Utrecht University

Master Thesis

TOWARDS WASTE MANAGEMENT IN A CIRCULAR ECONOMY

POLICY EFFECTS ON WASTE FLOWS IN THE MUNICIPALITY OF UTRECHT

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ABSTRACT

Current global resource extraction, consumption and disposal patterns are unsustainable. In recent years, the notion of a Circular Economy has gained increasing attention as a possible means to address this. The transition to a circular economy requires effective waste management. This thesis explores waste management policy in the municipality of Utrecht in order to determine to what extent municipal policies are contributing to the realization of waste management in the context of a circular economy. To this end, the manner in which municipal policy has been translated into interventions in the waste system of Utrecht has been studied for the period between 2015 and 2017. In addition, two material flow analyses of household waste in Utrecht were constructed for this period, and the changes in composition, mass and quality were analyzed in relation to the interventions. The main findings suggest that municipal policy has contributed to increasing waste separation and recycling rates, and reducing residual waste and incineration. With regards to waste separation and residual waste the municipality is on track to achieve its own stipulated targets. However, national targets are found to be out of reach with current policies. Furthermore, the quality of the collected waste has decreased, possibly due to perverse influence of national targets on waste management priorities. Finally, it is found that the current interventions address only a subset of the waste management strategies and apply only to a subset of the waste system. Recommendations are given for continued collaboration between *Stadsbedrijven* and the Copernicus institute in order to develop a decision support tool with which to plan, implement and evaluate interventions for waste management in a circular economy.

1. INTRODUCTION

1.1. PROBLEM BACKGROUND

Global material extraction has tripled in the past four decades to a level where it would take 1.64 earths to generate in one year the natural resources consumed in 2016 (Schaffartzik et al., 2014; Global Footprint Network, 2016). In light of this resource overexploitation and the associated environmental burdens it seems increasingly sensible to re-examine the nature of our economies (Iacovidou et al., 2017; Demirbas, 2011). Central to the current economic model is the linear progression of material extraction, production, consumption and disposal (EEA, 2016). This linear model can be contrasted with the notion of a 'circular economy' (CE), in which material and energy loops are closed while preserving and fostering economic, social and environmental value (Geissdoerfer et al., 2017; Kircherr et al., 2017). The concept of a circular economy, which owes intellectual debt to a wide range of academic disciplines, has recently gained increasing attention among academics, policymakers and practitioners (Reike et al., 2018; Kircherr et al., 2017).

The transition to a circular economy entails a reconsideration of the value of waste, as waste is treated as a potential resource in order to realize raw material savings (Lee et al., 2017). The availability of high-quality, secondary material inputs from waste that can be fed into production processes depends on the existence and management of resource recovery routes (Singh & Ordoñez, 2016). Consequently, waste management has a key role to play in increasing the sustainability of resource management, and can be situated as a main component of the transition to a circular economy (Lee et al., 2017; Cobo et al., 2018; EC, 2019).

Due to the relative novelty of the circular economy concept, research on waste management in relation to a circular economy is in its infancy (Lee et al., 2017). In order to aid the transition and generate more scientific knowledge, the link between waste management at a municipal level and the transition to a CE is further explored in this thesis by looking at waste management in the municipality of Utrecht as a case study.

In 2016 the Dutch Government released a government-wide CE policy program in which it formulates the ambition to achieve a fully circular economy by 2050 (Rijksoverheid, 2016). In order to achieve the national CE ambitions, a large responsibility is given to municipalities (Ibid). Municipal waste is one of the most polluting waste streams and has a high potential for improvement, and as such it is of interest for the transition to a CE (Lee et al., 2017). Municipal waste covers waste generated by households and waste similar in nature and composition to household waste (Eurostat, 2019). Municipalities are free to develop their own waste management systems, coupled to national performance targets. The current national targets are to increase the amount of waste separation of household waste to 75% by 2020 and to reduce the amount of residual household waste to less than 100kg/inhabitant by 2020, for each municipality of the Netherlands (Rijkswaterstaat, 2017).

In the municipality of Utrecht inhabitants produced an average of 233kg residual waste per person in 2015, and waste separation was carried out to a level of 42% (Gemeente Utrecht, 2017). Residual waste is collected at a facility situated next to the Amsterdam-Rhine canal, from which it is transported by ship to an incineration facility in Rotterdam. This can be considered suboptimal waste management that results in decimation of valuable materials and violates the principles of a circular economy (Geissdoerfer et al., 2017).

1.2. Scope and Aim

Since 2015 the municipality of Utrecht has started to reorganize the waste management system guided by the notion of waste as a potential resource (Gemeente Utrecht, 2016). The reorganization is given shape by multiple policy ambitions including reversed logistics waste collection (dubbed *'Het Nieuwe Inzamelen'*), 'smart'-collection logistics using sensors, food-waste awareness campaigns, and post-separation of residual waste. These interventions aim to make the waste landscape more 'circular', and to achieve national household waste targets (Gemeente Utrecht, 2016). The municipality of Utrecht has started translating these policy ambitions into new practices since 2015, and aims to complete implementation by 2021. While ambitious, the impacts of the reorganization and its relation to the overarching national transition to a circular economy are not yet clear, and it is not known whether current policy measures are capable of producing the effects required for the transition to a CE.

1.3. Thesis Objective and Structure

The main objective of this thesis is to answer the following research question: ***To what extent are the waste management policies of the municipality of Utrecht contributing to the realization of waste management in the context of a circular economy?*** In support of this question, the following sub questions have been answered:

1. How has the composition, mass, trajectory and quality of waste flows in Utrecht changed between 2015 and 2017?
2. What part of this change can be attributed to municipal policies?
3. What are the impacts of the changes in waste flows in relation to the strategies and targets of waste management in a circular economy?

The rest of this thesis is structured as follows. In chapter 2 the key concepts relevant for answering the research question are elaborated upon. In addition, a framework is presented with which to assess the circularity of waste management. In chapter 3 the methods that have been used are described, subdivided according to the four phases of the research. In chapter 4 the results of the research are presented. Chapter 5 discusses these results in relation to the theoretical framework and provides recommendations. In Chapter 6 the research question is answered and conclusions are drawn.

2. THEORETICAL FRAMEWORK

In order to examine the role that municipal waste management plays in the overarching national transition to a circular economy an analysis of the concept of circular economy is provided. In addition, the notion of waste management within a circular economy, and how this translates to waste management on a municipal level is explored. Next, the waste system of Utrecht is described. Lastly, indicators for measuring circular waste management are presented.

2.1. CIRCULAR ECONOMY

The concept of circular economy has gained widespread attention in the past years, as indicated by the rapid growth in the amount of peer-reviewed articles on the topic: from around 30 articles in 2014 to more than 100 articles in 2016 (Geissdoerfer et al., 2017). While often presented as a novelty, the concept of circular economy builds on a legacy of predecessors like waste recycling and separation, industrial ecology, eco-industrial parks and industrial symbiosis (Reike, Vemeulen & Witjes, 2018). Because of this broad background and widespread attention, many different definitions are circulating.

In their 2017 paper Kircherr et al. perform an analysis of 114 existing definitions of circular economy as found throughout the literature in order to come to a harmonized conceptualization. The circular economy is conceptualized as a move away from the current unsustainable linear production system of "take-make-waste" to a circular system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. (EEA, 2016; Geissdoerfer et al., 2017; Singh & Ordonez, 2016). It is often noted that CE requires fundamental systemic changes simultaneously at the micro, meso and macro level (Kircherr et al, 2017).

Scientific papers generally note that CE requires a holistic view on the three dimensions of sustainability: environmental quality, economic prosperity and social equity (Geisdoerfer et al., 2017). In contrast, Reike et al. (2018) note that especially consultancies and policy documents tend to embed CE into the current economic paradigm focusing only on economic growth, rather than on the holistic systemic change that CE requires.

With regards to materials and waste it can be stated that a circular economy aims at reduced consumption of natural resources, reduced waste and emissions, sustainable resource extraction, and security of supply of resources (Potting et al., 2017). In order to realize waste prevention and the supply of high-quality secondary resources waste management needs to be an integral component of the circular economy (Lee et al., 2017).

2.2. WASTE MANAGEMENT IN A CIRCULAR ECONOMY

Waste management encompasses the collection, transport, processing, recycling or disposal, and monitoring of waste materials (Demirbas, 2011). A waste management system can be seen as a system whose main input is waste and which consists out of a number of processes to sort this waste, and to give each fraction of this waste the most suitable treatment according to its composition and the desired function of the outputs (Cobo et al., 2018).

Circular waste management concerns a waste management system that seeks to enhance the circularity of resources by strengthening the links between collection and resource recovery. Thus, circular waste management can be seen as one of the instruments that helps to fulfill the goals of a circular economy (Cobo et al., 2018). Figure 1 gives a schematic overview of where waste management (WM) is situated in the process of closing material cycles within an idealized socio-economic system (Singh & Ordonez, 2016). The specific WM system of Utrecht is presented in section 2.3.

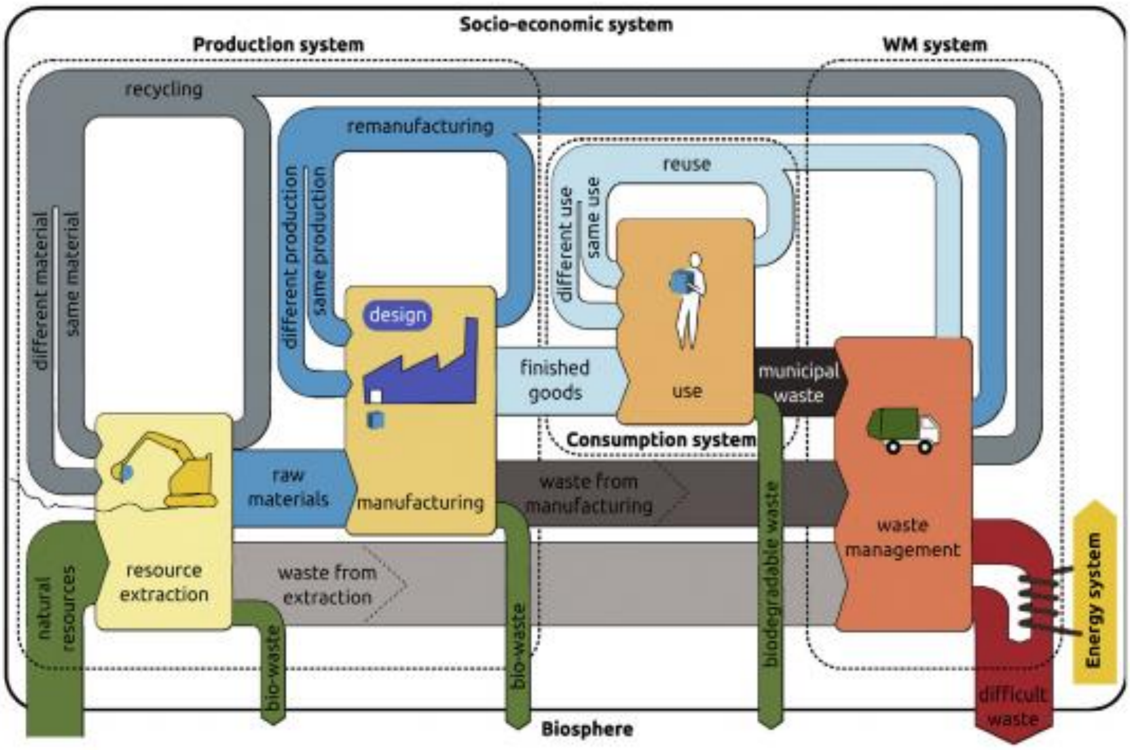


Figure 1. Waste management in a socio-economic system (Singh & Ordonez, 2016)

Waste, and municipal waste in particular, consists of a complex mix of heterogeneous materials, meaning that it cannot be treated in a single manner or by a single technology (Cobo et al., 2018). In order to differentiate the actions for processing, recycling and disposal according to the level of value that can be kept in the cycle, a material hierarchy can be employed (Lansink & de Vries, 2010; Kircherr et al., 2017).

2.2.1. Material Hierarchy

The inclusion of a material hierarchy, in the form of a R-framework, is seen as a core operationalization principle of a CE (Kircherr et al., 2017). Such an R-framework details value retention options for products and waste streams. An example of such a hierarchy is the *Ladder van Lansink*, which has been used throughout Dutch policymaking since its conception in 1979 (Lansink & de Vries, 2010). Since 2008, all EU Member States are directed to follow a waste management hierarchy, unless adequately justified by a life cycle assessment (EP and EC, 2008).

Currently, many variations of the R-framework are in circulation. For this research the framework by Potting et al (2017) is employed, as it is a distillation of many different existing frameworks. It shows a 10-step hierarchy of strategies that contribute to the realization of a circular economy (Potting et al., 2017). Figure 2 gives an overview of the 10-R strategies.

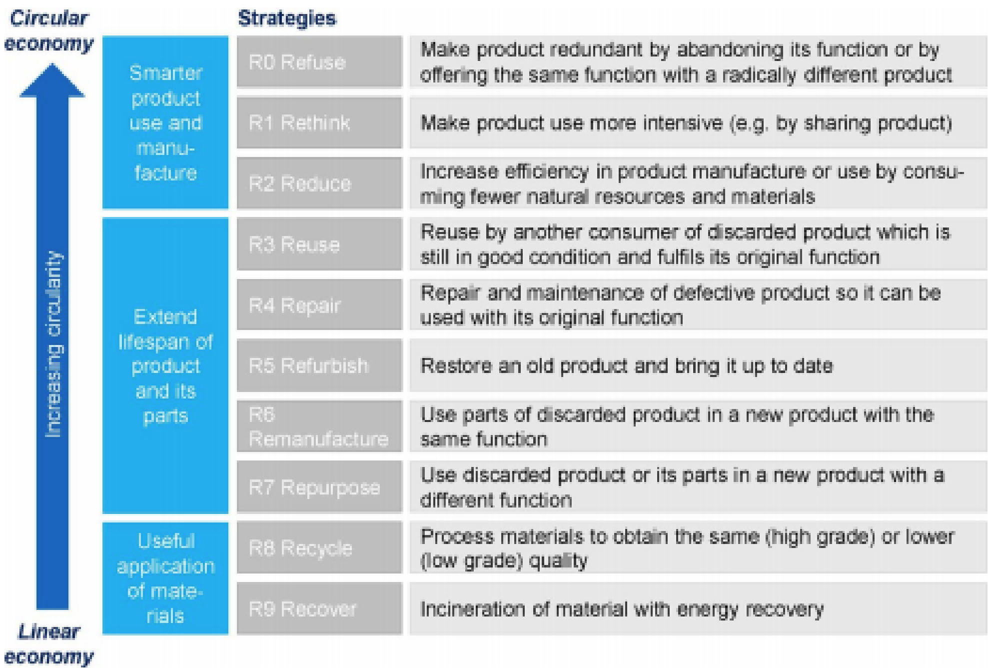


Figure 2. 10R Framework (Potting et al., 2017)

It can be seen that the majority of strategies focus on preventing discarded products becoming waste, focusing rather on cycling these products in shorter socio-economic loops (Potting et al., 2017). Smarter product use and manufacture in addition to extending the lifespan of a product and its parts have priority in a circular economy over processes that focus on useful application of materials in the discarded products (Potting et al., 2017).

In an ideal CE products are designed and optimized to eliminate waste by reducing material consumption, enabling efficient reuse, disassembly and refurbishment through strategies R0 to R7 (Singh & Ordonez, 2016). In the current predominantly linear system however, there is a lot of mixed waste (e.g. packaging waste) that ends up at the 'bottom' of the hierarchy, and is consequently incinerated or sent to landfills (Polzer & Persson, 2015). For these waste flows the resources can be recovered through recycling and energy recovery (R8&R9). As such, recycling and recovery activities remain important components of a waste management system, and require separate recovery routes (Singh & Ordonez, 2016).

2.2.2. Recovery Routes

Material recovery from waste depends on the existence of resource recovery routes and a subsystem for materials sorting (Cobo et al., 2018). For recycling of municipal waste, sorting can either be achieved through source sorting, where consumers offer their waste in separated fractions (multi-stream collection), or through a post-separation process where different materials are separated mechanically and/or through manual labor after being collected in a single-stream (Cobo et al., 2018; Mueller, 2013). The sorted products and materials are then offered or sold to actors facilitating remanufacturing and refurbishment, or to recycling facilities and industries (Haupt et al., 2017).

Because of the importance of quality of the recycled materials, the choice for source or post-separation can depend on the materials in question, and the manner in which the separation can be executed. One of the concerns of municipal waste management is the prevention of pollution of different waste streams in the collection process (Lee et al., 2017). With source separation there is less mixing of waste streams that can potentially pollute each other, thus ensuring higher quality of the waste streams (Lee et al., 2017).

To assess the efficiency of recovery routes, recycling rates can be used (Haupt et al., 2017). The recycling rate of a given material is defined as the input into the last recycling step (after sorting out impurities), in relation to the amount of goods consumed (EC, 2015). As information on the quality of secondary materials is often not communicated, it is difficult to determine the precise amount of material savings achieved through recycling (Geyer et al., 2015).

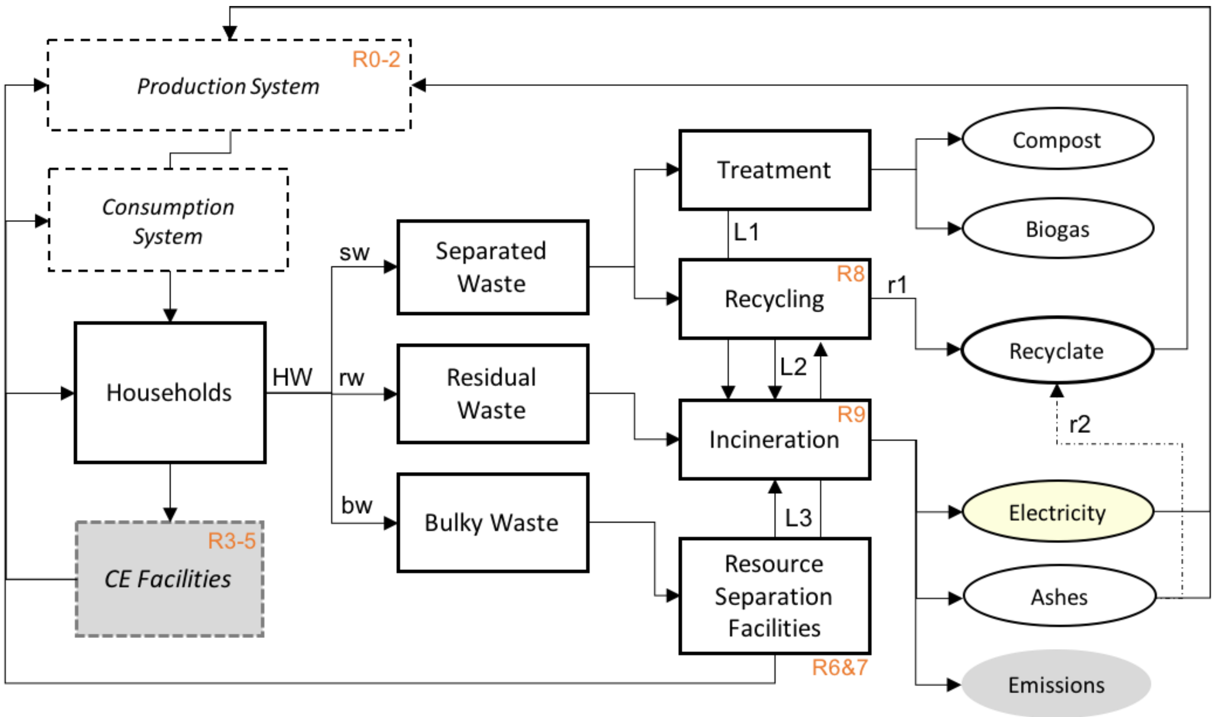
2.2.3. Household waste generation

Optimizing planning and operation of waste management requires information on the amount of waste generated in a given region and on the composition of the waste streams (Bandara, 2007; Beigl et al., 2004). This means there is a demand for reliable data on the amounts and types of waste, which is generally difficult to achieve on a disaggregated level (Beigl et al., 2008). In order to address this, waste generation forecasting based on modeling techniques are often employed (e.g. Beigl et al. 2004; Dyson & Chang, 2005). Beigl et al (2004) present a model for forecasting municipal solid waste generation in major European cities. In this model Gross Domestic product, age structure, and household composition were found to have significant impact on the amount of municipal solid waste generated (Beigl et al., 2004). This aligns in part with the findings of Mazzanti & Zoboli who identify three main drivers of waste generation: economic, structural and policies (Mazzanti & Zoboli, 2008).

2.3. Waste in Utrecht

In the municipality of Utrecht, the department *'Stadsbedrijven'* is responsible for the development and execution of waste policy and the management of the waste system.

The waste system of Utrecht concerns itself with the collection of municipal waste, the operation of three resource separation facilities (RSF), and the establishment of contracts and logistics with regional and national processers and recyclers (Gemeente Utrecht, 2016). The waste system of Utrecht corresponds to the schematically depicted 'WM system' in figure 1, and it is situated in the larger socio-economic system of resource extraction, production and consumption. For household waste in Utrecht specifically, the waste management subsystem has been mapped out in more detail in figure 3. Where applicable, the strategies of a CE are included in the system. The system element labeled *'CE Facilities'* will be discussed at the end of this thesis.



The strategies (R0-R9) of a CE are depicted in orange where applicable. Losses occurring during processing of waste due to contamination are depicted as L1, L2 & L3. Recovered materials from bottom ash after incineration are indicated with r2. The total amount of waste separation (%) is calculated as ((sw+bw-L3)/HW). The amount of source separation (%) is calculated as (sw/HW). The recycling rates (%) of individual materials are calculated as (r1+r2/HW).

Figure 3. Waste management system for Utrecht household waste (Own work, 2019).

Municipal waste consists of waste generated by households and waste similar in nature and composition to household waste, and includes packaging and food waste (EC, 2017). Table 1 provides an overview of the waste fractions present in Utrecht, the manner in which they are handled, and the contracts for processing and recycling.

WASTE FRACTIONS	COLLECTED	ACCEPTED AT RSF	CONTRACT WITH PROCESSER
Organic waste	X	X	Attero in Wilp
Plastic, metal & drink cartons (PMD)	X	X	Suez in Rotterdam
Glass	X	X	Maltha glasrecycling in Heijningen and Emmen
Paper & cardboard	X	X	Peute Recycling in Dordrecht

Clothing & textiles	X	X	Leger des Heils ReShare in Utrecht
Residual waste	X	X	AVR afvalverwerking in Rotterdam
Consumer electronics		X	WeCycle
Chemical waste		X	
Metal		X	
Wood		X	
Debris		X	

Table 1. Waste fractions (adapted from Gemeente Utrecht, 2017).

The waste policy of the municipality of Utrecht, shown in table 2, complies to national policy with regards to the following programs: *Nederland circulair 2050*; *LAP3: Landelijk afvalbeheerplan*; and *VANG: Van afval naar grondstof* (Gemeente Utrecht, 2016).

In these documents the ambitions of realizing a fully circular economy by 2050 are outlined, and translated into specific waste objectives. With regards to household waste the targets are to realize 75% waste separation by 2020, and to reduce the amount of residual waste per inhabitant to below 100 kg in 2020 (Rijkswaterstaat, 2017). The manner in which these are calculated is congruent with calculations in figure 3. With regards to virgin material consumption and emissions an interim target is given for a 50% reduction by 2030 for the whole of the Netherlands (Rijksoverheid, 2016). The manner in which this is calculated is not elaborated upon; for this research, the production of secondary materials and emissions resulting from incineration are taken into account (detailed in section 2.4).

To meet national targets and ensure that waste is treated as a resource at a high level of quality the municipality has identified three points for policy intervention in the waste management process (Gemeente Utrecht, 2016). These are the collection of household waste fractions, the processing (recycling and reuse) of separated waste fractions, and the processing of residual waste (Gemeente Utrecht, 2016). The first point of intervention, the collection of household waste fractions, has been developed into a new reversed logistics collection scheme called 'Het Nieuwe Inzamelen' (HNI).

Document Type	Title	Focus
Policy report 2015 - 2018	Waste as a resource	Circular economy and waste policy for the period 2015 - 2018
Enforcement directive 2018	Public space and built environment	Reflection on the period 2015 – 2018 and focus on affecting behavioral change
Web resource	'Het Nieuwe Inzamelen'	Explanation of new collection system and information for citizens

Table 2. Policy documents

2.3.1. Het Nieuwe Inzamelen

In 2015, after a pilot experiment in the neighborhood of Lunetten, the municipality of Utrecht decided to transition nearly the entire waste system of Utrecht to a new manner of reversed collection logistics, 'Het Nieuwe Inzamelen' *or* 'The New Way of Collecting' (Geldof, 2016). Figure 4 gives an overview of the collection facilities under HNI.

** An asterisk indicates the facility was added under HNI compared to the pre-HNI situation*

Figure 4. Facilities under HNI in Utrecht (adapted from Gemeente Utrecht, 2016)

In the old waste system in Utrecht residual waste was collected on a bag-by-bag basis and facilities existed for depositing glass, textile and paper & cardboard. Under HNI, residual waste is disposed of in underground containers, and more fractions are collected separately by the municipality. The separately collected fractions are paper & cardboard, plastic, metal & drink cartons (PMD), and organic waste. For high-rise and low-rise the manner of collection differs. For low-rise residential areas, which are generally more spacious, individual containers are provided by the municipality to each household. For high-rise residential areas, which make up 57% of all households in Utrecht, collective containers are installed in communally accessible areas (Geldof, 2017). For both high- and low-rise residential areas general facilities exist for the disposal of residual waste, glass and textiles (Gemeente Utrecht, 2016).

2.4. Measuring Circular Waste Management

Waste management policy in the municipality of Utrecht, and the accompanying practices, aim to induce changes in the composition, mass, trajectory and quality of waste flows. The changes in these flows can be measured in relation to how they work towards achieving waste targets, and how they enable the hierarchy of circular strategies to be respected. Figure 3, section 2.3, includes an overview of the 10R strategies relevant to the waste system of Utrecht.

The 10R-framework can be used to assess how waste practices contribute to the realization of a circular economy by looking at the extent to which the municipal waste practices enable or hamper the realization different strategies (Potting et al., 2017; Kircherr et al., 2017). Additionally, waste practices can be assessed by looking at how they work towards achieving quantitative targets of a circular economy as set out by the national government (Cobo et al., 2018; Rijksoverheid, 2016).

2.4.1. Indicators for waste in Utrecht

In order to assess how changes in municipal waste practice effect both strategies and targets of a circular economy the following indicators can be taken into account.

Total Waste
Ideally, a circular economy is a zero-waste economy (Rijksoverheid, 2016). The total amount of waste shows how far removed we are from this ideal situation. A reduction in the amount of total waste can be an indication of the extent to which strategies R0-R5 are being carried out effectively, as can be seen in section 2.3, figure 3. While less total waste is an indication that the circularity of the waste management has increased, care should be taken to account for other factors (e.g. economic & structural changes) influencing waste generation (Beigl et al., 2004).

Residual Waste & Incineration
In the current system all residual waste is sent to incineration (R9), the least desirable strategy. As such, the amount of incineration serves as a proxy to indicate the extent to which strategies R0-R8 are carried out effectively. Less residual waste and less incineration indicate the circularity of the waste management has increased (Lee et al., 2017). In alignment, the national target for municipal waste is set at a reduction of residual waste to less than 100 kg per inhabitant in 2020 (Rijkswaterstaat, 2017).

Waste Separation & Degree of Contamination
Waste separation is achieved through source separation by individual households of waste fractions mentioned in section 2.3, table 1. In addition, it consists of the amount of waste separated in post-separation processes at the resource separation facilities. Waste separation is a prerequisite condition for strategies R6 (Remanufacture), R7 (Repurpose) and R8 (Recycle) (Lee et al., 2017). In addition, the national target for municipal waste separation is set at 75% in 2020 (Rijkswaterstaat, 2017).

The degree of contamination speaks to the quality of the separated material, and the potential use of the material for further recycling processes (Geyer et al., 2015). Increased waste separation with less contamination is an indication of a more circular waste system (Cobo et al., 2018).

Recycling Rates & Secondary Material Produced
Recycling rates of materials reflect the entire process of resource recovery: from the amount of resources contained in waste leaving the households to the input into the last recycling step (EC, 2015). In addition, recycling rates provide information about secondary materials that can be produced from waste (Haupt et al., 2017). Recycling rates indicate the efficiency with which strategy R8 (recycling of materials) is carried out. As highlighted in section 2.2, this is an important strategy for dealing with household waste (Singh & Ordonez, 2016).

CO_2 Emissions
Carbon emission arise from both transport and processing of waste. The reduction of emissions is one of the main aims of the circular economy in general, and of the 'Nederland Circulair 2050' targets in specific (Rijksoverheid, 2016). As such, the change in emissions

resulting from the implementation of new waste practices give an indication of the circularity of the waste management system.

3. METHODS

3.1. RESEARCH SETUP

The aim of this research has been to understand the extent to which waste management practices resulting from municipal policy in the municipality of Utrecht are contributing to the realization of waste management in the context of a circular economy. Figure 5 gives a visual overview of the four phases of the research process, the elements under study, and the methods that have been used.

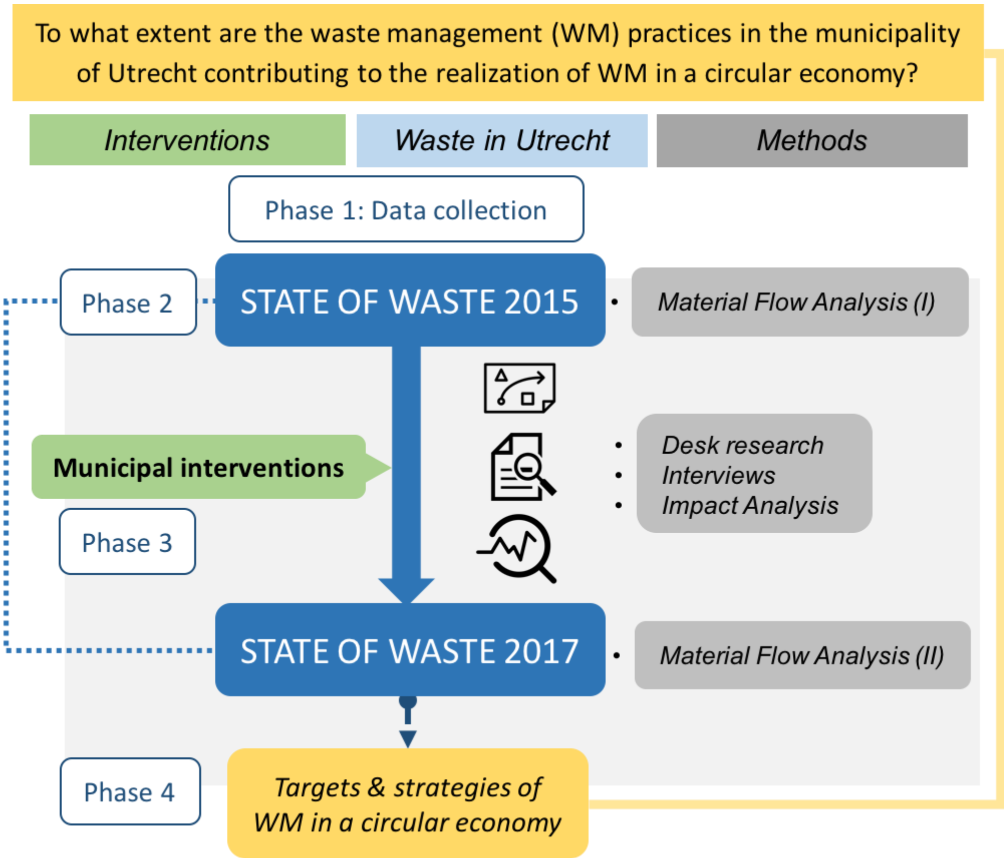


FIGURE 5. RESEARCH PHASES AND METHODS

At the start of the research communication was established with the municipality of Utrecht in order to gain insight into the workings of the waste system of Utrecht and to secure access to data sources. Data collection and organization are detailed in phase 1. Next, in phase 2 the methods for constructing, visualizing, analyzing and comparing the waste flows in Utrecht for the years 2015 and 2017 are presented. Phase 3 of the research concerns itself with determining the effect that the municipal interventions have had on the waste system in Utrecht. Lastly, phase 4 details how the values of the key variables were calculated for both 2015 and 2017.

3.2. Research Methods

3.2.1. Phase 1: Data collection and organization

The first step in the research process was establishing communication with the department responsible for waste management in the municipality of Utrecht and securing access to data sources. Waste management in the municipality of Utrecht is a task of the department *'Stadsbedrijven'*. The office is located at *Tractieweg 81*. Communication with the department was established in August 2018. Within the department, four central figures have been contacted. Their names and function titles are presented in table 5.

Name	Function Title (Dutch)
Ralph van der Zant	Unithoofd Gescheiden Inzamelen
Wanda Sloos	Senior Medewerker Bedrijfsbureau
Gerhard Schoonvelde	Senior Beleidsadviseur
Eric Velthuizen	Manager Ontwikkeling, Verkoop, Bedrijfsondersteuning

TABLE 5. STAKEHOLDERS AT STADSBEDRIJVEN

Through multiple meetings with the stakeholders mentioned in table 5, the following data was obtained:

- Dataset (spreadsheet) documenting the waste movements in Utrecht for the period October 2015 – November 2018;
- Annual reports submitted to the *Benchmark Huishoudelijk Afval* (BMHA) on waste statistics for the years 2015 - 2017;
- Letters to the city council and members of the committee *'Stad & Ruimte'* documenting the results of HNI intervention related waste measurements carried out in 9 neighborhoods.

The relevant data was compiled into a spreadsheet, which is available upon request. Furthermore, participation onboard the garbage trucks provided insight into the daily operations of the waste system. A more detailed overview of the workings of the waste system and the types of data collected in the spreadsheet is presented in section 4.1.

3.2.2. Phase 2: Charting the waste flows

The next step of the research was to construct an overview of the waste flows in Utrecht for the years 2015 and 2017. This overview takes the form of a Material Flow Analysis (MFA). A MFA is a systematic assessment of the flows and supplies of material in a system, which is defined in space and time (Kytzia, 2004). The MFA supports understanding of the inputs, outputs and flows of household waste within the municipality of Utrecht (Markic, 2019). To construct the MFA's, the data and statistics for 2015 and 2017 collected from the municipality were used.

In order to determine the composition of residual waste generated by households, data from sort analyses of residual waste was used (Eureco 2016, 2018). In addition, performance of the relevant processing and recycling industries was obtained through desk research. Finally, the quality and potential uses of the waste flows were examined using publicly available monitoring studies for both 2015 and 2017. The data is given in appendix A.

From the two MFA's the changes in relation to composition, mass and quality of waste flows between 2015 and 2017 were summarized using basic statistical methods including arithmetic mean, standard deviation, and percentual change, the calculation of which are included in appendix A.

3.2.3. Phase 3: Municipal interventions

The next phase of the research consisted of providing a framework to understand which part of the change identified in phase 2 could be attributed to specific interventions resulting from municipal waste policy. This was done in three steps detailed below.

Phase 3.1: 'Policy – System – Change' translation

First, the manner in which municipal policy was translated into specific interventions was studied to understand the system elements addressed by the intervention, the scale of the intervention, the expected impact, and the realized impact. This was done by reviewing policy documents listed in section 2.3, table 2 and through conversational interviewing with stakeholders from the municipality (specifically, Gerhard Schoonvelde and Ralph van der Zant, see table 5), in which the following questions were central:

- Which interventions have been carried out between 2015 – 2017
- What were the aimed and expected outcome of these interventions?
- At what scale where these interventions implemented?

From this, the interventions were localized in the waste system of Utrecht and the relevant indicators for change were highlighted.

Phase 3.2: Temporal and geographical comparison

Second, the relevant indicators for change from phase 3.1. were placed in temporal and geographical context in order to see whether the changes were unique for the period of time and the area under study.

For the temporal comparison, a search was conducted for historical data on waste generation, residual waste and waste separation in Utrecht. The data, reaching back to 2011, was analyzed for changes in average size of flows, and the average change was compared to the period 2015 – 2017 using the standard deviation. Calculations are shown in appendix A.

For the geographical comparison results of measurements performed in nine neighborhoods (Terwijde, Hoograven, Transwijk, Dichterswijk, Rivierenwijk, Tuindorp, Parkwijk Noord, Overvecht and Lunetten) in which the reversed logistics collection has been implemented were used. For these neighborhoods the municipality has collected data on three waste streams (residual, PMD and Paper & cardboard). The measurement results of these three waste streams were summarized and compared to the city wide data for these three waste streams.

Phase 3.3: Impact of other factors on household waste generation

Finally, alternative explanatory factors that can account for realized change were studied. From the explanation in section 2.3, the main factors potentially contributing to changing waste generation were summarized in function (1). Which posits that household waste generation (hhwg) is some function of Gross Domestic Product (GDP), the household composition in the region (HHc), and municipal policy (Mpol).

$$HHWG = f(GDP, HHc, MPol) \qquad (1)$$

From this, the economic and structural factors that potentially contribute to changing waste flows were examined for the city of Utrecht for the years 2015 - 2017. For economic data, the average household disposable income for Utrecht was used. For structural data the size and composition of households were used. The data was obtained from the online municipal statistics repository (www.wistudata.nl)

3.2.4. Phase 4: Key variables

The final step in the research process was to calculate the values of the key variables that provide insight into how the waste management system performs in relation to the targets and strategies of waste management in a circular economy. For an explanation of the relevant variables the reader is referred back to section 2.4. The following variables were calculated for both MFA's:

- **Total Waste (kt)** The total amount of waste collected.
- **Waste Separation (%)** The amount of separately collected waste and the amount of post-separation of bulky waste at RSF's as a share of the total municipal waste.
- **Degree of contamination (%)** The amount of losses in the recycling process due to contamination of separated waste flows, as a share of these specific waste flows.
- **Residual Waste (Kg/capita)** The amount of residual waste collected by the municipality and the amount remaining after post-separation of bulky waste at resource separation facilities (RSF).
- **Incineration (Kg)** The amount of waste that ends up being incinerated with energy recovery.
- **Emissions ($KgCO2_{eq}$)** CO_2 emissions that result from waste incineration.
- **Recycling Rates (%)** The amount of waste which enters the last step of the recycling process, after impurities have been sorted out, as a share of total material found in household waste.

4. RESULTS

This chapter presents all findings of the research. Section 4.1. starts with a short description of the waste system under study. After, the material flow analyses for 2015 and 2017 are presented and the main changes in mass, composition and quality are highlighted. In section 4.2, the manner in which policy has been translated into interventions is presented, the identified changes are placed in context and other explanatory factors are shown. Finally, section 4.3. presents the values of the key indicators for circular waste management for both MFA's. The implications of these results are further discussed in chapter 5.

4.1. WASTE IN UTRECHT

4.1.1. Waste & Data collection

The headquarters for waste management in the municipality of Utrecht is located at *Tractieweg 81*, indicated with star 1 in figure 6. It serves as the main hub for the fleet of garbage trucks, and houses the relevant organizational departments (e.g. policy, logistics, finance, and daily operations). Each day 40-50 trucks (depending on the collection schedule) with a collection capacity ranging from 4 – 8 tons depart from the *Tractieweg 81* to collect waste throughout the municipality of Utrecht. There are an estimated total of 60 garbage trucks covering a total of 386 different collection routes (registered in the period 2015-2017), indicating a fine grained coverage of the city. The trucks are exempt from most traffic rules, and skillfully navigate throughout the streets of Utrecht to reach their targets. Figure 6 shows a map of Utrecht, including the two main logistic hubs (indicated with red stars) and the three resource separation facilities (indicated with blue stars).

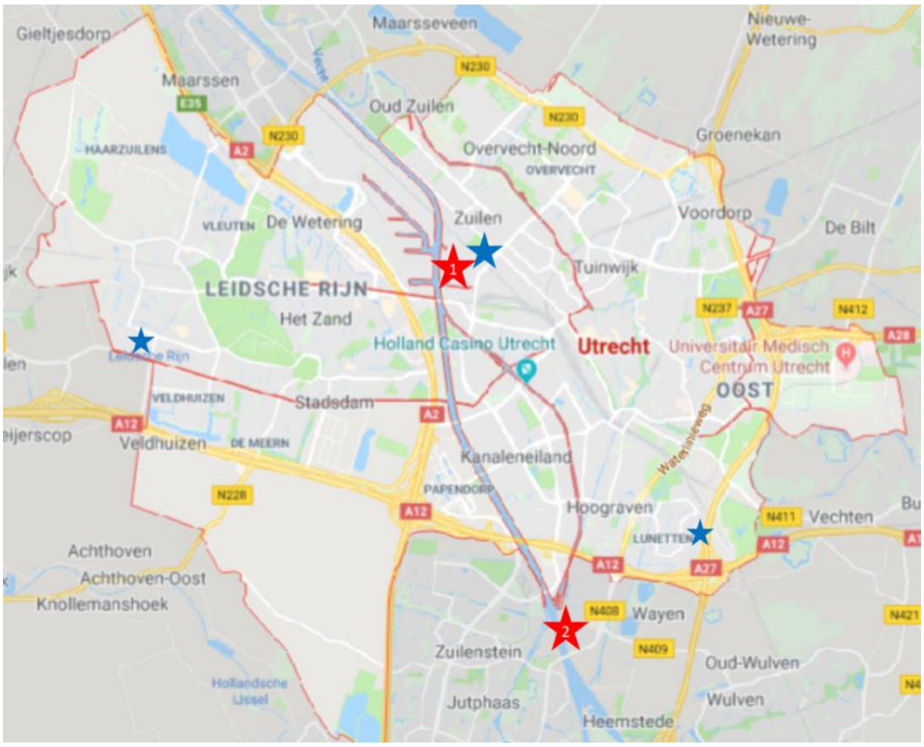


Figure 6. Map of Utrecht with waste elements marked.

In total there are 6 waste streams that are collected by truck (residual, organic, PMD, paper & cardboard, glass, bulk). In addition, the municipality of Utrecht operates 3 resource separation facilities, to which curbside collected bulky waste is brought, and to which inhabitants can bring their electronic appliances, chemical waste and bulky waste. When containers at the resource separation facilities are full, they are weighed and transported to contracted recycling processers (listed in section 2.3, table 4), all of which are located outside of Utrecht.

When the garbage trucks collecting waste throughout the city are full or when a shift has ended they are driven to the waste facility located on the bank of the Amsterdam-Rhine Canal in Nieuwegein (indicated with star 2 on the map). Informal conversations with the men and women operating the garbage trucks revealed that on a busy day a truck will make three trips from the city to the disposal facility, travelling an average distance of 100KM throughout the day. At the facility, the waste is deposited in a large hangar, from which excavators move the waste to separated piles for further transport by truck or ship. The trucks arriving at the facility in Nieuwegein are weighed before and after depositing waste, and the time, type of waste and weight are documented. This data is communicated to the municipality in the form of physical notes, which the municipality compiles into a central database.

4.1.2. Waste Flows in 2015

The MFA in figure 7 shows the mass (kiloton), origin, trajectory and destination of household waste flows in the municipality of Utrecht for the year 2015. The total amount of waste for 2015 amounts to 134,4 kt, which equals 401,9 kg per person in the municipality of Utrecht.

In descending order of prevalence, the waste consists of organic waste (29%), bulky waste (20%), paper and carton (16%), plastics, metals and drink cartons (PMD) (14%), glass (7%), textiles (3%), consumer electronics (2%) and chemicals (0,3%). Finally, there is a share of waste which cannot accurately be identified in separation analyses, and is represented as 'Other HH' (9%), generally this waste consists of sand, pieces of wood, and mangled and contaminated sludge.

It can be seen that for all waste streams the majority (58%) ends up in the residual bin and is consequently incinerated. A third (33%) of all household waste for which separation opportunity exists, is separated. After collection, this waste is transported to the contracted processors via the collection hub in Nieuwegein. During processing, for each waste stream, there is an outflow to incineration (1,14 kt in total), which is due to contamination of the waste.

Bulky waste, collected at the RSF's, makes up 20% of household waste. It consists of metal, wood, debris and other waste which is not fit for disposal in the typical household collection system due to size or nature. A share of bulky waste is labeled as 'residual', consisting of contaminated or otherwise unusable waste, and is sent to incineration. The remainder of bulky waste is handled by individual contractors, for which no information was available from the municipality. Hence, this outflow is labeled 'market' in the MFA.

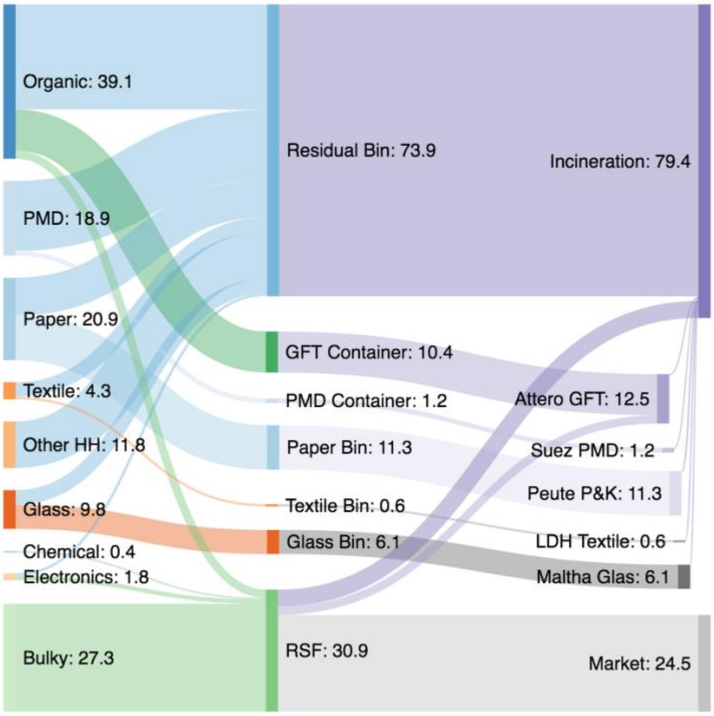


Figure 7. MFA of household waste in the municipality of Utrecht 2015 in kt.

4.1.3. Waste Flows in 2017

Figure 8 shows the MFA for the mass (kiloton), origin, trajectory and destination of household waste flows in the municipality of Utrecht for the year 2017. At first glance it would appear that not much has changed compared to 2015: the same actors, same currents and same distribution channels are involved. However, the realized changes become clear when looking at the details.

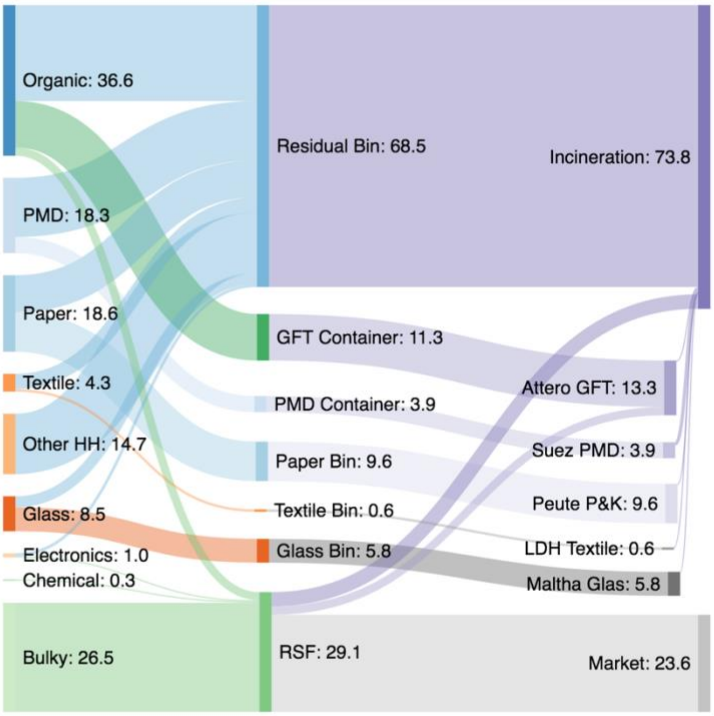


Figure 8. MFA of household waste in the municipality of Utrecht 2017 in kt.

In 2017, the total amount of waste was 132,3 kt, or 385,7 kg/person. This waste consisted of the fractions Organic (28%), bulky waste (21%), PMD (14%), Paper & cardboard (14%), Other (11%), Glass (7%), Textiles (3%), Electronics (1%), chemical waste (0,3%). Of all this waste, 73,9 kt (56%) ends up as residual waste, which is consequently incinerated.

The separated fractions (37%) are processed by respective contracted processors. During this processing, part of the separated waste stream is lost due to contamination. The contaminated waste (1,72 kt in 2017) flow is sent to incineration. It is interesting to note that none of the municipal waste of Utrecht is sent to landfills, as opposed to many other European cities (Gemeente Utrecht, 2016; Lee et al., 2017).

4.1.4. Change in Waste 2015 - 2017

Figure 9 gives an overview of the changes in total waste, residual waste, separated household waste, and bulky waste occurring between 2015 and 2017, expressed in kiloton.

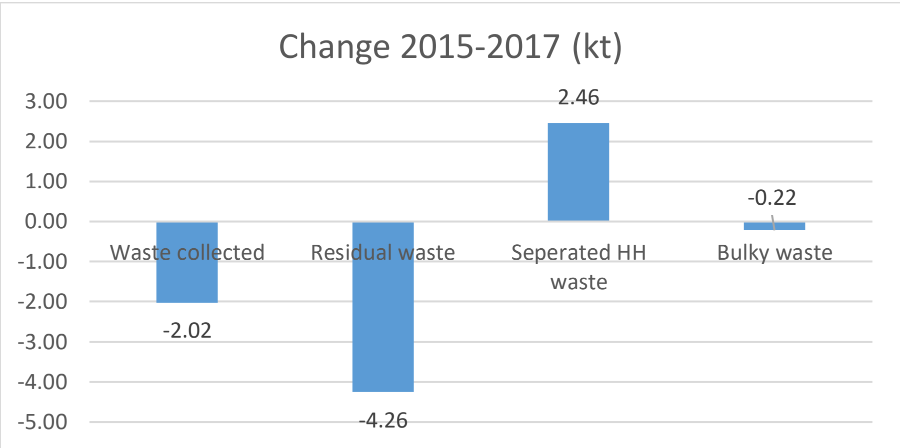


Figure 9. Changes in the amounts of waste 2015-2017 in kt.

The total amount of waste collected, residual waste and bulky waste have decreased in the period under study. The amount of separately collected household waste has increased. Residual waste and separated waste can be considered communicating vessels. Hence, it can be expected that the increase in separated household waste would correspond with an equal and opposite reduction in residual waste. Figure 7 shows that residual waste decreased by a larger amount than can be explained by increased waste separation. These findings will further be discussed in section 5.1.

The separated household waste consists of the fractions organic, paper & carton, PMD, glass, textile and bulk. Separation rates for these fractions are given in figure 10. For all waste streams except for paper & carton the separation rates have increased in 2017 compared to 2015. The biggest increase in separation rate was seen for the waste stream PMD, which increased from 6% in 2015 to 21% in 2017. This has been one of the streams addressed by the interventions, as we will see in section 4.2. The waste stream paper & carton has seen a decrease in separation rate from 54% in 2015 to 52% in 2017. The reason for this not clear, but an explanation for this can possibly be found with schools and sporting associations, who have traditionally served as collection hubs for paper in Utrecht. The overall separation rate has increased from 42% in 2015 to 44% in 2017.

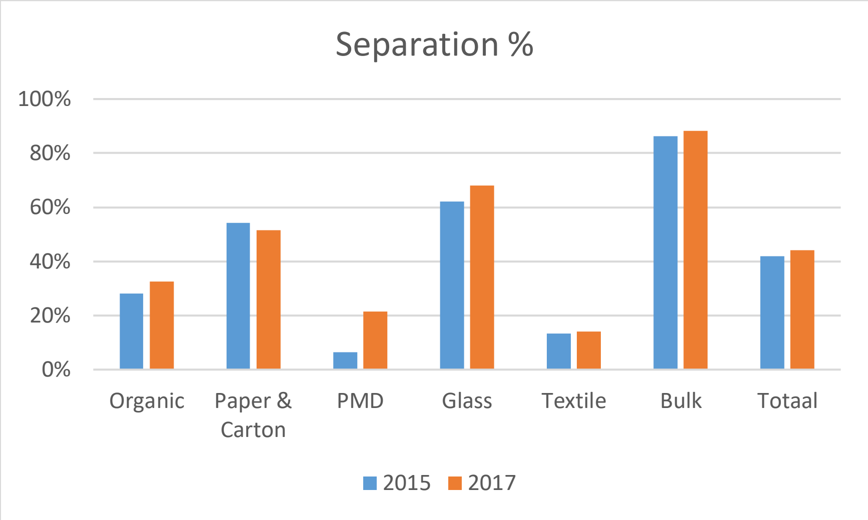


Figure 10. Separation rates for 2015 & 2017.

Simultaneously, while the amount of waste separation has increased, the quality of the collected waste has decreased, leading to more losses in the recycling process due to contamination, as shown in figure 11.

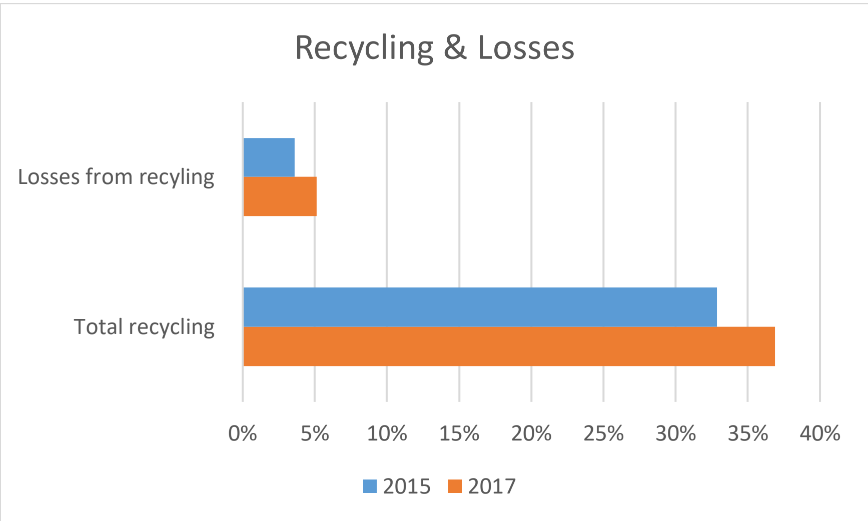


Figure 11. Recycling rates and losses from recycling for 2015 & 2017.

In 2015 there were 1,14 kt losses from recycling, in 2017 this was 1,72 kt, an increase of 50,5%. These losses as a share of the total amount of material that is recycled amount to 3,6% in 2015 and 5,1% in 2017. The total recycling of household waste fractions increased from 33% to 37%, taking losses into account.

The waste streams which have seen more losses due to contamination are organic waste and PMD. For the waste stream organic, the amount of contamination has increased from 2% in 2015 to 4% in 2017. For PMD, the contamination has increased from 12% in 2015 to 20% in 2017.

4.2. Policy Assessment

4.2.1. Policy Interventions

The policy of the municipality of Utrecht in relation to waste management is discussed in the theoretical framework in section 2.4. The interventions resulting from this policy are presented in table 6. For each intervention the waste stream, system element, aim & expected impact, scale of application and implementation date are shown.

The places where the interventions influence the waste system are marked in the map of the waste system of Utrecht in figure 13. From this map it is possible to examine how interventions in the waste system correspond to changes in the distribution of waste flows along the different system elements (see section 5.1)

Intervention	***Element***	***Aim / expected Impact***	***Scale***	***Status***
Reversed collection logistics	PMD, Paper, Organic	Increased source separation due to increased convenience. 45% in 2018.	Neighborhood level. Implementation goal: 67% of Utrecht in total. Current realization: 39%.	Started implementation in 2015. Scheduled to complete in 2021
	Residual waste	Reduced residual waste due to increased separation. 150 kg/person in 2018 for low-rise.		
	Total waste	Reduced total waste due to increased awareness of consumers		
Additional (underground) containers	PMD, Paper, Glass, Textile	Increased source separation due to increased opportunity. 45% in 2018.	City-wide distribution. 788 facilities in total.	Implemented in 2015
	Residual waste	Reduced residual waste due to increased separation. 150 kg/person in 2018 for low-rise.		
Information campaign	Source separation	Increased source separation due to increased awareness & knowledge. 45% in 2018.	Neighborhoods with reversed collection logistics	Implemented in 2015
Sustainability criteria in contract tenders	Emissions	Reduced emissions due to stricter contract criteria	Department 'stadsbedrijven'	Implemented in 2015

Extended opening hours of Resource Separation Facilities	Bulky waste	Increased separation due to increased opportunity	Three Resource Separation Facilities	Implemented in 2016
	Consumer electronics			
Dynamic Collection: Smart sensors on containers	Underground containers	Less illegal dumping due to availability of containers. Less traffic movements.	City-wide	Started in 2019
Pilot post-separation of residual waste high-rise	PMD	Less incineration/more recovery of PMD due to post-separation	High-rise buildings	Started in 2019
Waste feedback to citizens & normation information	Residual waste	Reduced residual waste due to information feedback	Households	Scheduled for 2019
	Source separation	Increased separation due to increased awareness	Households	
Opt-in system for paper advertisement	Paper	Reduced paper waste due to less proliferation advertisement folders	Households	Scheduled for 2020

Table 6. Interventions in the waste system of Utrecht

The first intervention, the reversed collection logistics, concerns the changing infrastructure and logistics of household waste collection, described in section 2.3. The expected impact of this intervention was a reduction of residual waste and an increase in source separation due to increased convenience for source separation through curbside collection of organic waste, PMD and paper & carton. Before the intervention, residual waste was also collected from the curbside. After the intervention, residual waste can only be disposed of in underground containers accessible with a keycard. The accompanying information campaign consisted of written letters sent to households affected by the intervention and included information on the new system and instructions on how to operate the underground containers.

The intervention has been implemented the neighborhoods Lunetten, Kanaleneiland, Overvecht, Hoograven, Wijk C, Parkwijk Noord, Terwijde, Transwijk, Rivierenwijk, Dichterswijk, Tuindorp. Which amounts to 52% of the target areas. The target areas concern the neighborhoods which have a relatively high amount of low-rise. The city of Utrecht has 43% low-rise, and the neighborhoods in which the intervention has been implemented consist of 61% low-rise. Figure 12 shows the implementation areas.

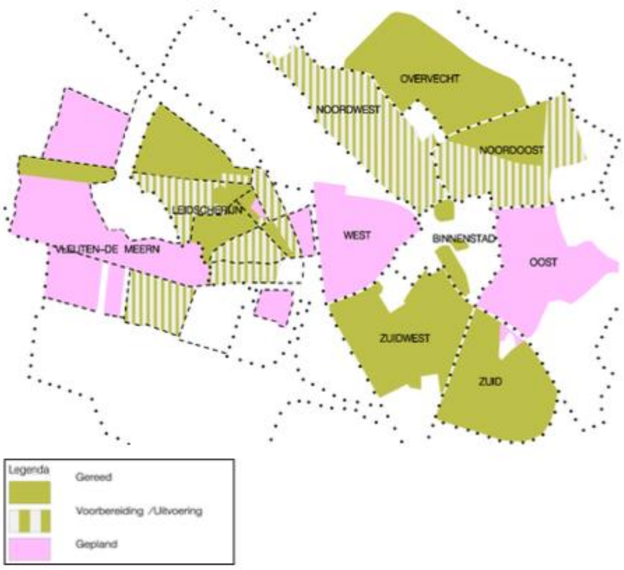


Figure 12. Implementation of reversed collection logistics.

The goal is to implement the intervention in an area which covers 67% of the population of Utrecht. Originally scheduled to complete in 2018, the date has been moved to 2020, due to more time being allotted for decision making procedures. While not operational in all neighborhoods, the impacts of the operational areas are included in the city-wide measurements and neighborhood specific measurements have been carried out, which are presented in section 4.2.3.

The second intervention concerns the placement of additional (underground) containers for textile, glass, paper and PMD throughout the entire city. Before the intervention these facilities already existed, but were not prevalent in every area. In 2014 the city counted 626 facilities. In the period 2015 – 2017 this increased by 162 to 788 facilities. After the intervention the following number of facilities existed: 253 for glass, 153 for PMD, 294 for paper & carton, 88 for textile. The aim has been to increase the amount of source separation by providing more opportunity to citizens to separate these waste streams and to simultaneously reduce the amount of residual waste.

The explicit targets for the first two interventions were to realize 45% waste separation in 2018, and to realize less than 150 kg residual waste in 2018 for low-rise areas. These targets were chosen in order to gradually realize the targets stipulated in national waste policy (see section 2.3).

The third intervention was a lengthening of the opening hours of the three resource separation facilities on Saturday and adding Sunday as an additional day of operation. The aim of this intervention was to increase the opportunity for citizens to dispose of their bulky waste, chemical waste and electronic appliances. The expected impact was an increase in the amount of separated bulky waste.

The fourth intervention consists of new criteria for the procurement process within the department. Specifically, criteria on to the amount of CO_2 emissions avoided by recycling have been taken into account when weighing the tenders for processing contracts. However, in the period 2015 – 2018 no new contracts between the municipality and processors have been realized. In most cases the contract had not ended, and in the case of PMD waste the contract has been extended unchanged with the same recycler (Suez PMD, in Rotterdam).

The conversation with stakeholders at the municipality further revealed a number of interventions which have been implemented in 2019 or are scheduled to be implemented in the near future, discussed in more detail in chapter 5. All points of intervention have been mapped out in figure 13.

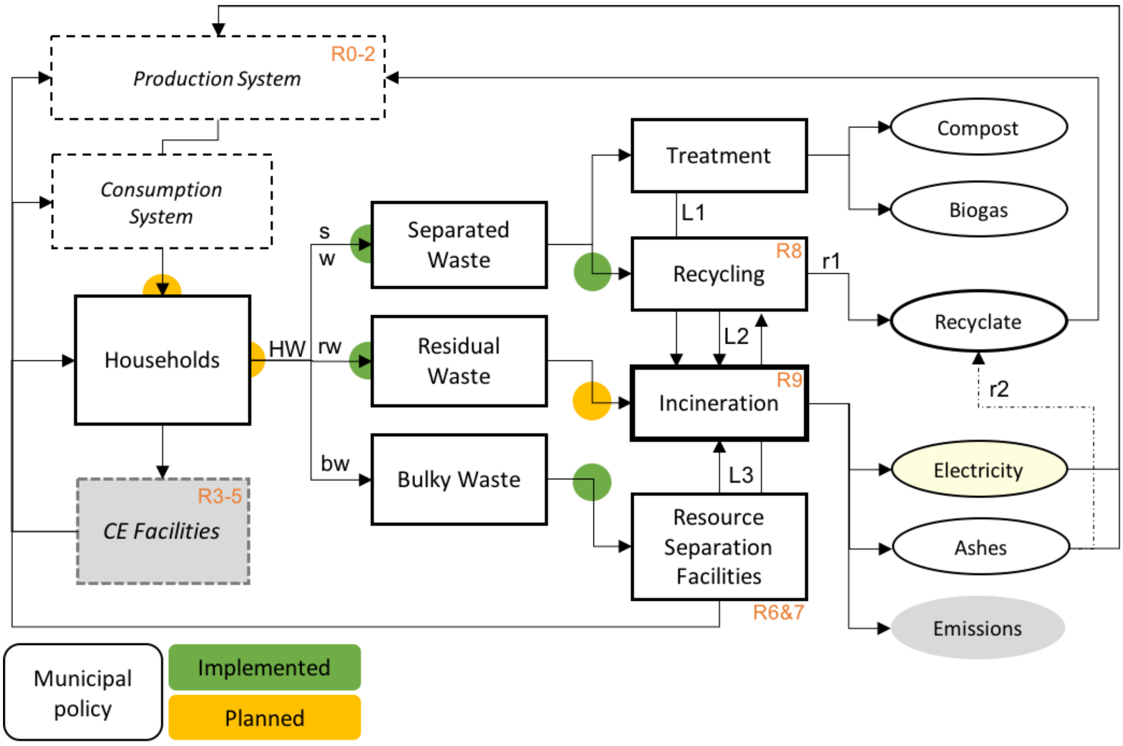


Figure 13. Intervention points in the waste system of Utrecht 2015 - 2017.

The figure provides insight into where in the waste system the interventions have been applied, and provides information on which strategies have been addressed with the interventions. This is further discussed in section 5.2.

4.2.2. Temporal Comparison

For the total waste, the separation of household waste and the amount of residual waste the change presented in section 4.1. for the period 2015 – 2017 has been compared to the historical trend for these three indicators in figure 14. This comparison was performed in order to see how the change in the period under study compares to changes in the past.

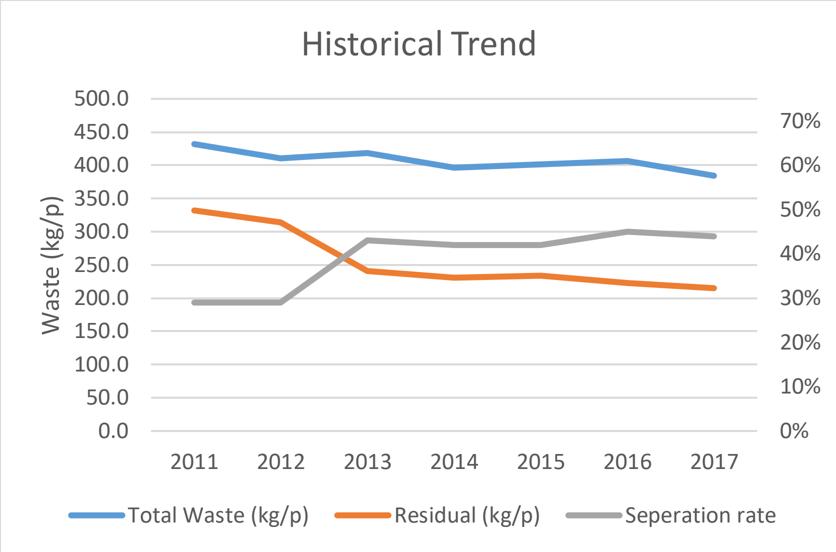


Figure 14. Historical trend of waste in Utrecht 2011 – 2017.

In the depicted period the total amount of waste and the amount of residual waste have been declining and the separation rate has been increasing. The increase in separation and decrease in residual waste witnessed between 2012 and 2013 can be explained by improved post-separation of bulky residual waste, in which bulky waste collected from the curbside was first sorted to retrieve valuable materials, instead of being incinerated in its entirety.

In table 7 the average values for the period 2011 – 2014 are compared to the average values for the period 2015 – 2017. The change between these periods is compared to the standard deviation to see if the change falls within the range of what has occurred in the past. For all three properties, the observed change exceeds the standard deviation, suggesting that the change is higher than what has been witnessed in the past.

	'11–'14 avg.	*'15-'17 avg.*	*Standard Deviation σ*	*Observed Change*
Total Waste	414	397	3,8%	-4,1%
Residual Waste	280	224	18,4%	-19,9%
Separation Rate	36%	44%	17,9%	22,1%

Table 7. Average change and standard deviation.

4.2.3. Geographical Comparison

For the period 2015 – 2017 the measurements studies of nine neighborhoods (Terwijde, Hoograven, Transwijk, Dichterswijk, Rivierenwijk, Tuindorp, Parkwijk Noord, Overvecht and Lunetten) in which reversed collection logistics was implemented and operational were obtained from the municipality. In these nine neighborhoods the weight of three waste streams was measured. These are residual waste, PMD, and paper & cardboard. Organic waste was not measured, because of seasonal fluctuation requiring yearlong measurements, and this was not done due to the extra logistics and costs involved. The average amount of waste collected for the measured waste flows for the 9 neighborhoods was calculated according to formula (2). This was compared to the citywide data from 2015 and 2017. Figure 15 gives the results.

$$W_y = \frac{1}{P_s} \sum_{n=1}^{9} P_n W_n \qquad (2)$$

In which W_y is the average waste generated per inhabitant in HNI neighborhoods, W_n is waste generated in a specific neighborhood, P_n is the share of population in that neighborhood, and P_s is the population size of the HNI sample.

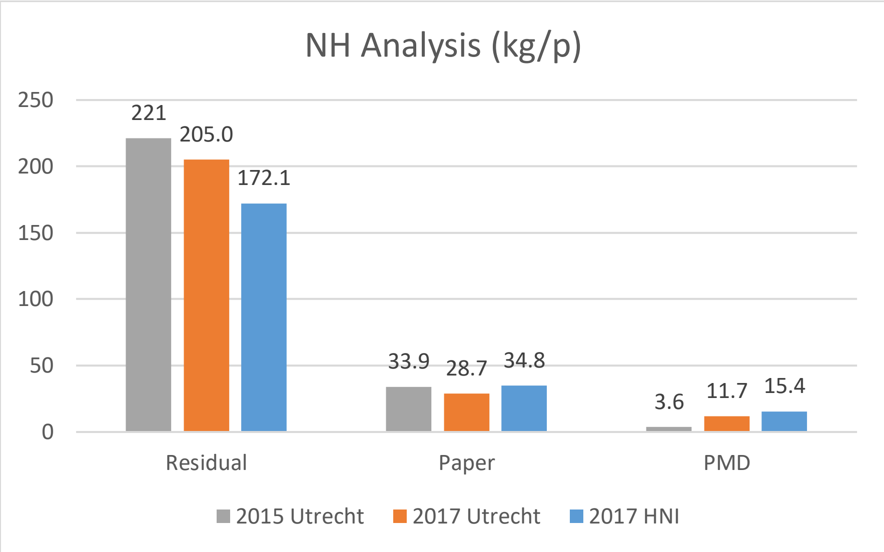


Figure 15. Neighborhood analysis of three waste streams.

Because no baseline measurements were carried out for these neighborhoods, the results have been compared to city-wide measurements for 2015 and 2017. For the neighborhoods in which reversed logistics has been implemented less residual waste is collected, more paper & cardboard (c.f. the city-wide decrease in collection of paper & cardboard), and more PMD is collected separately. This suggests that the reversed collection logistics intervention in these neighborhoods has had a substantial effect, discussed in more detail in section 5.1.

4.2.4. Impact of other factors on household waste generation

To determine the impact of other factors on household waste generation the economical and structural indicators selected in section 2.3 have been calculated for the period 2015 – 2017. Table 8 gives an overview.

	2015	2017	Change 2015 - 2017	Expected impact on waste generation
Structural				
Average age	35,2	35,2	0%	None
Single households	93273	92743	-1%	More waste
Households with children	44863	46306	3%	More waste
Economical				
Average spendable income per household (x €1000)	36,8	37,9	3%	More waste

Table 8. Structural and economic factors of waste generation.

For each factor, the expected impact on waste generation is derived from the literature in the theoretical framework, section 2.3. Due to the negative change in the share of single households, the positive change in the share of households with children and the positive change in average spendable income per household, an increase in waste generation would have been expected. However, figure 7 has shown that the amount of waste collected in this period has in fact decreased. This is interesting because it goes against what was found to be common for major European cities in the literature. Section 5.1. will discuss this finding in more detail.

4.3. Key Indicators

The relevant indicators to assess the waste management system with regards to the targets and strategies of waste management in a circular economy are presented in table 9. The indicators have been calculated based on the MFA's (for calculations see appendix A). For each indicator either the target or desired direction of the change have been added from section 2.5. The realized change is consequently compared to this desired change in order to check if the direction matches up (green), goes against (red), or cannot be determined for certain (grey).

	2015	*2017*	*Target / change*	*Change (%)*
Total waste (kg/person)	401,9	385,7	(-)	-4,0%
Total waste (kt)	134,4	132,3	(-)	-1,5%
Waste seperation	42%	44%	75%	5,6%
Residual waste (kg/person)	233,8	215,4	100	-7,9%
Resource separation facilities	79,7	77,0	(+/-)	-3,4%
Incineration (kt)	78,3	74,8	(-)	-4,46%
Emissions (kt)	34,3	32,8	(-)	-5%
Electricity (TJ)	80,1	76,4	(+/-)	-5%
Of which Renewable (TJ)	43,3	41,3	(+)	-4,6%
Biogas from GFT (TJ)	5,7	7,0	(+)	22,6%
Compost from GFT (kt)	3,7	4,0	(+)	9,0%

Total Renewable Energy (TJ)	49,0	48,3	(+)	-1,4%
Total recycling	33%	37%	(+)	11,1%
Losses from recyling %	3,6%	5,1%	(-)	41,9%
Losses kt	1,14	1,72	(-)	50,5%
Amount of secondary material (kt)	19,3	19,8	(+)	2,7%

Table 9. Key indicators for circular waste management.

The table gives us an overview of developments of the waste system of Utrecht for the period 2015 – 2017, and shows whether this development is line with realizing waste management in a circular economy. Section 5.3 provides a discussion of these findings.

5. DISCUSSION

The results of this study show how the mass, trajectory and quality of waste flows in Utrecht have changed between 2015 and 2017. To better understand the reasons behind these changes, and the implications for waste management in the context of a circular economy this chapter provides a discussion of the main findings. First, in section 5.1. the changes in waste flows identified in chapter 4 are analyzed in terms of how they relate to the different policy interventions. In section 5.2, the circularity of the waste management system of Utrecht is considered. Afterwards the limitations of the research are discussed. Finally, section 5.4. provides recommendations for future research and for the municipality.

5.1. EXPLAINING THE OBSERVED CHANGES

5.1.1. Increased household waste separation

One of the main observed changes in the period 2015 – 2017 is the increase in the amount of separation of household waste from 42% to 44%. For the Netherlands as a whole, the separation rate in 2017 was 64% (Rijkswaterstaat, 2018b). For municipalities with a similar amount of high-rise residential areas as Utrecht, the separation rate was 39% (Ibid). When placed in a temporal perspective the increase in separation in Utrecht in this period exceeds the standard deviation observed for the period 2011-2017, which suggests that the increase has causes specific to the period under study. This change can be decomposed into two parts: separation of household fractions and separated bulky waste.

The separation of household waste fractions (organic, PMD, paper & carton, glass and textiles) has increased from 33% in 2015 to 37% in 2017. For PMD, the highest increase has been seen, from 6% in 2015 to 21% in 2017. In this period the municipality has implemented two interventions aimed at increased separation of household waste fractions. These are the reversed collection logistics and the additional facilities installed throughout the city. To understand the effect of these interventions, waste separation can be considered in terms of motivation, capacity and opportunity (Nederstigt & Poiesz, 1999). The additional facilities installed have increased the *opportunity* for separation by providing the required infrastructure. The reversed collection logistics intervention has increased both the *opportunity* through infrastructure, and the *capacity* for separation by providing written information and instructions to citizens.

The nine neighborhoods in which measurements were carried out show an increase in source separation which exceeds the city-wide increase. In the nine neighborhoods the separation of paper and PMD were found to be higher than the city-wide numbers, which leads to the hypothesis that reversed collection logistics has had a substantial effect on these waste streams. However, because no measurements were carried out in these neighborhoods before implementing the intervention, no baseline exists with which to test this hypothesis.

Separation of bulky waste increased from 86% in 2015 to 88% in 2017. A possible explanation of this increase is the lengthening of the opening hours of the RSF's, resulting in more people bringing their waste to RSF's. According to public municipal statistics the number of visits to the RSF's has increased by 19.000 between 2015 and 2017, giving credence to this explanation (Gemeente Utrecht, 2017).

Furthermore, the three interventions discussed above have also increased the convenience of separation. Convenience of separation has been found an important attribute to explain for separation behavior (e.g. Mueller, 2013; Bernstad, 2014; Slavik et al., 2018). A 2014 study by Bernstad in Sweden which looked at the effect of both information and convenience on waste separation found that more information had no significant effect on household separation behavior, and that only better convenience to separate had a significant effect. In addition, a study by Mueller (2013) on the effectiveness of recycling policy options in Colarado finds that attributes of convenience are more important to encourage recycling than those that penalize disposal.

Ultimately, increased separation of household waste implies a behavioral change on the part of citizens which involves their motivation to separate. A review by Travaille (2016) on separation behavior found that the most effective strategies for influencing separation behavior are social psychological processes such as activating values and beliefs, setting explicit targets with feedback, and demonstrating socially desirable behavior. A study by Slavik et al (2018), who looked at the transition to a circular economy in Czech Republic, find that moral norms, available information and environmental concern are strong predictors of recycling behavior. While these factors have not explicitly been studied in this research, it was found that one intervention which has been scheduled for implementation in 2019 aims to address these aspects. This intervention includes providing feedback to citizens on their waste production, and normation information telling them how their neighbors are performing. In light of the literature discussed above, this is a promising strategy to increase separation.

5.1.2. Decreased residual waste

The amount of residual waste collected in Utrecht has decreased from 2015 to 2017 by 4,26 kt. Per capita this amount to 215 kg residual waste per year in 2017. In the Netherlands, the average amount of residual waste per capita is 182 kg/person. In municipalities with a similar share of high-rise residential areas the amount was 265 kg/person. The decrease realized in Utrecht does not correspond with the increase in the amount of separated waste, which is notable considering these categories can be considered communicating vessels. Therefore, the decrease in residual waste has had additional causes not directly related to waste separation.

Municipal policy has explicitly set out to affect change in the amount of residual waste produced. This has been translated into the interventions reversed collection logistics, underground containers, and information campaigns. The information campaign plays into the categories of motivation and capacity described in section 5.1.1. However, the effect of the information campaign remains questionable, as more information does not always positively influence waste disposal behavior (Bernstad, 2014). The infrastructure change resulting from the other interventions can be summarized as follows: for large parts of Utrecht, residual waste is no longer collected from the curbside. Instead, citizens are required to deposit their trash bags in underground containers accessible with a keycard. When discussing the decrease with employees at the municipality two possible explanations surfaced. First, the increased physical effort required by citizens to dispose of their waste could have resulted in a shift in awareness leading people to produce less waste, however this cannot be tested with the methods of this research.

Second, less illegal dumping of commercial waste could account for the decrease in registered residual waste. Commercial waste is waste produced by companies throughout the city, such as small businesses, retail, shops, restaurants and cafés. By law, these companies are required to dispose of their waste through private contractors or through municipal services, against payment. According to anecdotal discussion, it could have been possible that instead of paying for waste disposal, some companies placed their waste in areas designated for household waste collection. With the introduction of underground containers accessible only by keycard this illegal dumping of waste has been made more difficult. Similar practices of illegal dumping of commercial waste have been documented for the municipality of Zwolle (Milieuservice Nederland, 2015). While not an intended outcome of the underground container intervention, it qualifies as a likely explanation. More study could be done by looking at the municipal contracts for commercial waste disposal.

A third option, not mentioned by the municipality, that could account for the decrease in the amount of residual waste is the extent to which strategies R0 – R5 (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish) have been executed in the production and consumption system in the period under study. This is discussed is section 5.2.3.

5.1.3. Decreased Bulky Waste

Between 2015 and 2017 the amount of bulky waste decreased by 0,22 kt. Bulky waste consists of household elements with a long lifetime such as furniture, plumbing, household appliances, and waste resulting from demolition and construction. In the period under study there has been one intervention aimed specifically at bulky waste, namely the widening of the opening hours of the 3 resource separation facilities. This increase in accessibility was expected to lead to an increase in the amount of bulky waste collected. However, the amount of bulky waste has decreased.

The decrease in bulky waste presents two options: either households have produced less waste, or the waste has not properly been disposed of, and is consequently classified as residual waste. Bulky waste being deposited in the containers intended for residual waste would lead to the registration of a higher amount of residual waste. However, the total amount of residual waste in Utrecht has decreased substantially. In addition, the widening of the opening hours of the RSF's has increased the opportunity for proper disposal and a higher visitors count to RSF's has been registered, making this option unlikely (Gemeente Utrecht, 2017).

From this, we believe that the most plausible explanation is that households have produced less bulky waste in 2017 compared to 2015. When considering the lifetime of the objects deposited as bulky waste this decrease could be explained by a decrease in the amount of purchased goods in the past. As such, the 2007 economic crisis could account for the registered decrease in bulky waste in 2017 compared to 2015, if we take an average lifetime of 10 years. This line of reasoning was also shared by the policy makers of the municipality. In addition, the successful execution of strategy R3 – R5 (Reuse, Repair, Refurbish) can account for the decrease.

5.1.4. Decreased total waste

The combined effect of the changes in bulky waste, separated waste and residual waste presents itself as a decrease in the total amount of waste collected in Utrecht in 2017 compared to 2015 amounting to 2,02 kton. This decrease can, as we have seen above, in part be explained by the changes in the waste system of Utrecht. Another manner to understand this change has been to examine the economic and structural factors influencing waste generation in high-income cities.

The following relationships were found in the literature: elderly and single households generally produce less waste, households with children produce more waste, and households with higher disposable income produce more waste (Beigl et al., 2004). These indicators were analyzed for Utrecht for the period 2015 – 2017 and the development shows an expected increase in total waste production. Considering household waste generation as a function of economic, structural and policy factors, this leaves policy to account for the changes. However, the household income effect on waste generation can be hypothesized to behave like a Kuznets curve, which has been demonstrated by Ercolano et al. (2018) to hold for the Lombardy region in Italy. Whether this is also the case for the Netherlands remains to be seen.

5.2. Squaring the Circle

The indicators in section 4.3 can be used to show how the waste system of Utrecht has been changing with regards to the targets and strategies of waste management in a circular economy. Here, these indicators are discussed in more detail, and they are critically reflected upon.

5.2.1. Waste Separation, Recycling Rates & Degree of Contamination

Both European documents, national documents, and municipal policy include targets for waste separation in order to promote circular waste management (EC, 2019; Rijksoverheid, 2016; Gemeente Utrecht, 2016). The amount of waste separation is an indicator of the extent to which strategies R3 – R8 can be carried out within a circular economy. These strategies relate to extending the lifespan of a product and its parts, and the useful application of materials. The explicit national target has been set at achieving at least 75% waste separation in 2020 (Rijkswaterstaat, 2018a). The target for the reversed collection logistics in Utrecht has been set at 45% waste separation in 2018 (Gemeente Utrecht, 2016). In Utrecht waste separation has increased from 29% in 2011 to 44% in 2017, with a 2% increase having been realized in the period under study. A preliminary web update published by the municipality in April 2019 claims that the target of achieving 45% separation in 2018 has indeed been achieved (Gemeente Utrecht, 2019). However, with the current rate of improvement, assuming a linear behavior, it will take up until 2032 to reach the target of 75% separation.

Closely linked to the increase in separation is the increase in the recycling rates of the materials found in the different waste streams. Currently there is debate in the literature surrounding the manner in which recycling rates for both closed- and open loop recycling are calculated (Haupt et al., 2017). Confusion exists due to some sources using collection rates, which doesn't say anything about the secondary material produced, and others using recycling rates as a measure of the input into the last recycling step (Haupt et al., 2017). Most studies do not include information on the quality of the secondary materials, making it difficult to determine the amount of material savings achieved through recycling (Geyer et al., 2015). For this study, the recycling rates are calculated as the amount of separated waste that enters the recycling process, after sorting out impurities (EC, 2015). Measured in this way, recycling rates have increased for all materials, except for paper and carton, which has decreased, and metal scraps which has stayed constant. A study by Dijkgraaf & Gradus (2014) has looked at the effectiveness of Dutch municipal recycling policies on the recycling rates. They find that overall only taxing of the weight of residual waste (differentiated tariffs: DIFTAR) results in substantially higher recycling rates. They conclude that it seems nearly impossible to reach the EU-goal of reaching recycling rates of 70% by 2030 with the policies applied.

Furthermore, while separation has increased, the degree of contamination has also increased for the waste streams in Utrecht. This finding links in to concerns expressed by Cobo et al (2018), who emphasize the importance of assessing the effect of increasing the recycling rates on the quality of the materials. Higher separation levels are not indicative of better material quality (Cobo et al., 2018). This increase in contamination leads to problems in the recycling process, such as machine failure and harm to employees. In speaking with the municipality this issue also surfaced: there exists tension between the quantitative targets of waste separation and the quality of this separation. For example, aiming at increasing the weight of separated waste can lead to disregard for the quality of this waste, as contamination still weighs towards separation targets. This can lead to an undermining of the qualitative requirements of a functional circular economy (Haupt et al., 2017).

5.2.2. Residual waste, Incineration & Emissions

The second main target used by policy to promote circular waste management concerns the average amount of residual waste produced per citizen per year. The Dutch national target has been set at reducing this amount to less than 100kg per person per year by 2020 (Rijkswaterstaat, 2018a). For Utrecht the target has been set of realizing 150 kg/person in 2018 for low-rise residential areas (Gemeente Utrecht, 2016). Reducing the amount of residual waste is also a proxy for the extent to which strategies R0 – R8 are carried out effectively, preventing waste through smarter product use and extending the lifespan of a product and its parts (Potting et al., 2015).

The amount of residual waste has decreased from 332 kg/person in 2011 to 215 kg/person in 2017, showing a 7,9% decrease in the period under study. The majority of this reduction was caused by the introduction of post-separation of bulky waste in 2013, and this decrease can be considered low-hanging fruit. The decrease in the period under study is only partly attributable to interventions, as a share of the reduction cannot be explained by complementary increase in separation, as explained in section 5.1. At the current rate, assuming linear change, the target of 100kg/person residual waste would be reached in 2024. For the low-rise areas in which reversed collection logistics have been implemented, residual waste amounts to 172 kg/person, which is close to the stipulated municipal target of 150 kg/person. However, since no measurements were carried out in these neighborhoods prior to implementation of the intervention, it is not possible to evaluate the progress over time.

The third target of a CE is a 50% CO_2eq emission reduction in 2030 compared to 2015 (Rijksoverheid, 2016). For waste management, this target is closely linked with residual waste, as all residual waste is currently being incinerated. As no data on the change in transportation resulting from the interventions was obtained, the change of emissions from transportation was not considered for this study. The amount of CO2 emissions resulting from incineration showed a decrease of 4,6% between 2015 and 2017. A. The manner of incineration is coupled to electricity generation, and the biogenic fraction of residual waste being incinerated counts towards renewable energy production.

Conversely, due to increased separation, the reduced amount of organic waste being incinerated with energy recovery also registers as less renewable energy production (a 4,6% decrease). The increase of separated organic waste consequently being fermented for biogas produces 7TJ of biogas. The net amount of renewable energy produced shows a 1,4% decrease. While this appears to be a loss of renewable energy, it can be argued that it is a necessary setback in the shift to a circular economy in which more capacity for fermentation of organic waste is yet to be realized.

At the national level, the *Benchmark Huishoudelijk Afval* is the platform tasked with keeping track of progress in waste management, and it publishes reports on the key waste statistics for 180 municipalities in the Netherlands (Rijkswaterstaat, 2018b). A recent analysis of waste management in Dutch municipalities for the year 2017 concludes that the reversed collection logistics intervention coupled to DIFTAR is the most cost effective strategy for reducing the amount of residual waste (Rijkswaterstaat, 2018b). While Utrecht has implemented reversed collection logistics, differentiated tariffs for waste streams (DIFTAR) have not been implemented due to political disagreement in the board.

5.2.3. Unaddressed Strategies

When looking at the intervention points in the waste system of Utrecht as shown in section 4.2, figure 13 it becomes apparent that the municipal interventions only address 4 of the 10 strategies of waste management in a circular economy. Specifically, energy recovery (R9), material recovery (R8), repurposing (R7) and remanufacturing (R6) are addressed. The strategies that are left unaddressed relate to the wider socio-economic production and consumption system in which waste management is embedded. They are refuse (R0), rethink (R1) and reduce (R2), which are examples of system design. Additionally, the strategies relate to CE facilities (indicated in figure 13) which enable shorter loops for reuse (R3), repair (R4), refurbish (R5), remanufacture (R6), and repurpose (R7). Examples of such facilities include repair shops, thrift stores (kringloopwinkels), online platforms and sharing facilities. These strategies work towards waste prevention through extending the lifespan of a product and its parts. The waste system is currently primarily concerned with what happens when a product has become waste. However, for a circular economy the entire supply chain of a product is involved (Singh & Ordoñez, 2016). To address this, we suggest to consider all the outputs that are not fed into a next step to be considered as potential value streams. With this, front-end solutions will be stimulated versus the conventional end of pipe approaches.

These findings are in line with a study by Kalmykova et al (2018), who review theories, practices and implementation tools of a circular economy. They find that while much attention is given to recovery (including recycling), consumption and use parts of the value chain, many parts of the value chain such as manufacturing, distribution and sales are underrepresented in current CE approaches (Kalmykova et al., 2018).

There are however two interventions planned for the future which do broaden the scope as they are aimed specifically at households (see section 4.2). Households as consumers are the central enablers of a circular economy, and their decisions directly influence the reality of the waste landscape. Addressing the behavioral aspect of waste generation, separation and contamination are promising avenues.

Finally, it is possible that the reduction of waste that we have seen in section 5.1.2. could have been caused in part due to strategies R0 to R5 being applied in the production and consumption system. However, no indicators on these strategies have been included in the study. In addition, current policy has not been aimed at these strategies. It is interesting to note that in the EU in 2016 circular activities such as repair, reuse or recycling generated almost €147 billion in value added while accounting for around €17.5 billion worth of investments (EC, 2019).

5.2.4. Squaring the circle?

While this research has taken the concept of a circular economy as a given, it is noteworthy to state that much discussion on the validity of the concept exists. For example, the low efficiency of the recycling process is seen as sufficient to take the ground away from under the circular economy as over-extraction will always be required to compensate for the losses (Decker, 2018).

Similarly, it is often reflected that the current economic model of growth makes a circular economy impossible. Even if all materials were recycled and the amount of material recycled will always be less than the demand required for growth, and this will lead to continuous exploitation (Decker, 2018).

Also, an important question remains whether a circular economy should aim primarily to maximize the supply of secondary material or aim to minimize environmental impacts (Haupt et al., 2017).

5.3. LIMITATIONS

The aim of the chosen research setup was to study how municipal waste management practices have affected waste flows in Utrecht, and how these changes relate to the realization of a waste management in the context of a circular economy. Here, the main limitations of the research are considered.

First, the chosen time frame in which to study the changes of the waste system was found to be narrow, making it difficult to assess the significance of the realized changes. The timeframe was dictated by data availability, and it thus makes sense to evaluate policy at a later stage when more data becomes available. The research design used in this study can be used as a starting point to do this.

Second, the manner in which change was studied left out an important enabler of this change: household behavior. The available time for this research was spent in trying to organize the tangled system side perspective of the waste management system. Future research could include methods in the research design to study household behavior.

Third, the scope of the research was limited to waste management in Utrecht and was focused on waste collection, excluding a study of the processing of this waste. Future research can look more closely at the processing side of waste management, as this is an interesting area in which technological developments are being realized. It should be noted that the reliability of the key variables calculated for the framework is dependent in part on data from secondary sources on contamination and processing of materials. When available, this has been based on official reports.

Fourth, the framework to assess circular waste management relies on proxies for the strategies instead of more direct indicators of circularity, and is skewed towards end-of-pipe performance indicators, instead of indicators that give a more holistic and intricate system perspective. Developing the right performance indicators for the circular economy is an ongoing process and many challenges have yet to be overcome (e.g. standardized measurement of collection and recycling rates). For this thesis it was therefore decided to use currently available data to relate waste management to the strategies and explicit targets of a CE.

Fifth, a circular economy is defined as working towards all three (environmental, economic, social) dimensions of sustainability. However, the framework used to measure the circularity of waste management focusses mostly on environmental aspects of waste management, as a result of time constraints. Impacts in the economic and societal dimension also need to be taken into account for a more complete assessment. To do this, it can be useful to measure waste management with regards to impacts on the sustainable development goals (SDG's). This is suitable for Utrecht, as it has already identified itself as a 'Global Goals City' (Gemeente Utrecht, 2018)

5.4. Recommendations

The results of the research have given rise to the following thoughts and recommendations on realizing effective waste management in a circular economy.

First, waste management in a circular economy presents itself as a transdisciplinary challenge that requires involvement from both academics, policymakers and practitioners. It was found that current research does not adequately reflect this. In addition, in studying this topic, it was found that literature on policy evaluation in relation to waste management in a circular economy is scarce. While there is much being written on the programs that are being implemented in order to transition to a circular economy, the evaluation of these programs has not yet received the same attention.

Second, in working with the department *stadsbedrijven* responsible for waste management in the municipality of Utrecht, it became clear that they are serious about the concept of a circular economy, but also have limited time and resources to examine the implications. The core values of the municipality of Utrecht are to provide a safe, clean and whole environment for its citizens to live in, and this involves a lot of short-term priorities which take up a lot of time (Gemeente Utrecht, 2016). However, a long-term commitment to the concept of a circular economy is needed to ensure that the core values of the municipality can also be maintained in the future.

To address this, the main recommendation of this thesis is to develop a decision support system that incorporates the practical experience and policy expertise of the department *stadsbedrijven* at the municipality with the cognitive resources of the scientific community of the Copernicus institute of Utrecht University. Such a decision support system be envisioned to contain the following elements: a framework for circularity taking into account all three dimensions of sustainability (e.g. Raworth, 2012); comparative studies into best practices in other municipalities (e.g. Rijkswaterstaat 2018b); feasibility studies on interventions that are considered for the Utrecht waste system (e.g. Bowen et al., 2009); Data requirements and measurement studies for relevant indicators; and evaluation programs to assess impacts (e.g. Browne et al., 2009). Such a support system could be developed into a comprehensive tool that is applicable to waste management in other municipalities as well.

This approach can be pursued by continuing the collaboration between the municipality and Copernicus, for example through case-studies that the municipality supplies to the supervisor of this thesis, and which can be handled during courses of the master programs at the university. Additionally, future master thesis students could link into the groundwork laid out in this thesis and in this manner intensify collaboration between the municipality and the university.

Taking it a step further, it can be surmised that a specialized department or task force be created within the municipality which seeks to facilitate the cooperation between different municipal divisions in order to identify and work together on overlapping or competing areas of the transition to a circular economy. This task force could focus on ways in which to realize change in the larger system elements such as laws, taxes & subsidies. The key takeaway from a recent European Commission session on circular economy was the need to boost the *demand* for quality secondary materials, for example through mandatory recycled contents in existing products (EC, 2019). A first suggestion is to compel, by law, all new packaging materials to be produced with a certain amount of recycled content. In addition, and more locally, the differentiated tax for waste can be reevaluated in light of recent findings by the Benchmark (Rijkswaterstaat, 2018b). Finally, subsidies can be provided to those actors that seek to enhance the circularity of Utrecht at a ground-level, such as repaircafé's, sharing facilities, and kringloopwinkels.

6. CONCLUSION

In this chapter the answer to the research question is provided based on a synthesis of the discussion chapter. First, in Section 6.1 the purpose of the research and research question are restated. Next, in section 6.2. the answer is subdivided into three qualitative categories: the aspects of waste management in Utrecht in which progress has been made by the municipality, the aspects in which concerns in the waste system exist, and the aspects of waste management which are currently unaddressed by policies or interventions and provide opportunities for the municipality moving forward. Finally, section 6.3. provides closing remarks.

6.1. PURPOSE

There exists a growing corpus of scientific literature sharing the same center of gravity: the manner in which resources are managed within current global economic structures leads to an unsustainable future. This has given rise to the idea of a new economic model centered around closing material and energy loops to preserve environmental quality while simultaneously fostering economic prosperity and social equity, referred to as a circular economy. In a circular economy, waste is considered a mislabeled resource. As such, waste management is recognized as a central component of a circular economy (Lee et al., 2017; Cobo et al., 2018; EC, 2019). In Europe and its member states, the idea of a circular economy is being integrated into new policy, as evidenced by the adoption of a national circular economy program in the Netherlands (Rijksoverheid, 2016). In the Netherlands, the responsibility of waste management is delegated to municipalities. This research has set out to study the link between waste management at a municipal level and the transition to a circular economy more closely by looking at the municipality of Utrecht as a case study.

The central research question has been: *To what extent are the waste management policies of the municipality of Utrecht contributing to the realization of waste management in the context of a circular economy?* In support of this question, the following sub questions have been answered:

1. How has the composition, mass, trajectory and quality of waste flows in Utrecht changed between 2015 and 2017?
2. What part of this change can be attributed to municipal policies?
3. What are the impacts of the change in waste flows in relation to the strategies and targets of a circular economy?

6.2. PROGRESS, CONCERNS AND OPPORTUNITIES

6.2.1. Progress

Since 2015 municipal policy of Utrecht contains explicit reference to the national transition to a circular economy (Gemeente Utrecht, 2016). The main ideas driving a circular economy are adequately explained and the link to waste management is put forth in clear language: waste is to be reconsidered as a potential resource, and waste management has a clear duty to fulfil in this regard. In the period between 2015 – 2017 the municipality of Utrecht has translated the waste policy into five interventions in the waste system. These are a reversed collection logistics system for low-rise residential areas, an accompanying information campaign, additional underground facilities for waste disposal throughout the city, extended opening hours for the three resource separation facilities, and sustainability criteria in contract tenders with waste processors. The study of waste flows in Utrecht between 2015 and 2017 has revealed that progress in the waste system is being made on three accounts, in part due to these interventions.

First, the amount of waste separation has increased due to increased *opportunity* and *convenience* for separation resulting from the reversed collection logistics, additional facilities and the extended opening hours of RSF's. The increase has allowed the municipality to achieve its own stipulated target of 45% waste separation in 2018. The increased separation of waste is a prerequisite condition for further recycling and resource recovery, which is a key strategy of a circular economy. Furthermore, recycling rates for nearly all materials have also improved in the period under study. However, as we will see in the next section, the rate of improvement and the quality of this recycling is an issue of concern.

Second, the amount of residual waste has decreased by 7,9% to a level of 215,4 kg/person in 2017. Closely linked to the decrease of residual waste is the decrease of CO_{2eq} emissions resulting from incineration by 5%. The decrease in residual waste can - in part - be ascribed to the increase in separation presented above, and the addition of underground containers for residual waste accessible with a keycard. The decrease in residual waste and decrease in emissions from incineration work towards achieving the targets of a circular economy.

Third, the combined impact of the interventions in the waste system have (indirectly) addressed four of the ten waste management strategies from the framework by Potting et al (2015). These strategies are labeled Recover, Recycle, Remanufacture and Repurpose. The interventions that have been implemented in the period after 2017 address another 3 key strategies: Reuse, Repair and Refurbish.

Overall, the increase in separation, decrease in residual waste and effective execution of the strategies mentioned in section 2.2 indicate that municipal policy is indeed working towards realizing waste management in the context of a circular economy.

6.2.2. Concerns

While the amount of source separation has increased in the period under study, the separation rate for Utrecht (44%) is low compared to the national average (64%), and the national target of 75% separation in 2020 appears to be out of reach. Nearly two-thirds of all waste for which separation opportunities exist is still disposed of in residual waste bins, indicating a failure of citizens to engage in proper waste separation behavior which cannot be explained by lack of opportunity to separate. Instead, a lack of awareness or lack of motivation can be at play, and this is an issue of concern. Municipal policy has set to address the behavioral aspects of waste separation through only one intervention in the period under study, namely the information campaign, and there is much to be gained by intensifying this channel of approach.

Furthermore, while the amount of source separation has increased, the quality of the collected materials has decreased due to increased contamination of waste streams. Contamination is the result of inappropriate disposal of waste by citizens and negatively impacts the possibilities for further processing and recycling of this waste. As such, contamination hampers the realization of a circular economy. One of the concerns is that municipal policy has indirectly led to an increase in contamination by focusing on reducing the amount of residual waste at all costs, focusing solely on the quantity of separated waste that is collected. A key recommendation is that the focus on quantity needs to be complemented with a manner in which to assess the quality of the collected waste.

Finally, the rate at which the amount of residual waste (215 kg/person in 2017) is decreasing is not sufficient to reach the national targets (<100kg/person) by 2020. While the improvement in low-rise residential areas is promising, high-rise residential areas prove to be problematic due to limited space for disposal facilities. The results from the pilot for post-separation of residual waste from high-rise, implemented in 2018, will provide more insight into whether post-separation is a suitable intervention to address this concern.

In the period under study the municipality has introduced three interventions aimed at reducing residual waste, with the primary intervention being a reversed collection logistics. Results from the national Benchmark program on municipal waste in the Netherlands have shown that for all municipalities on average the most effective way to reduce residual waste has been a combination of reversed collection logistics with a differentiated tariff for residual waste. The municipality of Utrecht has decided against a differentiated tariff measure in the past, but in light of the recent findings of the Benchmark program should reconsider introducing some taxation system in order to further realize a reduction of residual waste.

6.2.3. The Missing

While municipal policy states that it seeks to enable the transition to a circular economy, the interventions resulting from this policy make no explicit reference to this goal. in the translation of municipal policy to interventions, the circular economy terminology seems to have gone missing. As a result, some important aspects are found to be missing in current practices.

First, the interventions only address four of the ten strategies of waste management in a circular economy, and the socio-economic system of production and consumption is left outside of the scope of the interventions entirely. While it can be argued that this wider socio-economic system does not currently fall under the sphere of influence of the municipal waste department, this existing structural limitation does not justify leaving out reference to the wider context in which waste management is embedded. Instead, as argued for in section 5.5. the department could reach out across municipal operations to establish a core circular economy task force which is tasked with charting all relevant operations, establishing cooperation between departments and integrating a holistic, systemic transition program for the municipality.

Second, interventions aimed at directly influencing household behavior are limited. While some plans have been executed in the period since 2017, the scale of activity does not correspond with the size of the opportunity that exists for this approach. Through everyday decision-making on which products to buy and how to dispose of waste, households determine the waste landscape. As such, they are a central enabler of the circular economy and should be treated as such.

Third, the indicators currently at the disposal of the municipality are too limited to accurately assess progress being made with regards to the transition to a circular economy. Suitable indicators with which to assess a majority of the waste management strategies from the 10R framework by Potting et al (2015) are missing. It would be especially useful to have insight into the extent to which strategies R3 – R5 (Reuse, Repair, Refurbish) are being carried out. This can be envisioned as information on the (economic) activity of repair shops, thrift stores and online sharing platforms and marketplaces.

6.3. Closing Remarks

To conclude, progress is being made with regards to increasing waste separation, increasing recycling rates, reducing residual waste and reducing incineration, but this progress is limited to end-of-pipe incremental improvements, while a more radical, systemic shift is required to reach national targets and realize a circular economy. Furthermore, the rate of contamination of the collected materials has increased, which limits recycling options. Finally, consumer behavior has not adequately been addressed in current waste management policy. The expectation of reaching a circular economy with current efforts is not grounded in reality. Considering the novelty, it is understandable that the systemic change required has not yet been realized. However, we have to walk before we can run, and it is time to start conceptualizing the systemic change that is required. To this end, the key recommendation of this study is that the department *stadsbedrijven* of the municipality of Utrecht and the *Copernicus institute* of Utrecht University continue their collaboration.

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APPENDIX A

Calculations for the MFA

Household waste quantities are derived from statistical analysis performed on the dataset by the municipality of Utrecht. Given quantities are the amount of residual waste (kg/person), the separated fractions (kg/person), and the amount of bulky waste by fraction (kg/person) for 2015 and 2017. The quantity of waste fractions contained in residual waste was calculated according to formula 2.

$$Wf_x = \frac{RW * \%FSA_x * Pop_y}{1 * 10^6} \qquad (2)$$

In which *Wfx* is the amount of waste of fraction f_x in kt, RW is the amount of residual waste (kg/person), $\%FSA_x$ is the share of waste fraction f_x in the sort analyses. Data from sort analyses were used as an input (Eureco, 2016;2018)

The amount of waste entering the recycling process was calculated based on the amount of separately collected waste and the degree of contamination according to formula 3.

$$Rf_x = SWf_x - (SWf_x * \%Cont_x) \qquad (3)$$

In which RF_x is the amount of waste fraction f_x entering the recycling process in kt, SWf_x is the amount of separately collected waste of fraction f_x, *and* $\%Cont_x$ is the average contamination was found through desk research. Contamination factors are shown in table x.

The total losses due to contamination were calculated according to formula 4.

$$L_t = \sum_1^x (SWf_x * \%Cont_x) \qquad (4)$$

The amount of waste sent to incineration was calculated according to formula 5.

$$Inc_t = RW + L_t \qquad (5)$$

The Recycling rates were calculated according to formula 6.

$$R_r = \frac{Rf_x}{Wf_x} * 100\% \qquad (5)$$

The amount of electricity, emissions, biogas & compost produced from the waste was calculated according to formula 6. In which $Output_x$ is the amount of specified output and PF_x is the processing factor. Table x gives the relevant processing factors.

$$Output_x = Rf_x * PF_x \qquad (6)$$

The total amount of waste is calculated according to formula 7.

$$TW = \frac{(SW+RW+BW) * Pop_y}{1*10^6} \qquad (7)$$

In which TW is total waste in kt, SW is separated waste (kg/person), RW residual waste (kg/person), BW bulky waste (kg/person) and pop_y is the population of Utrecht for the year in question.

The separation rate was calculated according to formula 8.

$$R_{sep} = (1 - \frac{RW}{TW}) * 100\% \qquad (8)$$

Calculations for comparison

The statistical formulas that have been applied are the arithmetic mean (9), standard deviation (10), and percentual changes (11).

$$\bar{x} = \frac{\sum x}{n} \qquad (9)$$

$$s = \sqrt{\frac{(x-\bar{x})^2}{n-1}} \qquad (10)$$

$$\Delta\% = \frac{(x_{t+1} - x_t)}{x_t} \qquad (11)$$

The following tables provide processing factors and contamination rates.

Waste type	Property	Number	Source
Residual waste	Emissions	433 kg CO2e/tonne	Wise, 2017
	Energy	1,01 GJ/tonne	Wise, 2017
	Aluminium recovery from bottom ash	62%	Allegrinie et al., 2015
Organic	Energy	23,4 MJ/Nm^3	Agentschap NL, 2011
	Fermentation	100 NM^3 biogas/tonne GFT	Agentschap NL, 2011
	Compost	40% per tonnne GFT	Elferink & Vlaar, 2010

Contamination	2015	2017	Source
PMD	12%	20%	Suez, 2016; AVU, 2018
Organic	2%	4%	Attero, 2017; Bogdanovic, 2019
Paper & carton	3,18%	2,83%	PRN, 2016
Glass*	5%	5%	Duurzaam glas, 2017
Textile*	15%	15%	Schoonvelde, 2018
*For glass and textile no data on increase in contamination were found.			