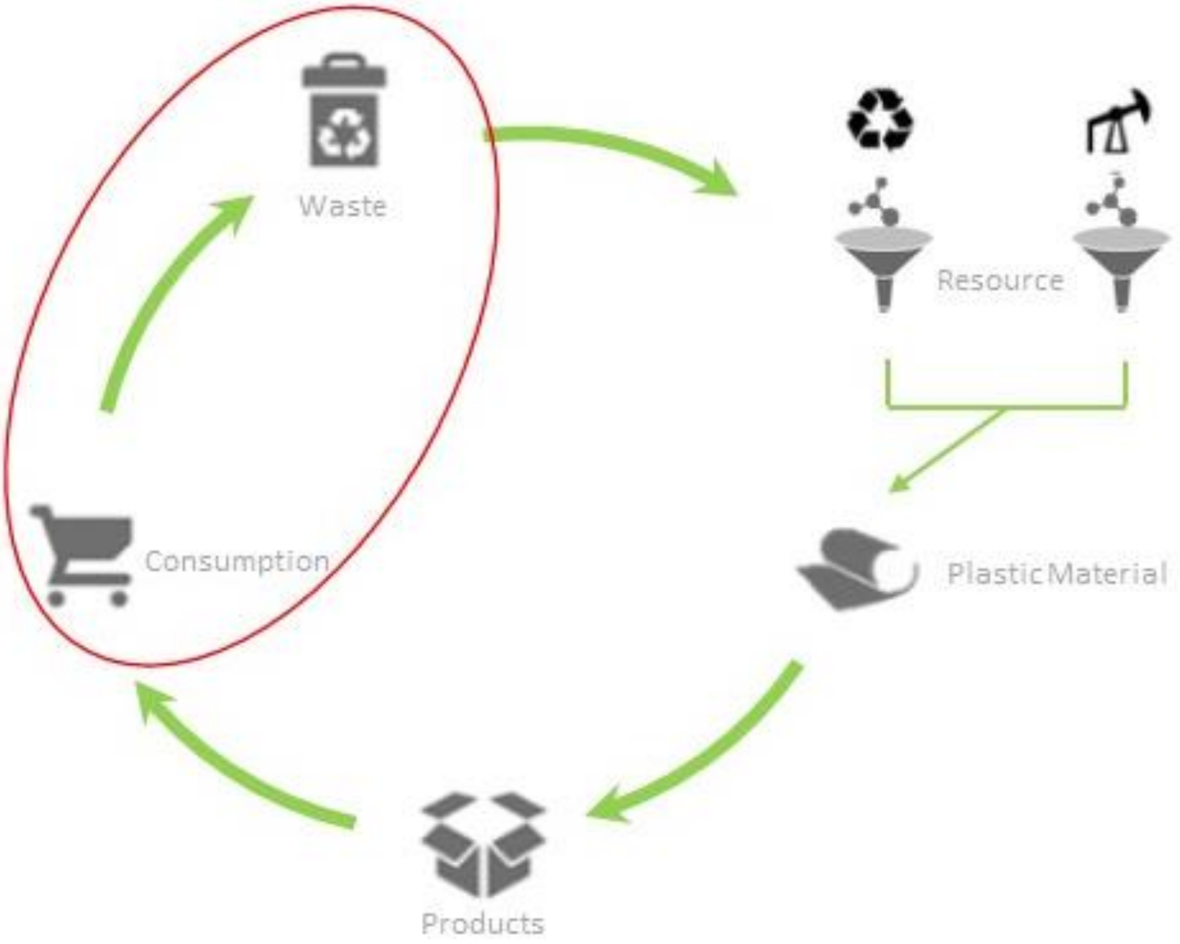


Figure 16 Plastic Circulation

6.3 Determination Geographical Scope

The geographical scope defines the geographical boundaries of this research. All processes, household waste material is used, transformed and executed in, are taken into consideration. Within the chosen area different geographical scales are used to analyses material flows. The high accumulated city level enables the analysis of the current performance of the different supply chains. Possible changes to the supply chains can be analysed and compared. The low neighbourhood level allows in depth analysis of total waste generation or separation and contextual factor exploration.

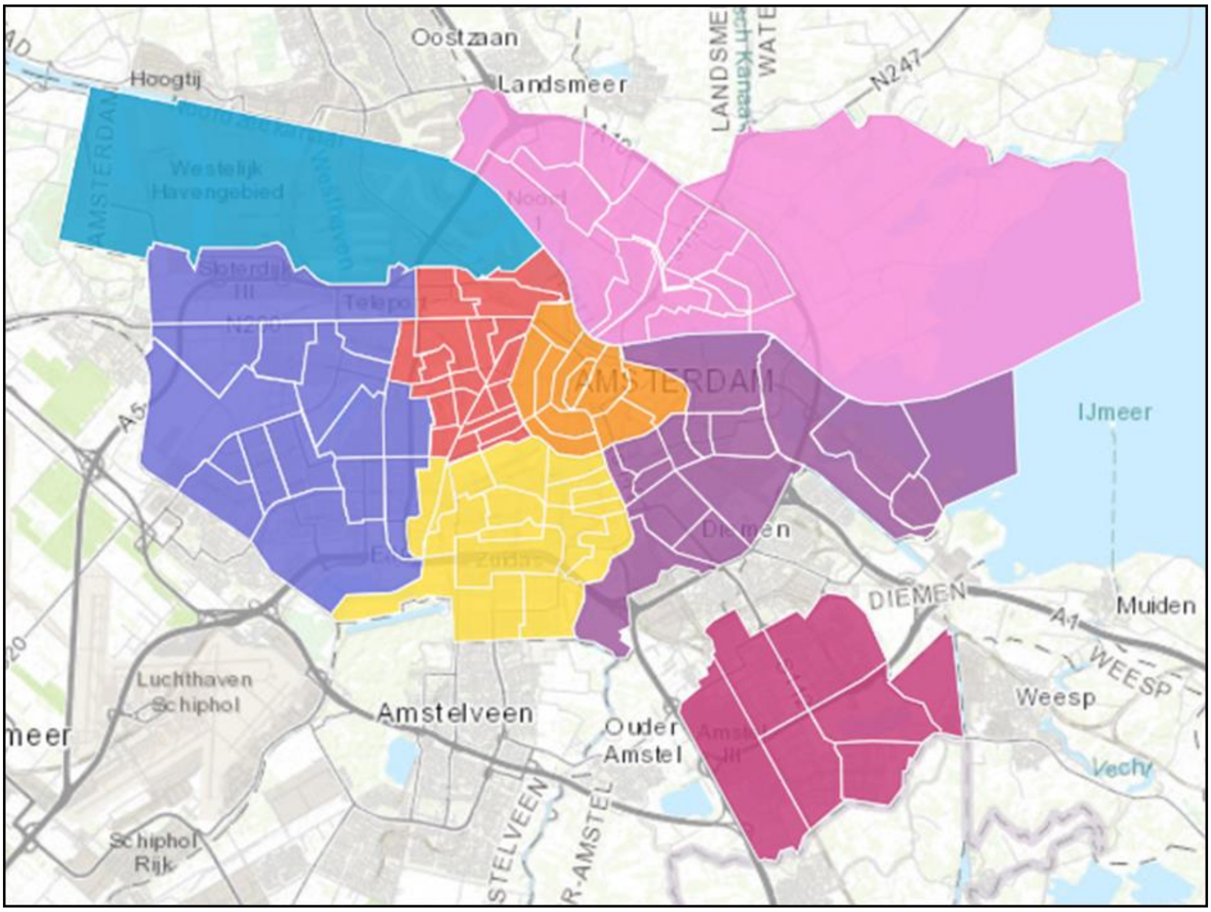


Figure 17 Geographical Overview Amsterdam Suburbs & Neighbourhood's

The geographical scope of the research is the city of Amsterdam and its neighbourhoods as shown in figure 16. The municipality has a geographical size of 219.32 km^2 with seven districts and 97 neighbourhoods. Some neighbourhoods are purely commercial or industrials area and in some neighbourhoods the waste is collected without data collection. The city centre for example has a lack of space being a main barrier for more underground containers to be installed. This is the reason why residual waste is still collected on certain week days in plastic sack on the curb side. Commercial, industrial areas or neighbourhoods with diverging collection methods are not considered in this research. A full list of all neighbourhoods and whether or not they are part of the analysis can be found in Appendix B.

6.4 Description Case specific Material Supply Chain

The supply chain of different waste types described earlier is specified for the case of Amsterdam in this fourth step. Material flow directions, processes and tasks are described and the responsible group of actors is assigned. Figure 17 shows all these aspects of the Amsterdam household waste supply chain.

Retail Markets

Retail stores and markets sell their products to the citizens. The amount and type of products distributed determine the potential amount of waste produced. According to market economical principals does the consumption behaviour determine the offer.

Households

The households consisting of one or more citizens use the products bought. Consumers could change the offer retailers by only buying products with a low waste potential or profile, long life expectancies and reuse or repair potential. Based on a consumer judgement a product reaches its life's end and is either offered for reuse to other consumers or fed to the waste supply chain. If the waste is disposed, consumers can either recycle a products material in the specific fraction container or dispose it collectively in the residual waste containers.

Municipality

The municipality arranges the collection and transport of waste to the separation and reproduction facilities of different recycling companies. For some waste streams collection might be done by the recycling companies themselves, if arranged so by the municipality.

Suez

The separated plastic is collected and processed by Suez. It is a French-based waste management company operating in multiple Dutch municipalities. After collection of the separated waste from the different districts, the waste is transported to the second separation facility in the commercial area close to the harbour of Amsterdam.

AEB

Waste placed in residual waste is collected and transported to the incineration facility of AEB Amsterdam. Without a second separation process waste is incinerated to recover energy from it. Hot water steam is used to generate electricity and heat as a by-product. The ash is scanned for metals to be recovered.

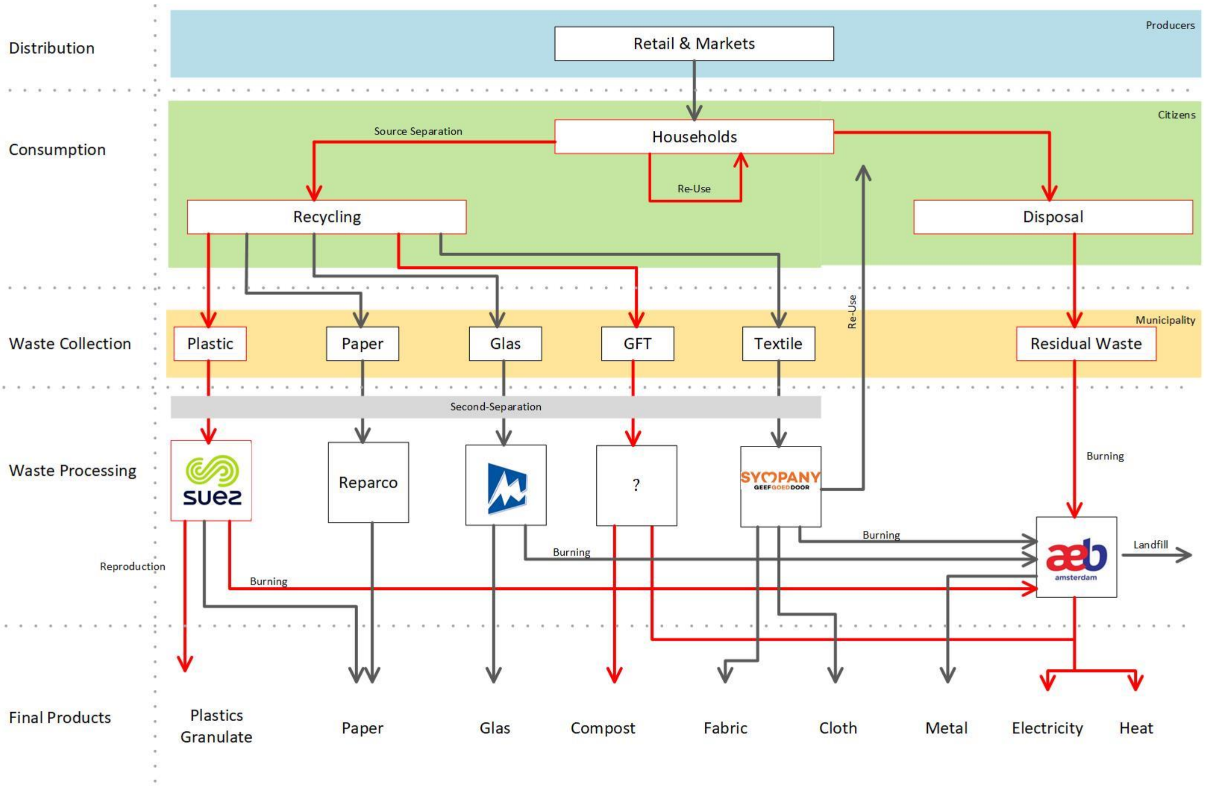


Figure 18 Overview Waste Supply Chains

6.5 Modelling of Mass Flows

The mass flows of the household waste streams are modelled for the plastic fraction as well as GFT. The waste generation data is used as input of the model and form the base for the calculation of the flows of waste through the supply chains. This creates a monthly picture of the waste within the different steps of the supply chains.

The flows of materials through existing and potential future supply chains is modelled with stocks and flows shown in figure 20 and 21. Stocks are material reservoirs within the different supply chains. Flows are the connections between those reservoirs and determine input and output of stocks. The time variable of stocks and flows are month. As shown in figure 19, stocks represent a process and can have one or multiple inputs.

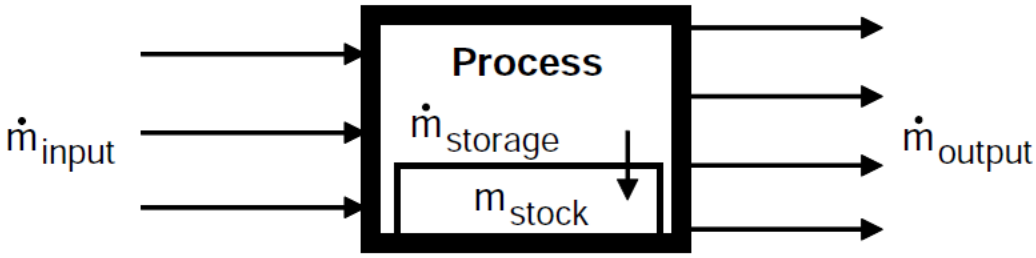


Figure 19 Consideration of Process Stock's (P. H. Brunner & Rechberger, 2004)

The plastic stock model shown in figure 20 is a representation of the two plastic material supply chains. As a whole the plastic supply chains have one input and four outputs. The input is discarded plastic and the outputs are CO_2 emissions, Energy, Plastic and Paper. The different supply chains the discarded plastic it flowing into can be mostly distinguished in the incineration and recycling supply chain. The incineration supply chain has the stocks residual plastic waste, residual waste transportation, and residual waste incineration. The recycling supply chain consists of the stock separated plastic waste, separated plastic transport, second separation and plastic reproduction. The municipality collects drink packaging with the plastic waste mostly made out of paper. This is separated within the mechanical separation of the second separation stock and fed into paper reproduction stream. However, the paper reproduction supply chain is not considered in this research.

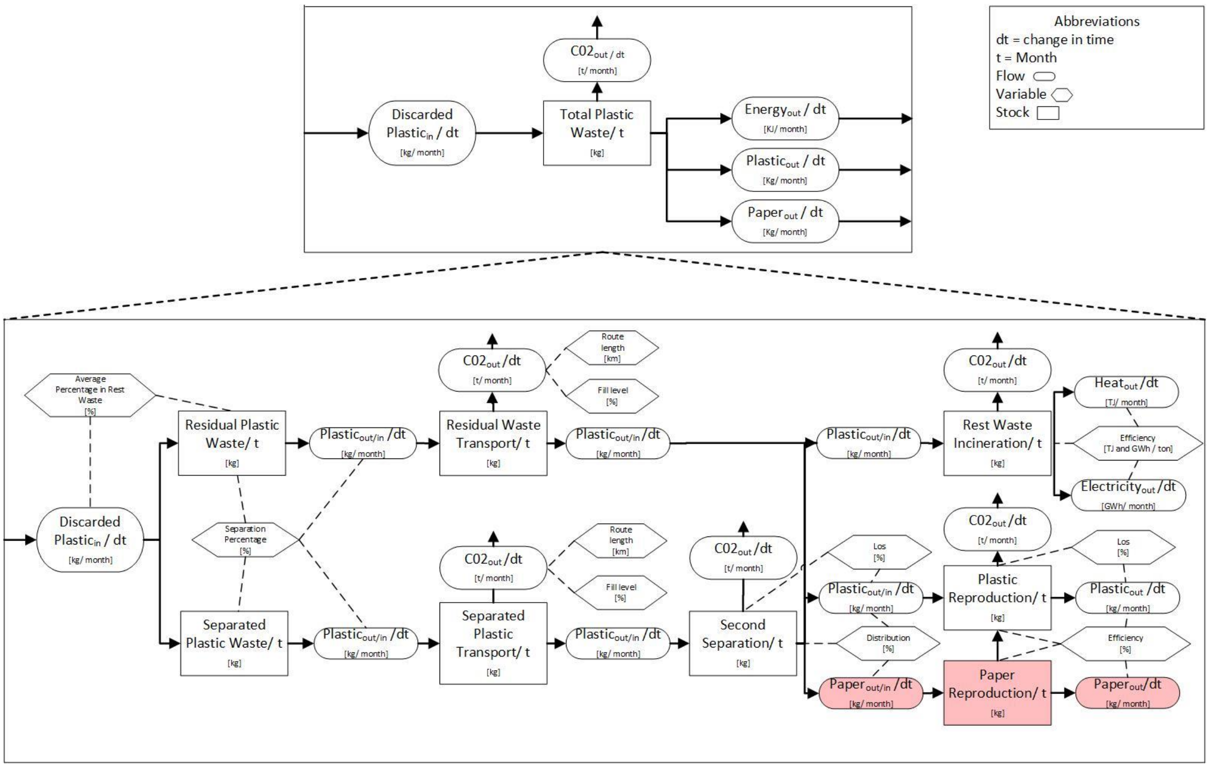


Figure 20 Stock Flow Model Plastic

The GFT model shown in figure 21 is representation of the current GFT supply chain of incineration and the possible future supply chain of fermentation. In general, both supply chains together have one input and three outputs. The input discarded GFT waste and the outputs CO_2 emissions, energy and compost. The current GFT supply chain of incineration consists of the stock’s residual GFT waste, residual waste transport and residual waste incineration. The possible future supply chain of GFT fermentation consists of the stock separated GFT, separated GFT transport, fermentation and composting. The composting stock and its in- and outputs are not taken into consideration in this research due to time constraints and its relatively low importance due to its value.

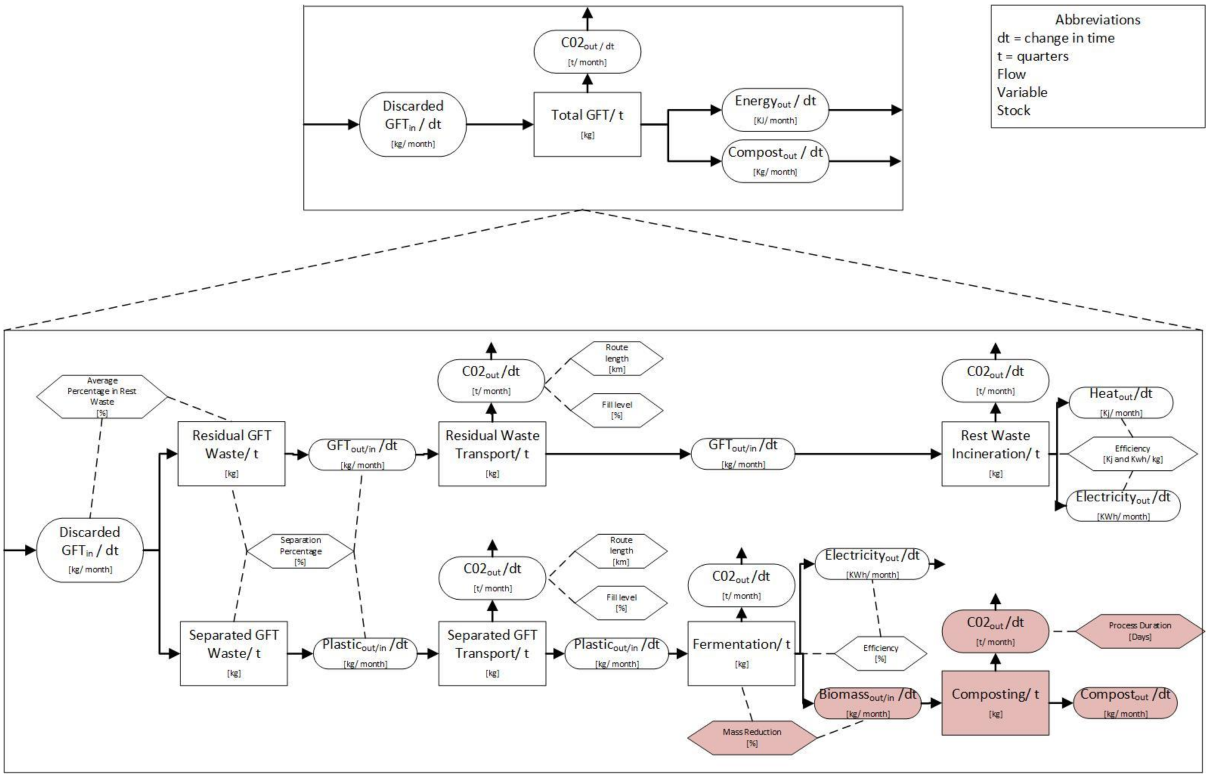


Figure 21 Stock Flow Model GFT

To be able to calculate the different stocks and flows assumption are made based on literature. The overall input of the stock model is the waste data described in chapter 5.4.1. Composition of residual waste, material losses, efficiency levels of material and energy recovery were calculated based on the waste data and assumptions. Table 3 shows the material flow assumptions. These assumptions are used in the next step of Mass Balance 6.6.

Variable	**Description**	**Value**	**Source**
% of Plastic in Residual Waste	Compositions of residual waste in Amsterdam	10.4%	(CREM, 2017)
% of Bio Waste in Residual Waste	Compositions of residual waste in Amsterdam	37%	(CREM, 2017)
Incineration			
Energy generation by incineration of waste	Amount of energy produced by the incineration process of residual waste	10.1 GJ per t waste	(M. B. J. (Matthijs) Otten & Bergsma, 2010)
Electricity percentage	Percentage of total energy generation generated in electricity	26%	(M. B. J. (Matthijs) Otten & Bergsma, 2010)
Heat percentage	Percentage of total energy generation generated in heat	2%	(M. B. J. (Matthijs) Otten & Bergsma, 2010)

Loss Second Separation	Loss of plastic during second separation processes	5%	(Boeren, Roos Lindreen, & Bergsma, 2019)
Loss Reproduction	Loss of plastic during reproduction	11%	(Boeren et al., 2019)
Fermentation			
Electricity generation fermentation	The amount of electricity generated by fermentation of GFT waste. Incineration of biogas to fuel electrical generator	154 kwh per t waste	(Banks, Chesshire, Heaven, & Arnold, 2011)
Heat generation fermentation	The amount of heat generated by fermentation of GFT waste.	256 kwh ton per waste	(Banks et al., 2011)

Table 5 Assumptions Materia Flow Analysis

6.6 Life Cycle Assessment

The emissions LCA part of the analysis is conducted in combination with the MFA. The quantities of waste processed in the different supply chain steps are used to calculate the emissions for each of the processes and the overall emissions of different supply chains.

Calculation of CO_2 emissions for each process are done with the assumptions shown in table 6, which are derived from the literature. Transportation emissions are calculated with the use of an CO_2 emissions factor of a truck, the average distance between treatment facility, average fill level of trucks and the capacity of a truck. The emissions of the other processes are calculated based on the amount of waste processed and an emissions per ton of waste factor. These assumptions are used in the next step of Mass Balance 6.6.

Variable	**Description**	**Value**	**Source**
CO_2 Transport	Average CO_2 Emissions per kilometre for a truck of >20 t within a city	0.258 kg CO_2 per km	(M. Otten, ’t Hoen, & den Boer, 2017)
Average distance between suburb and Waste treatment facility	The distance centre of suburb and waste treatment facilities calculated with Google Maps	Full table in Appendix B	Google Maps
Average fill level	Average fill level of container when emptied effecting effectiveness of waste collection cycle	15 %	Peter de Boer, Municipality Amsterdam
Standard Size Waste Transporter	Standard size of trucks for waste transportation and their load capacity	11.425 t	(RDW, 2019)

CO_2 Second Separation	The amount of emissions produced during second separation by energy used in this process	0.028 t CO_2	(Boeren et al., 2019)
CO_2 Incineration	CO_2 generated during the incineration process of residual waste	3 t CO_2 per t waste	(Boeren et al., 2019)
CO_2 Fermentation	CO_2 emissions generated during fermentation of GFT waste and incineration of biogas to generate electricity.	0.114 t CO_2 per t waste	(Banks et al., 2011)
CO_2 Reproduction	CO_2 emissions emitted during reproduction	-0.5 t CO_2 per t waste	(Boeren et al., 2019)

Table 6 Assumptions Life Cycle Assessment

6.7 Mass Balance

The mass balance step of the analysis consists of the calculation of the different stock and flows. The formula shown in figure 22 the calculations are based on. It is assumed that the waste is never longer than a month in the different stock. This means the storage is equal to zero meaning input equals output. Extensive documentation of all variables and formulas can be found in Appendix B. The calculations are made with python in the notebook with the name “Material Flow Analysis” on Github.

$$\sum_{k_I} \dot{m}_{\text{input}} = \sum_{k_O} \dot{m}_{\text{output}} + \dot{m}_{\text{storage}}$$

Figure 22 Mass Flow Balance Equation (P. H. Brunner & Rechberger, 2004)

6.8 Scenario’s

To be able to discover future improvement of the plastic and GFT supply chains scenarios are defined to be explored in the MFA and LCA. For both supply chains only two scenarios are defined due to time constraints of this research. The selected scenarios are the worst and most promising ones for future development of the environmental and material recovery aspects

The rather complex issues of plastic waste discussed in chapter 6.2.2 is the base for the two scenarios analysed in the MFA and LCA. Although a lot has to change on different levels in the plastic supply chain, the municipality of Amsterdam has to contribute its part to environmental impact and amount of material and energy recovered from it. Increasing the amount of separation percentage and its quality is essential to achieve the aimed for improvements. Before looking into separation of waste and its quality the question of, what material and energy amounts, and emissions would be recovered or generated by increasing the separation percentage of plastic waste. Therefore, the two scenarios of Incineration, considering the situation in which all plastic waste is incinerated as part of the residual waste, and recycling, considering all plastic waste to be separated and used for reproduction purposes.

The complexity and potential of improving the environmental and material or energy recovery of the GFT supply chain discussed in chapter 6.2.1. The three structural improvement options, home composting, worm hotels, and fermentation, are all of interest for the municipality. Since, this research tries to find the best and most comprehensive solutions, only the fermentation option is considered in the scenario analysis. Worm hotels as well as home composting are of interest on a low scale. However, they cannot be applied as a systematic solution due to space and participatory requirements. Not everyone is able to home compost or place a worm hotel in their near surrounding. Both solutions also require certain amount of dedication and effort exceeding the simple separation is discarding of waste. On top of these issues home composting and worm hotels are not as efficient and resources are lost in comparison to centralized fermentation. The centralized fermentation is compared to the current solution of incineration of GFT waste in terms of environmental impact and resource recovery. The potential financial aspect of the necessary separation infrastructure and facilities are not explored in this research, but are discussed in chapter 9.

7. Statistical Analysis

To deepen the understanding of waste separation and waste generation different statistical analysis are executed. As defined in chapter 5.2.2, the methods used in the step are time series, geospatial and correlation analysis. This chapter addresses the choices and steps taken in the analysis executed with each of the methods.

7.1 Time Series

The time series analysis has the purpose to compare the separation and generation behaviour over time with the goal of identifying overall patterns and differences in patterns between geographical locations and waste types. The time scale of this analysis is month and the total length is a cycle of one year. Due to data quality issues in past years, analysis of a longer period was not possible. This also prevents the possibility of forecasting. Therefore, only exploratory analysis of waste generation and separation patterns are conducted. The geographical dimension of the analysis are neighbourhoods.

7.2 Geospatial Analysis

Geospatial analysis consists of two steps. First is the visualization of normalized waste quantities for each neighbourhood. The visualization enables the visual comparison and identification of focus areas. The values are normalized by dividing the yearly waste generation of a suburb by its number of citizens, which has quantity of waste per person in on year in the specific neighbourhood as a result. The second step is only executed separated plastic waste. To identify and compare waste densities of neighbourhoods a proximity circle is drawn around every plastic waste container. A proximity circle is a circle with a certain geographical radius. In this research a radius of 100m is selected. No research has been done yet into the influence of a specific distance to a separation container. Therefore, 100m is an educated guess. All age groups can walk 100m with their separate plastic without too much effort. This to steps help to compare waste generation and separation on a geographical scale and give insights into a possible relation to separation of waste and infrastructure density. The analysis and visualization are executed in ArcGIS.

7.3 Correlation Analysis

The geospatial analysis enables a first visual comparison of possible relationships between waste generation or separation behaviour and demographic variables as income, housing type, education level or origin. If the visual inspection indicates a possible relationship, further numerical analysis of a potential relationship is conducted. The chosen method is **Spearman Rank Order** correlation analysis. The waste separation quantities are normalized by sorting them into five categories forming an ordinal scale, while all the demographic data is either on ratio or interval scale. With the correlation analysis hypothesis testing between the normalized separated waste quantities and different demographic variables is possible. As mentioned in chapter 4.3, so far, a clear or definite relation between income, housing type, education level or origin and separation behaviour could not be established. A reason could be the fact that the data used for those studies was based on surveys a small sample size. This research tries to increase knowledge by testing the following hypotheses:

H_0 : { Income, Housing Type, Education Level or Origin } does not have a significant influence on the separated plastic waste quantity per citizen.

H_{1-4} : { Income, Housing Type, Education Level or Origin } does have a significant influence on the separated plastic waste quantities per citizen.

Whether the H_0 hypothesis can be rejected or not is determined by the two-sided p-value with a threshold of 5% (0.05).

8. Results

The results coming forth from the analysis are presented in the following chapter 8. First, the different plastic and GFT flows determined by the material flow analysis are explored on different time and spatial levels. Second, the life cycle assessment of the current situation and exploration of possible future changes. Third, the relation between separation behaviour and the existing collection infrastructure in different neighbourhoods is explored. Finally, the exploration of different waste generation patterns in different neighbourhoods and their possible relation with different demographic variables. The conclusions drawn are the base the definition of different policy strategies for the municipality of Amsterdam.

8.1 Material Flows

The fine plastic and GFT household waste in separated and non-separated flows are analysed on different time and spatial levels. Since GFT waste is not collected separated yet and the non-separated part is derived from the residual fraction, only plastic is shown in separated fractions. Total material flows throughout the year are, however, calculated for plastic and GFT. On top of that material and energy recovery of the current supply chains is presented at the end.

8.1.1 Separated & Non-Separated Waste

The amount of non-separated and separated plastic waste throughout the year is shown in figure 23. Non-separated plastic waste generation in the whole of Amsterdam varies between 400 tons and 575 tons per month, and 6000 tons per year. This shows a clear difference of non-separated generated waste in different times of the year reflected by a mean of 493.9 tons standard deviation of 49.7 tons. The separated plastic fractions vary between 48 tons up to 250 tons per month, and 1700 tons per year. The variation of separated plastic waste per month is higher than the one of non-separated waste, with a mean of 142.3 tons and a standard deviation of 59 tons. Separation percentages fluctuates between 12%-43% in different month.

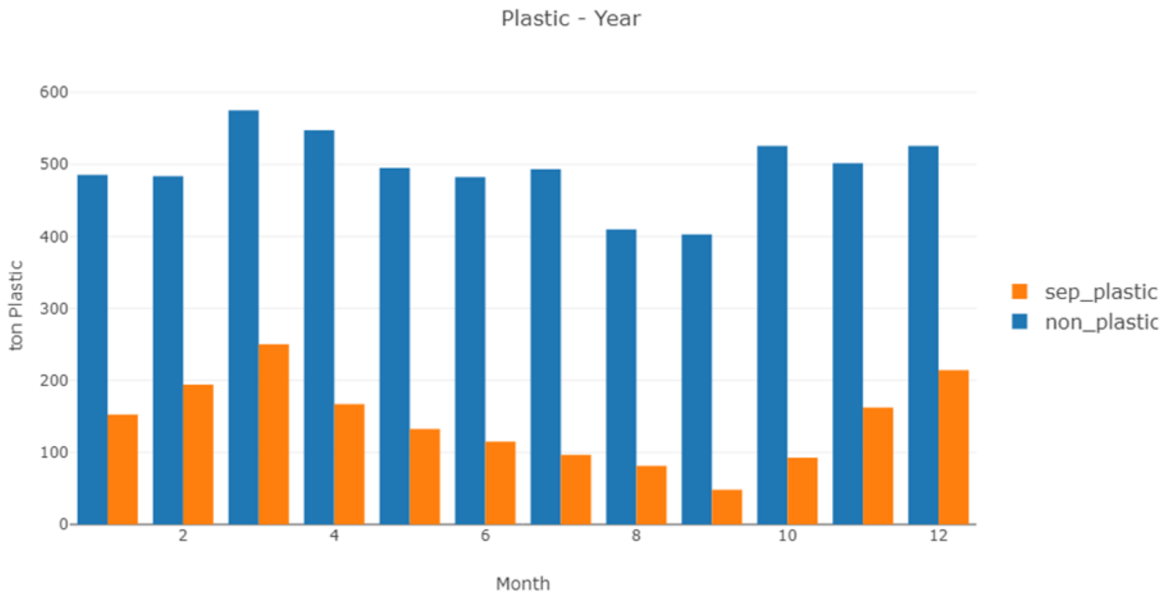


Figure 23 Separated and Non-Separated Plastic – One Year Cycle – City Level

Figure 24 shows the disregarded non-separated and separated plastic waste generation on a neighbourhood level. Non-separated plastic waste of 60 neighbourhoods with a mean of 98 tons per month, a standard deviation of 73,68 and a max of 257 tons. Separated plastic waste of 82 neighbourhoods with a mean of 20 tons, a standard deviation of 15,76 tons and max of 70 tons. The difference in number of neighbourhoods is due to the difference in collection methods and type of neighbourhoods as mentioned in chapter 6. A full list of all neighbourhoods and consideration reasoning can be found in appendix B.

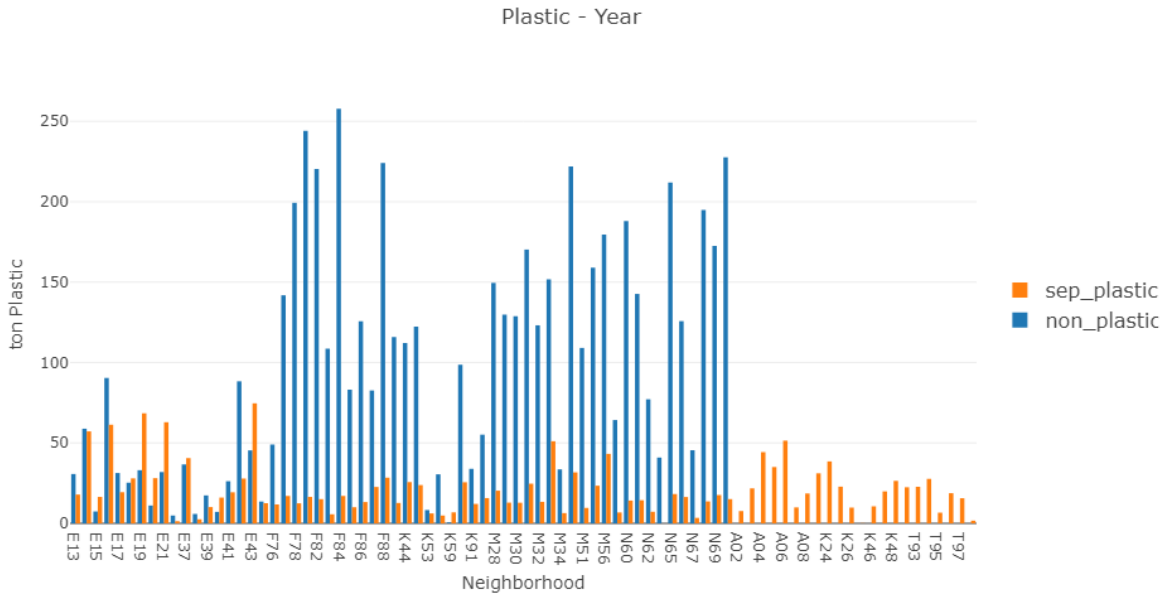


Figure 24 Separated and Non-Separated Plastic – One Year –Neighbourhood Level

The amount of non-separated and separated GFT waste throughout the year in the whole of Amsterdam is shown in figure 25. Non-separated GFT waste per month varies between 1.960 tons and 2798 tons per month and accumulates to a total of 28.854 tons per year.

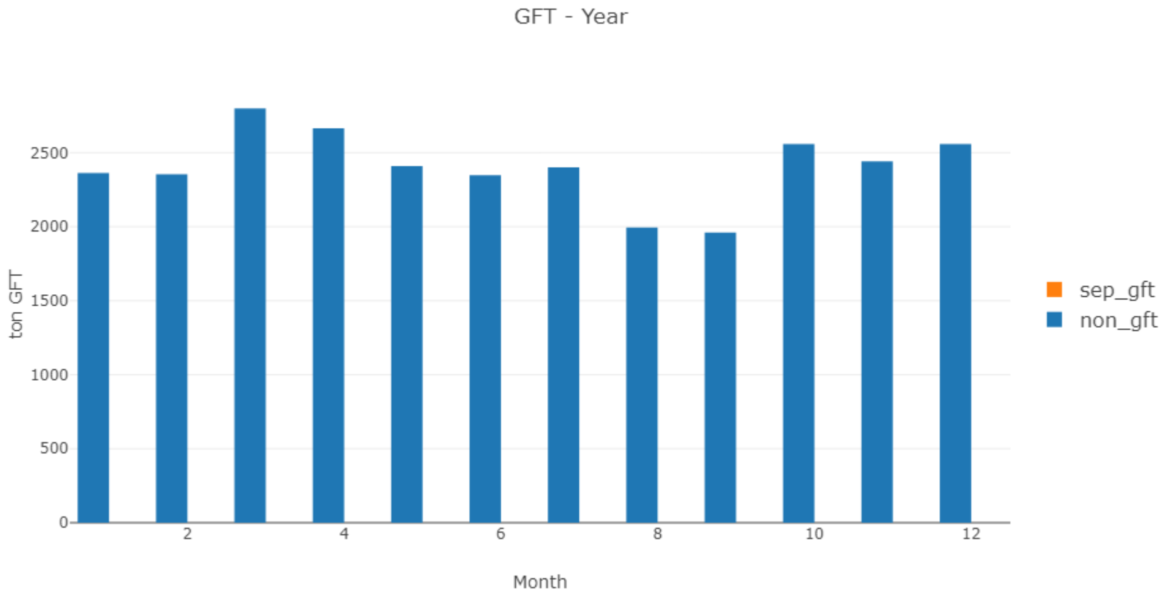


Figure 25 Separated and Non-Separated GFT – One Year Cycle – City Level

The non-separated waste generation on a neighbourhood level is shown in figure 25. In 60 neighbourhoods an average of 480 tons per year are generated with a standard deviation of 358 tons and a max of 1.254 tons.

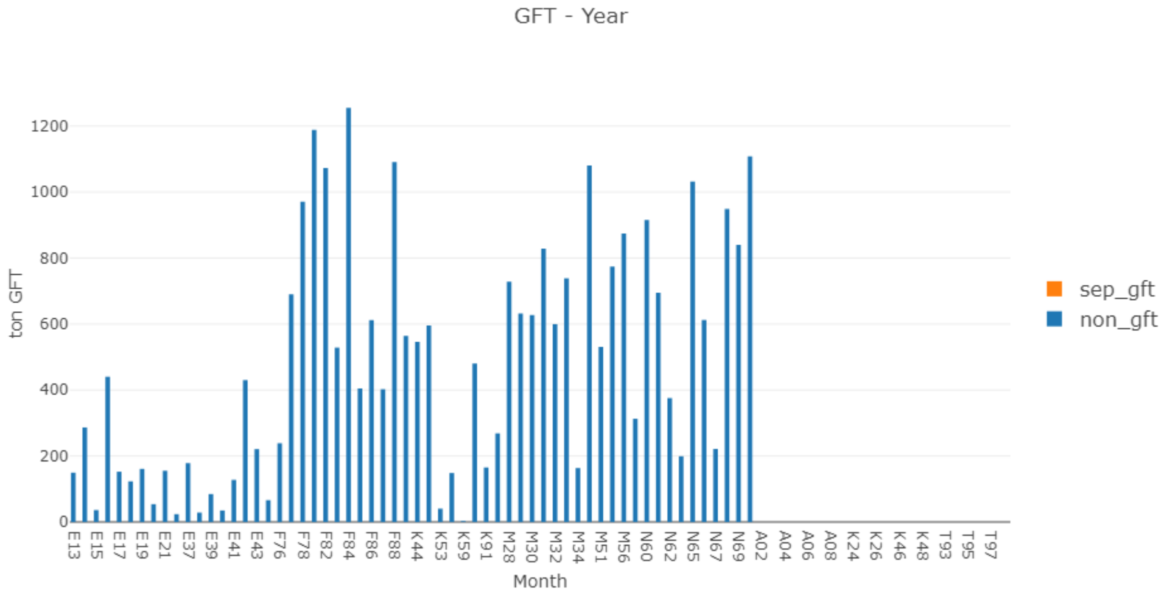


Figure 26 Separated and Non-Separated GFT – One Year – Neighbourhood Level

8.1.2 Material Loss

Plastic and GFT are currently either part of the residual or separated plastic supply chains. They are the input of these supply chains and are transformed by processes into energy or reusable material. The movement and transformation of plastic and GFT waste in the different supply chains elaborated next.

The Sankey diagram of the plastic waste in Amsterdam shown in figure 27 describes the flows between the different process steps and indicates their relative size. As mentioned in step 6.2.2 most of the plastic is discarded into the residual waste and transported as non-separated plastic to the incineration facility. A significantly smaller part is separated and transported to the second, mechanical, separation facility. The incineration produces mostly Co2 emissions emitted into the Atmosphere. The primer energy output of incineration, electricity and heat, are fed into power grid and a district heat system. During second separation, source separated plastic waste is divided into paper drink packaging and plastic, and different levels of quality. The mechanical separation of the waste, produces indirect Co2 emissions emitted to the atmosphere. The second separated plastic in different quality levels goes to the reproduction facility where it is reproduced into different raw material granulates to be used in production processes of different products. This facility also emits Co2 due to energy use due to operations.

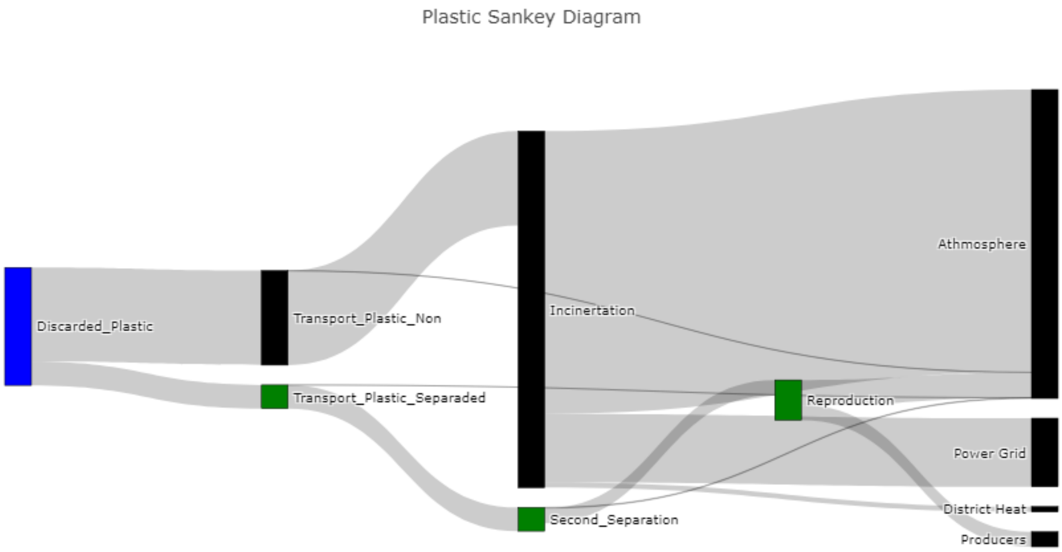


Figure 27 Sankey Diagram Plastic Current Situation

The specific amounts of energy recovered by incineration in the current situation and the plastic recovered are shown in figure 28. Incineration recovers 331 MwH of heat and 4.311 MwH of electricity from plastic waste. This is equivalent to the yearly electricity need of 1437 households according to MilieuCentraal (2019), which on average use 3.000 kwh of electricity a year. Heat is commonly generated with gas in Dutch households. MilieuCentraal (2019) estimated the yearly gas use of Dutch households to an average of 1.470m^2 equal to 15.508,5 kwh. 80% percent of their gas use are used for heating and 20% for cooking and hot water. The heat is generated by plastic waste incineration, therefore equals the heat use of 28 households per year.

The plastic reproduced from separated plastic waste is equal to 1082 metric tons. However, as mentioned inf chapter 6.2.2 the complexity of the plastic supply chains is related to the issues of material composition. Different types and quality levels of plastic exist. According to Partners for Innovation & Rebel (2018) 9% of separated plastic is PET(DKR 328-1), 9% is HDPE(DKR 329), 11% is PP(DKR 310), 24% is Foil(DKR310) and 46% is Mix(DKR 350). The plastic reproduction supply chain of Amsterdam therefore produces 97 tons PET and HDPE, 119 tons P, 259 tons of foil and 497 tons of Mix per year.

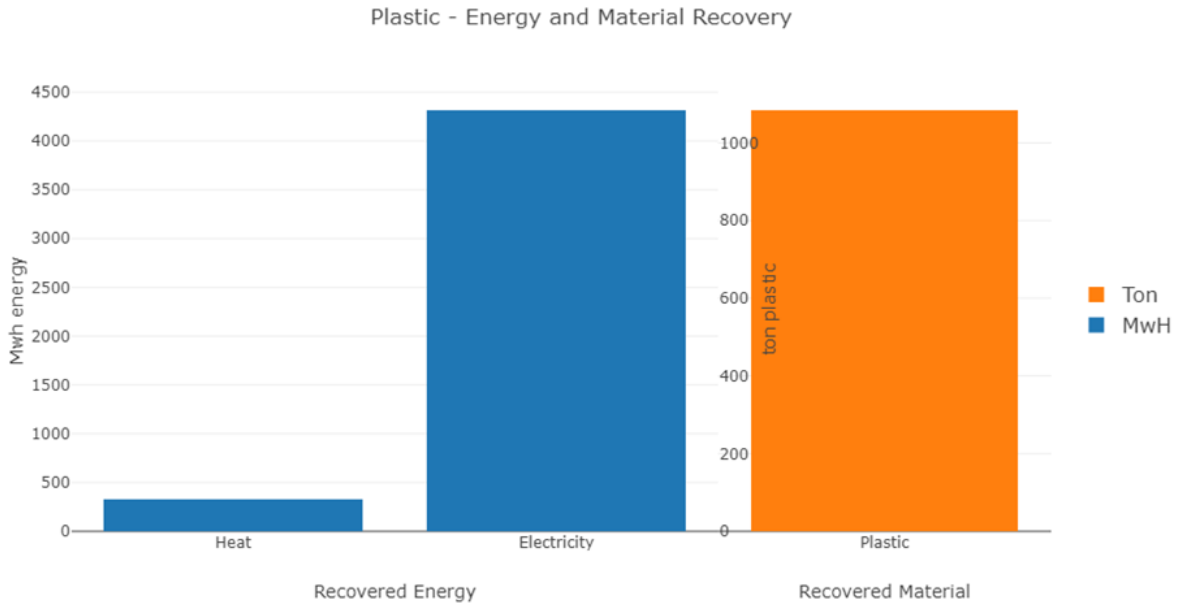


Figure 28 Material and Energy Recovery Plastic Current Situation

The GFT waste flows through the different waste supply chain steps of Amsterdam is visualized in the Sankey Diagram shown in figure 29. All the discarded GFT waste is still officially part of the residual waste fraction. The GFT takes the same steps as the non-separated plastic waste.

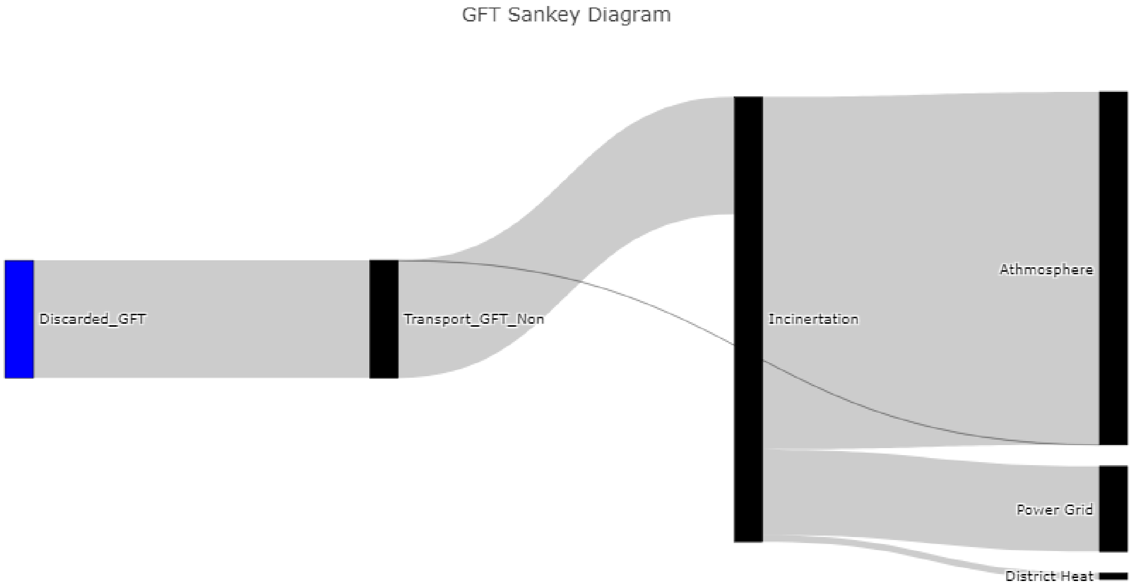


Figure 29 Sankey Diagram GFT Current Situation

The energy recovered from GFT waste with incineration is shown in figure 30. The heat and electricity revered are equal to 1.614 Mwh respectively 20988 Mwh of energy. According to MilieuCentraal (2019) average energy consumption numbers this recovered energy is enough for heat need of 135 households and electricity need of 7.000 households.

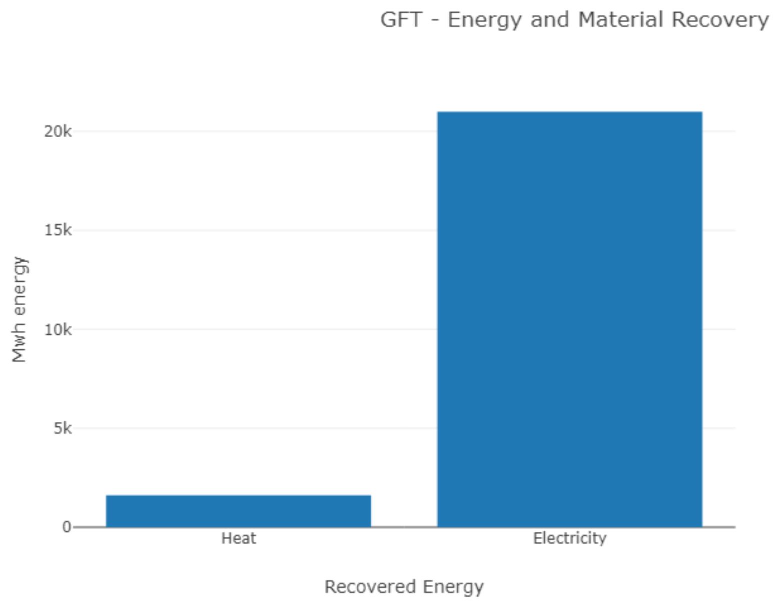


Figure 30 Energy and Material Recovery GFT Current Situation

8.2 Life Cycle Assessment

The results of the LCA, defined in chapter 6, are described in this chapter 8.2. First, the current direct and indirect emissions of the different supply chain steps are described. Second, changes to the supply chain structure or material flows are described in a scenario analysis.

8.2.1 CO2 Assessment Current Supply Chain

The Sankey diagram in chapter 8.1 of the different supply chains already indicated the amount of CO_2 emissions emitted by the different supply chain steps. In this chapter 8.2 the supply chain steps specific emissions are described and compared specifically.

The CO_2 emissions of the incineration and recycling supply chain of plastic waste are shown in figure 31. The incineration supply chain consisting of transport and incineration produces 14 tons CO_2 and 17.780 tons CO_2 respectively. The recycling supply chain consisting of transport, second separation and incineration. Their respective emissions are 4 tons CO_2 for transportation, 48 tons CO_2 for mechanical separation and -1825 tons of CO_2 for reproduction. The reproduction emissions are negative, because of prevented use of virgin material for new products. The emissions caused by transportation are not significant in comparison to the emissions of reproduction and incineration.

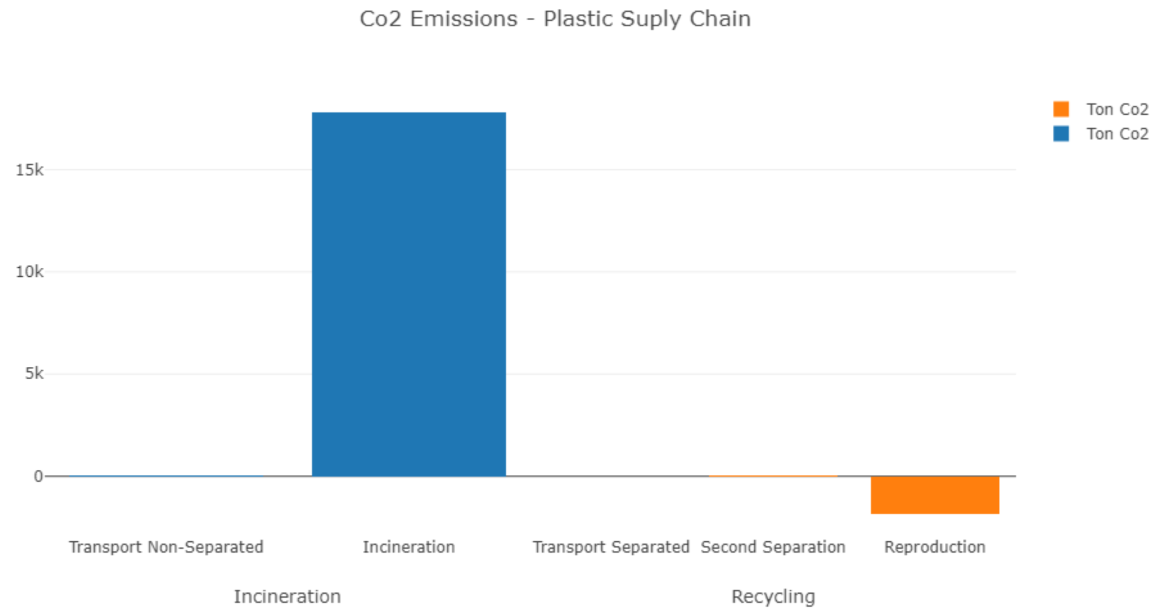


Figure 31 Plastic CO_2 Emission Current Situation

The CO_2 emissions of the GFT incineration supply chain are shown in figure 32. The CO_2 emissions of transportations are 67 tons and of the incineration 86.563 tons.

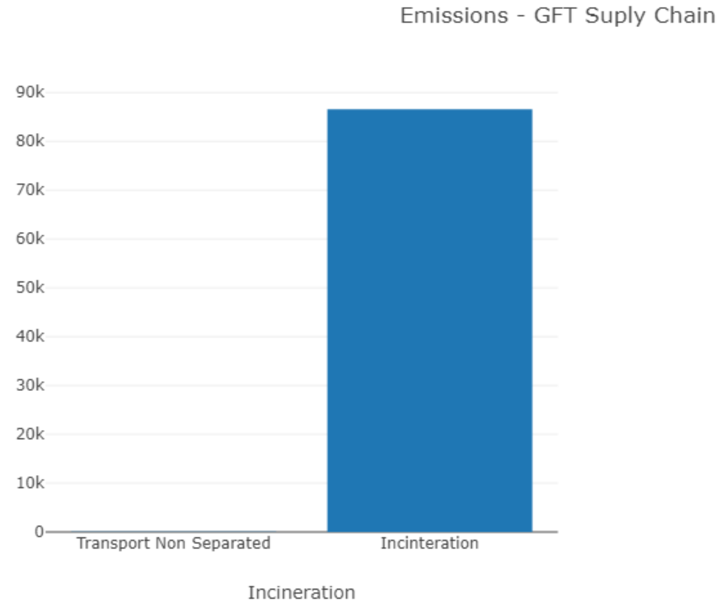


Figure 32 GFT CO_2 Emission Current Situation

8.2.2 Comparison different supply chain processes

The two scenarios defined in chapter 6.6 are the improvement of separation in the plastic supply chain and the inclusion of separated collection of GFT and fermentation process.

The potential improvement of the plastic waste supply chain is shown in figure 33. Both Scenario's, Incineration and Recycling, consider all plastic waste being treated in either one of the supply chains. The emissions shown are therefore the total emissions of either option. Even though, this might not be realistic and both supply chains have to coexist, it gives an indication for priorities. Similar to the current situation analysis, transportation emissions are not significant in comparison to the emissions of other processes in the supply chain. Both scenarios have transportation emissions of 16,5 tons of CO_2 per year for transporting all plastic waste of the Amsterdam region. The incineration of all this plastic produces 21.513 tons of CO_2. This leads to a total of 21.529.5 tons of CO_2 emissions for scenario incineration. In the recycling scenario the second separation generates 200 tons of CO_2 emissions per year for mechanical separation if all plastic is source separated. The reproduction process generates -10.756 tons of CO_2 emissions due to the prevention of products of virgin material. This accumulates to a total of -10.539,5 tons of CO_2 emissions for Scenario Recycling.

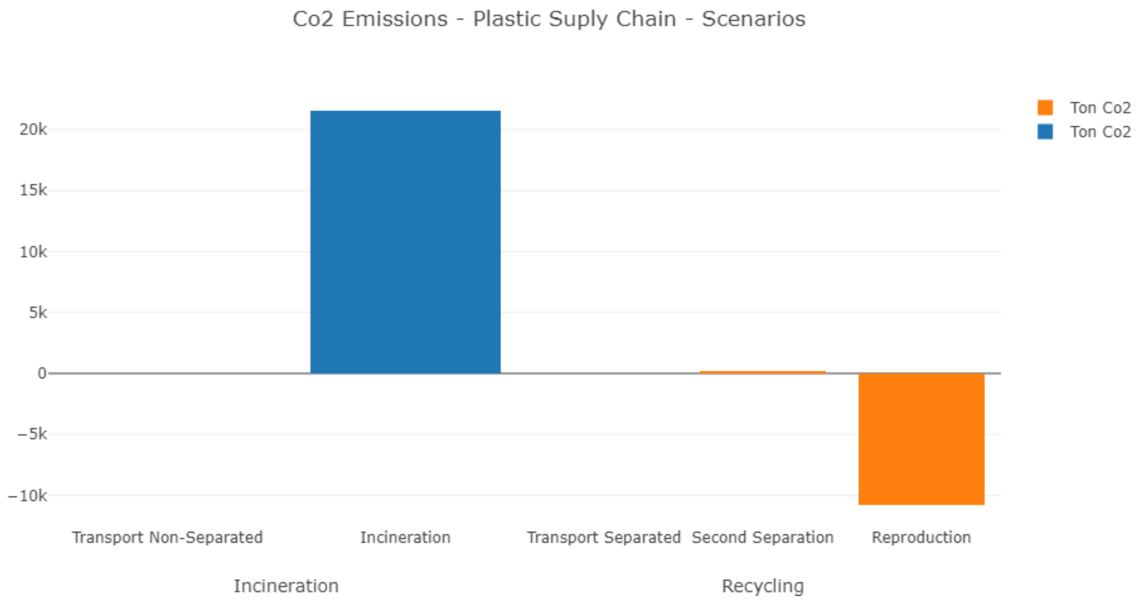


Figure 33 Plastic CO_2 Emissions Scenario's

The potential improvement of the GFT supply chain is shown in figure 32. It describes a possible future situation in which all GFT waste is either incinerated or fermented in a dry fermentation facility. Similar to all the other scenarios are the transportation emissions rather low. For both scenarios, incineration and fermentation, are the transport emissions 68 tons of CO_2 per year. The Incineration of all GFT waste emits 86.563 tons CO_2 per year. In comparison, fermentation of the all GFT waste generates 3.289 tons CO_2, which is significantly lower than incineration. In total the incineration and fermentation scenarios generate 86.631 and 3.358 tons of CO_2 respectively.

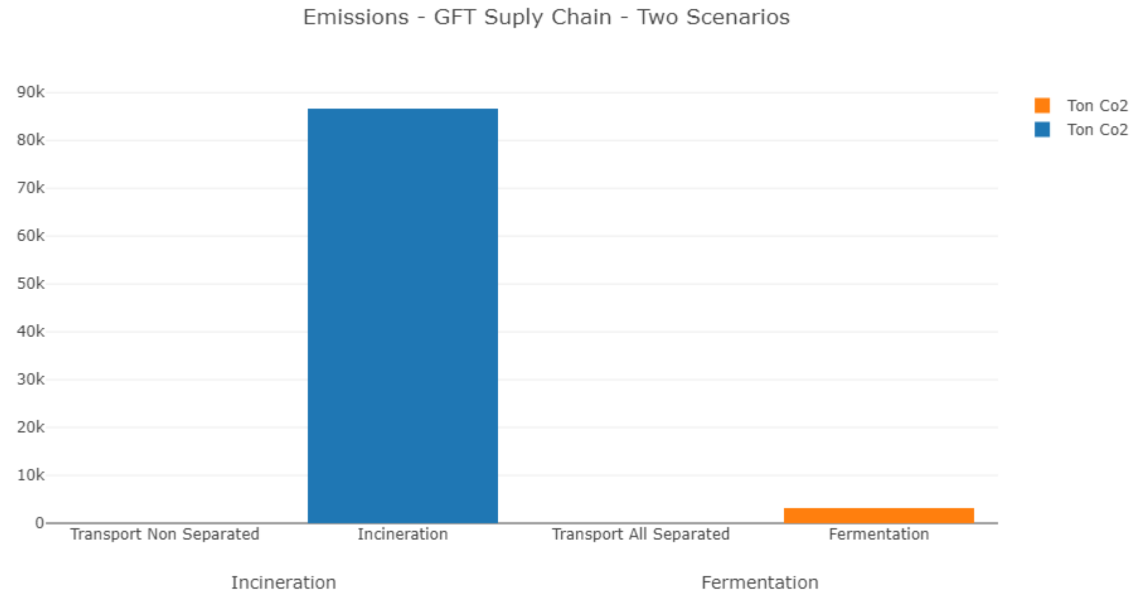


Figure 34 GFT CO_2 Emissions Scenario's

The material and energy recovery results from the two GFT scenarios are shown in figure 35. Incineration and fermentation of GFT waste enables the recovery of heat and electricity. Also, the heat recovery of fermentation is higher than of incineration, the total energy recovery of fermentation is lower due to the significantly higher amount of electricity recovered by incineration.

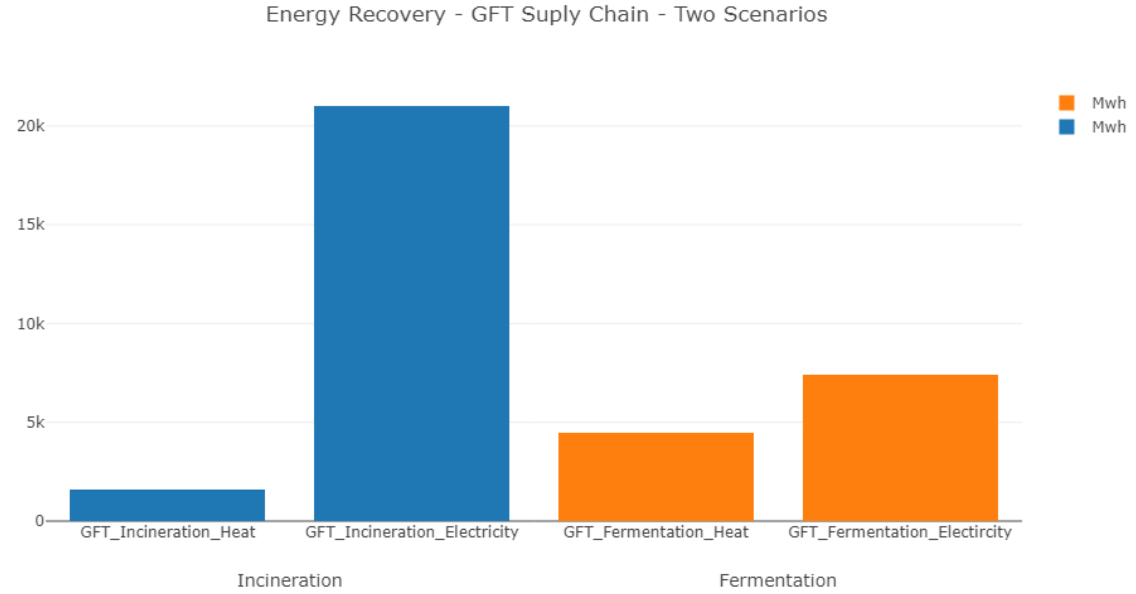


Figure 35 Energy and Material Recovery GFT Scenario's

8.3 Statistical Analysis

The results of the statistical analysis are described and explained in this chapter. First, the separation behaviour time series and focus areas analysis results are discussed. Second, are the overall waste generation behaviour time series and focus areas.

8.3.1 Time Series Separated Waste

The amount of separated waste within the different suburbs and their neighbourhoods per month in the cycle of one year are shown in figure 36-42. The amount of waste separated per month and neighbourhood are not normalized, since it is about their separation patterns rather than the amount of separated waste. Although all of the suburbs and their neighbourhoods show fluctuating behaviour, no suburbs or show an identical mean pattern.

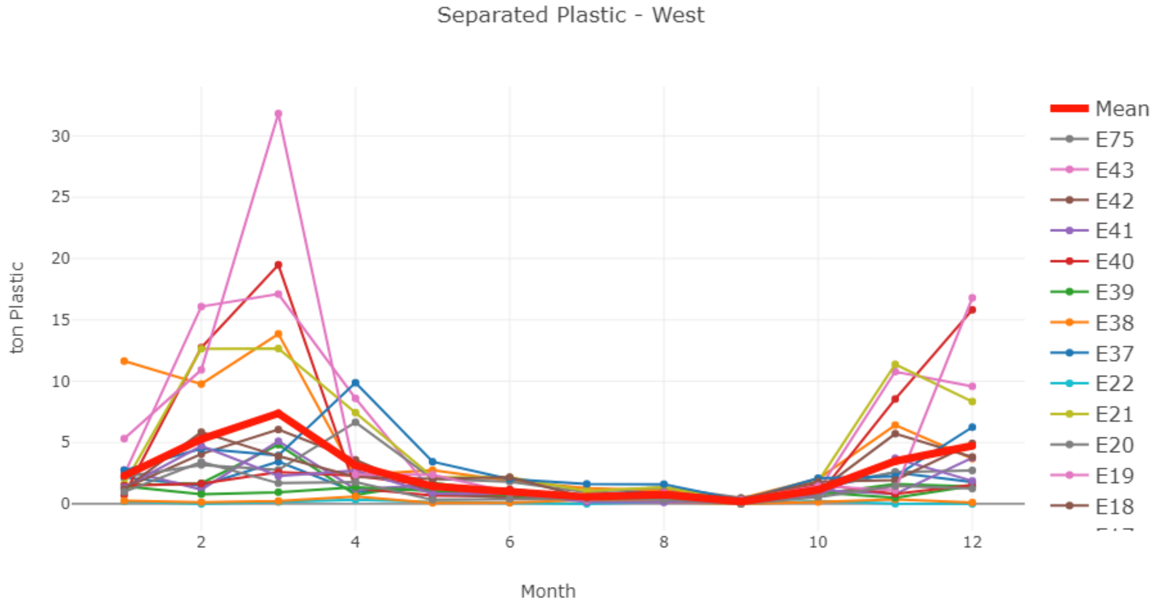


Figure 36 Time Series Separated Plastic Neighbourhoods in Suburb West

The time series of the neighbourhoods in suburb **West** are shown in figure 36. The mean shows an overall peak in month three, lows from month six to nine and a high towards the end of the year. Some neighbourhoods show significantly different behaviour than others. **E43**, **E19, E21**, and **E14** show an extreme high in month three. Their divergence from the mean in comparison to other neighbourhoods is reflected by the standard deviation (std). The mean with a std of 2,23 in comparison to E43, E19, E21, and E14 with a std of (9,5), (6,4), (4,89) and (4,56) respectively. Complete descriptive tables are listed in Appendix C.

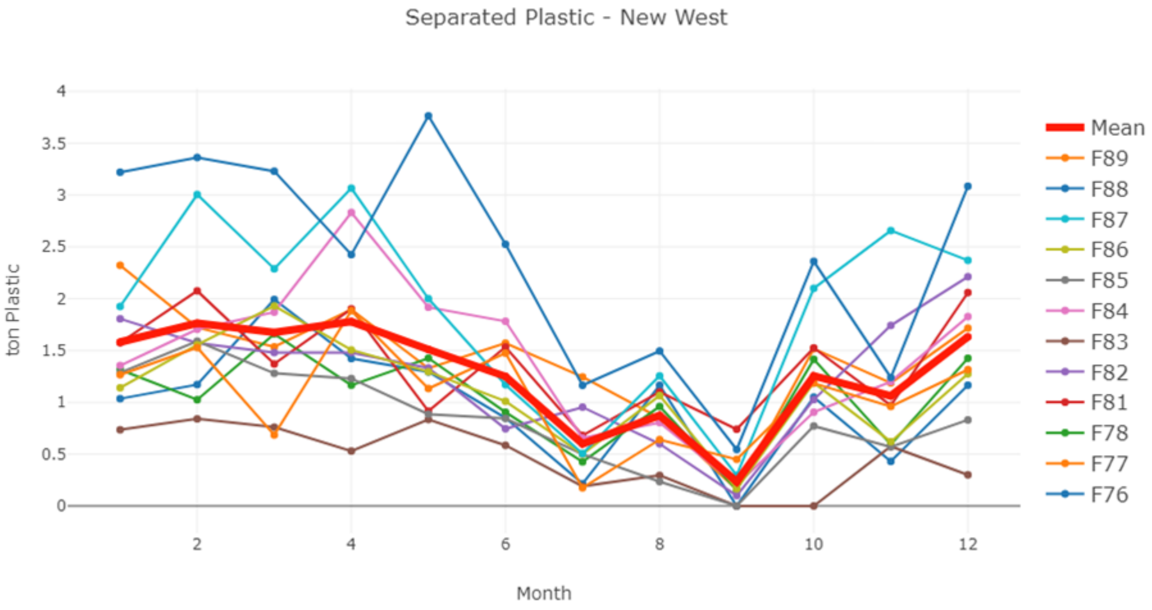


Figure 37 Time Series Separated Plastic Neighbourhoods in Suburb New West

The times series of the neighbourhoods in **New-West** are shown in figure 37. The mean is rather stationary in the beginning of the year moving towards a low in month nine. Toward the end of the year it is moving towards the stable level of the start of the year. Despite the mean being rather constant in the beginning of the year, the individual neighbourhoods show fluctuating pattern. Nonetheless, are the std of the most neighbourhoods close to the mean std of 0,9. Only the std of **F88** and **F87** are significantly bigger with 1,03 and 0,9 respectively.

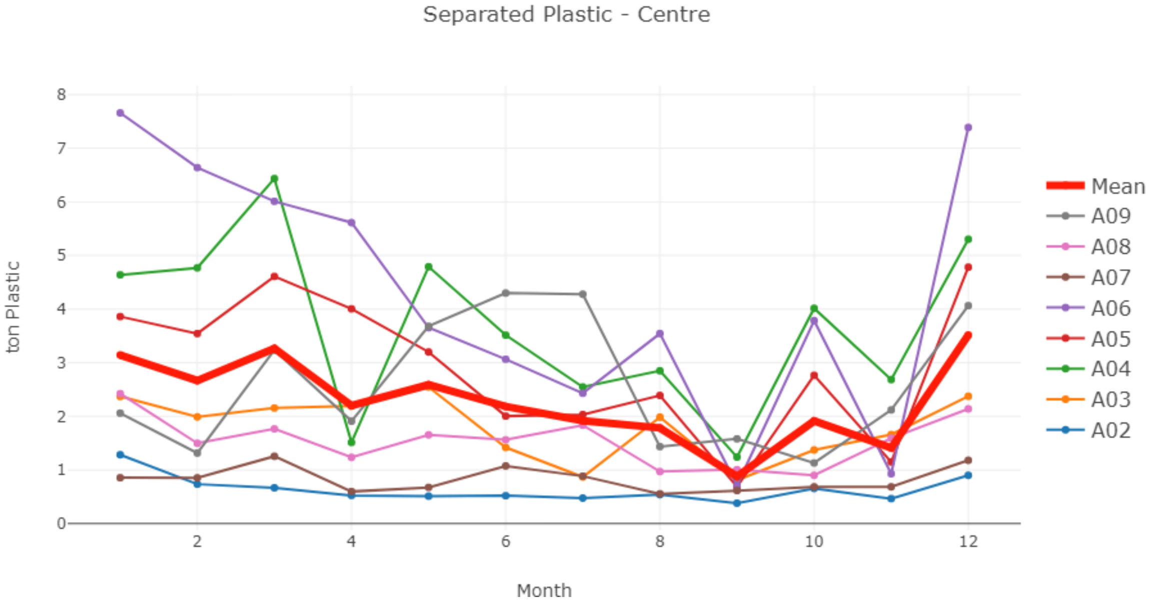


Figure 38 Time Series Separated Plastic Neighbourhoods in Suburb Centre

The time series of the neighbourhoods in the **Centre** are shown in figure 38. The mean shows a continues decrease from the beginning of the year until a low in month nine followed by a strong increase towards the end of the year. Besides some exceptions most of the neighbourhoods show less fluctuant behaviour than the ones in the other suburbs. With a std of 1,57 and 2,36, only **A04** and **A06** diverge significantly from the mean std of 0,78.

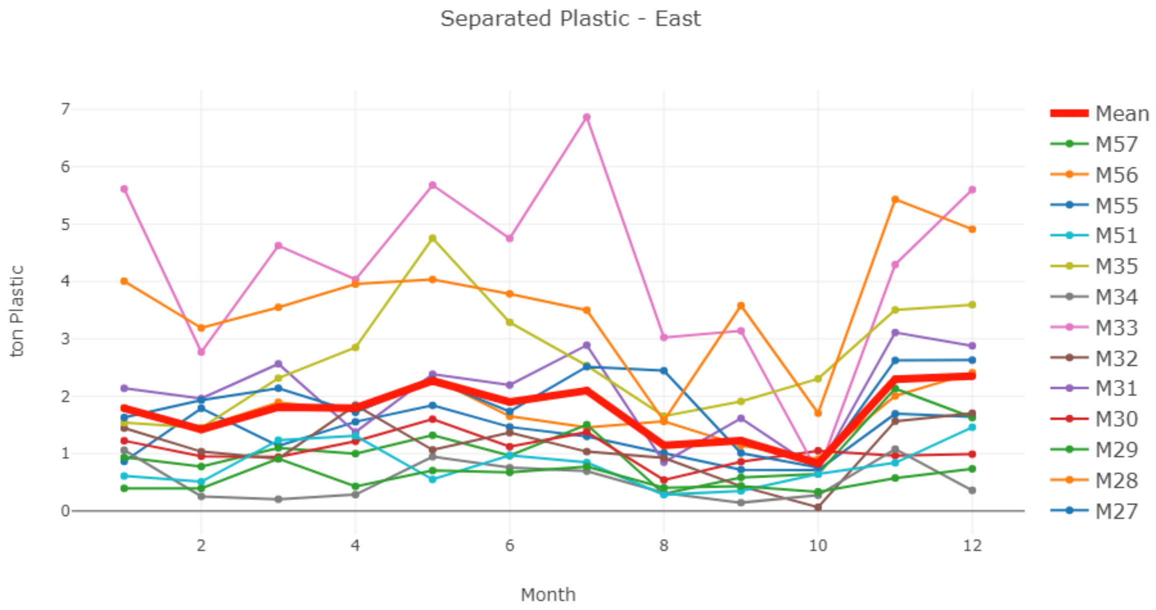


Figure 39 Time Series Separated Plastic Neighbourhoods in Suburb East

The time series of the neighbourhoods in **East** are shown in figure 39. The mean shows a rather stationary behaviour except the rather low level between month eight and nine. Most of the neighbourhoods show a similar pattern as the mean. Only **M33**, **M35**, and **M56** show significantly different pattern. Their std of (1,67), (0,99) and (1,10) respectively, diverges significantly from the mean std of 0,49.

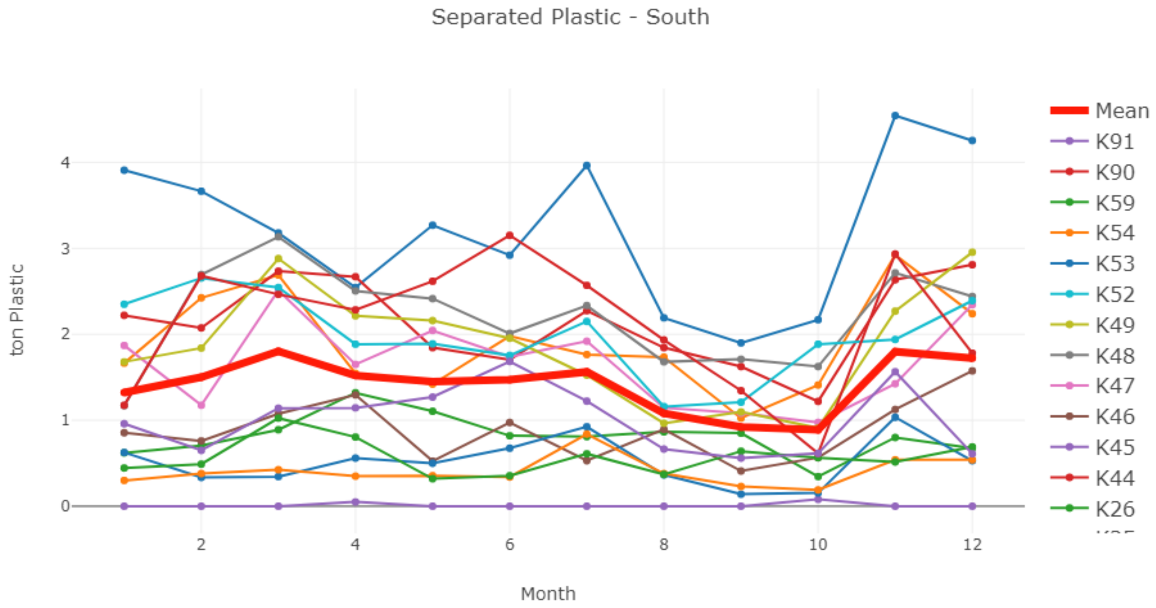


Figure 40 Time Series Separated Plastic Neighbourhoods in Suburb South

The time series of the neighbourhoods in **South** are shown in figure 40. The mean shows a quite stationary behaviour with small fluctuations above and under de mean. The neighbourhoods **K24** and **K90** with a std of 0,87 and 0,77 respectively, deviate significantly form the mean std of 0,31. In comparison to the other suburbs the difference is, however, rather small.

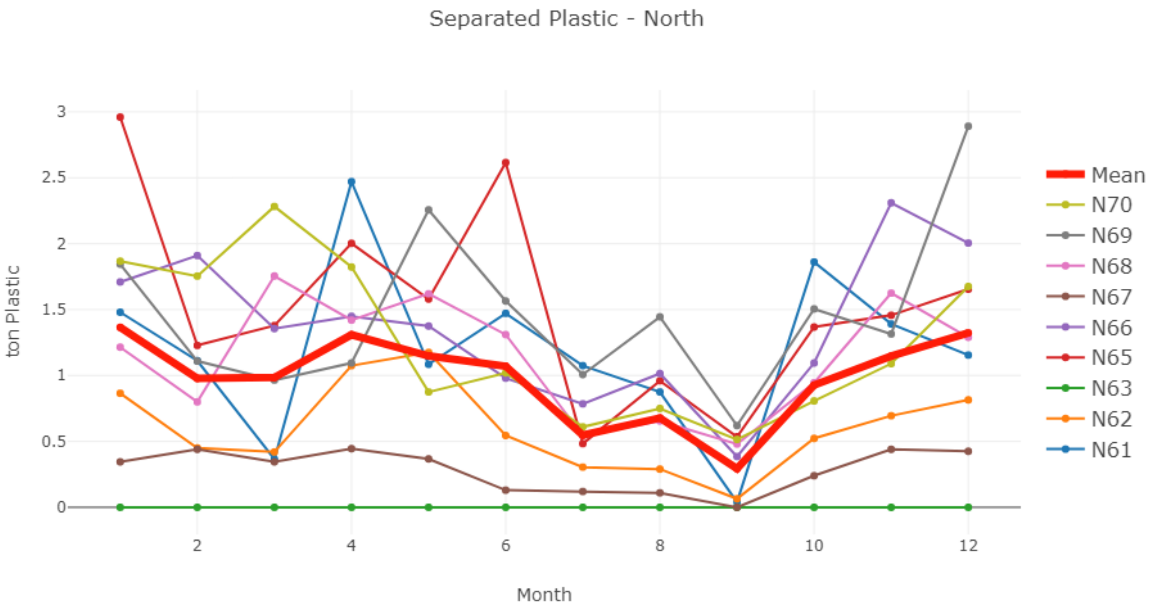


Figure 41 Time Series Separated Plastic Neighbourhoods in Suburb North

The time series of the neighbourhoods in **North** are shown in figure 41. The behavioural patterns of most of the neighbourhoods is reflected by mean. Only **N62**, **N67** and **N68** with a std of (0,33), (0,15), 0,44 are not significantly deviating from the mean std of 0,33. All the other neighbourhoods fluctuate a significantly more.

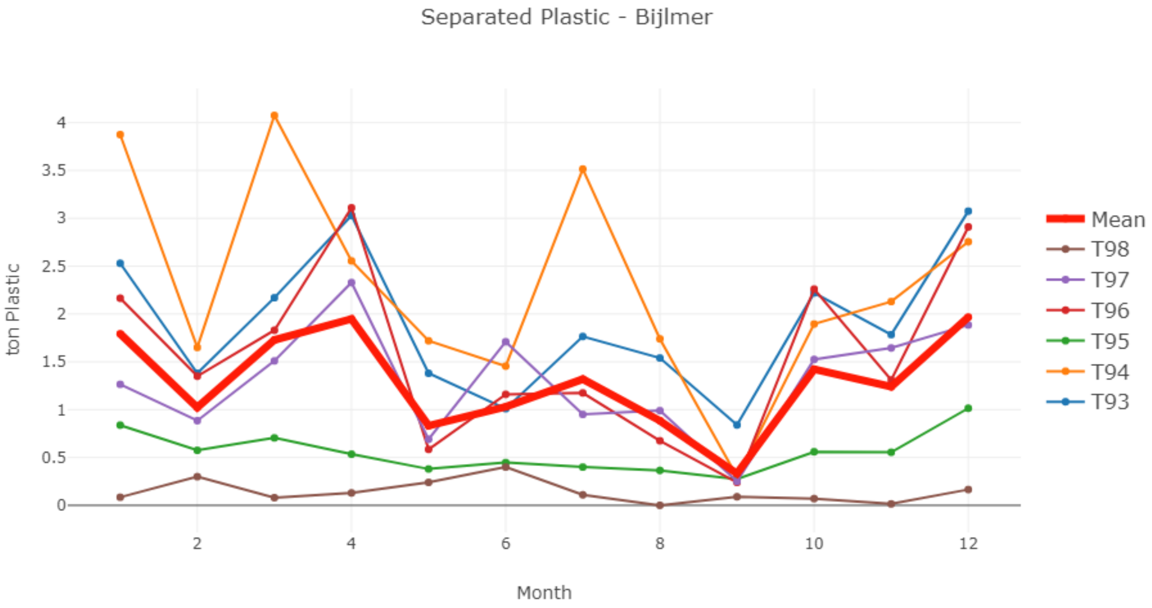


Figure 42 Time Series Separated Plastic Neighbourhoods in Suburb Bijlmer

The time series of the neighbourhoods in **Bijlmer** are shown in figure 42. The mean shows a non-stationary pattern with a low in month two, a high in month four, a low in month five, a low in month nine and a high toward the end of the year. The neighbourhood **T95** has significantly higher std of 1,10 than the mean with a std of 0,5. However, the pattern seems to be similar to the overall pattern with more extreme fluctuation.

8.3.2 Separated Plastic Waste

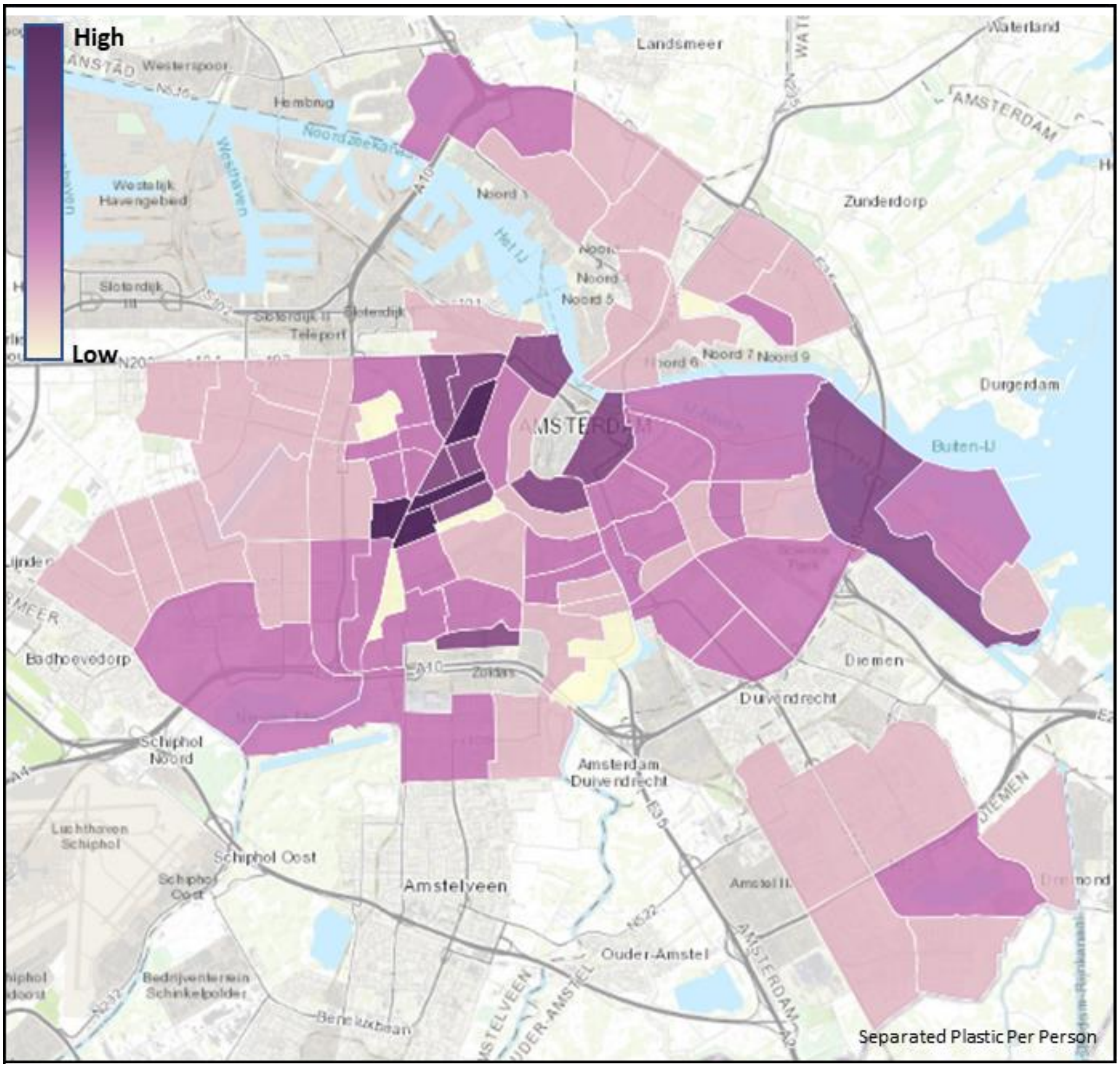


Figure 43 Geographic overview normalized separated plastic

The distribution of separated plastic is shown of plastic is shown in figure 44. The data presented shows the amount of plastic waste separated per person per year. The total amount of separated plastic waste per person in one year is calculated dividing the total amount separated plastic waste per year by the total number of citizens for each neighbourhood. The distribution is a right skewed or positive skew distribution. This is due to its longer tail on the positive site indicating that a higher number of neighbourhoods are separating less waste in comparison to a rather small group of high separating neighbourhoods.

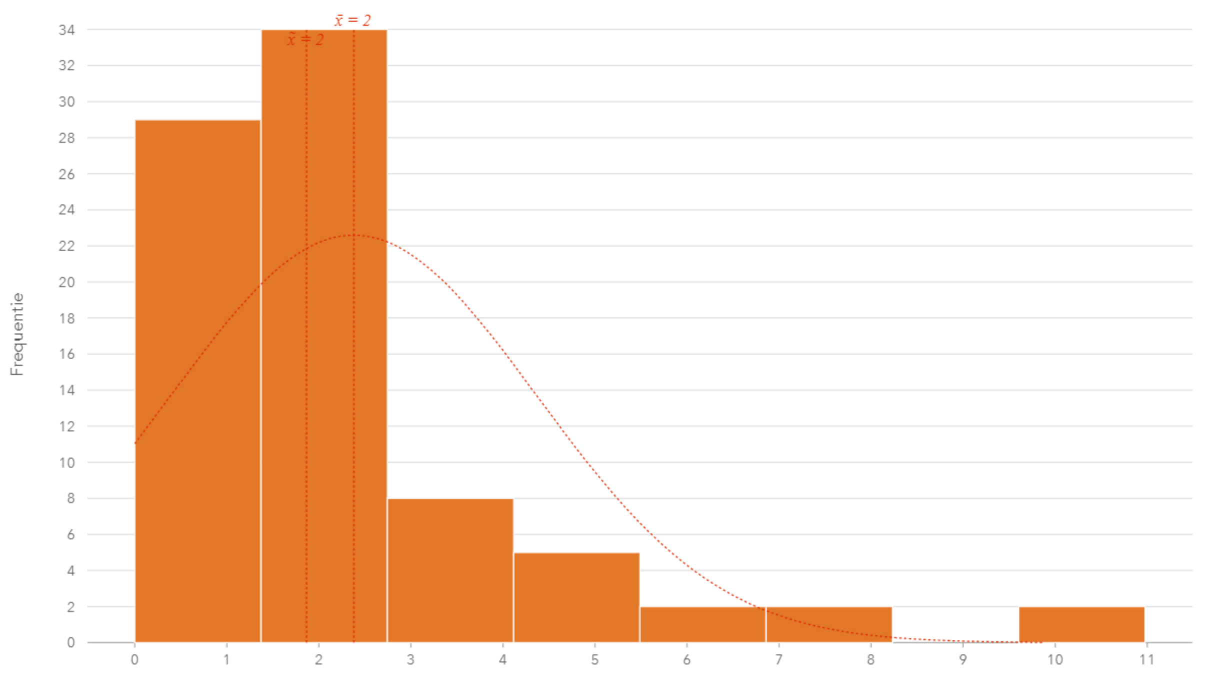


Figure 44 Distribution Normalized Separated Plastic

A geographical overview of the separated plastic waste in the different neighbourhoods is shown in figure 43. The colours indicate the amount of waste separated with dark purple indicating high separation and light purple indicating low amount of separated plastic waste per person. A clear hotspot of relative high separation per person can be identified in the suburb **West**. The **South** and **East** show medium to low separation amounts. The **North**, **New-West** and **Bijlmer** show low to medium separation amounts. For further analysis neighbourhoods from high and low scoring suburbs are selected to investigate their level of infrastructure and demographic characteristics. The high scoring neighbourhoods are only selected based on their high level of separated waste. Neighbourhoods from low scoring suburbs are selected based on their level of infrastructure and level of separation. It has to be stated that "high" and "low" in the context of this research are related only to the city of Amsterdam. As found in the material flow analysis is the current state of separation far from the goals set from different governmental organizations. Therefore, the high might not be high in comparison to those regulations, however, it is high in comparison to the rest of the city of Amsterdam.

8.3.3 High Separation Neighbourhoods

The neighbourhoods with the highest amount of separated plastic per person in one year are all located in the suburb **West**. To better understand the possible reasons for their relatively high amount of separated waste their level of infrastructure is described as well as demographic characteristics of their population.

8.3.3.1 West

The four neighbourhoods with the relative highest amount of separated plastic per person are shown in figure 45. Table 7 lists different demographic characteristics of the four neighbourhoods. A list with the full name of the neighbourhoods can be found in Appendix B. Overall West can be characterized as a neighbourhood with relatively high educated, high income and more western than non-western citizens in relation to the city mean.

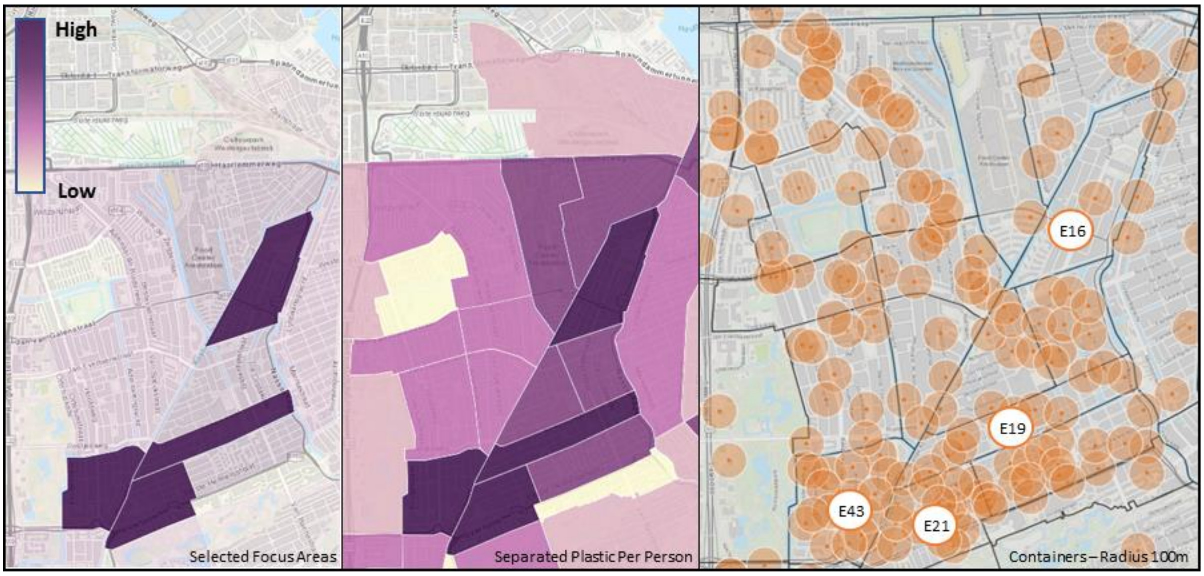
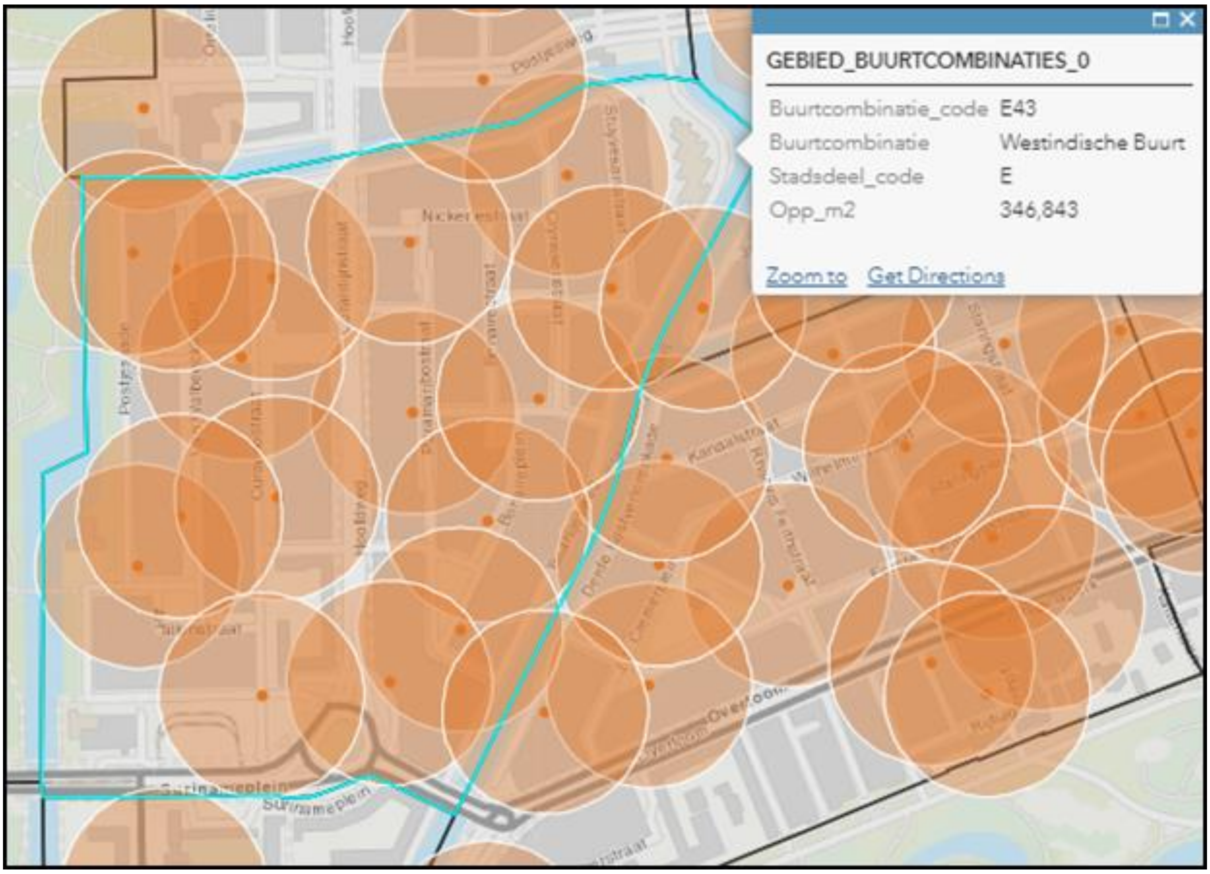


Figure 45 Geographical Overview Focus Areas West

Neighbourhoods	**Low Education**	**Medium Education**	**High Education**	**Average Income Household**	**Western**	**Non-Western**	**Number Single House**	**Number Flats**	**Separated Plastic Per**
E16	16%	27%	57%	€ 34.200	52%	48%	0	1198	7,30
E19	21%	29%	50%	€ 29.800	41%	59%	75	3660	9,64
E21	8%	24%	68%	€ 40.600	65%	35%	42	4188	8,17
E43	13%	27%	60%	€ 36.500	53%	47%	163	5285	10,98
City Mean	*23%*	32%	44%	€ 38.004	40%	60%	514	4047	2,37

Table 7 Demographic Characteristics High Separation Neighbourhoods

8.3.3.1.1 Westindische Buurt – E43



GEBIED_BUURTCOMBINATIES_0

Buurtcombinatie_code	E43
Buurtcombinatie	Westindische Buurt
Stadsdeel_code	E
Opp_m2	346,843

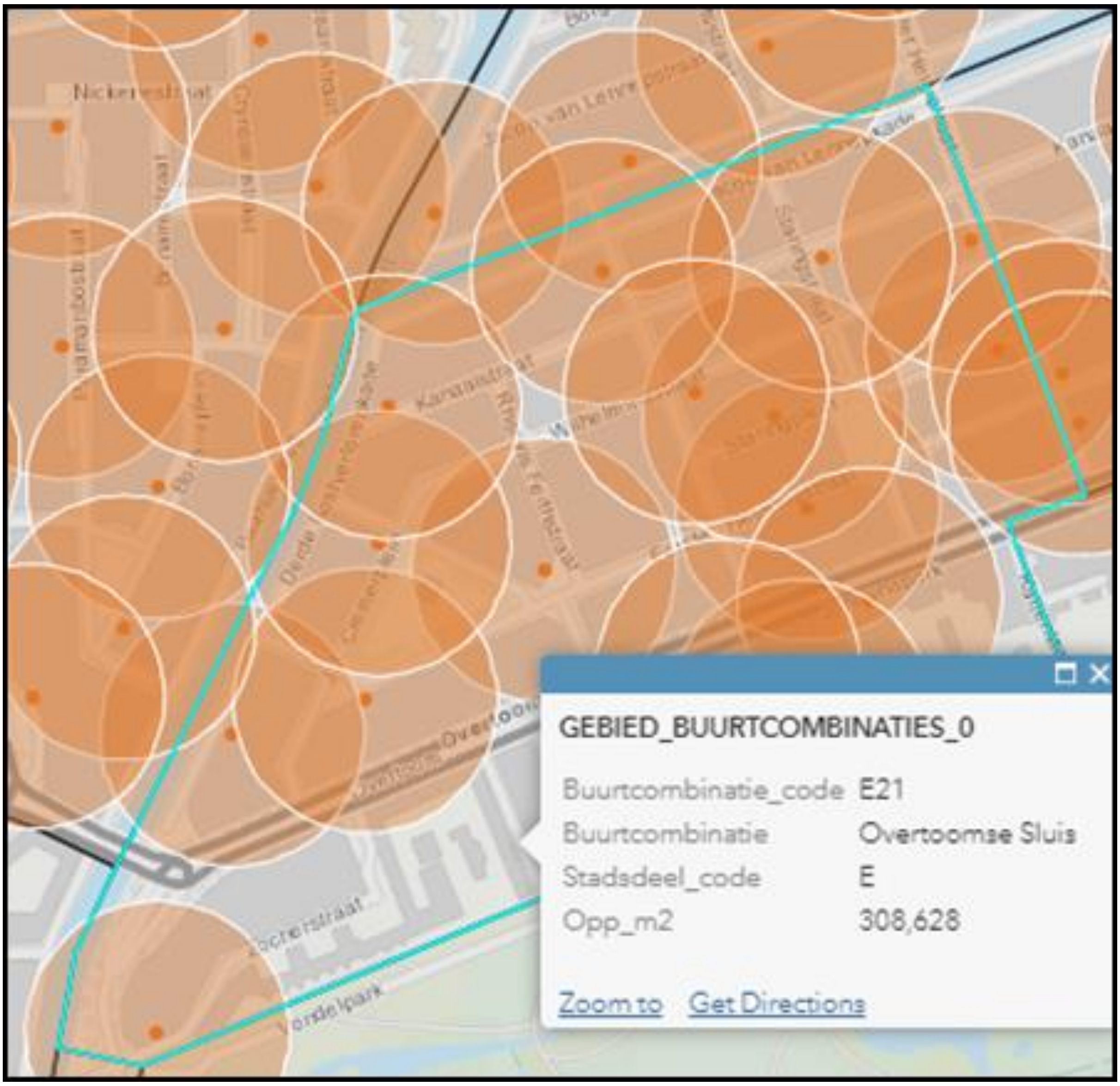
Figure 46 Infrastructure Density Westindische Buurt

The neighbourhood „Westindische Buurt – E43" is located in the south west of the suburb West in the city of Amsterdam. It has a population of 6.800 citizens and is 346.843 m^2 in size. Yearly 10,98 kg of plastic per citizens are separated, which is the highest amount per person in the hole of Amsterdam. In figure 46 the size and shape as well as its plastic fraction containers infrastructure are shown. The separation infrastructure us really dense, since nearly the whole neighbourhood is covered with the orange circles indicating the area around a separation container with a radius of 100m. In some areas the circles even overlap indicating multiple plastic containers within walking distance of 100m. This entails that no citizen in the E43 neighbourhood has to walk further than 100m to the closest plastic containers. On average it might even be closer and some do even have multiple options.

The demographic characteristics shown in table 7 are partly diverging and overlapping with the other high scoring neighbourhoods and the overall city mean. The percentages of education level, low, medium and high, are about the same in comparison to the other high scoring neighbourhoods. They have a roughly 60% high educated, 25% medium educated and 15% low educated citizens. In comparison to the city mean the high educated percentage is higher and the medium and low educated percentages are lower than the city average. The average income per household of 36.500€ is below the city mean, but significantly above the lowest of the high scoring neighbourhoods. The percentage of western and non-western in the population of E43 is different from the city average having more western originating people living there. In comparison to the other high scoring neighbourhoods it shows similarity with a slightly higher percentage of western than non-western citizens. Most of the households are living in flats rather than single household houses as in all of the high scoring neighbourhoods. The number of single houses is also under the city mean, but the proportion of single houses to flats is similar. Overall the neighbourhood appears to be a rather typical neighbourhood within the suburb West, however has some significant differences with the city mean.

8.3.3.1.2 Overtoomse Sluis – E21

The neighbourhood "Overtoomse Sluis – E21" is located in the south west of the suburb West in the city of Amsterdam. Its population amounts to 7.700 citizens and its geographical size is 308.628 m^2. Yearly 8,17 kg of plastic per person are separated in the neighbourhood E21. In comparison to the other high scoring neighbourhoods it is considered average. The shape and size as well as the container infrastructure of E21 is shown in figure 47. Similar to E43 it has an excellent container infrastructure. In the whole neighbourhood at least one plastic separation container is available within a maximum of 100m walking distance.



GEBIED_BUURTCOMBINATIES_0

Buurtcombinatie_code E21
Buurtcombinatie Overtoomse Sluis
Stadsdeel_code E
Opp_m2 308,628

Figure 47 Infrastructure Density Overtoomse Sluis

The demographic characteristics of E21 are shown in table 7. Important to mention is the relative high amount of high educated citizens, the high average income and the high percentage of citizens with western roots. This is in comparison with the other high scoring neighbourhoods and the city mean, also the difference compared to the city mean is significantly bigger.

8.3.3.1.3 Van Lennepbuurt – E19

The neighbourhood “Van Lennepbuurt – E19” is located in the centre of the suburb West in Amsterdam. Its population amounts to 7.100 citizens and its geographical size is 287.631 m^2. Yearly 9,64 kg of plastic waste per person are separated in E19, which is about average in in the high scoring neighbourhoods. In figure 48 the shape and size as well as the plastic container infrastructure of E19 is shown. The level of infrastructure in E19 is less dens than the infrastructure of E43 and E21. Most of the neighbourhood is still covered by the orange circles, however some areas are not covered and might have to walk around two hundred meters to the closest container. This is still not very far, but significantly lower than in the other two neighbourhoods.

The demographic characteristics of E19 are listed in table 7. In contrast to E21 the education level, average income and percentage western citizens are rather low for the suburb. Education level and western origin percentage are close to the city mean. The average household income is low in comparison to city mean as well as suburb specific.


GEBIED_BUURTCOMBINATIES_0

Buurtcombinatie_code	E19
Buurtcombinatie	Van Lennepbuurt
Stadsdeel_code	E
Opp_m2	287,631

Figure 48 Infrastructure Density Van Lennepbuurt

8.3.3.1.4 Frederik Hendrikbuurt - E16

GEBIED_BUURTCOMBINATIES_0

Buurtcombinatie_code E16

Buurtcombinatie Frederik Hendrikbuurt

Stadsdeel_code E

Opp_m2 421,207

Figure 49 Infrastructure Density Frederik Hendrikbuurt

The neighbourhood „Frederik Hendrikbuurt – E16" is located eastern centre of the suburb West within the municipality of Amsterdam. Its population amounts to 8.400 citizens and its geographical size is 421.207 m^2. The size and shape as well as the plastic container infrastructure is shown in figure 49. Yearly 7,3 kg of plastic waste per person are separated in E16. Therefore, it comes with a surprise that the infrastructure is of a low density. Only one container is located in the centre of the neighbourhood. Most of the citizens in E16 have to walk further than at least 200 m to be able to separate their plastic waste.

The demographic characteristics of E16 are listed in table 7. The education level and western percentage are typical for West, which includes a higher value for both variables than the city mean. The average income per housing type is, however, below city mean.

8.3.4 Low Separation Neighbourhoods

The suburbs with low per person separation amount are **New West**, **Bijlmer** and **North**. From all of the three suburbs three neighbourhoods have been selected based on their level of infrastructure density and amount of separated plastic waste per person.

8.3.4.1 New West

The selected neighbourhoods in New West are F84, F85 and F88. The selected neighbourhoods, the whole suburb and its waste collection infrastructure are shown in figure 50. Overall New-West has a rather low to medium educated and not-western population in comparison to the city mean. The average income per household is, however, quite different between the individual neighbourhoods. The selected focus areas are F84, F88 and T85 due to their different separation quantity, size and infrastructure density.

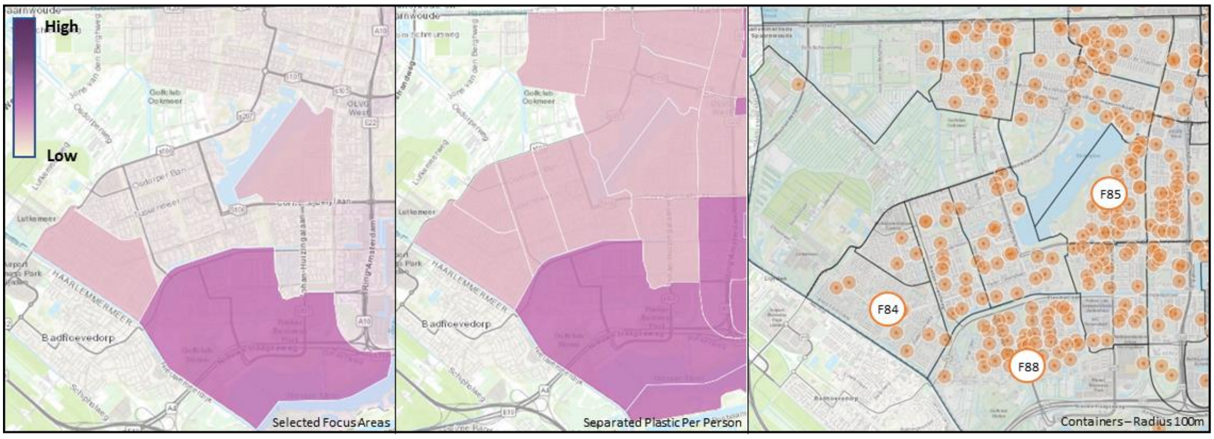
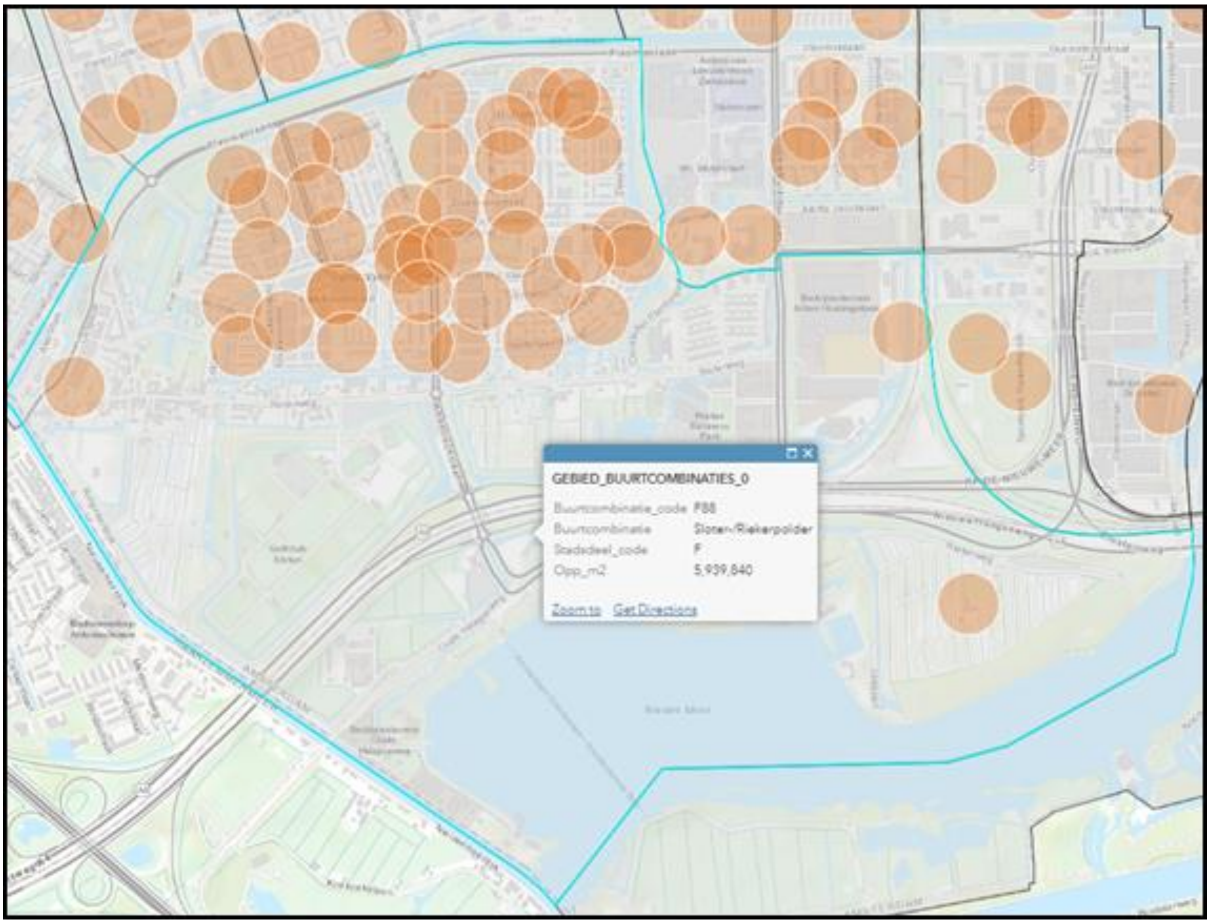


Figure 50 Geographical Overview Low Separation Neighborhoods New West

Neighbourhood	Low Education	Medium Education	High Education	Average Income Household	Western	Non-Western	Number Single House	Number Flats	Separated Plastic Per Person
F84	31%	40%	29%	€ 44.700	21%	79%	0	3675	1,18
F85	34%	36%	31%	€ 34.100	26%	74%	0	3218	1,25
F88	26%	38%	35%	€ 44.700	36%	64%	130	6359	2,06
City Mean	*23%*	32%	44%	€ 38.004	40%	60%	514	4047	2,37

Table 8 Demographic Characteristics Low Separation Neighbourhoods New West

8.3.4.1.1 Sloten/Riekenpolder – F88


GEBIED_BUURTCOMBINATIES_0

Buurtcombinatie_code F88
Buurtcombinatie Sloten/Riekenpolder
Stadsdeel_code F
Opp_m2 5,939,840

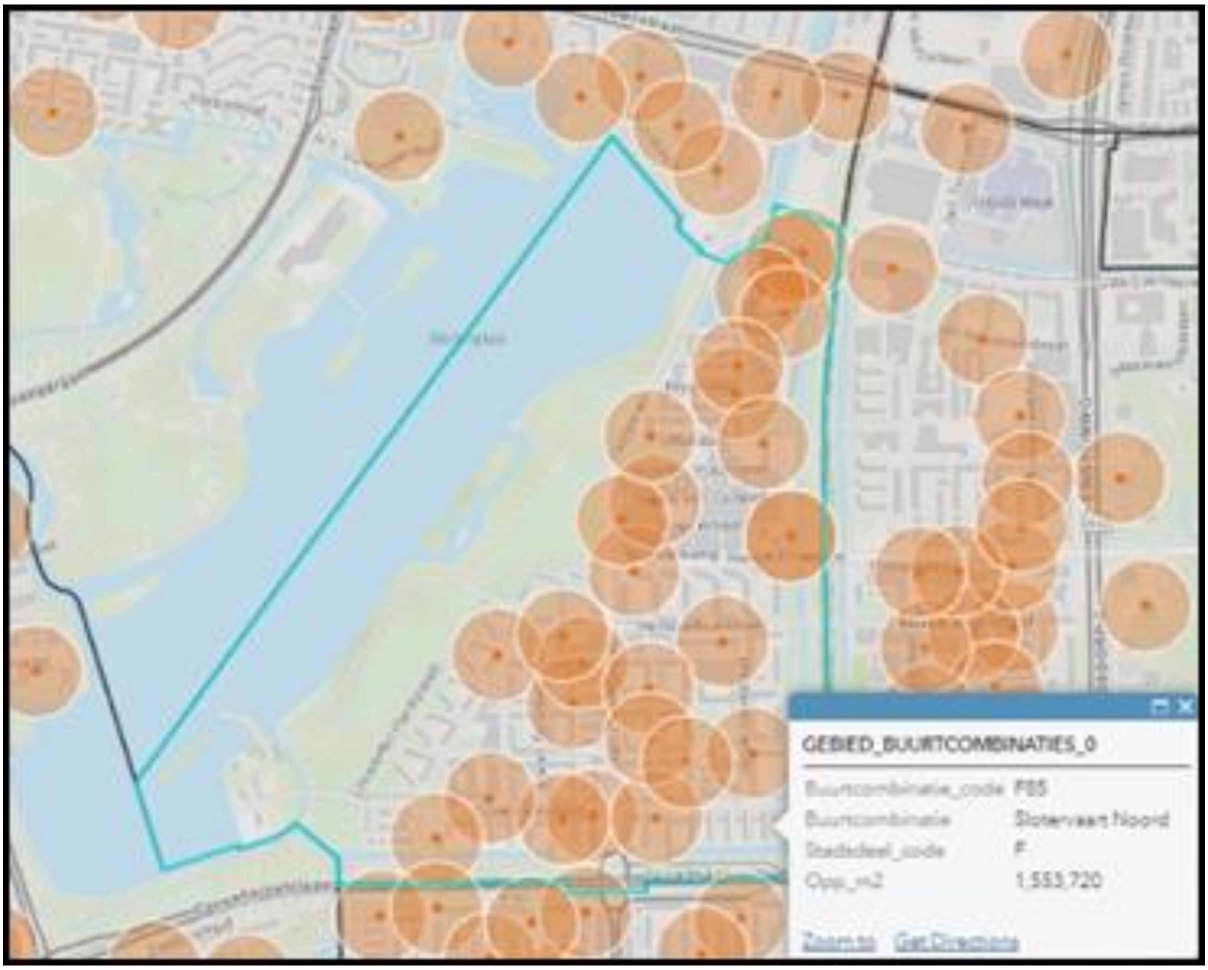
Figure 51 Infrastructure Density Sloten/Riekenpolder

The neighbourhood "Stloten/Riekenpolder – F88" is located in the south of suburb New West. Its population amounts to 13.800 citizens and its geographical size is 5.939.840 m^2. The size and shape as well as the container infrastructure of F88 is shown in figure 51. Yearly 2.06 kg plastic per person are separated in F88. Also, the level of infrastructure seems not to be dense, a big part of F88 is commercial, agricultural and recreational area. Within the housing areas the infrastructure is relatively consistent and dense. Nonetheless, are not all citizens living within a walking distance of 100m of a separation container while some have multiple within this 100m range. In comparison to the other neighbourhoods of New-West the infrastructure is dense. In comparison to the neighbourhoods of West the density is on a medium level.

The demographic characteristics of F88 are listed in table 8. The education level, western/non-western percentages and housing types of F88 are close to the to the city mean. The average household income with 44.700 is significantly higher than the city mean.

8.3.4.1.2 Slotenvaart Noort – F85

The neighbourhood "Slotenvaart Noort – F85" is located in the eastern part of suburb New-West. Its population amounts to 8.000 and its geographical size is 1.553.720 m^2. Size and shape as well as plastic collection infrastructure of F85 is shown in figure 52. Yearly 1,25 kg of plastic waste per person are separated in F85. This low level of separation occurs despite the fact that the separation infrastructure does not have a low density. However, some of the areas are not within the 100m radius of a plastic separation container, while some have multiple within the 100m range.



GEBIED_BUURTCOMBINATIES_0

Buurtcombinatie_code F85
Buurtcombinatie Slotervaart Noord
Stadsdeel_code F
Opp_m2 1.553.720

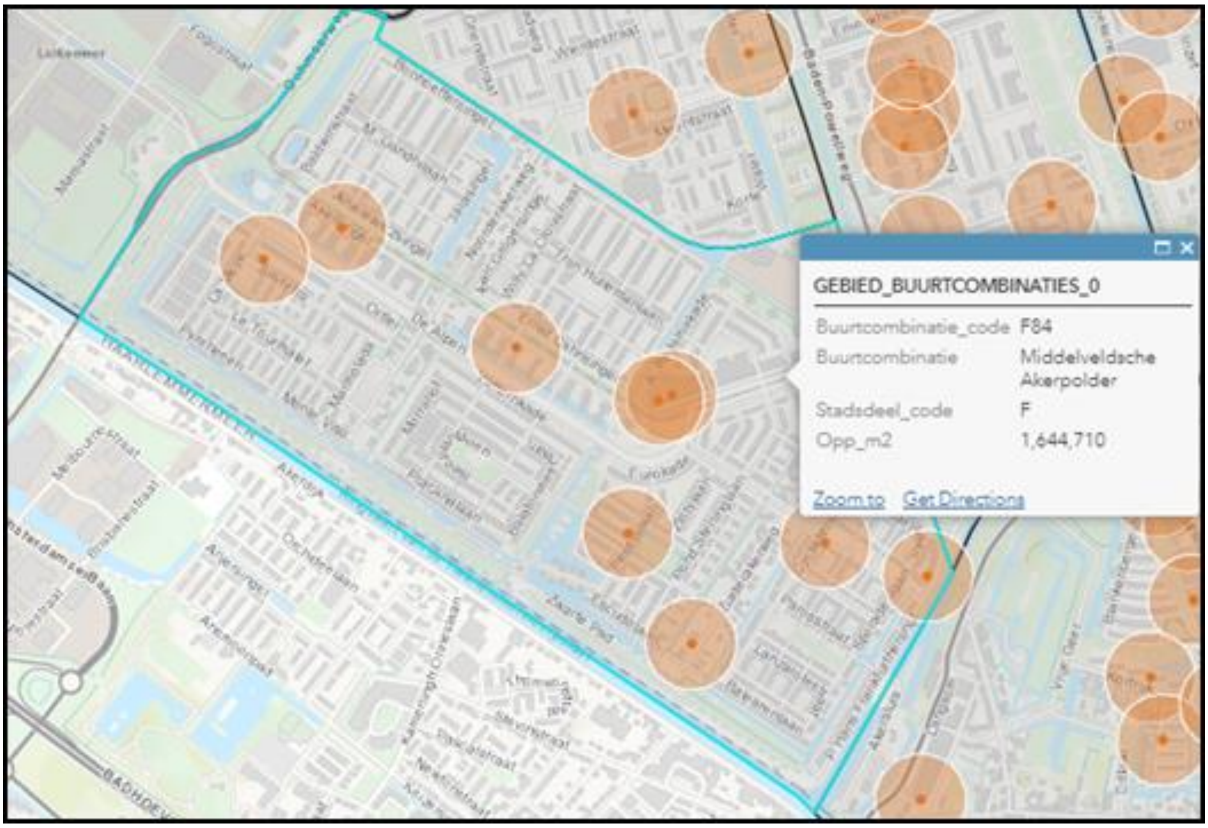
Figure 52 Infrastructure Density Slotenvaart Noort

The demographic characteristics of F85 are listed in table 8. The education percentages of low and medium level are relatively high in comparison to the city mean. Notable is also the high percentage of not western citizens and a relatively low average household income of 34.100€.

8.3.4.1.3 Middenveldsche Akerpolder – F84

The neighbourhood “Middenveldsche Akerpolder – F84” is located south west border of the suburb New-West and Amsterdam itself. Its population amounts to 14.400 citizens and a geographical size of 1.633.710 m^2. Shape and size as well as its separation infrastructure are shown in figure 53. Yearly, 1.18 kg of plastic waste per person is separated in F84. This is only slightly less than in F85, however, the infrastructure in F84 is significantly less dense than in F85. Most of the separation containers are placed on the main road in the centre of the neighbourhood.

The demographic characteristics of F84 are listed in table 8. Similar to F85 it has a relatively high percentage of low and medium educated citizens. However, its average income is significantly higher than the one of F85 and the city mean with 44.700€.



GEBIED_BUURTCOMBINATIES_0

Buurtcombinatie_code	F84
Buurtcombinatie	Middelveldsche Akerpolder
Stadsdeel_code	F
Opp_m2	1,644,710

Figure 53 Infrastructure Density Middenveldsche Akerpolder

8.3.4.2 Bijlmer

The Bijlmer is another suburb with a relatively low amount of separated waste per person on a yearly basis. Its geographical characteristics, selected focus areas and container infrastructure are shown in figure 54. It is located in the south east of the municipality Amsterdam. Overall Bijlmer is a suburb with a relatively low to medium and not-western population in comparison to the city mean. The average household income is also significantly below the city mean. The selected focus areas are T93, T96 and T95 due to their different separation quantity, size and infrastructure density.

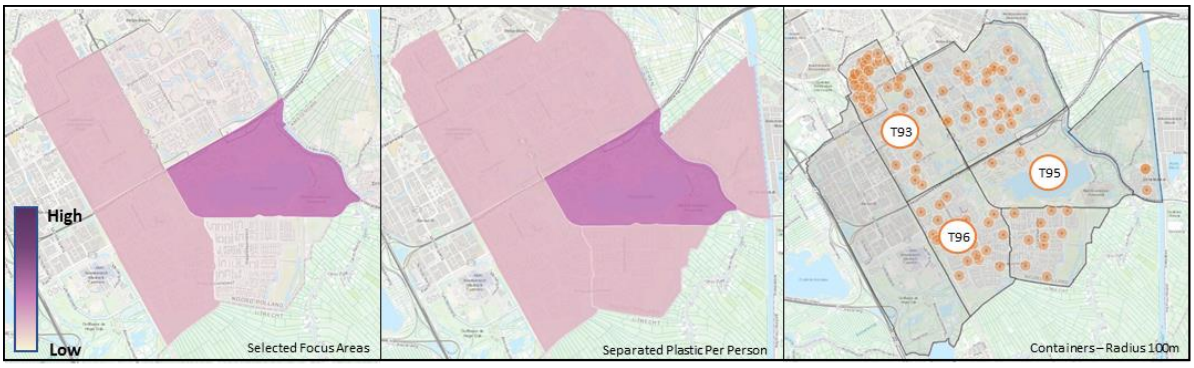
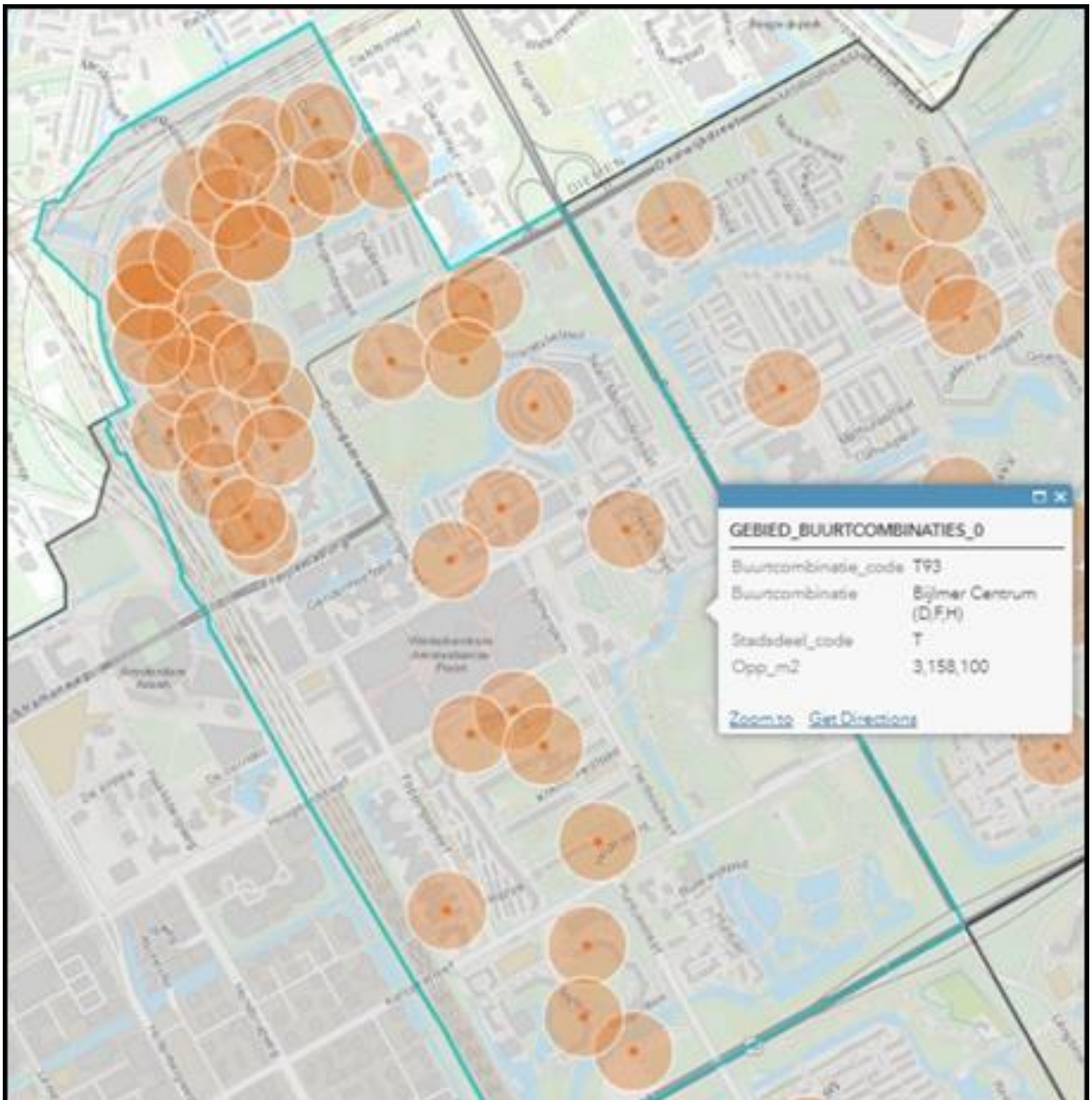


Figure 54 Geograhpical Overview Low Separation Neighborhoods Bijlmer

Neighbourhood	Low Education	Medium Education	High Education	Average Income Household	Western	Foreign	Number Single House	Number Flats	Separated Plastic Per Person
T93	40%	42%	17%	€ 26.000	14%	86%	949	10909	0,98
T95	21%	42%	37%	€ 33.300	36%	64%	17	1663	2,22
T96	40%	42%	18%	€ 29.500	13%	87%	2251	6085	1,03
City Mean	*23%*	32%	44%	€ 38.004	40%	60%	514	4047	2,37

Table 9 Demographic Characteristics Low Separation Neighbourhoods Bijlmer



GEBIED_BUURTCOMBINATIES_0

Buurtcombinatie_code T93

Buurtcombinatie Bijlmer Centrum (D,F,H)

Stadsdeel_code T

Opp_m2 3,158,100

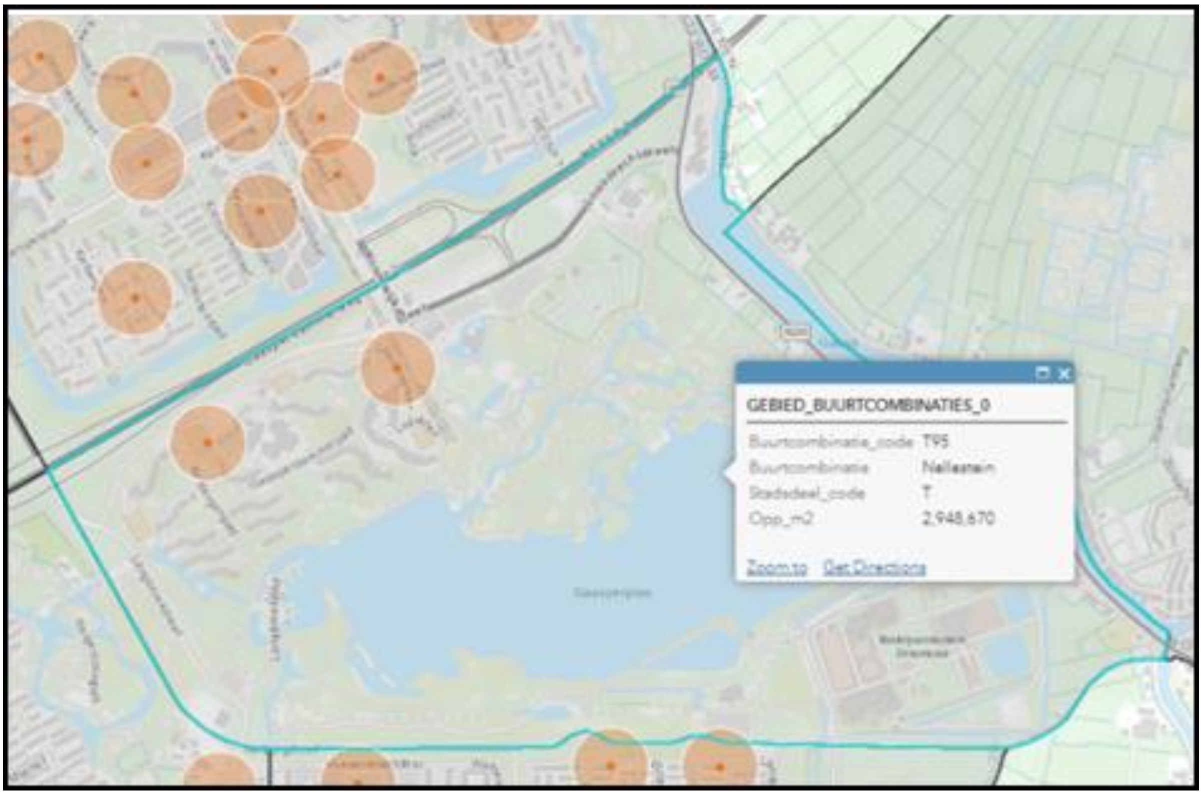
Figure 55 Infrastructure Density Bijlmer Centrum

8.3.4.2.1 Bijlmer Centrum – T93

The neighbourhood “Bijlmer Centrum – T93” is located in the north west of the suburb Bijlmer. Its population amounts to 23.200 citizens and its size is 3.158.100 m^2. Shape and size as well as its separation infrastructure is shown in figure 55. Yearly, 0,98 kg of plastic waste per person are separated in T93. The density of its plastic infrastructure is varying a lot. In the northern part it shows a high density with a lot of overlapping orange container circles. In the middle and southern the infrastructure is less dense with a lot of gaps in between the circles.

The demographic characteristics of T93 are listed in table 9. Notable are the very high percentages of low and medium educated, the very low average income and high non-wester population percentage. All these values are significantly different from the city mean.

8.3.4.2.2 Nellenstein – T95



Buurtcombinatie_code T95
Buurtcombinatie Nellestein
Stadsdeel_code T
Opp_m2 2.948.670

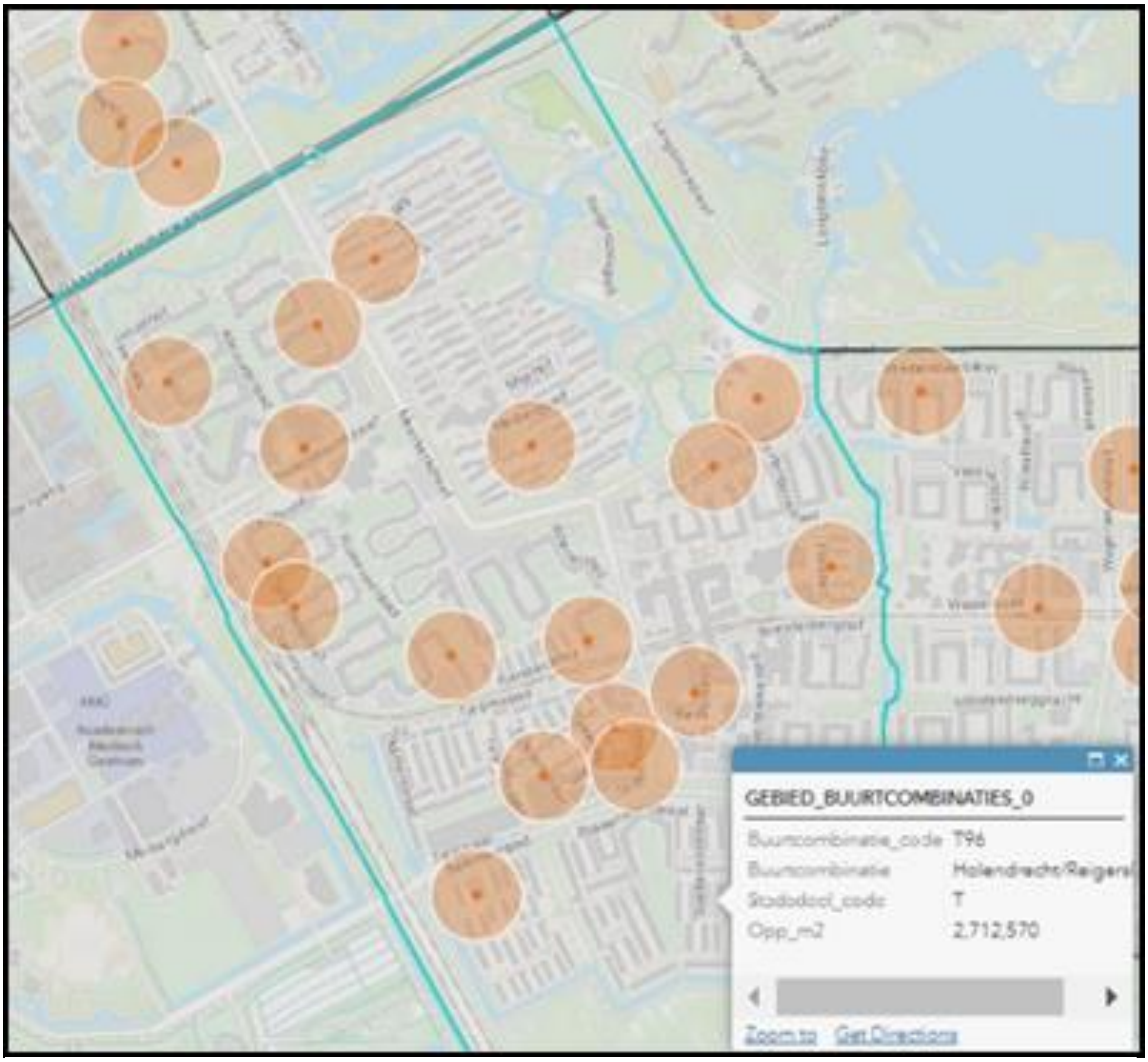
Figure 56 Infrastructure Density Nellenstein

The neighbourhood “Nellenstein – T95” is located in the south east part of the suburb Bijlmer. Its population amounts to 3.000 citizens and its geographical size is 2.948.670 m^2. The size and shape as well as the separation infrastructure of T95 are shown in figure 56. Most of the neighbourhood area is a lake and recreational area. Yearly, 2,22 kg of plastic waste are separated in T95. This is a relatively high amount for the suburb. Even more impressive given the relatively scattered level of plastic separation infrastructure.

The demographic characteristics of T95 are listed in table 8. Notable is the for Bijlmer relatively high percentage of high educated and low percentage of low educated. Also, the average amount of income per household and the western/non-western population percentages differ significantly from T95 and T96, and are closer to the city mean of Amsterdam.

8.3.4.2.3 Hollendrecht – T96

The neighbourhood “Hollendrecht – T96”is located in the south of the suburb Bijlmer. Its population amounts to 3.000 citizens and its geographical size is 2.712.570 m^2. The size and shape as well as the separation infrastructure of T96 are shown in figure 57. Yearly, 1,03 kg of plastic waste per person are separated in T96. The plastic separation infrastructure has a rather low density. Big parts of the neighbourhood are not covered by the orange container range circles.



GEBIED_BUURTCOMBINATIES_0

Buurtcombinatie_code T96
Buurtcombinatie Holendrecht/Reigers
Stadsdeel_code T
Opp_m2 2.712.570

Figure 57 Infrastructure Density Hollendrecht

The demographic characteristics of T96 are listed in table 8. Overall the demographics are similar to the ones of T93. Notable differences are the higher number of single houses and a slightly higher average household income.

8.3.4.3 Noord

The suburb Noord is another suburb with relatively low plastic separation quantity per person. It is located in the northern part of Amsterdam. In figure 58 the selected focus areas, all neighbourhood and the plastic separation infrastructure are shown. The selected focus areas are N66, N70 and N68 due to their different separation quantity, size and infrastructure density. Similar to the other low scoring suburbs, Noord has a rather low to medium educated population, below city mean average household income and a high percentage of non-western citizens.

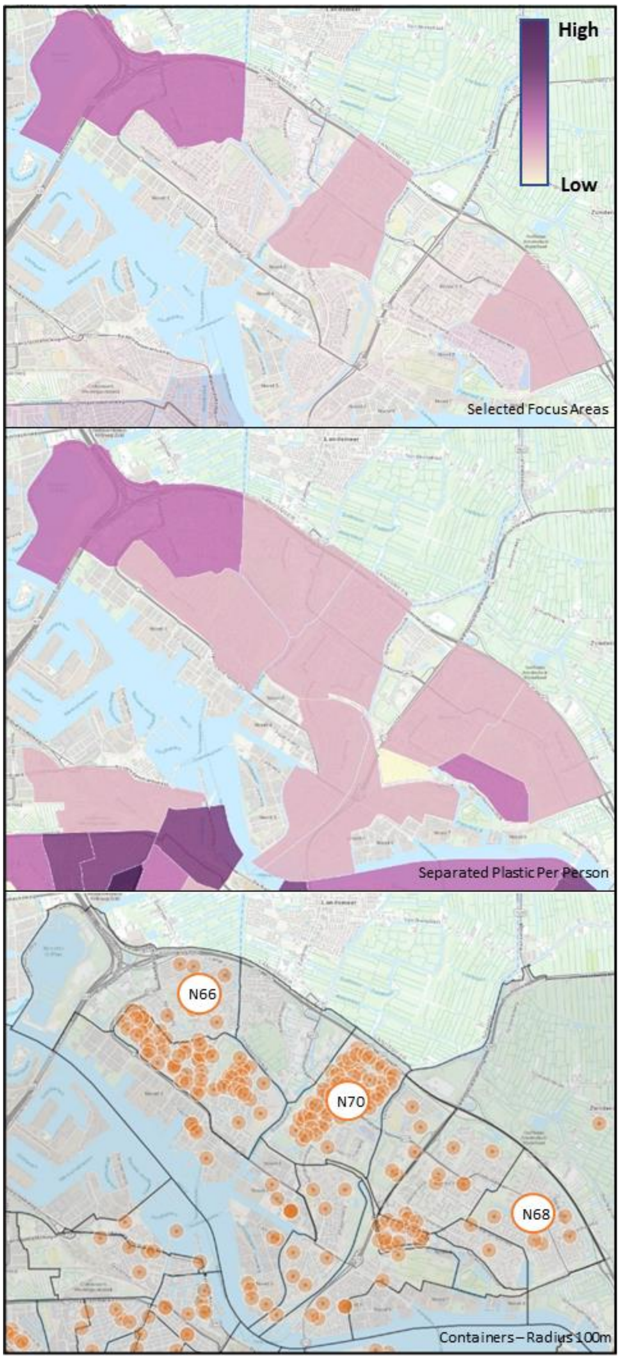


Figure 58 Geographical Overview Low Separation Neighborhoods North

Neighbourhood	Low Education	Medium Education	High Education	Average Income Household	Western	Non-Western	Number Single	Number Flats	Separated Plastic Per Person
N66	34%	43%	23%	€ 37.300	27%	73%	702	1897	1,88
N68	44%	37%	19%	€ 31.000	17%	83%	1006	2348	1,04
N70	42%	37%	20%	€ 31.100	18%	82%	0	5612	1,09
City Mean	*23%*	32%	44%	€ 38.004	40%	60%	514	4047	2,37

Table 10 Demographic Characteristics Low Separation Neighbourhoods North

8.3.4.3.1 Oostzanerwerf – N66

The neighbourhood "Oostzanerwerf – N66" is located in the western part of the suburb Noord. Its population amounts to 8.700 citizens and its geographical size is 3.322.190 m^2. The size and shape as well as the plastic waste collection infrastructure of N66 are shown in figure 59. Yearly, 1,88 kg of plastic waste per person are separated, which is a little bellow city mean and nearly twice the amount of the other focus areas N68 and N70.

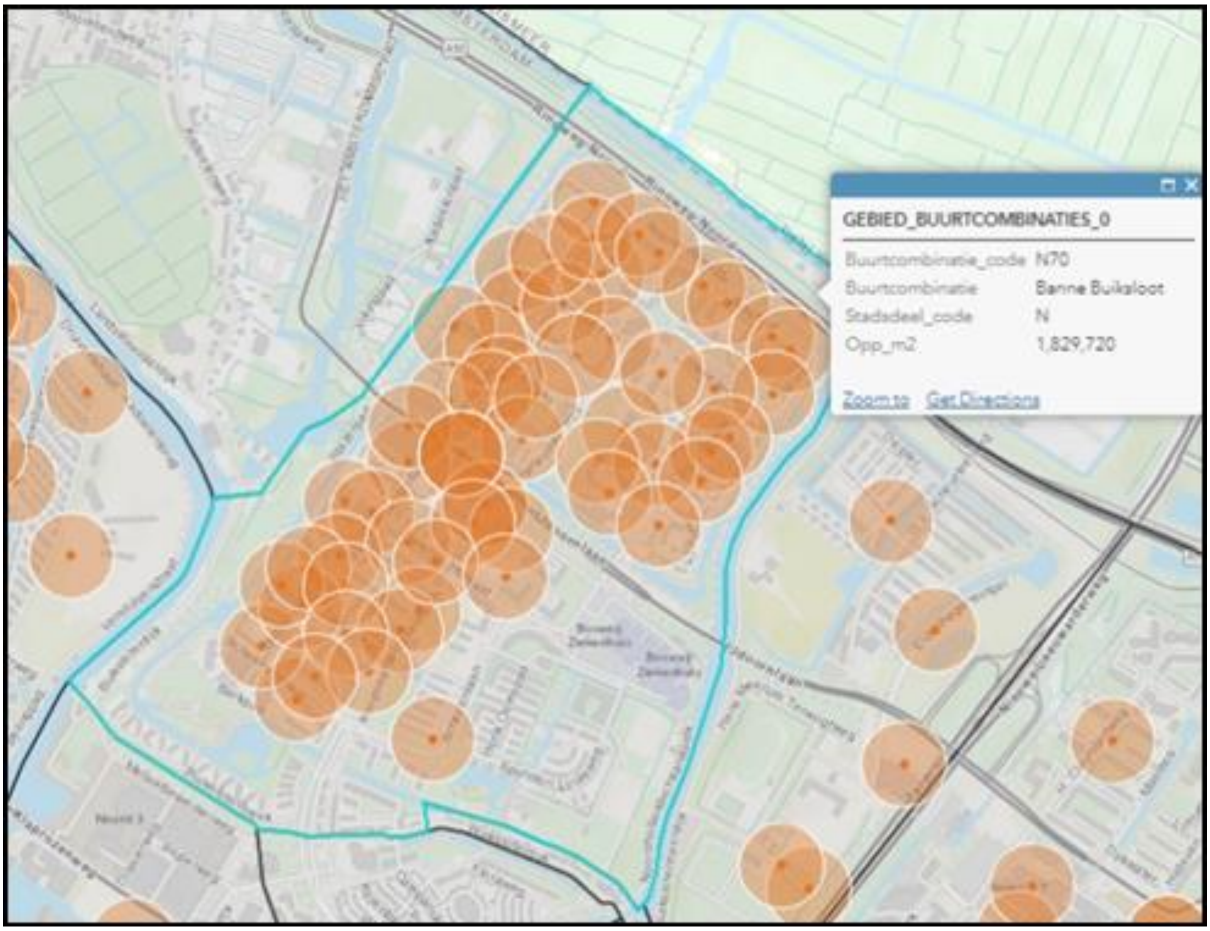
GEBIED_BUURTCOMBINATIES_0

Buurtcombinatie_code N66
Buurtcombinatie Oostzanerwerf
Stadsdeel_code N
Opp_m2 3,322,190

Figure 59 Infrastructure Density Oostzanerwerf

The demographic characteristics of N66 are listed in table 10. Overall the demographics of N66 are close to the typical north characteristics with a higher percentage of low and medium educated citizens, a higher Non-western percentage and smaller average household income in comparison to the city mean. However, N66 slightly diverged from these typical characteristics, if compared to the other focus areas N68 and N70. The average household income, with 37.300€ slightly below city mean, diverges even significantly.

8.3.4.*3*.2 Benne Buiksloot – N70



GEBIED_BUURTCOMBINATIES_0

Buurtcombinatie_code N70

Buurtcombinatie Banne Buiksloot

Stadsdeel_code N

Opp_m2 1,829,720

Figure 60 Infrastructure Density Benne Buiksloot

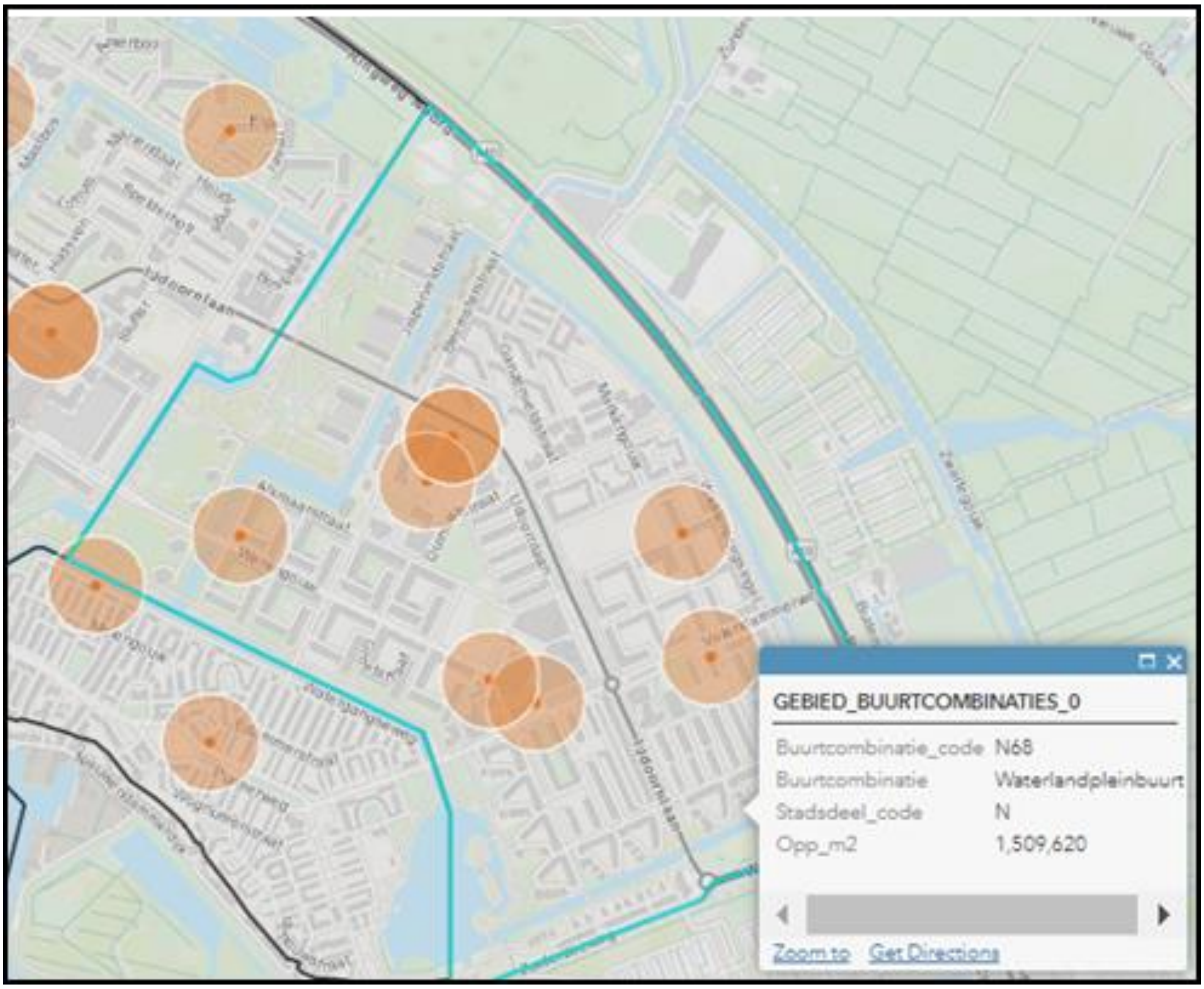
The neighbourhood "Bene Buiksloot – N70" is located in the centre of the suburb Noord. Its population amounts to 13.800 citizens and a geographical size of 1.890.720m^2. The size and shape as well as the plastic separation infrastructure of N70 is shown in figure 60. Yearly, 1,09 kg of plastic waste per person is separated, which is halve of the city mean. Therefore, the highly dense plastic separation infrastructure in N70 comes as a surprise. Only in the suburb Noord there are suburbs with significantly lower infrastructure density, but higher separation quantities as N66. Even on a city level the density of infrastructure is only matched by the relatively high scoring neighbourhoods of suburb West.

The demographic characteristics of N70 are listed in table 10. Overall N70 can be seen as a typical neighbourhood in North as described earlier. The only notable difference with the other Noord focus areas is the fact that it only has flats and no single party houses.

8.3.4.*3*.3 Waterlandpleinbuurt – N68

The neighbourhood "Waterlandpleinbuurt – N68" is located in the eastern part of the suburb Noord. Its population amounts to 13.100 citizens and its geographical size is 1.509.620m^2. Size and shape as well as its plastic separation infrastructure are displayed in figure 61. Yearly, 1,04 kg of plastic waste per person are separated in N68, which is halve as big as the city mean and nearly equal to the separation quantity of N70. In contrast to N70 the plastic separation infrastructure of N68 is significantly less dense. Most of the citizens has to walk further than 100m to the closest plastic container.

The demographic characteristics of N68 are listed in table 10. Similar to N70, N68 can be characterized as a typical neighbourhood in the suburb North as described earlier. In contrast to N70, N68 has a significant amount of single party houses.



GEBIED_BUURTCOMBINATIES_0

Buurtcombinatie_code	N68
Buurtcombinatie	Waterlandpleinbuurt
Stadsdeel_code	N
Opp_m2	1,509,620

Figure 61 Infrastructure Density Waterlandpleinbuurt

8.3.5 Correlation Separation Behaviour

The results of the focus area analysis are summarized in table 11. The demographic, waste separation and infrastructure density variables are marked based on their relative score. Red indicates a relatively low, yellow a medium and green a low score. All in relation to the other suburbs and the city mean. The aim of this indication is to identify clear differences between high and low scoring separation neighbourhoods. High separation neighbourhoods all score high on the separation per person variable. Three of the four high separation neighbourhoods have a high density of separation infrastructure. Low separation focus areas score either low or medium on the separation per person variable. Five out of nine low separation neighbourhoods have a low, three a medium and one a high infrastructure density. The average income per household varies between high and low separation neighbourhoods and low clear relation can be identified. Education level and, western or non-western origin indicate a possible relation and are discussed in depth next.

Neighbourhood	Low Education	Medium Education	High Education	Average Income Household	Western	Non-Western	Number Single House	Number Flats	Separated Plastic Per Person	Infrastructure Density
City Mean	*23%*	32%	44%	€ 38.004	40%	60%	514	4047	2,37	
				High Separation						
West										
E16	16%	27%	57%	€ 34.200	52%	48%	0	1198	7,30	Low
E19	21%	29%	50%	€ 29.800	41%	59%	75	3660	9,64	High
E21	8%	24%	68%	€ 40.600	65%	35%	42	4188	8,17	High
E43	13%	27%	60%	€ 36.500	53%	47%	163	5285	10,98	High
				Low Separation						
Nieuw-West										
F84	31%	40%	29%	€ 44.700	21%	79%	0	3675	1,18	Low
F85	34%	36%	31%	€ 34.100	26%	74%	0	3218	1,25	Medium
F88	26%	38%	35%	€ 44.700	36%	64%	130	6359	2,06	Medium
Bijlmer										
T93	40%	42%	17%	€ 26.000	14%	86%	949	10909	0,98	Medium
T95	21%	42%	37%	€ 33.300	36%	64%	17	1663	2,22	Low
T96	40%	42%	18%	€ 29.500	13%	87%	2251	6085	1,03	Low
Noord										
N66	34%	43%	23%	€ 37.300	27%	73%	702	1897	1,88	Low
N68	44%	37%	19%	€ 31.000	17%	83%	1006	2348	1,04	Low
N70	42%	37%	20%	€ 31.100	18%	82%	0	5612	1,09	High

Table 11 Overview High and Low Separation Neighbourhood Characteristics

8.3.5.1 Education

The education level is one of the demographic variables analysed. In table 11 the high separation neighbourhoods all have a high percentage of high educated citizens and a low percentage of low and medium educated citizens. Most of the low separation neighbourhoods have shown the opposite scores: high low and medium educated and low high educated percentages. Exceptions are neighbourhood F88 in Nieuw-West and T95 in Bijlmer with multiple diverging education percentages. This divergence could be the reason why those neighbourhoods show medium separation quantities as well.

The clear difference of education level between low and high separation neighbourhood indoctrinates a possible relation between level of education and separation quantities. Since, the focus area analysis analysed only the highest separation and a selection of low separation neighbourhoods a comprehensive picture of all neighbourhoods and their education percentages of high and low educated citizens is shown in figure 62. The dark coloured neighbourhoods indicated high variable values for separated waste per person and percentages of high and low educated citizens respectively. This maps also indicate a possible relation between education level and the quantity of separated plastic waste per person.

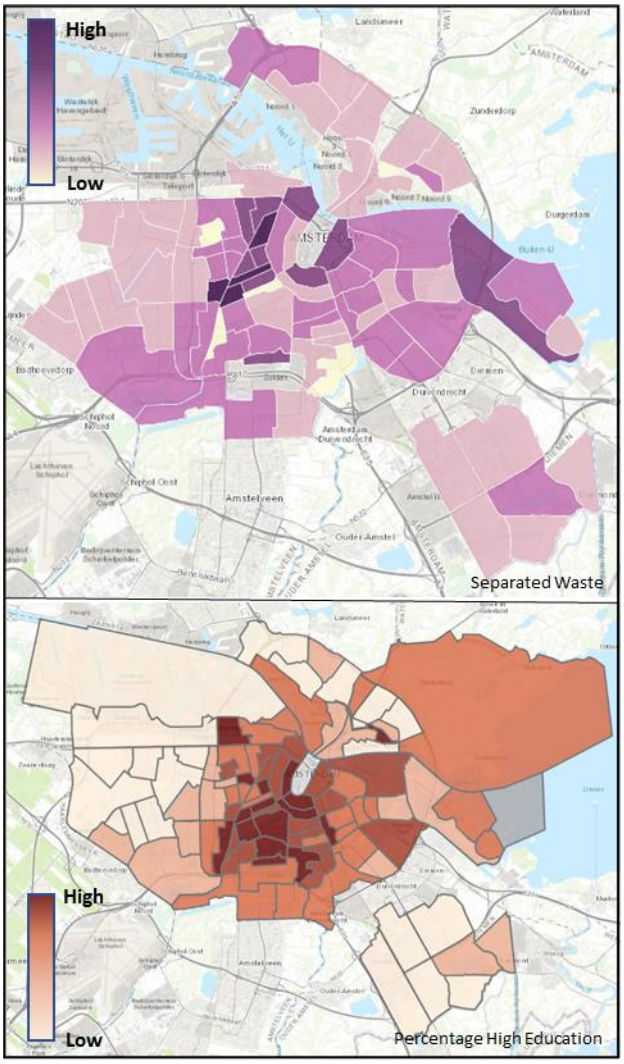


Figure 62 Geographical Overview Separated Waste and High Educated percentage

The suggestion of a possible relation between level of education and separation quantities from the focus area and geographical analysis is also supported by the results from a ranked spearman correlation test shown in table 12. With a p value of **4,11E-07** and **2,08E-06** for the relation between low and separation quantity and high education level and separation quantity respectively, indicates a significant relationship. The correlation coefficients of low, **-0,52,** and high education percentages, **0,49**, describe a moderate negative effect of low education on separation quantities and a moderate positive effect of high education on separation quantities. Therefore, the null hypothesis H_0 defined in chapter 7.3 can be rejected and the hypothesis H_3 can be accepted.

8.3.5.2 Origin

Most of the high separation neighbourhoods have a high west and a low non-western percentage in comparison to the city mean. Only E19 has a west/non-west distribution close to the city mean. In contrary, the low separation focus areas mainly show a low west and high non-western percentage. F88 and T95 show a medium distribution close to the city mean. Possible due to the same reason they diverged from the education scores, being the fact, they show a medium separation quantity. This clear difference between high and low separation neighbourhoods suggests a relation between separation quantities and west/non-western population distribution.

To further investigate the possible this possible relation a geographical analysis is conducted. The results in the form of three maps is shown in figure 63. Dark coloured neighbourhoods indicate high variable values of separation quantities and west/non-western population percentages. The maps support the suggested relation. Also, some high western populated suburbs show a low separation quantity.

This rather moderate relation is as well indicated by the results of a ranked spearman correlation shown in table 12. The p values of **2,58E-05** for both variables indicate a significant relationship. The coefficients of **0,446773** and -**0,446773** indicated a moderate positive effect of high western and negative effect of high non-western population percentages on the separation quantities. Therefore, the null hypothesis H_0 defined in chapter 7.3 can be rejected and the hypothesis H_4 can be accepted.

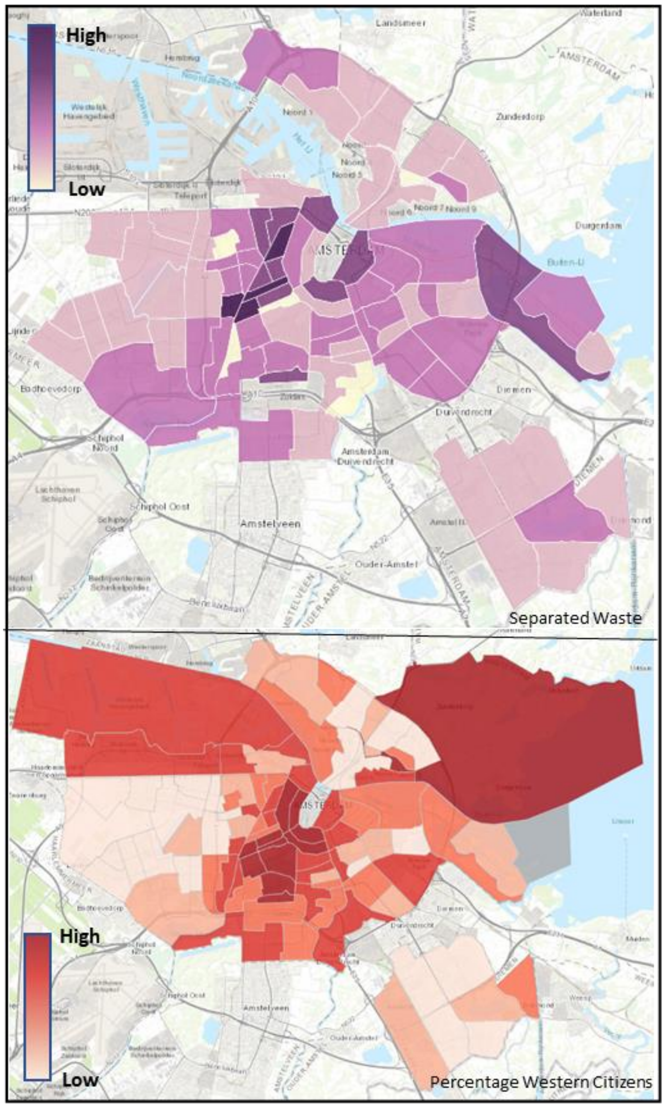


Figure 63 Geographical Overview Separated Waste and Western Citizens Percentage

The other two tested hypotheses, H_1 and H_2, could not be accepted due to a too high p value as shown in table 12. This means that the Null Hypotheses stays in place for Income and Housing Type. No relationship between these variables and the separated plastic quantities was detected.

	Low Education	**Medium Education**	**High Education**	**Number Citizens**	**Average Income Household**	**Western**	**Non-Western**	**Number Single Houses**	**Number Flats**	**Separated Plastic**
Low Education	1	0,607581	-0,94795	0,306774	-0,54633	-0,91073	0,910729	0,236226	0,056735	-0,52504
Medium Education	0,607581	1	-0,82786	0,113164	-0,42253	-0,62171	0,621713	0,201653	0,053621	-0,31582
High Education	-0,94795	-0,82786	1	-0,26661	0,559232	0,892418	-0,89242	-0,24929	-0,06142	0,496647
Number of Citizens	0,306774	0,113164	-0,26661	1	-0,18944	-0,34633	0,346335	0,23288	0,4283	-0,27074
Avrg. Income	-0,54633	-0,42253	0,559232	-0,18944	1	0,682284	-0,68228	-0,08885	-0,03571	0,107736
Western	-0,91073	-0,62171	0,892418	-0,34633	0,682284	1	-1	-0,26115	-0,03278	0,446773
Non-Western	0,910729	0,621713	-0,89242	0,346335	-0,68228	-1	1	0,261149	0,032782	-0,44677
Single Houses	0,236226	0,201653	-0,24929	0,23288	-0,08885	-0,26115	0,261149	1	-0,04711	-0,2218
Number Flats	0,056735	0,053621	-0,06142	0,4283	-0,03571	-0,03278	0,032782	-0,04711	1	0,000408
Separated Plastic	-0,52504	-0,31582	0,496647	-0,27074	0,107736	0,446773	-0,44677	-0,2218	0,000408	1
Low Education	0	1,42E-09	1,63E-41	0,005059	1,1E-07	1,84E-32	1,84E-32	0,032629	0,61266	4,11E-07
Medium Education	1,42E-09	0	8,75E-22	0,311411	7,68E-05	4,56E-10	4,56E-10	0,069259	0,632329	0,003848
High Education	1,63E-41	8,75E-22	0	0,01547	4,74E-08	2,23E-29	2,23E-29	0,023915	0,583569	2,08E-06
Number of Citizens	0,005059	0,311411	0,01547	0	0,088274	0,001436	0,001436	0,035249	5,97E-05	0,013889
Avrg. Income	1,1E-07	7,68E-05	4,74E-08	0,088274	0	1,69E-12	1,69E-12	0,427306	0,750111	0,335337
Western	1,84E-32	4,56E-10	2,23E-29	0,001436	1,69E-12	0	0	0,017798	0,769998	2,58E-05
Non-Western	1,84E-32	4,56E-10	2,23E-29	0,001436	1,69E-12	0	0	0,017798	0,769998	2,58E-05
Single Houses	0,032629	0,069259	0,023915	0,035249	0,427306	0,017798	0,017798	0	0,674277	0,045209
Number Flats	0,61266	0,632329	0,583569	5,97E-05	0,750111	0,769998	0,769998	0,674277	0	0,997098
Separated Plastic	4,11E-07	0,003848	2,08E-06	0,013889	0,335337	2,58E-05	2,58E-05	0,045209	0,997098	0

Table 12 Spearman Correlation Results – Top: Coefficient; Bottom: P-Value

8.3.6 Waste generation

8.3.6.1 Time Series Non-Separated Plastic Waste

Figures 64-68 show time series of non-separated plastic waste of the different neighbourhoods grouped by the suburbs “West”, “New-West”, “South”, “East” and “North”. Two observations can be made. It appears that the waste generation over one year does have a certain cycle or seasonality. However, the extend and time of this seasonality or highs and lows cannot be generalized. The level of uniformity, and level and number of disruptions differs between the different suburbs and neighbourhoods. New-West, East and North show a rather stationary overall pattern. In contrary to West and South showing clear high and lows.

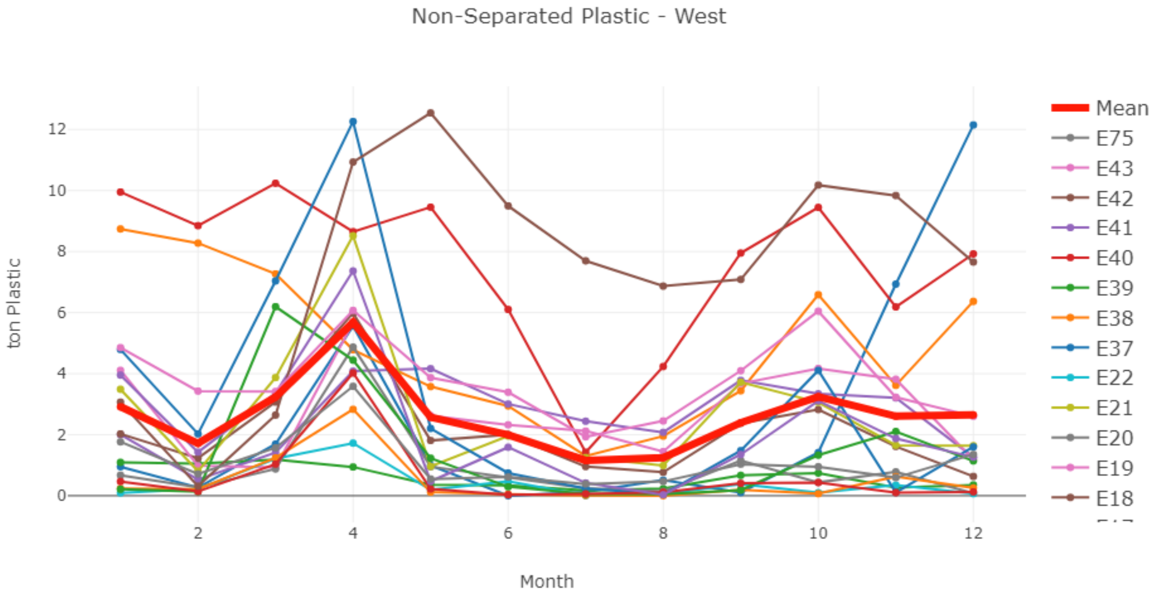


Figure 64 Time Series Non-Separated Plastic Neighbourhoods in Suburb West

In **West** time series neighbourhood **E42** and **E39** show significantly different behaviour form the other neighbourhoods. Although, all neighbourhoods show a lot of disruptions, the size of disruption E43 and E39 show is way bigger and their patterns seem somehow delayed. The main pattern is a low in month two, a high in month four, a low in month seven and eight and a high towards the end of the year.

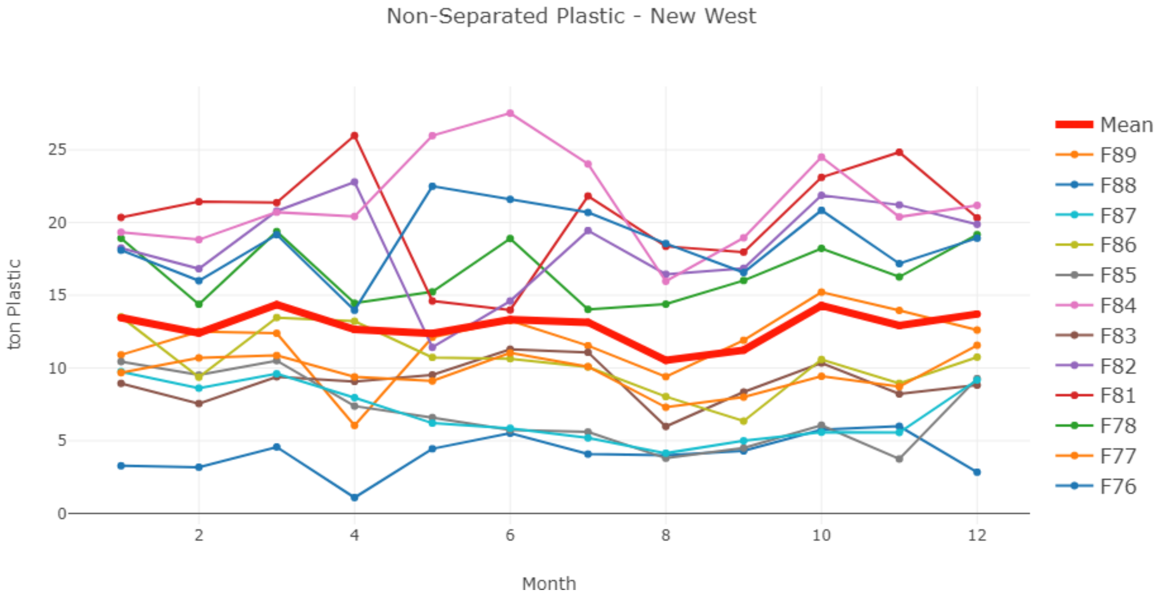


Figure 65 Time Series Non-Separated Plastic Neighbourhoods in Suburb New West

In **New-West** the behaviour of the neighbourhood's waste generation is rather stationary. Nonetheless, disruptions a cure in different neighbourhoods, at different points in time and with a different magnitude. In general, a low in month eight can be observed.

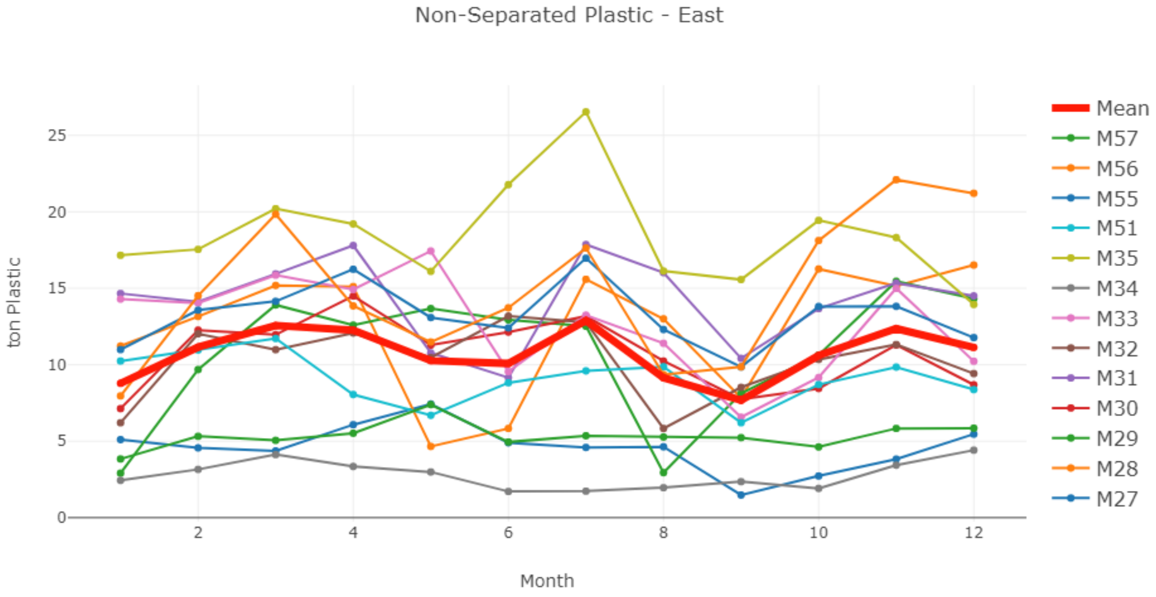


Figure 66 Time Series Non-Separated Plastic Neighbourhoods in Suburb East

In **East** more fluctuation in waste generation can be observed. Similar to West, the waste generation seems to be less constant, but with a clear overall pattern. This pattern shows a high in month three, a low in month five, a high in month seven, a low in month nine and a high in month eleven.

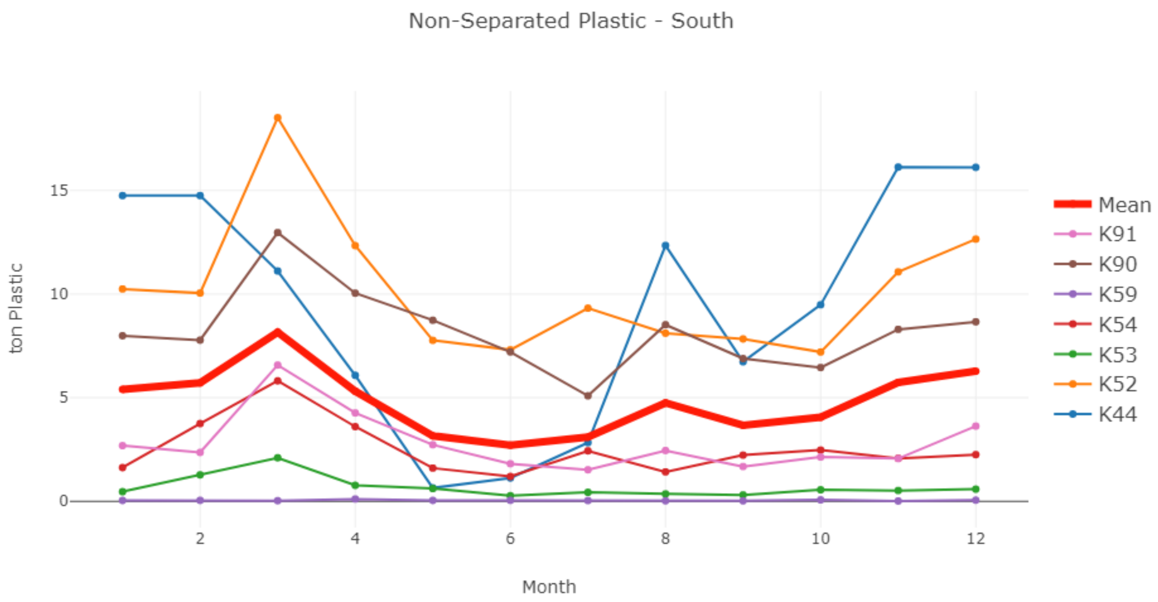


Figure 67 Time Series Non-Separated Plastic Neighbourhoods in Suburb South

The neighbourhoods in the **South** show a fluctuating, but clear overall pattern of waste generation as well. This pattern shows a high in month three, a low in month six and an increase towards the end of the year.

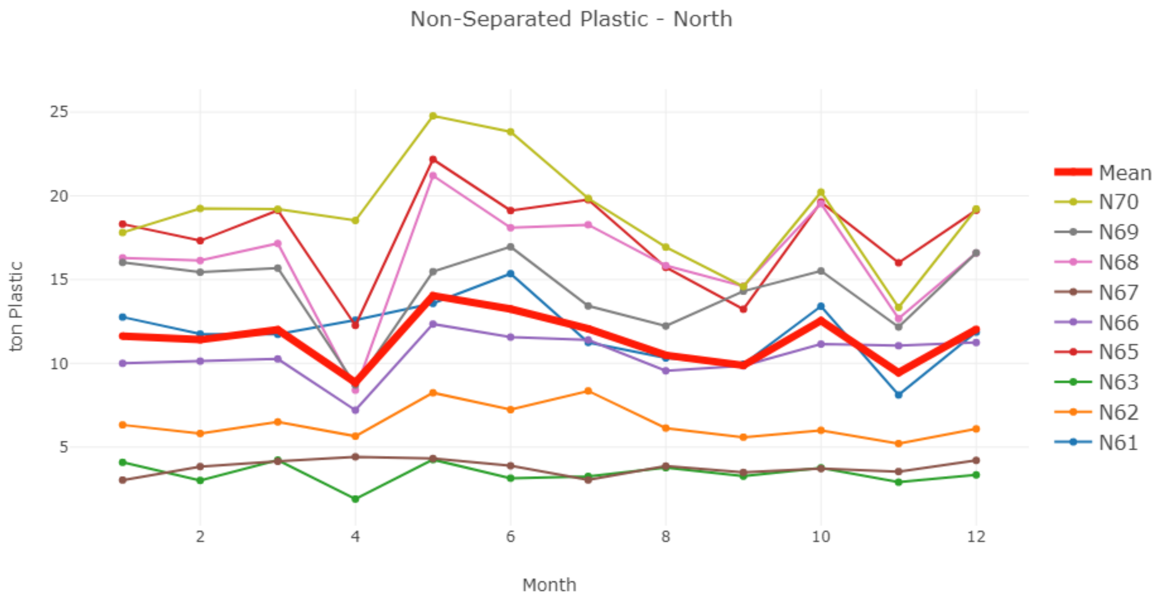


Figure 68 Time Series Non-Separated Plastic Neighbourhoods in Suburb North

The **North** shows a more constant overall waste generation pattern. Also, in month four a sudden low followed by a sudden high is observed.

8.3.6.2 Non-Separated Plastic

The Non-Separated waste distribution is shown in figure 69. It is a slightly right skewed distribution with the mean of 10.66 kg per person per year and a median of 10.89 kg. In comparison to the separated waste distribution, the Non-Separated waste is not as strongly skewed. There are clear differences between neighbourhoods and their non-separated per person quantities.

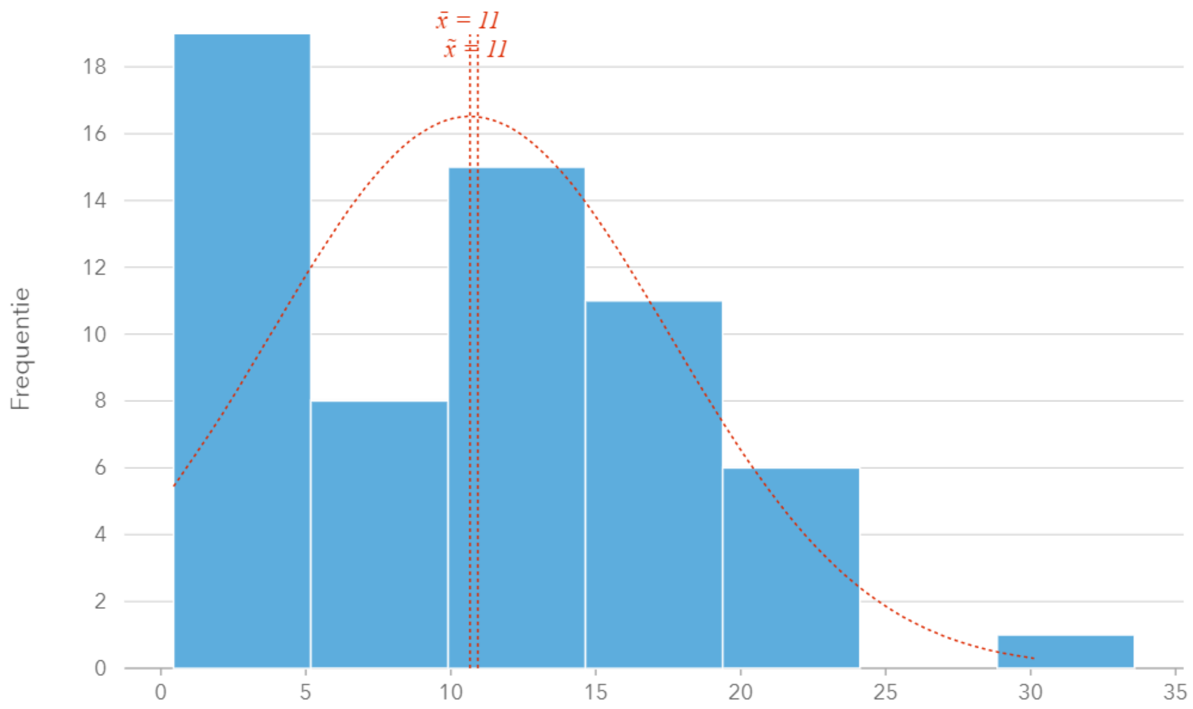


Figure 69 Normalized Non-Separated Distribution

These differences are shown on a geographical scale in figure 70. Dark neighbourhoods show have a relatively high quantity of non-separated waste and light neighbourhoods have a relatively low quantity of non-separated waste per person. The suburb West shows overall a rather low waste quantity. In contrary North, but also East and New-West show rather high quantities of non-separated waste. Since West was also the suburb with the highest separation quantities, one could suspect their non-separated waste quantities to be lower and the once of low separation suburbs to be higher. This can only be answered by looking into the total plastic waste quantities per person.

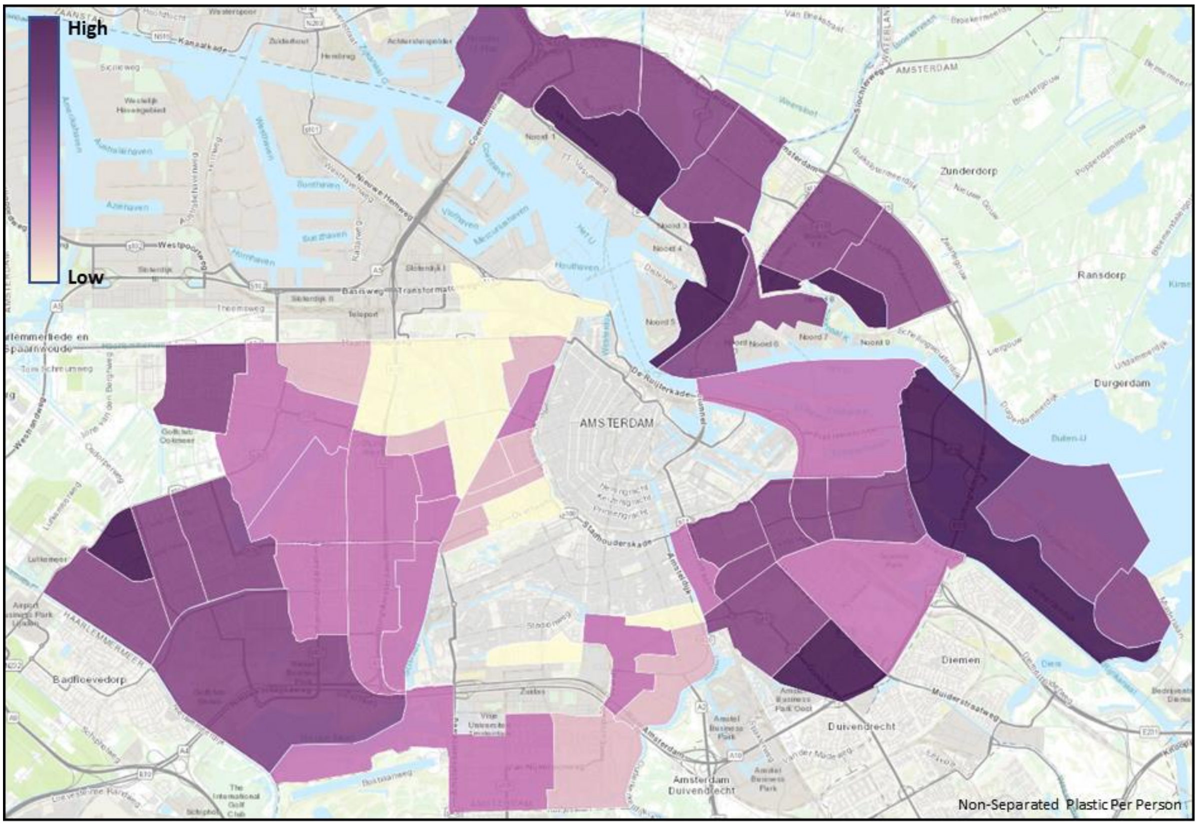


Figure 70 Geographical Overview Normalized Non-Separated Plastic Waste

8.3.6.3 Total Plastic

The distribution of total plastic waste quantity per person, a combination of separated and non-separated waste, are shown in figure 71. Its mean of 13,17 kg per person per year is a little higher than the mean of non-separated waste. The difference can be explained by the addition of separated plastic waste with a mean of 2,3 kg per person per year, which is about the difference.

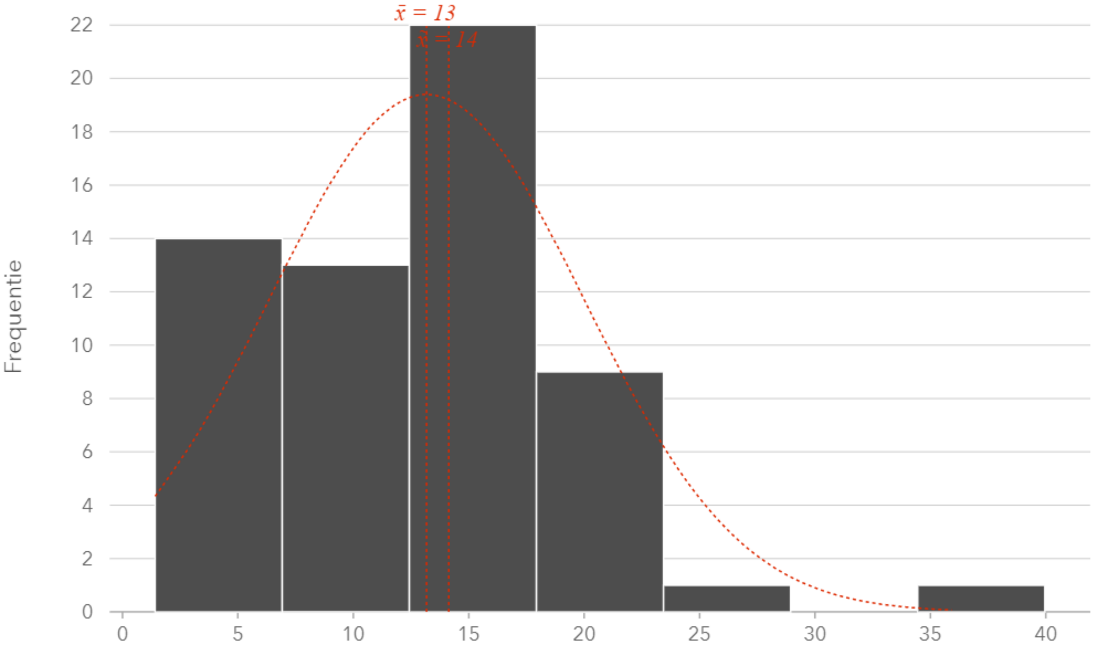


Figure 71 Normalized Total Plastic Waste Distribution

Comparing the total plastic waste per person per year on a geographical level, shown in figure 72, to the non-separated and separated plastic quantities of the different neighbourhoods does not indicate a clear relationship. The in the literature indicated possible higher total waste generation in high separation neighbourhoods cannot be observed. West, in general a high separation suburb, shows relatively low total waste. The Suburbs North, New-West and East show a relatively high total plastic waste generation. Their separation quantities are relatively low for North and New-West. East separation quantities are in the mid-range.

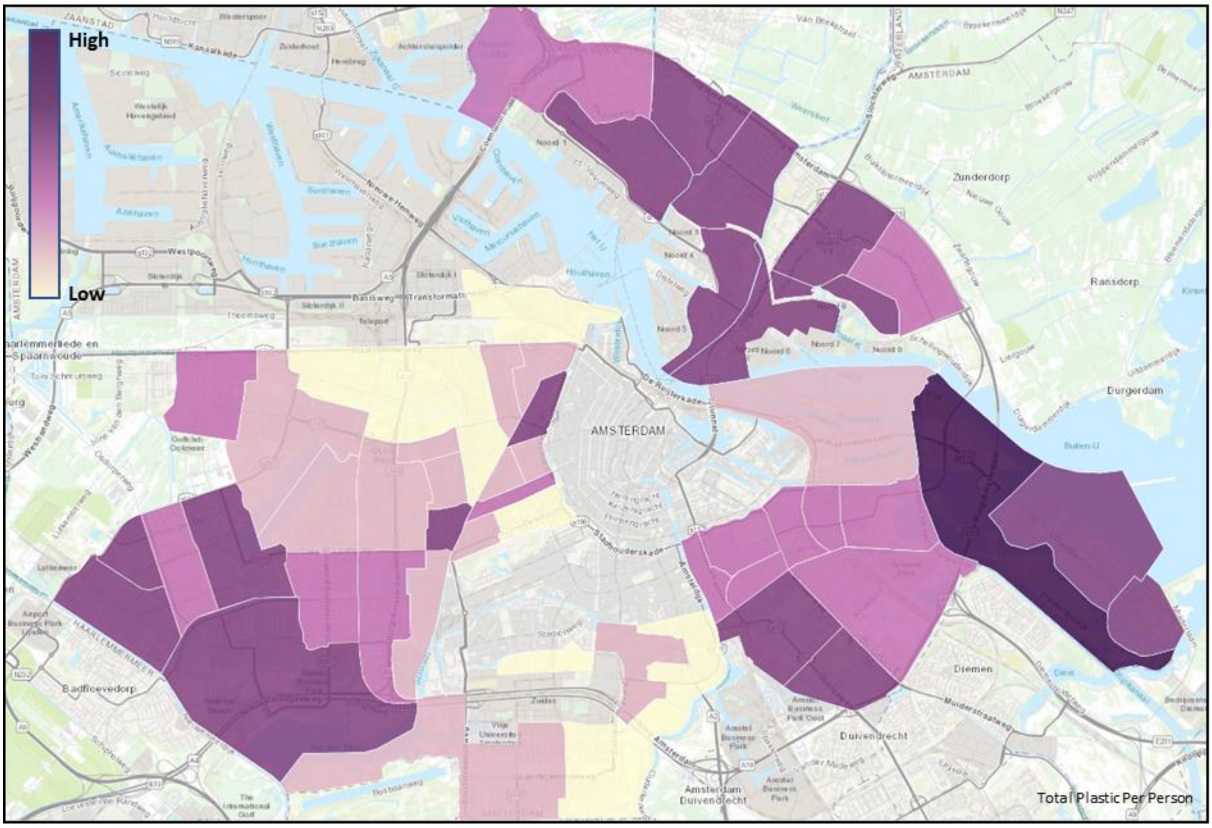


Figure 72 Geographical Overview Normalized Total Plastic Waste

The form from the literature suggested relation between level of income and waste generation cannot be supported by this research. The map of total plastic waste quantities and average income for each neighbourhood shown in figure 73 does not indicate this relationship. Some areas with high income show relatively high waste production. Others with low income show high waste production as well. In contrast to that, some high-income neighbourhoods show low waste generation as well.

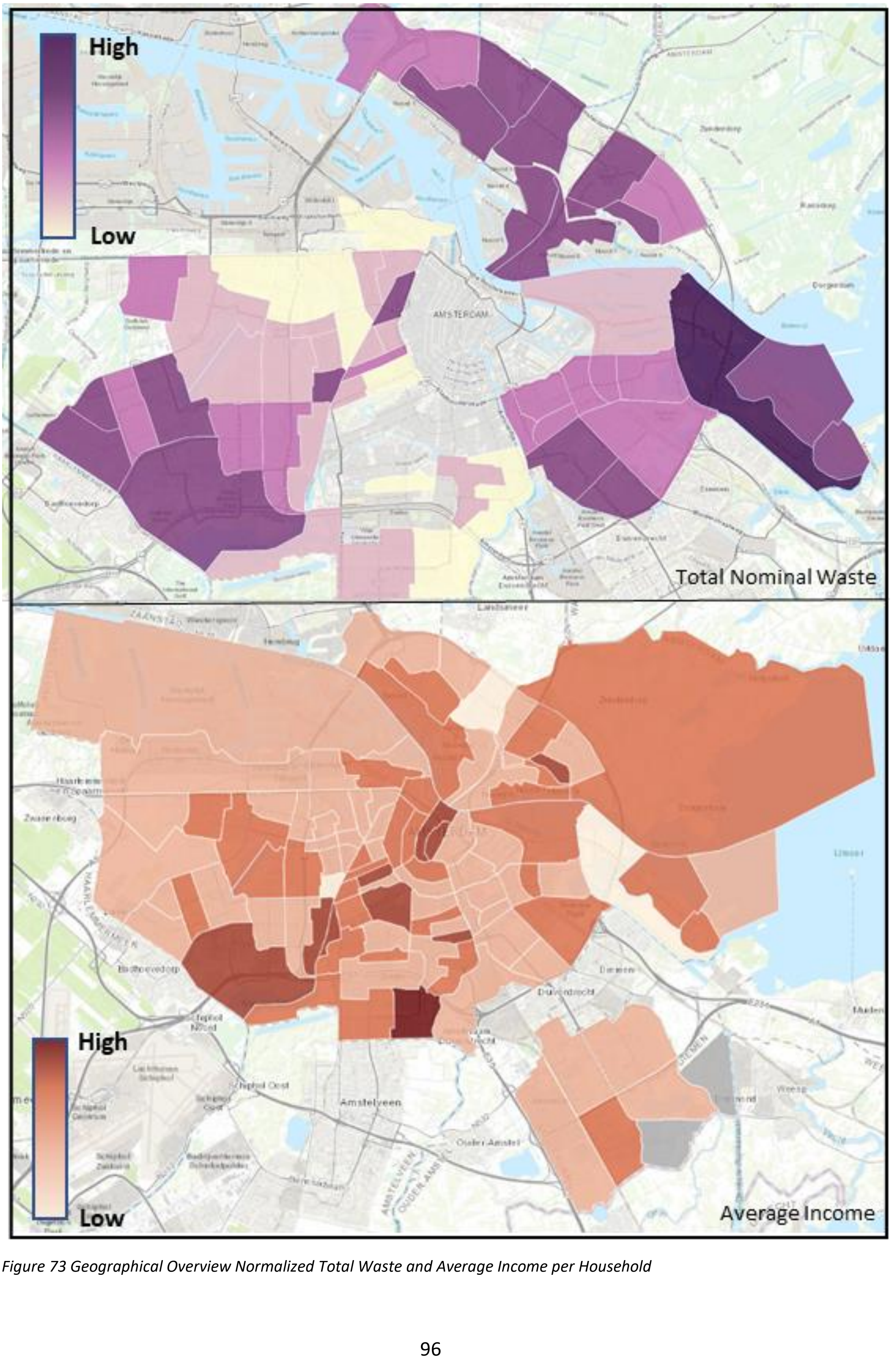


Figure 73 Geographical Overview Normalized Total Waste and Average Income per Household

9. Discussion & Recommendations

Chapter 9 discusses the results in relation to the analysis objectives defined in chapter 5 and formulates recommendations. Creating a comprehensive picture and placing the results into context is essential for formulating policy advise for the municipality of Amsterdam. The structure and flow of the analysis define the flow of the discussion. Only the aspects considered in this research are discussed. Neglected aspects are discussed in the limitations section.

9.1 Discussion

9.1.1 Process Optimization

The process optimization aspect of the analysis was defined in chapter 5. It considers the technological, cost and needs aspects of the processes to reduce impact, minimize material use and maximizes material outputs. A combination of processes forms a supply chain. Different supply chains are analysed in the MFA and LCA with all their pros and cons.

The results from MFA and LCA show that different current and possible future supply chains, generate different kinds of impact, outputs and efficiency of material use. Incineration with on the upside a highly efficient recovery of energy and on the downside loss of valuable material and CO^2 emissions, are an example of theses implications. The right balance between **energy recovery**, **material recovery**, **emissions** and process **efficiency** are important to consider in the process of determining a waste management strategy.

Most of the GFT and plastic in household waste are currently collected in the residual waste. This residual fraction is used for Energy Recovery by incineration. With an efficiency percentage of 30% this process generates heat and electricity for a couple of thousands of households in Amsterdam (Partners for Innovation & Rebel, 2018). These advantages are part of a trade-off. On the downside big amounts of valuable material are lost and CO^2 are emitted into the atmosphere. Roughly 22.000 tons CO^2 are emitted from incinerating plastic waste per year. This emissions are quite significant compared to the CO^2 emissions per capita in one year of 9.92 ton in 2014 (Worldbank 2019). Important to note is the fact that non-separated plastic waste only makes up around 10% of the residual waste, resulting in a significantly higher total amount of CO^2 emitted by incineration of residual waste in Amsterdam.

Another technology for energy recovery is the dry or wet fermentation of separated GFT waste. The results have shown, that the fermentation is less efficient than incineration in terms of energy recovery. However, the CO^2 emissions are significantly smaller as well. Two other positive aspects, not considered in this research, are the reduction of wet waste in residual waste and generation of compost as a by-product.

Recovering material from the plastic waste supply chain reduces the amount of virgin material. This leads to a negative CO^2 footprint of the recycling supply chain. However, the complexity of material and inefficient of processes as well as the organizational difficulties prevent the effective material recovery. The complexity of the plastic waste supply chain explained in chapter 6.6. form a big disadvantage in contrary to the positive effect of CO^2 reduction.

While some supply chains show a higher output, others have lower impact or waste less material. Even if energy recovery might have a higher efficiency, it might be less favourable, since energy can be generated differently. Lost material or CO^2 emitted is a loss or impact not to be reverted. Nonetheless, some materials might not be recoverable and therefore incineration could be the best option. Finding the right balance between output, material use and impact in relation to the input is crucial to increase sustainability of urban waste management systems.

9.1.2 The Human Factor

The human factor describes the aspects of importance in relation with citizens and their waste generation and separation behaviour. The aspects are lifestyle, usability, socio-economics and awareness. Their influence on waste generation as well as separation behaviour determines the impact, output and material use of the different waste supply chains. The results of waste generation and separation behaviour and its possible relation to socio-economics and usability are discussed and put into perspective

The time series analysis results in general show more fluctuation in separation than in overall waste generation behaviour. This difference could be explained by changing or fluctuating separation attitude. People might feel the urge of contributing to environmental issues, but decreasing dedication results in varying separation between month. Waste generation in general, however, is more or less stable. Peaks or lows in the waste generation time series could occur due to vacation periods or events. At least no general trend in waste reduction or increase can be observed.

The analysis of differences in waste separation quantities has significant differences between suburbs and neighbourhoods. Relatively high separation quantities are observed in neighbourhoods of suburb West and lower quantities in New-West, Bijlmer and North. Important to note is the fact that even the highest separation quantity of 10,98 kg per capita just reaches the mean of overall plastic waste generation of 11 kg per capita. This would result in a separation percentage of 50% in the best case, which would be still far beneath the separation goals set on European, national and city level described in chapter 4. Interesting to see was that infrastructure density not necessarily resulted in at least a relatively high amount of separated waste. Both neighbourhoods with high and low density of infrastructure showed high and low separation quantities. Further analysis of demographic characteristics showed a significant correlation of separation quantities and the education level or origin of citizens. Neighbourhoods with high educated or western originating citizens showed a higher separation quantity. This research, by no means aims to suggest an intentional behavioural pattern or tries to discriminate certain population groups. Nonetheless, it is important to understand why this phenomenon occurs.

Possible reasons for the relation could be the information availability or communication method, and cultural differences. Barr, Gilg, & Ford (2001) concluded that recycling predictors are mainly logistical, meaning available recycling facilities and knowledge about them is sufficient to predict recycling behaviour. Since this research showed that in Amsterdam there is no clear relation between recycling facilities and recycling behaviour, the issues could be related to the availability and quality of the information provided. This potential lack of transparency of the household waste supply chain needs to be addressed on different levels. People not only need to know where the containers are, but what to put in them and what not. To address the myth of the fact that in the end all separated waste is thrown together and separated a second time anyway, making the separation efforts of citizens senseless, more information of the following processes has to be provided as well. People have to become aware of the complexity of for example plastic waste and the issues of reproduction as well as the products made from recycled material.

The waste prevention or generation behaviour is, as stated in the system demarcation, more complex than separation behaviour. Another issue is that waste prevention behaviour is difficult to monitor or be observed with data. The geographical analysis showed at least that there is no clear relation between waste generation and income of citizens. Since more income means more potential consumption and most of the waste worldwide is generate by developed countries, this relationship is commonly established in the literature. A possible explanation, for the fact that Amsterdam does not show this relationship, could be that cheaper products use more packaging than more expensive products. A deeper analysis of this possible relationship is necessary to prove this potential relationship. As well as the income waste relationship, no relation between high waste and high separation quantities could be established. Barr (2003) suggested people could tent to generate more waste in cases of high separation. Their feeling of already contributing to the issue might let them care less about the quantity they generate. Although, some high separation neighbourhoods also are in the high overall generation neighbourhood groups, a clear relation is not observed.

9.1.3 Limitations

The research design, assumptions made and results generate all have limitations due to choices made in the research process. Some aspects, necessary to truly achieve the goal of comprehensiveness, where not addressed in the analysis, because of time and resource constraints. The product design aspect of the waste supply chain analysis is an essential aspect. Material compositions and detailed consumption patterns of citizens can give insights into material quality and patterns of waste generation. Not addressing them in this research was mainly due to time constraints and the unavailability of data. Another reason is the relatively low influence of the municipality of Amsterdam, the main stakeholder of this research, on the product design. To achieve a truly integral change and improve the sustainability of waste streams further research of the product design has to be conducted. Also, important it is the financial aspect of new infrastructure and change in supply chains. To be able to include fermentation in the GFT supply chain and increase container density in all neighbourhoods, a financial analysis has to be executed to explore the feasibility of those changes. On top of that not all waste streams where considered. Other fractions as glass, paper and textile have to be analysed to compare separation behaviour between different fractions and to better understand possible underlying dynamics of those fractions. The scope of this research only looked into plastic and GFT due to time constraints, potential of improvement and media attention they are receiving.

Assumptions made to be able to calculate emissions and material flows are only estimations and give indication of actual situation. This means that the results cannot be translated directly into the real world. It enables the comparison of different current and future situations. Data quality issues, also, effect the accuracy of the results and form a limitation for this research.

Despite the limitations of the research the knowledge gathered helps to create a better picture of the household waste situation in Amsterdam. Worth mentioning is the unique disaggregated level of analysis and quality of data used. Studies so far made use of waste samples and questionnaires with a small samples size. Correctness of people’s answerer over their recycling or separation as well as waste generation behaviour often influenced the outcomes of those studies. The weight data gathered by the municipality of Amsterdam is of tremendous values and enables the unbiased and disaggregated statistical analysis of waste generation behaviour.

9.2 Recommendations

9.2.1 Policy Advice

The results of the analysis have proven the complexity of the waste management situation and given insights into material flows and separation patterns. A lot is still unknown, but the picture is becoming more clearly. In the last step of the comprehensive UM approach defined in chapter 2, policy recommendations are formulated to help the municipality in their process of increasing sustainability of its waste management system. As mentioned in chapter three, truly increasing the sustainability of an urban waste management system is only possible with an integral approach to things. This integrity starts at the producer of products and goes all the way to the reproduction of different materials and from technical to social implications. Hence, the municipality cannot achieve integral change of the system by itself. The policy advice, as well as the research, therefore, focuses mainly on the jurisdictional area of the municipality. However, indicates necessary steps to be taken on other levels of the system.

The goals of the municipality for separation waste percentages of 65% in 2020 are high. At least if the current rates are considered. This research showed that even in the highest scoring neighbourhoods this percentage is far from being achieved. Waste management strategies aim for zero waste and circular economy. On average roughly 70% of the waste is incinerated, generating huge amounts of emissions and destroying potentially reusable materials for a relatively small amount of energy, taking zero waste rather literally. The regulatory goals set and the big discrepancy between these goals and reality, create an odd situation. A mismatch between policy strategies and system structure. Davoudi (2006) addressed this mismatch between urban environmental policy goals and reality based on evidence created by research with a rational technical approach. This technical rational approach taken is not supplying the evidence needed to address the complexity of urban environmental problems. According to Owens, Petts, & Bulkeley (2006) understanding the interaction between environment and society, can only be achieved with multidisciplinary research approaches. However, in practice mostly natural science and technical conceptions are applied to issues of urban sustainability, leaving political and social dimensions out of scope. These findings are in line with what this research tries to accomplish with the application of a comprehensive urban metabolism approach for policy making. Overcoming a purely technical approach by combining it with other dimensions of the urban environment, to truly understand its dynamics and improve its performance. This combination of social and technical rationality, also suggested by Davoudi (2006), provides evidence to close the gap between sustainability city policy goals and urban system structure.

9.2.1.1 Resource Recovery: from quantity to quality

Endless circulating resources are a nice idea, which does not reflect the current situation of the urban environment. At least for the next decennia, but probably forever, waste will be part of this environment. To cope with it, recovering resources from it rather than incinerating them should be one of the priorities of the municipalities. To increase the amount of resources recovered the municipalities has to accomplish three policy goals: Ensure the existence of resource recovery supply chains, roll out sufficient separation infrastructure and improve separation behaviour. Figure 74 shows an overview of the measures to be taken for improvement of the resource recovering system in the municipality.

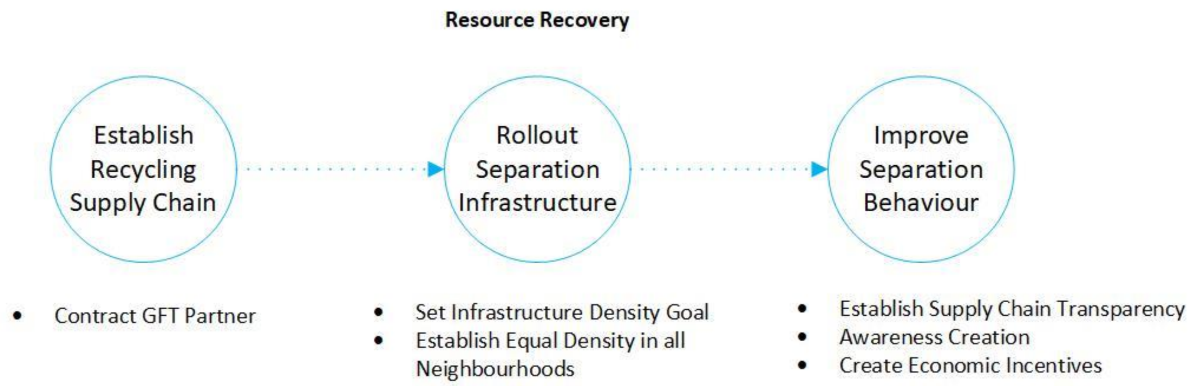


Figure 74 Policy Strategy for Material Recovery

While a plastic recycling supply chain already exists, GFT waste is currently not separated an incinerated with the rest of the residual waste. Since the municipality makes use of third-party services for the recycling processes, a new third party has to be contracted for the collection and fermentation of separated GFT waste. It has to be noted that a financial analysis of the business case and the costs for the municipality are yet to be executed, to get a full picture and better compare fermentation and incineration of GFT waste.

The separation infrastructure of GFT waste is not existent and some areas show big gaps in the plastic container infrastructure. To create an equal and fair situation for all citizens, the density of infrastructure should be increased and brought to the same level in all neighbourhoods. Not necessarily the same as in this research, but an average walking distance should be taken to set a density goal, enable progress evaluation and comparison between separation infrastructure in different neighbourhoods. Space scarcity and costs can potentially form barriers to this role out and are not part of this research, however, have to be looked into before the execution.

In addition to the rather technical improvements of recycling supply chain creation and infrastructure rollout, separation behaviour improvement is a more complex task. It does not mean increasing quantity of separated waste per se. Especially, for plastic the quality rather than the quantity is essential. Improving the quantity of separated waste first, after which the quality of it should be improved, moving from quantity to quality. This research proposes three essential parts of this improvement process. The increase of supply chain transparency, awareness creation and the use of economic incentives. The out of side out of mid mentality has to be addressed by creating transparent waste supply chains. Let people know what can be made out of what and what happens if waste is not separated. This is an essential first step in the process of awareness creation. Another is to target neighbourhoods based on their current separation performance. Weight data generation enables the municipality to monitor the different neighbourhoods. Information about right separation, the transparent supply chain, location of containers and current performance of a neighbourhoods could possibly be communicated with a mobile application. This tool could significantly increase transparency, create awareness and improve separation behaviour. Creating a feedback mechanism.

Regardless the quality and accessibility of information, and the usability of infrastructure, individuals or groups within the population might not see the necessity to separate waste. The commonly applied PAYT policy, discussed in chapter 4, creating an economic incentive for waste separation, might be necessary to stimulate better separation behaviour. If environmentally aspects are not convincing enough, economic incentives might just do it. However, such a system is not feasible until the infrastructure rollout is not completed, creating an equal situation for all citizens.

Another alternative could be a rewarding system rather than a taxation of waste. Rewarding citizens for handing in high quality waste material might give a more positive impression and emphasizes the importance of quality above quantity. Current attempts to create such a rewarding system cost too much extra effort or do not supply the right rewards, resulting in the fact that only already aware and active separating citizens participate.

9.2.1.2 Waste Prevention

As concluded in chapter 4, waste prevention or minimization behaviour is significantly more complex than separation behaviour and rather related to personal values than availability of infrastructure. Actively preventing waste is often connected with a lot of extra effort by the consumer. On top of that product design often makes the prevention impossible or the prize of low packaging product makes it unaffordable for certain citizens groups. Therefor this research argues that the systematic change of household waste prevention needs to be accomplished on national and supranational levels. Forcing producers to reduce packaging, increase repairability or increase purity of materials used for better recycling. Nonetheless, the municipality is able to contribute by the stimulation of businesses and initiatives like stores selling food without packaging, second hand stores or repair shops on a local level, enabling households to minimize their waste.

9.2.1.3 Other Levels

Other institutional levels as national or supranational play an important role in the integral improvement of waste reduction and resource recovery. This research sees the main task of the governmental institutions on those levels to simulate or force producers reduce material use, eliminate non-recyclable products, increase re-usability and repairability, and increase the use of recycled material. By achieving those goals citizens and local governments are able to significantly increase their efficiency of resource use.

9.2.2 Further Research

The policy advice given is a starting point, however, this research did not supply all the evidence necessary to implement and definitely change the waste management in Amsterdam. Further research has to be conducted to even better understand the waste separation and generation behaviour, analyse the waste fractions not looked into, determine ways to enable recycled material compete with virgin material, and compare and determine different PAYT or rewarding systems for the creation of economic incentives for waste separation or prevention.

10. Conclusion & Reflection

The goal of the research was to come up with a more comprehensive UM approach, not only looking at technical aspects of material flows, but considering the role of actors and system aspects influencing and shaping them. The analytical results are supposed to help policy makers with their decision for increasing sustainability of material flows in urban areas. Besides that, new insights into the underlying dynamic of urban waste flows were to be generated. After developing the new approach in chapter 2, it was applied to the case of Amsterdam household waste management. The reason for selecting this case are mainly related to data availability and the importance of waste management on the political agenda. To conclude the research questions summarizing the research objectives are answered. Finally, the author reflects on the scientific and societal relevance of this research.

10.1 Answering the Research Question

The answer to the main research question was found by addressing the sub questions step by step. The first three sub question are answered in chapter 2, the design of the comprehensive UM approach.

Sub Q1: *What system aspect have to be considered to create a comprehensive UM approach?*

The system aspects considered are the social, economic, institutional, technical and environmental aspects. The systematic literature review in chapter 2 showed that most of the UM studies focus on a single or two of the system aspects without even stating the others. At least describing all system aspects and mentioning possible issues creates a comprehensive picture of the urban system. Originating from the field of Industrial Ecology, the rather technical and environmental focused traditional UM approaches take the first few steps. However, they lack a couple of system aspects to go all the way in the direction of more sustainable material flows in cities. With the addition of social, economic and institutional system aspects a more complete picture of the situation is created. Increasing system understanding to determine suited solutions. Technical feasible solutions which are socially acceptable, environmental efficient and economically affordable. Enabled by the right institutional setting of regulations and policies.

Sub Q2: *How and why should the actor role be incorporated into a comprehensive UM approach?*

The research identified the three actor groups businesses, governments and citizens. All of them directly or indirectly influencing and thereby shaping the urban system. To be able to understand material flows in the urban area, the actors using, consuming and governing them are considered. Their roles are explained in the first step of the approach the system demarcation, executed in chapter 4. Based on the outcomes of the case related system demarcation, a deeper analysis of potential behavioural influence of actors on the material supply chains is conducted in the metabolism analysis. Businesses are able to change the waste supply chain structure, materials used for product and the durability of products. This empowers them to directly influence quantity and quality of material flows. Citizens also have this direct impact. Their consumption behaviour as well as reuse and waste behaviour influence urban material flows. Governments on different levels govern the system and can influence the system indirectly with policies and regulations. To be able to formulate policies to indirectly increase material use efficiency of businesses and citizens, their direct influence on the current systems is investigated. This identification of actor capabilities and analysis of what influence their behaviour has on the system, offers the potential for goal-oriented formulation of analytical objectives and policy interventions.

Sub Q3: What analytical dimensions and methods should be applied to enable analysis of underlying material flow dynamics?

On top of the extension of system aspects considered and the focus of actor roles, the analytical dimensions are extended with the following aspects in comparison to traditional UM approaches. Using multiple time and local geographical dimensions in the analysis enables behavioural pattern discovery and comparison of small geographical areas. The availability and use of bottom-up data is necessary to accomplish this extension. In addition to the commonly applied material flow and life cycle assessment methods complementary statistical analysis enables the deeper analysis of actor behaviour and identification of underlying material flow dynamics. In the specific case of household waste management this means analysing the influence of demographic characteristics and separation infrastructure density on waste separation and generation behaviour of citizens. Due to data availability and time constraints this research has chosen this specific set of methods and analytical objectives. However, other methods to further investigate for example separation behaviour could be applied. Methods as agent-based modelling could use the theoretical insights of separation behaviour as input. A detailed description and discussion of the methods used and the analysis conducted can be found in chapter 5 to 7.

Sub Q4: *What theoretical insights of resource flow dynamics can a comprehensive UM approach generate?*

The theoretical insights this research generated by applying the comprehensive UM approach to the household waste management create new evidence over waste generation and separation behaviour of citizens. Past research had difficulties to identify relationships between waste related behaviour and demographic or other variables. The literature review on waste generation and separation behaviour in chapter 4 pointed out a clear difference between the two types of behaviour. Separation behaviour being more related ability and ease of waste separation. The availability and usability of infrastructure as well as the complexity and guidance by information of the separation task were suggested as potential determents of waste separation quantities. On top of that the literature suggested relationships with education, housing type or origin of citizens. Generation behaviour on the other hand appeared to be more related to values and personal relation with the environment. The only established relationship is the relationship between wealth and generated waste. Developed countries generate significantly more waste than developing countries. More wealth enables consumers to spend and therefore consume more.

Based on the statistical analysis of separation behaviour stated in chapter 8 and their discussion in chapter 9 the following conclusions can be draw. Waste separation behaviour knows different behavioural patterns over time. For some yet to be determined reason it can either show a fluctuating seasonal or a stationary pattern. The Availability of infrastructure is necessary for the ability to separate waste. However, different infrastructure density levels do not significantly influence the amount of separated waste in neighbourhoods. A significant medium relationship between separated waste quantities and the origin and education of citizens was identified. Neighbourhoods with more western originating citizens separated significantly more waste. Neighbourhoods with a higher high educated citizen percentage showed a significantly higher amount of separated waste. This does not suggest that those groups consciously separate more or less waste, however, their background or the current complexity of separation might explain this causality.

The statistical analysis of the waste generation behaviour found the following. The waste generation behaviour over time in general has a rather stationary pattern. However, the total waste generation of different geographical areas differed significantly. Regardless of the ability to determine this difference, no clear relationship with income level of citizens and their waste generation behaviour was found.

Sub Q5: *What analytical insights does a comprehensive approach create for policy makers?*

The system demarcation of chapter 4 enabled this research to create a comprehensive and systematic picture of the problem setting. Based on this, clear analytical objectives were formulated to give direction to the urban metabolism analysis in chapter 5. This has the advantages of knowing where and what to look for. The results of the analysis generate insights directly addressing the core issues of the problem. Since the objective are determined from a comprehensive system demarcation considering current system structure, the outcomes are easy to connect to possible system changes and how to stimulate them. On top of that, issues not analysed due to different reasons can be stated and their implications can be taken into consideration. The analytical results of current throughput as well was impact of current plastic and GFT supply chains in combination with the geographical statistical analysis citizens waste separation and generation behaviour were valuable insights for policy makers. Not only suggesting the necessary structural changes of the supply chains. But creating insights into the separation behaviour is essential to accomplishing a shift from incineration to material recovery. On top of that, these behavioural insights are not aggregated, but give detailed information of neighbourhood's separation performance and their characteristics as infrastructure and demographics.

"How can an Urban Metabolism approach facilitate a comprehensive and actor-centred analysis of urban material flows, generating knowledge of material flow dynamics and enabling policy makers to formulate strategies for sustainability increasement of urban material flows?"

The conclusion is that the designed Comprehensive Urban Metabolism approach can enable comprehensive understanding of urban material flows and the actors shaping them to provide evidence supporting policy making for sustainability increase. It accomplishes this by first demarcating the system to understand its complexity and define objectives for the analysis. Second, is the metabolism analysis combining technical and social analysis of material flows and related actor behaviour, to create evidence for better understanding of the system behaviour. In the last step this evidence is used to formulate policy advice for improving the system sustainability. Taking a more systematic perspective and combining material and behaviour analysis makes the difference in comparison to established approaches.

10.2 Reflection

Not all aspects of the comprehensive UM approach are analysed and executed to full extend. The number of interviews for the system demarcations was low. Most of the information gathered was collected from literature and other documents. Increasing interaction with actors could improve system understanding and quality of the research. Furthermore, the economical aspect is not addressed due to time and data constraints. This leaves one of the system aspects out of the scope important for decision making. On top of that the depth of the different analysis steps can be improved. However, for the exploratory purpose of this research and potential comparison with other case the analysis was well suited. Despite these limitations the research contributed significantly to science and society.

One of the biggest barriers of Urban Metabolism studies has always been data availability. With developments as Internet of Things (IoT), data is gathered with high granularity and real-time. The prior barrier of data availability thereby becomes an opportunity and increases the potential of Urban Metabolism research. Enabling high timely frequency and low spatial level of analysis. This research showed the potential this development offers in practice. Combining statistical and material flow analysis to not only monitor the material flows, but understanding their relation with their urban environment. Opening up and troughing light into the up to this point Urban Black-Box.

11. Literature

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Annex A: Interviews

Peter de Boer - Project Manager, Strategic, Logistics and Innovation Advisor of the Waste Supply Chain – Municipality Amsterdam

Meeting 27.03.2019 -Amsterdam

- Organizational focus of waste management in Amsterdam was decentralized and delegated to different district. This decentralization is changed back to a more centralized organization again
- Waste management orientation divided into two focus areas: operational optimization and long-term strategy
- Operational Optimization
    - Looking for Technological innovations for waste management
        - Waste sector very conservative
    - Instalment of new containers up to a total of roughly 13.000 in 2019
    - Data collection of waste container weight
    - New operational system to be developed by external partner
    - Dynamic collection process
        - Currently fixed routes and days of waste collection
            - Inefficient due to empty containers: average of 15% fill level
            - Exception is during King’s day and week after Christmas
        - Route optimization
            - Datapoint Amsterdam developed algorithm for waste production prediction
            - Enabling optimization of routes based on predictions
    - Dumping of waste big issue – Waste Tourism
        - Enforcement has to be improved
        - Picture recognition could be a solution
- Waste Management Strategic
    - Percentages of waste separation should be let go, since the focus should be to enable citizens to insert resources back into value chain
        - Even if municipality is losing the opportunity to sell waste to third parties, this is truly sustainable and circular
        - Focus needs to shift from aim of creating a “clean” city to the creation of a circular city
    - Focus on GFT fraction
        - Besides a few exception GFT is not collected on a large scale in Amsterdam
        - It makes up 37% of residual waste
        - Heavy, high potential for reuse and contaminates residual waste
            - Contamination makes separation of residual waste really difficult
            - Elimination of GFT waste from residual waste could allow combined collection of plastic in residual waste.
    - Combination of source and second separation
    - Implementing ways of resource reintegration into daily routine of citizens

        - Diaper collection at daycare locations to be recycled by Procter & Gamble (P&G) in special facility (https://www.nonwovens-industry.com/contents/view_breaking-news/2019-02-19/pilot-diaper-recycling-program-underway-in-amsterdam/13587)
        - Installation of Worm Hotels to offers opportunity to reuse GFT waste locally (https://www.amsterdam.nl/wonen-leefomgeving/zelfbeheer/compost-maken-buurt/)
        - Textile Future fashion
    - DIFTAR or PAYT not possible in Amsterdam
        - Peter de Boer does not believe in the DIFTAR system
        - Different collection processes in suburbs make a DIFTAR system difficult to implement
        - Rather reward citizens for reinserting resources than let them pay for waste

Annex B: Material Flow

Data Cleaning

The waste data collected appears to be of good quality, especially its pragmatic quality is remarkable. High timely and spatial resolution represent a high level of pragmatic timeliness and completeness. The main data quality issues of the data used in this research are related to semantic accuracy, mapping consistency and completeness. The completeness related missing values are rather easy to address. A small number of weight data points does not have a “site_id” and “net_weight”. It is assumed that these are disrupted measuring attempts. Due to this assumption and the small number of missing values they are erased from the data.

Challenging are the accuracy and mapping consistency semantic quality issues of the waste data. Four issues had to be addressed to improve and guarantee sufficient data quality. Negative “net_weight” and “second_weight” values are the first two accuracy related issues, both obviously significantly diverging from real-world values. Negative “net_weight” data points appear to be wrong multiples of other weight data points. Identical data points generated at the same point in time give the impression of a wrongly generated multiple. Data points with a negative “net_weight” are therefore erased from the data. Negative “second_weight” data points result in a significant higher “net_weight”, because the weight of the container itself is not subtracted from the “first_weight”. Since there are no multiples of those data points with the exact same time it is assumed those are unique valid measures. To assure data accuracy the “net_weight” data points with a negative “second_weight” is replaced with the average “net_weight” of that container site and its specific fraction. The defined container site consisting of multiple containers and their ids are not consistent between the Container Side and Kilogram data frame. This case of mapping inconsistency was addressed together with the fourth issue being a semantic accuracy issue. Some data points are assigned the wrong “fractie” during the measuring process. This was discovered by the fact that measures of fractions at places without a container for this fraction appeared. Since the ids of containers sites where different between different data frames the container site information could not be used. However, every measurement comes with a geographic location generated at the moment om measurement via GPS> Every of the roughly 13.000 different containers are listed in detail in a data frame as well. The geographical coordinates of the measurements and the addresses of all containers had to be linked in order to determine the site of measurement and the potential mistake of assigning the wrong fraction to the measurement data. In order to achieve this the addresses of all the containers where transformed into geographical coordinates. By comparing the measuring data location with the geographical coordinates of the containers the closest container to the place of measurement was determined. Analysing the location of a measurement and the containers close by as well as the “net_weight” of the measurement made it possible to detect wrongly assigned fractions to measurements.

Neighbourhoods

Code	Suburb/Neighbourhood	Distance (km)	Considered	Comment
A	**Centrum**			
A00	Burgwallen-Oude	11.1	Not	Due to space constraints not possible to collect residual waste
A01	Burgwallen-Nieuwe	11.1	Not	Due to space constraints not possible to collect residual waste
A02	Grachtengordel-West	9.8	No Residual	Due to space constraints not possible to collect residual waste
A03	Grachtengordel-Zuid	11.6	No Residual	Due to space constraints not possible to collect residual waste
A04	Nieuwmarkt/Lastage	10.6	No Residual	Due to space constraints not possible to collect residual waste
A05	Haarlemmerbuurt	8.7	No Residual	Due to space constraints not possible to collect residual waste
A06	Jordaan	9.5	No Residual	Due to space constraints not possible to collect residual waste
A07	De Weteringschans	13.1	No Residual	Due to space constraints not possible to collect residual waste
A08	Weesperbuurt/Plantage	11.6	No Residual	Due to space constraints not possible to collect residual waste
A09	Oostelijke Eilanden/Kadijken	13.4	No Residual	Due to space constraints not possible to collect residual waste
B	**Westpoort**			
B10	Westelijk Havengebied	1.9	Not	Mostly harbour and commercial area
E	**West**			
E12	Houthavens	8.4	Not	Harbour
E13	Spaarndammer- en Zeeheldenbuurt	7.5	Yes	Big part is park and rail
E14	Staatsliedenbuurt	7.8	Yes	
E15	Centrale Markt	9.5	Yes	Big part is shopping centre
E16	Frederik Hendrikbuurt	9.2	Yes	
E17	Da Costabuurt	9.6	Yes	
E18	Kinkerbuurt	9.5	Yes	
E19	Van Lennepbuurt	9.2	Yes	
E20	Helmersbuurt	11	Yes	

E21	Overtoomse Sluis	9.6	Yes	
E22	Vondelbuurt	10.9	Yes	
E36	Sloterdijk	6.8	Not	Commercial area
E37	Landlust	6.9	Yes	
E38	Erasmuspark	7.5	Yes	
E39	De Kolenkit	5.7	Yes	
E40	Geuzenbuurt	8.5	Yes	
E41	Van Galenbuurt	7.5	Yes	Half is hospital and school
E42	Hoofdweg	7.9	Yes	
E43	Westindische	9.6	Yes	
E75	Chassébuurt	9	Yes	
F	**New-West**			
F11	Bedrijventerrein	2.4	Not	Big commercial area
F76	Slotermeer-Noordoost	4.9	Yes,but	Residual and GFT waste are collected in roll containers once a week
F77	Slotermeer-Zuidwest	5.2	Yes,but	Residual and GFT waste are collected in roll containers once a week
F78	Geuzenveld	3.9	Yes,but	Residual and GFT waste are collected in roll containers once a week
F79	Eendracht	4.3	Not	Mostly agricultural land
F80	Lutkemeer/Ookmeer	8	Not	Mostly agricultural land
F81	Osdorp-Oost	6.1	Yes	
F82	Osdorp-Midden	7.5	Yes	
F83	De Punt	11.8	Yes	
F84	Middelveldsche	11.7	Yes	
F85	Slotervaart-Noord	11.8	Yes	
F86	Overtoomse	7.4	Yes	
F87	Westlandgracht	11.3	Not	Big part is agriculture, rail and commercial area
F88	Sloter-/Riekerpolder	15.2	Not	Big part is agriculture, rail and commercial area
F89	Slotervaart-Zuid	11.8	Yes	Big hospital
K	**South**			
K23	Zuidas	21.6	No	Zuidas commercial area
K24	Oude Pijp	17.2	No residual	Partly sack collection
K25	Nieuwe Pijp	16.2	No residual	Partly sack collection

K26	Zuid-Pijp	16.5	No residual	Partly sack collection
K44	Hoofddorppleinbuurt	9.8	Yes	Half is commercial area
K45	Schinkelbuurt	11	No residual	Partly sack collection
K46	Willemspark	10.6	No residual	Big part is park and partly collected in sacks
K47	Museumkwartier	11.6	No residual	Partly sack collection
K48	Stadionbuurt	13.3	No residual	Big part is football stadium and partly collected in sacks
K49	Apollobuurt	14.6	No residual	Partly sack collection
K52	Scheldebuurt	15.3	Yes	
K53	IJselbuurt	16.4	Yes	
K54	Rijnbuurt	15.5	Yes	
K59	Prinses Irenebuurt e.o.	14.8	Yes	
K90	Buitenveldert-West	14.8	Yes	
K91	Buitenveldert-Oost	15.4	Yes	
M	**East**			
M27	Weesperzijde	21	Yes	
M28	Oosterparkbuurt	21.8	Yes	Big Park
M29	Dapperbuurt	13.5	Yes	
M30	Transvaalbuurt	20.7	Yes	
M31	Indische Buurt-West	13.2	Yes	
M32	Indische Buurt-Oost	13.2	Yes	Big Park
M33	Oostelijk Havengebied	12.5	Yes	Harbour and commercial area
M34	Zeeburgereiland/Nieuwe	19.6	Yes	Island
M35	IJburg-West	21.7	Yes	
M50	IJburg-Oost	21.7	No	
M51	IJburg-Zuid	23.1	Yes	Island
M55	Frankendael	20.7	Yes	Big Park
M56	Middenmeer	26.2	Yes	Big commercial area
M57	Betondorp	19.9	Yes	Big park
M58	De Omval/Overamstel	18.2	No	Big commercial area
N	**Nord**			
N60	Volewijck	15.6	Yes	
N61	IJplein/Vogelbuurt	18.1	Yes	
N62	Tuindorp Nieuwendam	18.9	Yes	

N63	Tuindorp Buiksloot	17.1	Yes	
N64	Nieuwendammerdijk/Buiksloterdijk	18.2	No	
N65	Tuindorp Oostzaan	12.5	Yes	
N66	Oostzanerwerf	10.7	Yes	
N67	Kadoelen	12.8	Yes	Partly lake
N68	Waterlandpleinbuurt	18.4	Yes	
N69	Buikslotermeer	15.7	Yes	
N70	Banne Buiksloot	14.1	Yes	
N71	Noordelijke IJ-oevers-West	16.2	No	Big commercial and harbour area
N72	Noordelijke IJ-oevers-Oost	17.9	No	
N73	Waterland	21.2	No	
N74	Elzenhagen	16.3	No	
T	**Bijlmer**			
T92	Amstel III/Bullewijk	22	No	Big commercial area
T93	Bijlmer-Centrum	21.2	No residual	Partly containers
T94	Bijlmer-Oost	22.6	No residual	Partly containers
T95	Nellestein	30.1	No residual	Partly containers
T96	Holendrecht/Reigersbos	27.7	No residual	Partly containers
T97	Gein	28.7	No residual	Partly containers
T98	Driemond	31.1	No residual	Partly containers

Mass Balance

The formulas of all calculations for the mass balance are listed in this chapter. First, all variables are explained. Second, is a list of formulas for all flows and stocks.

Variables

x= Waste type

t= Time step in month

f= Capacity waste transport vehicle

L = Distance between collection area and treatment facility

s_x = Separation percentage of type x

f_x= Percentage of waste type x in residual waste

I_h= Heat energy per ton waste

I_p= Electricity per ton waste

S_t^x = Separated waste of type x at timestep t

R_t = Residual waste at timestep t

E_T = Emissions per ton waste and km ridden

E_S = Emissions per ton waste separated

E_I = Emissions per ton waste incinerated

EX_R = Emissions per ton waste reproduced of waste type X

$D_t^{in\,x}$ =Disposed waste of type x inflow at timestep t

SX_t^{out} = Separated waste outflow of type x at timestep t

SXT_t^{in} = Separated waste transport inflow of type x at timestep t

SXT_t^{out} = Separated waste transport outflow of type x at timestep t

SXS_t^{in} = Second separation inflow separated waste of type x at timestep t

SXS_t^{out} = Second separation outflow separated waste of type x at timestep t

SXR_t^{in} = Reproduction inflow separated waste of type x at timestep t

XR_t^{out} = Reproduction outflow material of type x at timestep t

RX_t^{out} = Non-Separated waste outflow of type x at timestep t

RXT_t^{in} = Non-Separated waste transport inflow of type x at timestep t

RXT_t^{out} = Non-Separated waste transport outflow of type x at timestep t

RXI_t^{in} = Incineration inflow non-separated waste of type x at timestep t

$ETS_t^{out\,x}$ = Emissions transport outflow separated waste of type x at timestep t

$ETR_t^{out\,x}$= Emissions transport outflow non-separated waste of type x at timestep t

$ESS_t^{out\,x}$ = Emissions second separation outflow separated waste of type x at timestep t

$EIR_t^{out\,x}$ = Emissions incineration outflow non-separated waste of type x at timestep t

$HIR_t^{out\,x}$= Heat energy generated by burning waste of type x at timestep t

$PIR_t^{out\,x}$= Electricity generated by burning waste of type x at timestep

Formulas

Disposed Waste

$$D_t^{in\,x} = S_t^x + R_t * f_x \qquad (1)$$

$$RX_t^{out} = D_t^{in\,x} * (1 - s_x) \qquad (2)$$

$$SX_t^{out} = D_t^{in\,x} * s_x \qquad (3)$$

Transported Waste Separated Waste

$$SXT_t^{in} = SX_t^{out} \qquad (1)$$

$$ETS_t^{out\,x} = \frac{SXT_t^{in}}{f * L} * (E_T * D) \quad (2)$$

$$SXT_t^{out} = SXT_t^{in} \qquad (3)$$

Transported Non-Separated Waste

$$RXT_t^{in} = RX_t^{out} \qquad (1)$$

$$ETR_t^{out\,x} = RXT_t^{in} * f * (E_T * L) \qquad (2)$$

$$RXT_t^{out} = RXT_t^{in} \qquad (3)$$

Second Separation Separated Waste

$$SXS_t^{in} = SXT_t^{out} \qquad (1)$$

$$ESS_t^{out\,x} = SXS_t^{in} * E_T \qquad (2)$$

$$SXS_t^{out} = SXS_t^{in} * L_S + \sum_{i=m}^{n} SXS_t^{in} * f_m \qquad (3)$$

Incineration Non-Separated Waste

$$RXI_t^{in} = RXT_t^{out} + SXS_t^{in} * L_S \qquad (1)$$

$$EIR_t^{out\,x} = RXI_t^{in} * E_I \qquad (2)$$

$$HIR_t^{out\,x} = RXI_t^{in} * I_H \qquad (3)$$

$$PIR_t^{out\,x} = RXI_t^{in} * I_P \qquad (4)$$

Reproduction Separation Separated Waste

$$SXR_t^{in} = SXT_t^{out} \quad \sum_{i=m}^{n} SXS_t^{in} * f_m \qquad (1)$$

$$ESS_t^{out\,x} = SXR_t^{in} * EX_R \qquad (2)$$

$$XR_t^{out} = SXR_t^{in} * L_{RX} + \sum_{i=m}^{n} SXR_t^{in} * f_m \qquad (3)$$

Annex C: Statistical Analysis

Time Series

Descriptive Tables Separated Waste

Center

	A02	A03	A04	A05	A06	A07	A08	A09	mean
count	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00
mean	0,64	1,81	3,69	2,92	4,29	0,83	1,55	2,59	2,29
std	0,25	0,58	1,58	1,31	2,36	0,24	0,47	1,23	0,78
min	0,38	0,81	1,24	0,69	0,72	0,56	0,90	1,13	0,88
25%	0,50	1,41	2,65	2,03	2,91	0,66	1,18	1,54	1,88
50%	0,53	1,99	3,76	2,98	3,72	0,77	1,58	2,09	2,19
75%	0,68	2,24	4,78	3,90	6,17	0,93	1,78	3,78	2,79
max	1,28	2,55	6,44	4,78	7,66	1,26	2,42	4,30	3,52

East

	M27	M28	M29	M30	M31	M32	M33	M34	M35	M51	M55	M56	M57	mean
count	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00
mean	1,31	1,69	1,07	1,07	2,06	1,12	4,26	0,53	2,64	0,80	1,95	3,60	0,56	1,74
std	0,41	0,44	0,51	0,27	0,79	0,52	1,67	0,35	1,00	0,38	0,61	1,11	0,19	0,49
min	0,71	0,91	0,30	0,54	0,72	0,07	0,67	0,15	1,45	0,29	0,76	1,58	0,34	0,83
25%	0,98	1,45	0,74	0,95	1,56	0,92	3,11	0,27	1,85	0,54	1,70	3,42	0,40	1,37
50%	1,38	1,70	0,98	1,02	2,17	1,05	4,46	0,34	2,43	0,74	2,04	3,68	0,51	1,80
75%	1,65	1,92	1,37	1,22	2,64	1,48	5,60	0,80	3,34	1,04	2,46	4,01	0,71	2,14
max	1,84	2,41	2,14	1,60	3,11	1,85	6,86	1,08	4,76	1,46	2,63	5,43	0,91	2,35

New West

	F76	F77	F78	F81	F82	F83	F84	F85	F86	F87	F88	F89	mean
count	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00
mean	0,98	1,42	1,04	1,37	1,25	0,47	1,42	0,84	1,10	1,89	2,37	1,06	1,27
std	0,55	0,55	0,46	0,49	0,59	0,31	0,71	0,46	0,49	0,91	1,03	0,49	0,49
min	0,00	0,16	0,16	0,68	0,10	0,00	0,21	0,00	0,17	0,30	0,55	0,18	0,23
25%	0,75	1,23	0,83	0,96	0,90	0,27	0,88	0,55	0,91	1,23	1,43	0,67	1,01
50%	1,11	1,53	1,10	1,45	1,41	0,55	1,53	0,84	1,17	2,05	2,48	1,16	1,38
75%	1,20	1,72	1,42	1,66	1,61	0,74	1,84	1,24	1,35	2,44	3,22	1,36	1,64
max	1,99	2,32	1,66	2,08	2,21	0,84	2,83	1,59	1,93	3,07	3,76	1,89	1,78

North

	N61	N62	N63	N65	N66	N67	N68	N69	N70	mean
count	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00
mean	1,20	0,60	0,00	1,52	1,36	0,28	1,14	1,47	1,26	0,98
std	0,63	0,33	0,00	0,74	0,55	0,16	0,44	0,62	0,59	0,33
min	0,04	0,07	0,00	0,48	0,39	0,00	0,48	0,62	0,52	0,29
25%	1,03	0,39	0,00	1,16	1,01	0,13	0,76	1,07	0,79	0,86
50%	1,13	0,53	0,00	1,42	1,37	0,35	1,25	1,38	1,06	1,03
75%	1,47	0,83	0,00	1,74	1,76	0,43	1,47	1,64	1,77	1,19
max	2,47	1,18	0,00	2,96	2,31	0,45	1,76	2,89	2,28	1,37

South

	K24	K25	K26	K44	K45	K46	K47	K48	K49	K52	K53	K54	K59	K90	K91	mean
count	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00
mean	3,21	1,90	0,82	2,14	0,01	0,88	1,66	2,20	1,87	1,98	0,52	0,41	0,57	2,13	1,01	1,42
std	0,88	0,57	0,24	0,51	0,03	0,35	0,51	0,57	0,68	0,47	0,28	0,17	0,20	0,77	0,39	0,31
min	1,90	1,03	0,35	1,22	0,00	0,41	0,98	1,17	0,91	1,16	0,14	0,19	0,32	0,62	0,56	0,89
25%	2,46	1,51	0,70	1,81	0,00	0,56	1,17	1,70	1,42	1,85	0,34	0,33	0,43	1,67	0,64	1,26
50%	3,23	1,75	0,82	2,15	0,00	0,88	1,70	2,38	1,90	1,92	0,52	0,37	0,54	2,38	1,05	1,49
75%	3,92	2,29	0,87	2,64	0,00	1,09	1,95	2,55	2,23	2,36	0,64	0,45	0,65	2,63	1,23	1,60
max	4,55	2,93	1,32	2,81	0,08	1,58	2,51	3,14	2,96	2,66	1,04	0,84	1,03	3,15	1,69	1,80

West

	E13	E14	E15	E16	E17	E18	E19	E20	E21	E22	E37	E38	E39	E40	E41	E42	E43	E75	mean
count	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
mean	1,49	4,77	1,37	5,11	1,61	2,33	5,70	2,34	5,24	0,11	3,38	0,21	0,84	1,34	1,61	2,32	6,22	1,05	2,61
std	0,89	4,56	1,21	7,11	1,49	2,18	6,41	1,58	4,89	0,11	2,58	0,16	0,43	0,69	1,50	1,71	9,51	0,95	2,23
min	0,11	0,45	0,14	0,10	0,31	0,00	0,11	0,49	0,23	0,00	0,28	0,00	0,16	0,21	0,12	0,39	0,30	0,00	0,19
25%	1,02	1,73	0,70	0,56	0,73	0,68	0,84	1,38	1,56	0,00	1,91	0,10	0,49	0,79	0,52	1,14	0,94	0,38	0,97
50%	1,26	2,54	1,13	0,70	1,14	1,14	1,72	2,11	2,18	0,12	2,49	0,18	0,87	1,46	1,09	1,99	1,91	0,76	1,86
75%	1,87	7,26	1,63	9,59	1,83	3,88	9,88	2,73	9,10	0,18	4,08	0,27	1,13	1,60	2,38	2,62	6,72	1,52	3,79
max	3,43	13,86	4,82	19,49	5,10	6,06	17,10	6,65	12,67	0,35	9,88	0,61	1,45	2,58	4,72	5,85	31,82	3,42	7,38