Master's Thesis – Master Sustainable Business and Innovation

A Material Flow Analysis for Defining Utrecht University's Zero-Waste Goals Thesis

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Abstract

Introduction

As the European Union and the Dutch government are moving towards a circular economy, Utrecht University (UU) has set a goal of becoming a zero-waste organization by 2030. Circularity is often contextualized using the R-ladder, which provides a hierarchy for waste management. UU's current definition of zero-waste requires materials to be processed at a level of recycling or higher. Since understanding of current waste streams remained vague, this study investigated the university's waste flows, how they are processed, and recycled material yields as well as potential mitigation solutions.

Theory and methods

A material flow analysis (MFA), a commonly used tool for evaluating the performance of the existing waste systems, was conducted to investigate waste management at UU. Two scopes were used: a narrower scope examining the sources of waste at the university and a boarder scope incorporating downstream processing. The MFA looked at solid waste categories collected by waste handlers in the year 2022. Potential mitigation ideas were then collected via stakeholder interviews and desk research.

Results

The largest problematic waste streams were residual and hazardous waste. Residual waste originated from a variety of buildings while hazardous waste was generated by faculties of Geosciences, Sciences, and Veterinary Medicine. These natural science faculties created more waste per person than other faculties and had more varied waste streams. The expanded scope showed a 12.9% increase in waste sent to incineration and revealed recycled material yields of 43.6% and 75.7% for waste sent to composting/anaerobic digestion and sorting/recycling, respectively. Waste mitigation ideas identified included the elimination of single use items, increasing waste separation, focusing on circular procurement, and collaborating with external parties to identify novel mitigation ideas.

Discussion

The additional material loss identified in the expanded scope suggests the importance of considering the downstream processing when establishing a zero-waste goal. Prioritizing R-ladder ambitions at higher levels is suggested to avoid downstream losses. Limitations to the study include the snapshot nature the MFA, data uncertainties, and a constantly changing regulatory environment. Special attention was drawn to the data gap on exact waste stream composition and insufficient communication regarding UU's waste policies.

Conclusion

The research demonstrated the barriers and opportunities for UU to become zero-waste. Some of the university's essential functions generate waste for which there are currently no alternatives. Further research into the composition of waste streams, monitoring of waste management using the expanded scope, and aiming at higher R-level strategies is recommended.

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1. Introduction

The EU aims to address climate and pollution issues through its Green Deal by becoming a circular economy (CE) (European Commission, 2020). As a part of this transition, the Circular Economy Action Plan, adopted in 2020, strives to reduce the consumption of virgin raw materials by decreasing waste and increasing recycling (European Commission, 2022). In line with the EU strategy, the Dutch government's long-term goal is to become completely circular by 2050, with the intermediary goal of decreasing the consumption of primary raw materials by 50% by 2030, as compared to a 2016 baseline (Government of the Netherlands, n.d.). Accordingly, Utrecht University (UU) has integrated circularity into its agenda by aiming to be a zero-waste organization by 2030.

To conceptualize circularity, the EU Waste Framework Directive provides a waste hierarchy that promotes waste prevention, reuse, and recycling above energy recovery from incineration and disposal (European Commission, 2008). The Dutch government has adopted this approach and uses a more detailed waste management hierarchy system called the circularity or R-ladder (Rijksdienst voor Ondernemend Nederland, 2020). By switching to options higher up on the ladder organizations can become more circular (Ministerie van Infrastructuur en Waterstaat, 2021, pp. 24-26). UU uses an adapted version of the R-ladder for waste management practices (table 1). Zero-waste is defined by the University using this R-ladder and requires waste streams to be managed at the level of recycling (R8) or higher. However, it is currently unclear how to reach the set goal.

Zero-waste is also used as a goal at other universities globally, but the definition of the term varies and is related to the regulations in the region. Zero-waste goals for universities in the United States and the United Kingdom often aim for lower targets of avoiding landfilling, with occasional waste quantity reduction policies being introduced (table 2). Dutch universities focus on CO_2 neutrality and their ecological footprint while also introducing some waste reduction targets (table 2). Wageningen University's goal of a 50% or more reduction of incineration and recycling by 2030 (Potting et al., 2019, p. 2) is similar to UU's intermediate goal of reducing waste sent to landfill and incineration by 50% by 2026, compared to 2022. While the specific goals across universities differ, they often rely on R-ladder concepts in their strategies to decrease waste quantities and the environmental impact from waste (Dobbelsteen & Gameren, 2022, pp. 209-214; Potting et al., 2019, p. 11). Furthermore, there is no specific framework or guidelines to achieve the waste goals.

***Table 1**. R-ladder used by the EU (European Commission, 2008), according to the Dutch Circular Economy Implementation Program (Rijksdienst voor Ondernemend Nederland, 2020) and the system used by UU. Throughout this research, when referring to the R-ladder levels, the UU definitions will be used.*

R#	EU/Dutch R-ladder	PBL R-ladder	UU	UU Definition
R1	Prevention	Refuse and rethink	Refuse	Preventing the use of raw materials
R2	Preparing for reuse	Reduce	2a. Reduce 2b. Redesign	Reducing raw materials/unit Redesigning the product with circularity as a starting point
R3	Recycling	Reuse	Reuse	Reusing the product (second hand)
R4	Other recovery, e.g., energy	4a. Repair 4b. Refurbish, repurpose, and remanufacture	Repair	Maintaining and repairing the product
R5	Disposal	Recycling	Refurbish	Refurbishing or modernizing the product
R6		Recover (energy)	Remanufacture	Reusing product parts to make a new product
R7			Repurpose	Reusing the product for another purpose
R8			Recycle	Processing and reuse of materials
R9			Recover	Energy recovery from materials
R10			Landfill	Materials that cannot remain in the production chain are deposited

Table 2. *Waste definitions and environmental goals at universities.*

	University	Country	Goal	Zero waste definition	Waste management goals
Zero-waste goals in place	Stanford University	USA	Zero-waste by 2030	Less than 10% of waste going to landfill (Stanford University Office of Sustainability, 2020)	
	University of Texas	USA	Zero-waste by 2030	90% reduction of waste being sent to the landfill (The University of Texas, 2022)	
	Keele University	UK	Zero-waste direct to landfill	Less than 1% of waste sent directly to landfill (Keele University, n.d.)	
	University of Edinburgh	UK	Zero-waste by 2030 (as far as practically possible)	Zero-waste: 99% landfill diversion (The University of Edinburgh, 2018)	10% reduction of quantity of waste by 2023 against 2016\17 baseline
	University of Twente	NL	CO_2 neutral 2030 Waste free campus 2030	10.5kg of non-recyclable waste (including residual waste) per person (Dragtstra et al., 2023)	
No specific zero-waste goal identified	University of Groningen	NL	CO_2 neutral by 2035	N/A	-95% waste separation by 2026 -15% reduction in total waste by 2026 compared to 2019 -Residual waste circular by 2026 (University of Groningen, 2021)
	Wageningen University & Research	NL	50% reduction in abiotic material use by 2030 compared to 2014		50% reduction of materials going to incineration and recycling by 2030 (Potting et al., 2019)
	TU Delft	NL	CO_2 neutral and circular by 2030		Emissions from waste are included in CO2 neutrality goal (Dobbelsteen & Gameren, 2022)
	University of Amsterdam	NL	25% reduction of ecological footprint by 2026 from 2021		25% reduction in quantity of waste incinerated and recycled by 2026, compared to 2021 (University of Amsterdam, 2021)

To reduce waste, UU has taken some initial steps that involve separation and recycling initiatives. The university installed new waste bins in buildings, allowing for the separation of residual waste, paper & cardboard, packages, and organic waste. Recycling schemes are also being tested, ranging from initiatives that dismantle old furniture for reuse or recycling to working together with local companies that use old coffee grounds to grow oyster mushrooms. Notwithstanding these initiatives, the university is still far from achieving its zero-waste goals and a deeper understanding of the current waste flows and management processes is required. Several universities support the view that an understanding of the waste flows is required before steps can be taken to improve waste management and claim that KPIs on the amounts of waste recycled, recycling rates, and information about products made from the waste is needed (Dragtstra et al., 2023). UU's Facilities Service Center (FSC) started collecting waste flow data from the main handlers but lacks a more thorough analysis of the waste streams and downstream waste management practices that could provide a complete understanding of waste processing and accurate information on the fate of materials.

Reaching the university's intermediate waste reduction goal requires an understanding of how waste is currently handled and identifying potential areas for improvement. In 2022, UU produced 1 947 320 kg of waste. To achieve its intermediate target, finding alternative waste management of over 300 000 kg of residual waste is necessary. This large reduction requirement is further complicated by the complexity in the downstream waste management chain, where the amounts of waste recycled can be lower than reported. In 2017, the officially reported recycling yield for post-consumer plastic packaging waste in the Netherlands was 50%, while researchers found the net recycling chain yield to be around only 38% (Brouwer et al., 2019). Multiple separation steps and processing were involved in plastic waste recycling with material losses present in each, resulting in a low net recycling yield (Brouwer et al., 2018). While studies have been conducted on the plastic waste stream in the Netherlands, other waste streams have received less attention. Therefore, to determine the actual processing of waste streams, it was necessary to investigate the downstream waste management.

The larger goal of this research is to determine how UU can get closer to its zero-waste goal and give insights on the scope and ambition of the set goal. The research aims to provide UU with an understanding of the waste flows, how they are processed, and how much material is inserted back into use, as the current waste streams remain vague, and data is outdated. Some information on the waste streams had been given by the main waste handler, however, actual amounts of secondary raw materials obtained from recycling processes remained unclear. Therefore, the downstream supply chain was investigated to identify how much material is being kept in the system and the losses that occur during waste management. After the mapping, waste mitigation options were investigated and recommendations on UU's waste goals are made, which were a secondary aim to this research.

To address the knowledge gaps regarding UU waste flows and R-ladder strategies, the following research question with two main sub questions was proposed:
How can Utrecht University become a zero-waste organization while considering the impact of an expanded scope and varying R-level ambitions on waste flows?

1. What are UU's main waste flows and how are they currently being managed?
   1.1. What activities and buildings do UU's waste streams originate from?
   1.2. How do the waste streams change when expanding the scope to include downstream waste management practices?
2. What are the measures that could improve waste management corresponding to different R-level ambitions?

To answer the main research question, the current waste streams needed to first be investigated and understood research could be conducted into improvement measures and recommendations to the scope and ambitions could be made. Therefore, two sub-questions were posed, with the first sub-question investigating waste sources as well as a varying scope. The first sub-questions are answered by performing a material flow analysis (MFA) that maps the waste flows and processes in the chosen system. To answer question 1.2, MFAs with varying scopes are performed to identify key waste flows and determine whether these change when considering downstream waste management practices by waste handlers. This helps to identify main problematic waste streams and highlight differences in using different scopes for the zero-waste target. After generating an understanding of the waste flows, the R-ladder is used as guidance in analyzing the current waste management situation and prioritizing ideas for potential future improvements. This project can serve as an example or case study for other universities and organizations attempting to improve their waste management, helping to reduce waste and increase circularity.

2. Theory

This section discusses the concepts of circular economy and zero-waste in the context of waste management. Additionally, the importance of incorporating a waste hierarchy, such as the R-ladder, will be explored. Furthermore, background on the theory and application of MFAs is provided, highlighting its relevance as a valuable tool in waste management.

2.1 Circular economy and zero-waste

CE has garnered considerable attention in academic literature in sustainability. Interpretations of the concept vary across different works and there are diverse perspectives on how to define it (Kirchherr et al., 2017). One of the most common definitions determines CE as "an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models," (Ellen MacArthur Foundation, 2013). Many R-frameworks have been proposed in academia and practice as core principles of CE (Kirchherr et al., 2017), such as mentioned in the introduction (table 1). Applying these as a waste hierarchy has been noted as a means to recover materials for reintegration into the economy with improved environmental outcomes compared to a linear system (Pires & Martinho, 2019). Using methods higher on the hierarchy can in theory prevent the use of additional raw materials and avoid emissions and negative environmental impacts associated with the production of those raw materials (Reike et al., 2018). The combination of reduce, reuse, and recycle activities, however can often overlook the systemic shift necessary for the transition (Kirchherr et al., 2017).

In the context of CE and waste management, the concept of zero-waste has been seen as an aspirational goal that promotes sustainable resource use (Zaman, 2015). It has been defined by the Zero Waste International Alliance as "the conservation of all resources by means of responsible production, consumption, reuse, and recovery of products, packaging, and materials without burning and with no discharges to land, water, or air that threaten the environment or human health," (Zero Waste International Alliance, 2018). Zero waste is closely connected to the idea of material management as seen in the CE definition. However, it is interpreted in various ways by different organizations, as shown in table 2. The significance of establishing a hierarchy of material management is emphasized when incorporating the zero-waste concept into sustainability practices (Singh & Hussain, 2021). While the definitions of zero waste and CE, along with the supporting core principles, vary in society, using a hierarchy approach that prioritizes material avoidance can be beneficial, preventing companies from solely focusing on incremental recycling efforts. UU's R-ladder is therefore a useful first step in applying the concepts discussed but more evidence-based guidelines are needed to ensure successful material reintroduction and associated environmental benefits.

2.2 Material flow analysis

To reach the circularity goals set by the EU and the Netherlands, companies and organizations are required to take steps to reduce their waste and improve waste management. To make these changes, it is important to understand what waste is being generated currently by the organization and how this is being handled. A suitable tool for this purpose is a material flow analysis (MFA). An MFA is a systematic assessment of matter within specific boundaries and a time frame. According to the law of conservation of mass, the input, stocks, and output of matter in the system and each process within the system must remain in balance (Brunner & Rechberger, 2016, p. 3). Hence, the flow of materials can be traced, and the information obtained can be analyzed and used in decision-making processes. Waste MFAs are commonly used to understand what substances and material flows exist in a country or region and the result can indicate to decisionmakers whether there are more efficient management possibilities of the generated waste flows (Allesch & Brunner, 2017). An MFA can also be performed on a company-level to identify areas for resource use reduction, to improve recycling and minimize environmental impact. This following section provides a general overview of an MFA, while the methodology chapter will specify the aspects chosen for this project.

2.2.1 Steps of an MFA

At first, the problem is defined, and the goal of the MFA is determined. The procedure of an MFA composes of seven steps. According to Brunner & Rechberger (2016), these include the selection of substances, system definition, identification, determination, and assessment of material flows, stocks, and processes, calculation and presentation of results.

The first procedural step is the selection of relevant substances depending on the purpose and system of the MFA. In an MFA, the term *material* refers to both *substances* and *goods*. Chemicals and compounds are considered to be *substances*, while *goods* are used to refer to matter that has an economic value and is composed of one or more *substances*. Main import and export flows of goods are identified, with a recommendation of covering at least 90% of total flows, and indicator substances are determined where appropriate (Brunner & Rechberger, 2016, pp. 51-53). Conducting an MFA on the level of goods can be useful for understanding the waste management system and connections between the involved parties (Allesch & Brunner, 2015).

Following this, the system for the MFA is defined in terms of space and time. The spatial boundaries must correspond to the scope of the project and are preferably small enough, ensuring detailed data is available, while remaining comprehensive. Temporal boundaries should account for the variability that may arise within the system and are typically one year.

The next procedural steps involve an initial rough identification of material flows stocks and processes that are necessary to understand and describe the system, accounting for all important material flows. After this, the mass flows, stocks, and concentrations are determined using direct data from sampling and organizations themselves, indirect data from research papers and statistics from administrative bodies, or proxy data that assumes similar material flows between similar systems. The following step assesses the total material flows and stocks, which includes optimizing balances and uncertainty assessments.

The final steps are the calculation of results, which is done for the checks of uncertainties as well as reconciliations, giving information on the structural quality and consistency of the model. The results are then presented using figures or a Sankey diagram, which condenses the main findings from the MFA, giving a clear message to decision-makers (Brunner & Rechberger, 2016, pp. 78-89).

2.2.2 Use of MFA for waste management decision-making

In waste management, MFAs are most commonly used as a tool for evaluating the performance of the existing system, comparing waste treatment systems, or as a way of analyzing the current system (Allesch & Brunner, 2015). The results of an MFA provide useful information for understanding waste management systems through giving a clear image of material flows. It is a cost-efficient way of identifying the areas that have the potential for improvement (Brunner & Rechberger, 2016, pp. 29-30). Where appropriate an MFA can be repeated or used as an assessment method to monitor changes as demonstrated by Brouwer et al (2019) in the assessment of the Dutch post-consumer plastic packaging recycling network. The results of waste management MFAs are typically combined with other assessment methods that focus on aspects such as quantifying resource potential, environmental impacts, release of hazardous substances, or energy efficiency (Allesch & Brunner, 2015). Studies are conducted on the level of goods, substances, or a combination of both, depending on the goal and the aspects of interest. MFAs on the level of goods are helpful in analyzing material flows in the system and implementing regulatory mechanisms, as the input they provide can be used in communication between parties involved in the decision-making (Allesch & Brunner, 2015).

3. Methodology

The research was conducted in two main steps, which reflect the two main sub questions of the research (figure 1). To understand UU's waste flows, an MFA was performed, which was followed by an identification and assessment of potential measures to reduce those waste flows.

Figure 1. *Outline of the research methodology.*

3.1 MFA

To answer the first sub question on UU's main waste flows and how they are currently being managed, an MFA was conducted. The aim of the MFA was to provide an understanding of which buildings and activities the waste originates from as well as give insight into downstream processing of waste. As explained in section 2.2.2., MFAs are a common tool for investigating waste management systems. An MFA was specifically suitable for this project as it provided an understanding of the waste management system and allowed for the identification and quantification of the main waste flows (Allesch & Brunner, 2015) in the scope of UU operations, as well as further downstream. The results helped determine where the management processes lie on the circularity ladder.

3.1.1 Definition of the system

The temporal scale selected for this project was one year, which is in line with most MFA studies (Brunner & Rechberger, 2016). This timescale accounted for the fluctuation in the number of people using the university buildings throughout the year, as well as any other seasonal variabilities. Waste data from 2022 was used. While the year 2022 was still affected by lockdowns imposed due to the COVID-19 pandemic, it was more representative of the university's typical functioning than the years 2020-2021 and provided the most recent waste figures available.

To answer research (sub)question 1.2 of how the main waste streams change when expanding the system boundaries to include downstream waste management, and MFA was be carried out with two different spatial scopes. The first scope focused on the type of initial processing chosen for each waste stream while the second scope delved further downstream and attempted to determine the useful outputs of each waste stream. This is done to understand the most important streams to target for waste reduction, and for further consideration of how far the university's zero-waste ambitions should extend regarding scope. Considering activities beyond the university's own operations is necessary, because while the university sends waste for processing, the actual fate and processed quantities of waste can be complex and complicated to determine as seen by the discrepancies in reported and actual recycling yields (Brouwer et al., 2019). The two scopes are discussed in detail below:

<u>Scope 1</u>

Scope 1 is waste from UU-owned buildings, where the university is legally responsible for waste management and has operational control. This includes buildings in the Science Park campus and city center which can be used as offices, for teaching and research, as well as any administrative and dining buildings that are operated by UU. Waste from dining-related external parties which are located within the buildings such as the small SPAR shops and Espressobar Gutenberg are included within this scope as these services are a part of the university's functioning. This waste is also mostly collected in the bins of the buildings they are located in and estimating their waste fractions would introduce uncertainties into the study. Additionally, waste from heat and electricity cogeneration plants in Science Park are included as well as outputs from internal recycling facilities that are collected by waste handlers. The latter refers to the Tankhal and Milieustraat, which are efforts by the university to separate UU waste into material streams to reduce the amount of material going to residual waste (described below in this section).

Waste from external parties: TNO, Stichting Deltares, Sportcafe Olympos, SPAR, Bisschoppen apartments, and Grand Café de Basket, are excluded as UU has no operational control over these entities and their waste is weighed separately by the waste handlers. Buildings where UU operates that are rented from external parties, such as Bolognalaan 101, are excluded from the scope, as the university mostly rents only a part of a building, making it difficult to estimate the fraction of waste that is associated with solely UU activities.

It is noteworthy that included within this scope is *free rider* waste. This is waste from external parties, where UU has no control over waste generation and is not contractually responsible for waste management, however, the waste ends up in UU waste bins. Several businesses that are legally responsible for their own waste (e.g., food trucks, Pizzeria Tricolore) are located in the middle of the campus, next to the Science Park Library (see figure 2). However, the external parties' waste bins are insufficient for the amount of waste generated and waste is mostly disposed into adjacent UU-owned waste bins or brought to other buildings by students and staff. This problem has been acknowledged by the university as UU still manages the extra waste generated by the free riders but has no operational control over it. The quantity of free rider waste is difficult to estimate and distinguish from UU waste without direct measurements.

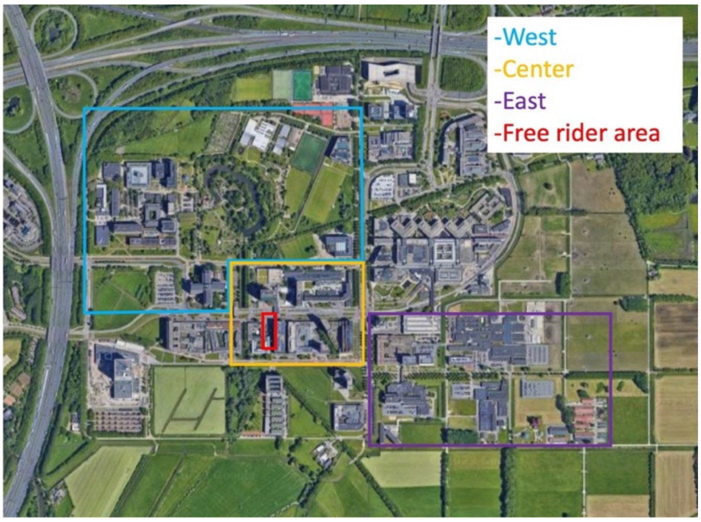

Figure 2*. Rough regions of the Utrecht University Science Park Campus in which most Science Park UU-owned buildings that are included withing the scope of the research are located. A full list of buildings can be found in Appendix B.*

The system boundary is at the level of the first waste handlers. The first processing step to which the handlers sent the collected waste to was identified.

Scope 2

Scope 2 includes waste from all the same buildings as Scope 1. The downstream processing of each waste stream, including the location of each step where possible, was further investigated. Identifying the downstream processing beyond the first waste handler and first processing step was important as each waste stream goes through multiple transport, sorting, and recycling steps. The sequence of these processes and the technology used was obtained from the best available data. Material is discarded or lost at each of these steps, and often sent to incineration. This leads to a lower output of recycled materials that can be inserted back into the loop in comparison with the amount of material from each waste stream that is sent to recycling in Scope 1. An illustration of Scope 1 and 2 is provided below (figure 3). This difference is important in the context of circular economy and indicates the difficulty of labelling an organization as "zero-waste" while considering an expanded scope of responsibility. An investigation was conducted for each waste stream to gain a complete understanding of the system with the most accurate recycling yields possible. The system boundary is at the waste handling process where recycled materials that are used as inputs in new production processes are generated. Any additional processing or treatment of the recycled materials by new product manufacturers was not considered.

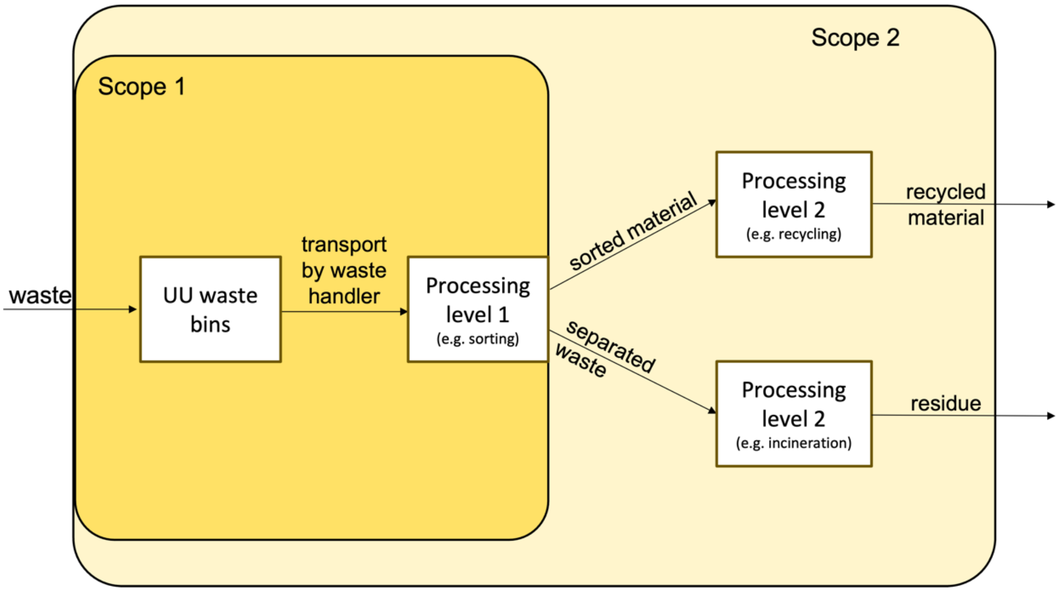

***Figure 3**. An illustrative image of Scopes 1 and 2. Scope 1 included reported waste processing data by the first level waste handler, while Scope 2 investigated the further processing of each waste stream.*

Milieustraat and Tankhal

The Milieustraat and Tankhal refer to two projects set up by individual initiatives at UU. Bulky waste from campus is collected at the Milieustraat location where it is separated into component streams of metal, wood, plastic, EPS, and residual waste. This prevents bulky waste from going directly to residual waste. The separated component streams are picked up by Renewi and weights are reported along with other waste streams. Materials that have the potential to be reused are gathered at the Tankhal. These can include clothes, electronic equipment, and water bottles from the lost and found that are sent to second-hand shops as well as furniture items that are repaired or remanufactured by a Technical Support Assistant. The quantity of material entering the Tankhal is not monitored due to a lack of workers. Objects sent to the Tankhal are also separated into various components. Materials for which alternative management options cannot be found are sent to the Milieustraat location to be picked up by Renewi.

3.1.2 Waste categories

For this project, the waste categories that are separately collected by the university and processed by the waste handlers were used in the analysis. Using waste categories was suitable as it provides a sufficient overview of material streams and the university and waste handlers do not collect data on the level of substances. The waste categories and respective waste handlers are presented below in table 3. Waste quantities were available by building for most waste streams and were allocated to faculties according to the building list summarized in Appendix B. The waste sources are mentioned for each waste category in the section below. In scope 1, the materials do not change form. In scope 2 the materials undergo processing and may change in form. Some waste categories have clearer sources and general material processing methods and outputs, while others can be more variable and uncertain due to unknown composition and type of contamination of the waste stream. The following sections provide a brief description of each waste category.

Table 3*. A list of waste categories, their mass in 2022, and respective waste handlers.*

Waste category	First-tier waste handler	Weight (kg)
Residual waste	Renewi and Stadswerken Utrecht	612 641
Paper and cardboard		
Paper/cardboard	*Renewi*	*194 026*
Confidential paper	*Renewi*	*27 574*
Paper towels	*Tork/Essity*	*1 830*
Plastics		
PMD	*Renewi*	*15 793*
Foils and hard plastics	*Renewi*	*14 193*
Styrofoam	*Renewi*	*980*
Organic waste		
GFT	*Renewi*	*26 812*
Swill	*Renewi*	*19 309*
Coffee grounds	*De Clique*	*28 288*
Soil	Renewi	45 100
Wood	Renewi	25 240
Manure	Renewi	33 600
Metal	Renewi	49 180
Glass	Renewi	30 079
Electronic waste	Renewi	
ICT equipment	*ARGO360*	*Reuse: 4324 devices* *Recycling: 12 587 kg*
Other electronic waste	*Renewi*	*24 523*
Construction and demolition waste	Renewi	29 460
Hazardous waste	Renewi	
Specific hospital waste	*Renewi*	*56 209*
Other hazardous waste	*Renewi*	*61 306*
Coffee cups	Renewi	900
Green maintenance waste		
Green waste, waterway waste, and bulky waste	*Sight Landscaping*	*528 200*
Green waste from botanical gardens	*Abacus*	*109 490*
Total		**1 947 320**

<u>Residual waste</u>

Residual waste bins are located in all of UU's buildings. The residual waste is assumed to contain waste generated by administrative and teaching activities as well as waste from products that are sold by vendors located in or near to UU buildings. In the Science Park, waste from the free riders ends up in UU waste bins, much of which is likely thrown into residual waste bins. Students and staff that use the city center buildings presumably also bring in waste from external parties such as supermarkets and coffee shops located nearby. Additionally, it can be expected that waste, such as packaging of food or other products that are brought from home to UU buildings by staff and students, is also disposed of in UU bins. As data on the specific composition of residual waste from UU buildings was not available, the composition is assumed to be similar to household residual waste in the Netherlands.

Residual waste is mostly collected at the buildings the waste is generated in. For certain city center buildings, the residual waste is taken to the central waste collection point at the city center library and is not reported under the specific building's waste figures. This includes buildings on Drift Street with the numbers 8/6, 10, 21, 23, 25, and 27. Residual waste from the university is collected by two waste handlers and therefore diverges into two streams by collection. Residual waste from several UU buildings in the city center region is collected and processed by the Utrecht city's municipal collector (see Appendix B for building list). The waste collected by the municipal collector is not weighed by the trucks and estimated weights are provided by the collector to UU. These estimates are considered to be relatively accurate. The residual waste from all other buildings is collected by Renewi and weighed.

Municipal collector processing

AVR, which processes residual waste from the city of Utrecht, operates post-separation facilities which sort plastic, metals, and drinking cartons from waste before incineration. Multiple steps are used to separate PMD from residual waste (AVR, n.d.). Firstly, the waste bags are opened and shredded so the waste is distributed on a conveyer belt. Magnets are used to remove metals, which are sent for processing. Vibrating screens then divide the waste based on its size. Ballistic separation is used to separate paper and foils from non-flat objects such as drinking cartons, wind shifting then removes the foils, and near infrared scanners separate plastics by material type. All the separated foils, plastics and drinking cartons are pressed into bales for easier transport. The remaining waste is incinerated with energy recovery. Dutch waste incineration plants use moving grate technology, which provides a continuous feeding of waste into the burners using bars or roller conveyers with air introduced from below the grate (Leeuw & Koelemeijer, 2022). The moving grate technology allows for large quantities of waste to be incinerated and can handle heterogenous waste with varying levels of calorific value without prior separation processes (Makarichi et al., 2018). Metals that are not recovered using post-separation, and minerals are recovered from the bottom ash following incineration. The metal is sent to recycling and the mineral fraction is used in construction applications such as roads (AVR, n.d.).

As specific composition data for UU's residual waste streams was not available, average recovery rates were used. In 2022 AVR recovered 25 kilotons of plastic, 2,6% metal, and 22,0% minerals from 2109 kiloton of residual waste (AVR, 2023). These figures are similar to values found in literature for metal recovery and bottom ash formation (Leeuw & Koelemeijer, 2022; Viva et al., 2020; Werkgroep Afvalregistratie, 2023). The energy output from AVR in 2022 was 7.8 petajoules, of which steam was 1.1 PJ, heat 4.9 PJ, and electricity 1.9 PJ (AVR, 2023). A small fraction, 43 kt of CO_2, was captured from the incineration emissions and can have an application in horticulture, however, the exact usage of this was not specified.

Renewi processing

The residual waste that is collected by Renewi from the remaining buildings is sent to a residual waste collection point. From there, around 42% of the waste is sent to the ICOPOWER installation in Amsterdam, where the high calorific fraction from the residual waste is mechanically separated and reduced into smaller sizes by a hammer mill (Grundmann, 2016). Ferrous metal, which accounts for around 2% of the waste input to ICOPOWER, is removed from the waste in two steps and chlorinated materials such as PVC are optically sorted out. The moisture content is measured, and the high calorific material is dried and pelletized. The mass yield of pellets is around 34% of the residual waste input, and the loss of moisture is around 29% (Renewi, 2023c). The energy pellets are sold to power stations and industrial plants such as cement industries and asphalt purification installations. These pellets which are a secondary energy source can also be shipped abroad, for example to Sweden for use as fuel in cement production (Renewi, 2019). The low calorific fractions and residues from ICOPOWER pellet production, as well as the remaining 58% of the waste collected is sent to incineration with energy recovery. As Renewi does not operate any waste incineration plants, this waste is sent to various facilities, such as AEB.

To determine the outputs from waste incineration, averages values from literature data were used. An estimated 22,8% of bottom ash was formed, 2,3% of the output was metal and 3,1% fly ash with the rest being emitted as CO_2 and water vapor. According to Renewi, part of the bottom ashes are sent to Heros Sluiskil for processing into construction materials that are an alternative to sand and gravel and can be used in asphalt, concrete, or road foundation (HEROS Sluiskil, 2022).

<u>Paper and cardboard</u>
The paper and cardboard waste stream includes separately collected paper and cardboard as well as confidential paper and paper towels.

Paper and cardboard
Paper and cardboard are collected as a separate waste stream from numerous buildings and are collected and processed by Renewi. Only clean paper is accepted for recycling and wet or contaminated paper is sent to incineration (Renewi, personal communication, 12 May, 2023). Materials accepted for sorting include printer paper, newspaper, writing pads, cartons, colored paper, magazines, and envelopes (Renewi, n.d.-b). Renewi separates paper into different qualities manually or using sieves and pneumatic technologies (Renewi, 2023c). It is pressed into bales so it can be sent to the paper manufacturing industry.

To make new paper, the paper from bales is mixed with water forming a pumpable suspension (Holwerda et al., 2019). Contamination larger than the fibers, such as metal paper clips, pieces of plastic, or sand, are removed using a series of sieves and centrifugal cleaners. To further purify the fibers for white paper production, the pulp can be cleaned from ink and wax using de-inking and disperging processes, respectively. Fibers can typically be reused up to 7 times for making new paper (Renewi, n.d.-b). Finally, the recycled pulp is dried to remove moisture and allow for production of new products such as toilet paper, tissues, and office paper.

Renewi has states that 79% of the paper collected for recycling is processed into new raw materials, based on a TNO report (Renewi, personal communication, 12 May, 2023). This recycling yield of pulp is in line with values from literature, which range from 60-95%, depending on the quality and type of paper (Keränen & Ervasti, 2014; Laurijssen et al., 2010; Van Ewijk et al., 2018).

Confidential paper
Certain documents generated from UU activities require separate handling from regular paper due to their sensitive content. The confidential paper is collected from the offices of faculties in the city center and Science Park, as well as the administrative buildings. Confidential paper is processed by Renewi Destra, where additional measures such as secure containers and adapted vehicles for transport are used (Renewi Destra, n.d.). Confidential paper and cardboard are first shredded into a size between 10 and 100mm between blades or cut into small pieces and strips. These are compressed between metal plates into bales and sent to the paper manufacturers. The additional shredding step involves slightly more weight loss compared to regular paper processing due to the formation of dust (Renewi, personal communication, 12 May, 2023). However, since this loss is mass is not expected to be significant and it is not measured by the company, it is not accounted for in the analysis. Materials collected with the waste paper that are not suitable for paper recycling are incinerated with energy

recovery. It is assumed that confidential paper has the same recycling yields as regular paper and cardboard.

Paper towels

Paper hand towels from toilets in the Bestuursgebow, Marinus Ruppertgebouw, Educatorium, USP Library, and Victor J. Koningsberger buildings are collected in separate bins designated specifically for hand towels and processed by Essity factories. The bins have labels and ask for other materials to not be thrown into the bins as this waste stream must be free of residual waste pollution to allow for recycling. The recycling of paper towels is more difficult and costly than regular paper as substrates and wet strength agents are added to the hand towels (Tork, 2021). As a first step, the paper towels are visually checked for purity and pressed into bales for easier transport. To recycle tissue paper the Tork PaperCircle© process is followed, where special dissolving methods are used to deactivate the wet strength agent after the papers have been mixed with water in the pulper. The pulp is heated to a high temperature for hygienic reasons, following which the fibers are separated and mixed with other pulp for the production of new paper towels. As this waste stream is relatively small, making up around 0,1% of the university's waste, the same recycling yields as for regular paper and cardboard are assumed.

<u>Plastics</u>

The plastics waste stream is composed of waste from the separate collection of three sub streams: plastic, metal, and drinking cartons (PMD), foils and hard plastics, and Styrofoam.

PMD

In the year 2022, plastic packaging, metal packaging, and drinking cartons were collected together. UU has placed separate collection bins for PMD packaging in all of its buildings as of the beginning of 2023. Therefore, in buildings where separate PMD collection bins were not yet placed in 2022, PMD was not reported as a separate stream and was disposed of in the residual waste bins. Renewi collects the PMD waste and transports it to its Nieuwegein location. Around 2% of the PMD waste stream is discarded due to contamination before processing (Renewi, personal communication, 12 May, 2023). On site, Renewi performs an acceptance check, presses the materials into bales and sends them to the German processing company Hubert Eing for mechanical recycling where streams of high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), and polyethylene terephthalate (PET) are sorted. As information on the specific quantities of the plastic, metal, and drinking carton fractions was not provided, literature values of PMD material fractions were used. Brower et al. (2019) determined that in 2017 in the Netherlands, the fractions from PMD sorting into plastic, metal, and cartons to be approximately 61%, 7%, and 8%, respectively. The rest was sorting residues and moisture and dirt. It is assumed that the plastics are mechanically recycled by milling, washing, and float separation, and then turned into granules and agglomerates. Polymer recycling yield percentages were taken from Brouwer et al. (2019) as Renewi was not able to provide the final yields. Yields from the recycling of plastics recovered from the post-separation of residual waste were also obtained from Brouwer et al. (2019). The polymers listed by Brouwer et al. (2019), corresponded with the product list on the Hubert Eing website (Hubert Eing Kunststoffverwertung, n.d.).

Foils and hard plastics

Foils and hard plastics are collected as a separate stream from the Sciences and Veterinary Sciences buildings, as well as the Milieustraat and the Tankhal. The waste stream from the two academic faculties are largely packaging foils, for example feed and hay that is transported on pallets. The foils are compressed into bales according to the quality and hard plastics are separated by type at Renewi Acht. The PE and PP mix is shredded and sold to recyclers (Renewi, personal communication, 12 May, 2023). As there is no separate information about the composition and recycling numbers of UU's foils and hard plastics was identified, same processing and recycling figures are used as for PMD waste.

Styrofoam (EPS)
Styrofoam is collected separately at the Milieustraat and FSC Residue Management locations from where it is picked up by Renewi. The Tankhal also separates EPS when possible and sends it to the Milieustraat for collection. Renewi sends the EPS to its Nieuwegein location and to Poredo for recycling (Renewi, 2023c). Approximately 98% of the EPS is recyclable (Poredo, n.d.). It is first shredded, followed by grinding and finally sifting according to grain size. The sorted grains are reused in furniture applications such as beanbag filling, in construction materials, or to produce new EPS products.

<u>Organic waste</u>
The organic waste stream includes the waste categories vegetable, fruit, and garden waste, swill, and coffee grounds.

Vegetable, fruit, and garden waste
In 2022, the vegetable, fruit, and garden waste (GFT) largely originates from the botanical gardens and other landscaping activities. This includes wastes such as pruning waste, plants, leaves, and potting soil. Since early 2023, separate organic waste bins have been in place in all university buildings. As these were not available in the prior year, the GFT waste such as food leftovers and teabags from students and staff is expected to have ended up mostly in residual waste for the 2022 waste figures.

Renewi collects the separately collected GFT waste and transports it to special installations at the Nieuwegein location. The company and its subsidiaries operate a multitude of facilities with different organic waste treatment technologies, with UU's waste being processed using aerobic composting (Renewi, 2023c). During aerated composting, microorganisms decompose the organic waste into compost, a soil-like matter which can be used as a fertilizer (Lohri et al., 2017). The composting process undergoes three stages: mesophilic, thermophilic, and cooling/maturation (Neklyudov et al., 2006). The temperature in the first and third stages can rise up to 55°C, where oxidative degradation happens in the most intensive phase of the first stage. In the thermophilic stage, temperatures can rise up to 70°C during which pathogenic microorganisms are killed. During these processes there is a loss of moisture, CO_2 is emitted, and leachate, a liquid waste, is produced (Lohri et al., 2017). Pollutant materials such as metal, plastic or glass are separated after composting and sent to incineration (Renewi, personal communication, 12 May, 2023). The output yields of the aerated composting process were obtained using average data from literature (Andersen et al., 2011; Bijleveld et al., 2021; Chazirakis et al., 2022; Zhang & Matsuto, 2011). The yield of compost is assumed as 40,5%, leachate as 6,2%, with the rest being emissions and pollutants. It is estimated that 11% of the GFT input is pollutant materials (Viva et al., 2020). The resulting compost can be filtered according to size, and specific quality requirements regarding the content of nitrogen, phosphate, and dry matter as well as pollutants such as heavy metals must be followed (Rijksoverheid, 2007). Compost produced by Renewi's facilities that meets quality criteria is sold to external customers (Renewi, n.d.-a).

Swill
Swill waste consists of cooked food waste and leftovers, including meat and fish, and various kitchen wastes. This type of waste is collected separately from cafeterias and dining facilities that are located within UU's academic buildings. Swill waste is sent to Renewi Organics Amsterdam (Renewi, personal communication, 12 May, 2023). Orgaworld, a subsidiary of Renewi, operates multiple organic waste treatment facilities if the Netherlands, including a site in Amsterdam, which is a likely destination for UU's swill waste. The technologies at the Greenmills site combine wet anaerobic digestion, sediment drying facilities, and MBR aerobic and anaerobic water purification to produce biogas that is converted into steam, heat, and energy, with residual products transformed into fertilizer.

As Renewi and its subsidiaries operate a multitude of facilities with different organic waste treatment technologies such as aerated composting, anaerobic digestion and fermentation, and there is no overview of which exact facility UU's GFT and swill waste is taken to, average figures from literature are used in determining the output of organic waste treated by Renewi. Viva et al. (2020) in analyzing the organic waste treatment from the city of Amsterdam, identified Orgaworld as one of the organic waste processors, which is currently a subsidiary of Renewi. The compost, biogas, water, and waste yield in the study was considered to be 700 kg, 120 kg, 70kg, and 110kg, respectively, per ton of wet mass of organic waste (Viva et al., 2020).

Coffee grounds

Coffee grounds used in the MAAS coffee machines are collected from buildings at Science Park that have the MAAS machines and are deposited at a storage point at Sorbonnelaan. The spent coffee grounds are not weighed per building so only the total quantity generated by the university is measured. The grounds are then picked up by De Clique, an Utrecht-based company that uses the spent coffee grounds to grow mushrooms (De Clique, personal communication, 6 June, 2023). An estimated 30% of the coffee grounds are mixed with soil and placed into bags which oyster mushrooms can grow on (De Clique, personal communication, 13 June, 2023). After use, the grounds that contain spores, as well as the coffee grounds that were not used for growing mushrooms are sent to composting and fermentation.

<u>Soil</u>

Contaminated soil is generated by research activities in the Geosciences faculty. The larger share of the waste stream originates from the Earth Simulation Lab, where a large metronome tank, a debris flow tank, and several smaller tanks are used to simulate river and coastal systems and sediment flows. To conduct the experiments, a mixture of clay, sand, and gravel is made. Brilliant blue FCF, as dye used in food and cosmetics industries, is added to water for experiments in the metronome tank. The contaminated soil therefore is composed of the mixture of these substances as well as plants and algae that may start growing in the tanks during the experiments. The experiments can last from several weeks to months in the metronome tank, where around 6000-7000 kg of soil is used per experiment. Up to 10 experiments a day can be conducted in the debris flow tank that can use 70-150 kg of soil per experiment. After soil is used for an experiment, it cannot be reused and is disposed of. The quantity and composition of the soil waste stream is therefore highly variable and dependent on ongoing research projects.

Renewi collects the contaminated soil from separate containers. Analyses are taken from soil in batches and sent for extractive or thermal cleaning, depending on the type of contamination. During thermal desorption soil is heated up to a temperature of 650°C for the organic pollutants to volatilize and evaporate, which is followed by the diffusion and migration of pollutants through the soil pores (B. Wang et al., 2021). Extractive cleaning involves the washing of the soil to remove inorganic pollutants, often with a combination of water and a surfactant (Grimison et al., 2023). During the thermal cleaning there is minimal loss of mass, and the soil can be recycled, while extractive cleaning can result in up to a 30% loss of mass as fine particles and pollutants which are deposited (Renewi, personal communication, 31 May, 2023). Renewi reports a soil recycling rate of around 98% that is processed into sand, gravel, and filler that can be used as construction materials (Renewi, 2023a). As the soil from UU's experiments is not highly contaminated, it can be assumed that it does not require extensive cleaning and is mostly recycled into construction materials.

<u>Wood</u>

Wood waste is separately collected by Renewi from the Milieustraat and FSC Residue Management locations and the Hugo R. Kruytgebouw. All wood from the university is treated as "class B" wood which can include treated wood, tables, chairs, cupboards, scrap wood, produce crates, etc. The wood is shredded and sifted at Renewi's facilities. Approximately 8% of the wood chips are of suitable quality for chipboard production (Renewi, personal communication, 12 May, 2023). The rest of the wood chips that are not sent to the chipboard industry are sent to biomass energy plants.

Manure

The Veterinary Sciences faculty operates farms with animals such as pigs, bovines, horses, sheep, poultry, etc. for controlled experiments and educational activities. The generated animal manure is collected by Renewi from the Nieuw Gildestein building and sent to Nijssen Fourages where it is composted. Average data from literature is used for determining compost outputs, with the same yields as the GFT waste for compost and leachate. Manure waste is expected to not contain the typical pollutant materials of paper, plastics, or metal that are collected with GFT waste.

Metal

Metal scrap is mostly collected from the Milieustraat and to a small extent the Hugo R. Kruytgebouw. At the Milieustraat various equipment and products are separated into components, and the metal parts are separately collected by Renewi. Renewi transports the metal firstly to their Nieuwegein location and then to scrap metal processing. The metal is sorted, bulked, and shredded (Renewi, personal communication, 12 May, 2023). Following this, the metal is sent to metal recycling companies. 96% of the metal scrap that is received by Renewi is sent to recycling, while the rest of the waste stream is pollution such as rubber, plastics, and insulation material that is sent to incineration or landfilling (Renewi, personal communication, 12 May, 2023). These figures are in line with literature estimations of metal yields of 95-97% from the scrap recovery process before it is sent to secondary smelters abroad (Haupt et al., 2017; Thoden van Velzen et al., 2020).

Glass

Glass is collected separately from a multitude of buildings with the largest quantities originating from the Academiegebouw and various buildings with dining facilities. The glass is collected by Renewi and after bulking, it is sent to processing by its subsidiary Maltha at the Heijningen location (Renewi, personal communication, 12 May, 2023). At Maltha, the glass is dried and the dirt and moisture dust residue is removed (Maltha, n.d.). Metals are removed from the glass using magnets and non-magnetic metal separators. Materials such as ceramics, stones, porcelain, labels, corks, and straws are extracted from the glass. The purified glass shards are sent to the glass industry for use in manufacturing new glass products. According to a TNO research report, 98% of the glass collected by Renewi is recycled as shards and 2% is various polluting materials that are sent to incineration (Renewi, personal communication, 12 May, 2023). Similar recycling yields of around 98% are also found in literature (Blengini et al., 2012; Haupt et al., 2017).

Electronic waste

Electronic waste from UU has two flows, which are managed differently. The first is ICT equipment which is used by UU staff and collected when it is replaced. The second flow is electronics products, refrigeration and freezing equipment, and monitors from Geosciences, Sciences, and Veterinary Science faculties.

ICT equipment

ICT equipment includes computers, laptops, monitors, docking stations, mobile phones, tablets, printers, network switches, etc. When this equipment is broken or exchanged for newer models it is collected by ARGO360. The company separates equipment that is still useable and sells it. The devices that cannot be reused are recycled. In 2022, ARGO360 processed 5422 devices from UU of which 4059 were inventoried or sold and 832 were recycled. The remaining 531 devices are split between inventory/sales and recycling; however, the fraction is unclear. Equal distribution between the two categories is assumed. In total, ARGO360 recycled 12 587 kg of ICT equipment from UU in 2022. The weight of the inventoried/sold devices could not be provided. The recycled devices that carry data are shredded for data protection purposes. At a recycling facility, From the recycled devices, 34% was recovered as steel and metal, which included copper, aluminum, gold, platinum, and palladium.

Electronics products, refrigeration and freezing equipment, and monitors
The electronic waste collected from natural science faculties at Science Park is categorized into electronics products, refrigeration and freezing equipment, and monitors. This waste streams are separately collected by Renewi and compose mostly of large lab equipment. The waste is sent to subsidiaries such as Coolrec, where it is shredded and sorted. Metals and plastics are separated and 76% of this waste stream is recycled, while 24% is sent to incineration (Renewi, 2020). Renewi was not able to provide more detailed quantities of waste recycling and fates of the e-waste stream.

<u>Construction and demolition waste</u>
Construction and demolition waste is collected separately from four buildings at Science Park. The largest quantity was generated by the Proefboerderij de Tolakker. This waste stream is collected by Renewi and transported to their Nieuwegein location. Renewi shreds, sorts, and separates the waste stream, recovering wood, rubble, metal, plastics, and sand (Renewi, 2023c). The remaining 50% of residue is sent to incineration. The composition of this waste stream varies and Renewi was not able to give specific figures for the fractions of recycled streams (Renewi, personal communication, 12 May, 2023). A typical breakdown of the composition of the C&D waste stream in the Netherlands in 2012 (Mulders, 2013) was used to estimate the fractions. The amount of metals, wood, and plastics was 12.88%, 6.10%, and 0.76%, respectively. It is assumed that the wood is somewhat contaminated and will be treated as B-wood. The amount of concrete and masonry material in Mulders (2013) was 64.02%. This includes rubble and sand; hence it is assumed that the remaining 30.26% of C&D waste that is sent to recycling by Renewi is rubble and sand.

<u>Hazardous waste</u>
Hazardous waste includes 33 separately collected waste streams from buildings in the Science Park. 48% of the hazardous waste stream is specific hospital waste (SZA). Other hazardous waste streams include low-calorific liquid, contaminated articles, inorganic acid/lye, and halogenated waste which are each under 1% of the total waste by mass from UU in 2022. Limited information about these waste streams and their processing was obtained. The mass of the rest of the separately collected hazardous waste streams that were not mentioned previously are each under 0,2% of the total waste from UU in 2022. These hazardous waste streams were incorporated collectively in the results diagrams to include the waste from research activities, but their downstream processing was not further investigated due to the lack of available information and small quantities.

Specific hospital waste (SZA)
Specific hospital waste is generated by the Sciences and Veterinary Sciences faculties' activities. It consists of biomedical waste from research activities and veterinary services. This waste is collected separately by Renewi and sent to Zavin for incineration (Renewi, personal communication, 12 May, 2023). Zavin uses gasification to process the hospital waste according to law in an oven that has two furnaces (Zavin, n.d.). The pre-processing furnace has four phases, where the waste is at first heated. In the second step, the waste is gasified while limiting the air inflow, leading to incomplete combustion. The produced gas is directed to post-combustion furnace, while the waste continues to the third step where the remaining carbon is burned at around 1000°C. The energy generated in the third step is used to maintain the first two phases mentioned previously. The remaining non-combustible residue continues to the fourth phase, where the slag is allowed to glow and anneal. The average mass fraction of slag from the process found from literature is 11.2% of the waste input (Gielar & Helios-Rybicka, 2013; Malkow, 2004; Messerle et al., 2018). The syngas directed to the post-

combustion furnace undergoes three processing stages before being sent to a waste gas boiler for energy generation (Zavin, n.d.).

Coffee cups
Single-use coffee cups are a separately collected waste stream from buildings in the Science Park. However, this stream makes up under 0,1% of the total waste from UU buildings and is excluded from the waste streams analysis.

3.1.3 Data collection

For the source side, data on waste quantities was collected from the first level waste handlers with whom UU has waste management contracts. In 2022, the university had five main waste collectors who managed various waste streams. The largest quantity of waste was collected by Renewi, who provided a breakdown of data by waste streams mentioned previously in Section 3.1.1 and the origin of these streams per UU building. The waste quantities were physically weighed by Renewi. Renewi also provided data from the collection of waste by the municipality from the city center buildings. Waste figures from the maintenance of landscaping at the Science Park grounds were obtained from Sight Landscaping, who provides landscaping services and manages the waste created from those activities. Waste quantities for three smaller streams: coffee grounds, ICT equipment, and hand paper towels were obtained from De Clique, ARGO360, and Tork (Essity), respectively. Qualitative information on the origin, waste contents and types of activities that generate waste was collected during meetings and conversations with individuals from the FSC team, Sustainability Office, Geolab, and ESL. Insights have been included in the waste stream descriptions in Section 3.1.1.

For Scope 2 and the waste management side, the contracted waste handlers were contacted via email and information on the location, method, and efficiency of recycling processes was asked. Due to the complexity of the questions and language barriers, communication with the waste handlers was primarily via email. This was preferred by the waste handlers due to the fragmentation of the information on waste streams within the organizations. For most waste streams it was difficult to obtain recycling yields and to identify specific technologies and locations for the processing of specifically UU's waste as this is not monitored by the waste handlers. The difficulties in obtaining information on waste processing and yields from waste companies has also been documented in literature (Viva et al., 2020).

While the first level waste handlers were able to provide the names of companies which conduct further processing and recycling activities, they could not provide direct contacts. Suggestions to approach the second-tier handlers via general contact information on their websites were followed, however, no replies were obtained. To supplement this lack of information, data from academic and grey literature, as well as details from the websites of the subsidiaries and downstream waste handlers was used. This included data such as waste bin contents, recycling technologies and efficiencies, material losses, and recycling output quantities. Literature data gathered using desk research was compared to data collected through communications to help qualitatively assess the reliability of data collected from waste handlers. Collected data was used to analyze waste generation per faculty and to create a Sankey diagram for both scopes, which can be found in the results section.

3.2 Waste management improvement measures

Following the MFA, the second research sub question on improving waste management was addressed. Firstly, the waste streams identified in the first part of the research were mapped to their R-ladder level to provide UU an idea of where they currently lie within their circularity ambitions. The R-level results and Sankey diagrams were presented to the FSC team. The waste streams were explained and the key differences between Scope 1 and 2 results were highlighted. During the meeting, the FSC team suggested streams they found most problematic and required mitigation solutions for.

3.2.1 Identifying improvement measures

Two simultaneous approaches were taken to identifying improvement measures. These were desk research about initiatives at other academic institutions and interviews with relevant UU stakeholders. The R-ladder was used as inspiration for the mitigation ideas.

For stakeholder interviews, various actors at UU were contacted to understand their opinion of waste management at the university and use their expertise on circularity to identify areas of improvement. Information from interviews is separated into two types as shown in table 4 below. While gathering data on the waste input side via unstructured interviews, discussions with the FSC team, and waste tours, ideas for potential solutions were identified. As these conversations held with people with inside knowledge on UU's waste management and current proposals for improvements provided insights that could not be obtained from interviews with other stakeholder, they were incorporated into the results. Furthermore, semi structured interviews were conducted with actors, where the topic of zero-waste was discussed (Clark et al., 2021). Guiding questions used are provided in Appendix C. Actors interviewed included employees at UU corporate and sustainability offices, students, and faculty. Sankey diagrams that resulted from the previously conducted MFA were shown to the participants who were asked about their opinions on UU's current waste flows. The participants were then asked to come up with ideas on how UU could reach zero-waste based on their own experience at UU and knowledge of waste-reducing strategies.

Table 4. List of stakeholders interviewed. Interviewee numbers assigned in this table are referred to in section 4.3.

Type of interview	Affiliation	Role	Interviewee number
Data gathering	FSC	Zero-waste project team presentation and discussion	-
		Zero-waste project manager	I1
		Waste specialist	I2
	University Corporate Office	Sustainability consultant	I3
		Environmental expert	I4
	GeoLabs	Lab waste tour organized by Sustainability Officer	-
Semi structured interviews	Green Office	Project coordinator	I5
	Sustainability Office	Embedded researcher	I6
	UULabs	PhD student	I7
	Faculty of Geosciences, Copernicus Institute of Sustainable Development	Assistant Professor	I8
	Faculty of Geosciences	Master's student (Sustainable Business and Innovation)	I9
	Faculty of Geosciences	Master's student (Water Science and Management)	I10

Desk research involved identifying activities happening at other universities which aimed to reduce waste or improve waste management. While waste ambitions and zero-waste definitions differ at universities globally, potential suggested improvement measures remain relevant. Keyword searches on Google were used with a combination of inputs such as: "zero-waste" AND "university" AND "initiative"; and "[waste stream]" AND "reduction" AND "university" AND "Netherlands". Ideas from the various universities were summarized and combined with suggestions from stakeholder interviews. The grouped solutions were mapped according to the corresponding R-ladder levels and are presented and analyzed in section 4.3.

3.3 Ethics

This research includes interviews, for which Utrecht University's codes of conduct and the General Data Protection Regulation were followed. No sensitive or special categories of personal data were collected during this project. All semi structured interview participants were required to fill in an informed consent form (Appendix D). A short introduction of the research and the purpose of the interview was given to the interviewee. Participants could request for their interview to be anonymous. Audio was recorded during the interview after receiving permission from the interviewee for recording. These recordings were deleted after the interview had been transcribed. The recordings and transcriptions are accessible to the student and their supervisors only. All participants could withdraw their consent at any given moment, following which their data would be deleted.

4. Results

In 2022, Utrecht University generated 1 947 320 kg of waste from its teaching and research activities in its buildings as well as landscaping of the Science Park campus. Around one third of the waste was sent directly to incineration or gasification, while separately collected waste streams were sent to a sorting or recycling process or composting and anaerobic digestion. For 17% of the waste, the destination is unclear. Waste quantities and composition generated varied per faculty and types of buildings and activities within them. Scope 1 and 2 results were found to differ with the expanded scope showing lower actual outputs of materials that can be inserted back into the loop.

4.1 Scope 1 material flows

In 2022 Utrecht University's largest waste streams were green maintenance waste, residual waste, and paper and cardboard (figure 4). These three combined accounted for 74% of the total waste. From the Scope 1 analysis, the residual and specific hospital waste are found to be sent to incineration and gasification, respectively. Energy is recovered during both of these processes. The small fraction of residual waste sent to sorting/recycling (0,69%) is from the post-separation sorting conducted by the municipality's waste handler that collects waste from the city center buildings. This fraction is negligible compared to the quantity of waste sent for incineration. On the R-ladder, the residual and SZA waste streams are mapped at R10 – incineration with energy recovery, which is one step lower than the target for the zero-waste goal for UU. In Scope 1, 34,1% (664 614 kg) of UU's total waste is found to be sent directly to R10 level processing.

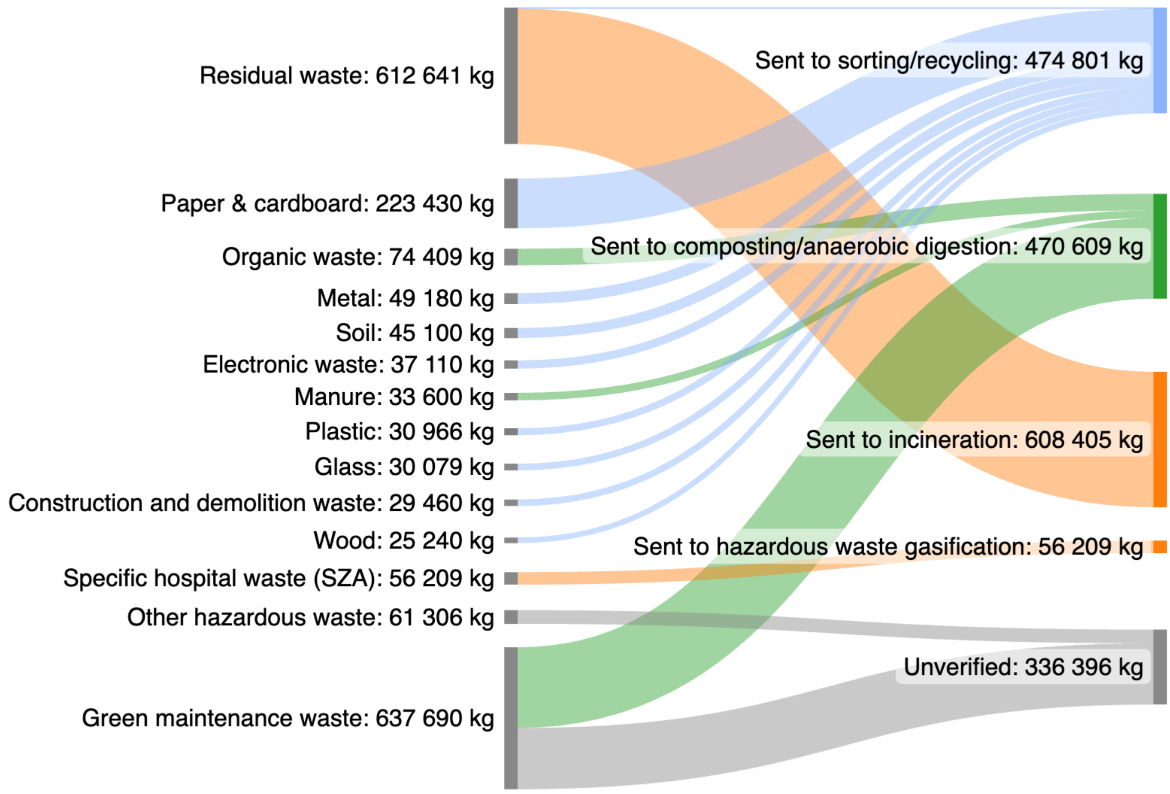

Figure 4. *Sankey diagram of Scope 1 waste flows. Mass flows of ICT equipment that were sent to reuse are not included in the figure.*

Paper and cardboard, as well as smaller separately collected waste streams of metal, soil, electronic waste, plastics, glass, construction and demolition waste, and wood are sent to sorting facilities to be processed before recycling. Recycling is considered as step R9 on the R-ladder, which is the lowest waste processing accepted according to the UU definition of zero-waste. The quantity of waste sent to sorting/recycling is 24,4% (474 801 kg) of the total waste of the university in 2022. Also, on step R9 on the R-ladder is the composting or anaerobic digestion of organic matter. UU's organic waste consists of GFT, swill, and coffee grounds. This organic waste, manure and a large fraction of the green maintenance waste is sent to a facility that processes organic matter either by composting or anaerobic digestion. A total of 470 609 kg of waste is processed using these technologies.

According to Scope 1, 48,6% of the total waste in 2022 is processed at a level of R8, which qualifies for UU's zero-waste definition. ICT equipment that is collected separately, repaired or refurbished when necessary, and sold to third parties by the ICT waste handler is considered to be on the UU circularity ladder level R3-R5. 4059 ICT devices were sent to be reused; however, the waste handler did not give the total weight of these devices (I4) and therefore they are not included in the waste flow figure 4. Additionally, there is a small fraction of items from the Tankhal for which alternative waste management options were found. These range from reuse to repurpose (R3-R7), but since the quantity of recovered material is mainly dependent on the work of three individuals and the weight is not recorded (I2), this stream is assumed to be negligible. The FSC also has a warehouse for furniture with potential to be reused and has set up an online portal through which other departments at UU can collect it. The quantity of furniture processed through this system is not monitored and only a few individuals have access to the portal (I2). Due to the lack of information, the waste stream is not included in figure 4. 34,1% of UU's waste is below the zero-waste requirement and sent to incineration with energy recovery. The processing for other hazardous waste streams and a fraction of the green maintenance waste could not be determined and is marked as unverified in the figures in order to portray the magnitude of those streams. Based on the limited information from the waste handlers, the unverified green maintenance waste is expected to be handled similarly to the verified quantity, using composting/anaerobic digestion. It is likely that large fractions of the unverified hazardous waste are sent to incineration with some form of energy recovery (Renewi, personal communication, 12 May, 2023), however, these assumptions need further verification. Hence, under half of UU's waste is recycled and qualifies for the zero-waste definition, while around one third of the waste is managed at a level below the zero-waste requirement in scope 1. The weight for the three material streams that are managed at a level higher than recycling (R8) is not documented. Recording this weight in the future would contribute to a more comprehensive understanding of materials processed at higher R-levels.

4.1.1 Waste per faculty

To understand how waste production differed by faculty and whether different mitigation approaches would be needed, the waste quantity and composition was broken down to a faculty level. 6 separate UU faculties within the Scope were distinguished: Humanities, Law, Economics, and Governance, Social and Behavioural Sciences, Geosciences, Sciences, and Veterinary Medicine. Each building was assigned to a category according to the main faculty within it on the respective website of the building (Appendix B). Buildings that did not belong to a faculty, but had educational purposes, such as the libraries and the Educatorium, were designated as "Education". Administrative services and other buildings such as the Academiegebouw and heat and power stations were separated into the category "Other". From the breakdown of waste per faculty (figure 5), it can be seen that natural science faculties that have scientific experiments: Geosciences, Sciences, and Veterinary Medicine, have a relatively high quantity of waste produced. The respective total quantities per year are 93 882 kg, 334 712 kg, and 297 234 kg. The most waste is produced by the Science faculty and both the Science and Veterinary Medicine faculties individually generate over double the amount of the waste from the third largest waste-producing faculty. The three faculties without natural science research labs (Law, Economics, and Governance, and Social and Behavioural Sciences) generated a significantly lower quantity of waste than other faculties.

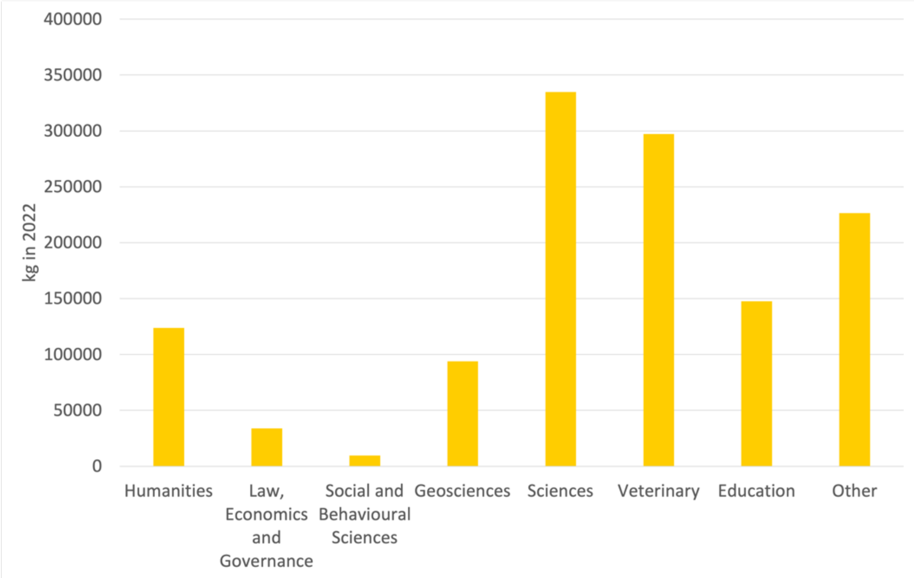

Figure 5. *Total waste quantity in 2022 by faculty in kg. Coffee grounds, green maintenance waste, and ICT waste are not included in the figures.*

Buildings with a focus on education activities, including libraries, showed high waste quantities. A small fraction can be explained by the free-rider problem of waste from external dining companies ending up in UU waste bins. To understand the extent of the free-rider problem and the exact quantity of waste from external parties, more detailed waste composition research can be conducted. Students and staff may be bringing in waste from outside the faculties as a part of their daily habits, for example lunch packaging. UU has no direct control over this waste; however, it will remain a part of the waste in those buildings. There is added uncertainty in the breakdown by faculty as buildings are often used by students from all faculties. Teaching activities are not located in specific faculty buildings for the respective students and students from the Faculty of Medicine and Hogeschool Utrecht can use waste bins in an outside of various buildings, adding to UU's waste figures.

4.1.2 Waste by faculty per person

A breakdown of waste per person was included to better compare the faculties as they have different numbers of students and staff (figure 6). Building users by faculty included the students enrolled in the faculty and full-time employees (FTE). The numbers were obtained from the University Corporate Office and as of October 1st, 2022. Figure 6 shows the natural science faculties still have higher waste than other faculties, which do not operate laboratories. The largest quantity of waste per person is generated by the Veterinary Medicine faculty, which is over 3.5 times higher than the next faculty. The average quantity of waste per person, which included all waste generated by UU and all students and FTEs was found to be 30,2 kg. This waste figure includes waste from administrative and educational activities as well as waste from the Milieustraat and Tankhal. The total quantity of waste is divided by all the FTEs and students of the faculties within the scope of the MFA and administrative employees. Students and staff of the Faculty of Medicine are not included. Since Sciences and Veterinary Medicine have higher waste per person generated than the average, these natural sciences faculties could be targeted with waste reduction measures for the university to get closer to their zero-waste goal. Additionally, it is important to exercise caution in interpreting these numbers as they are subject to inherent limitations in determining the system boundaries. While the figures give an indication of the waste by faculty, they should not be rigidly relied upon.

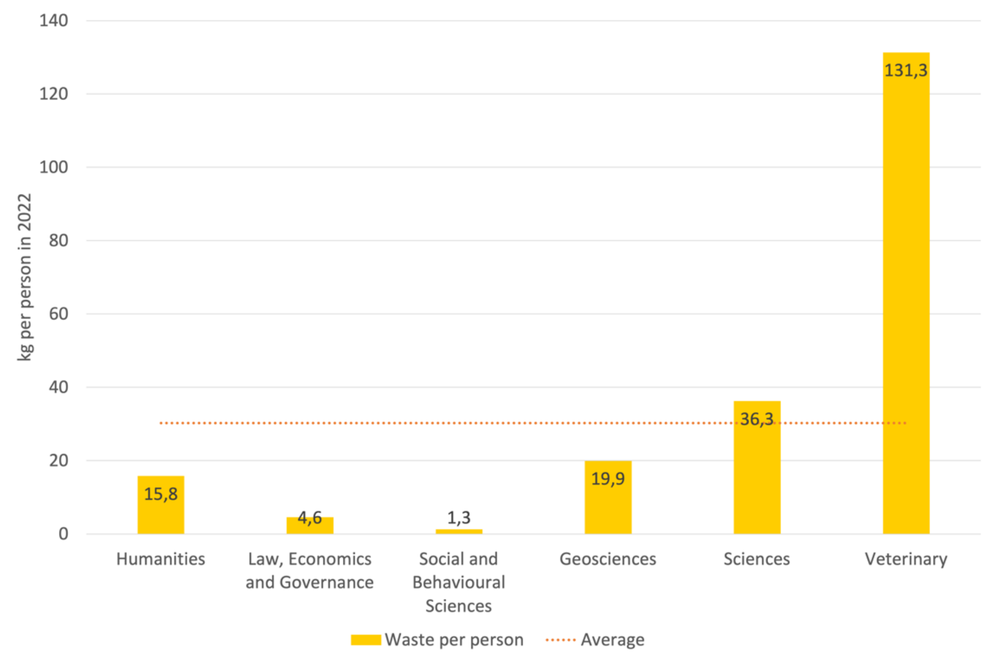

Figure 6. *The waste per person by faculty in 2022 in kg. Building users include students and FTEs. Coffee grounds, green maintenance waste, and ICT waste are not included in the figures.*

4.1.3 Waste composition by faculty

The waste composition by faculty was also investigated to determine how outputs differ by faculty. For all faculties, residual waste remains a large share, indicating the need to understand what the stream is composed of and find mitigation measures for it (figure 7). The exception is the Social and Behavioural Sciences, where it is likely that the residual waste was collected from a central collection point and not assigned to the respective buildings. Hence residual waste for the faculty does not show in figure 7 but is likely to still be generated and make up a relevant share of the waste.

As with the waste quantities, a difference between the waste composition for faculties with laboratory experiments and faculties without labs was found. Social sciences and humanities faculties in the city center have a fewer number of different waste categories with their waste being mainly residual waste, paper and cardboard, and PMD. It is likely that the PMD waste fraction is mostly reflected in the residual waste figures for 2022 as separate bins for PMD have been in place in all UU buildings only since 2023. The waste profile for educational buildings is similar to that of the social sciences and humanities buildings and has the highest fraction of residual waste of almost 80%. For the aforementioned building category, the free-rider problem applies, where waste from external parties ends up in UU bins without UU having operational control over it.

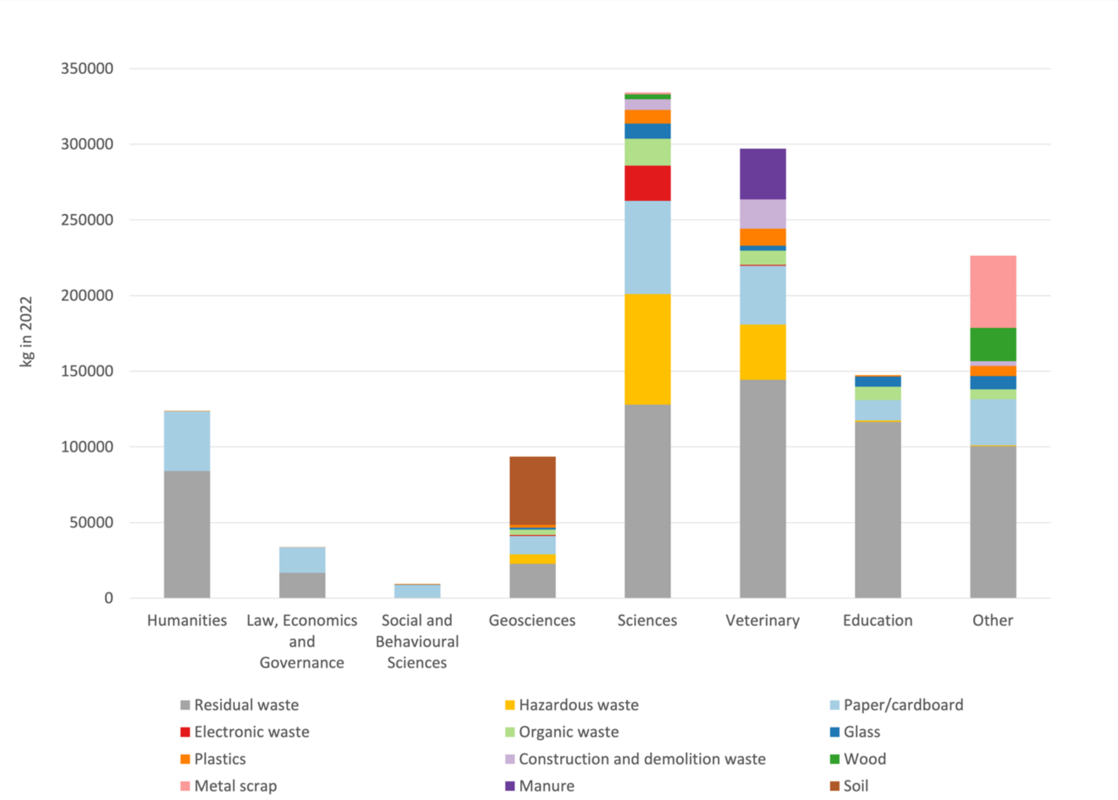

Figure 7*. Waste composition by faculty in percentages. Coffee grounds, green maintenance waste, and ICT waste are not included.*

The natural sciences faculties' waste profile is more complex and composed of a variety of smaller streams. This is due to the research activities which include different laboratories that require the use various equipment and substances. For the natural science faculties, residual waste makes up under half of the total waste (figure 7). They also include paper and cardboard waste, but the fraction is smaller due to other waste. These faculties have a noticeable amount of hazardous waste, which originates from lab activities and includes various chemicals, polluted materials, gloves, batteries, etc. The Sciences and Veterinary Medicine laboratories also generate biologically hazardous waste. The Geosciences faculty specifically has a large stream of soil waste. This makes up 48,0% of the faculty's waste and originates from laboratory experiments on sediment flows. Hence, the Geosciences waste profile by mass percentage differs most from other faculties. To address waste streams that are characteristic to only some faculties, different waste mitigation strategies per faculty may be necessary, for example targeting hazardous waste in Sciences and Veterinary Medicine faculties.

In the category "Other", residual waste remains the largest fraction and the typical waste stream of paper and cardboard is also observed. Differing from other faculties, it has important streams of metal and wood. These are created by the Milieustraat, where furniture and other bulky waste collected from the UU campus is broken down into components for improved waste separation.

4.2 Scope 2 material flows

The Scope 2 materials flows reveal a larger, more complicated system with multiple levels of waste handlers and recyclers (figure 8). When considering the expanded scope of UU's waste, the quantity of materials that can be inserted back into the material loop decreases when compared to the quantity of waste sent to sorting and recycling in Scope 1. The materials ending up in incineration processes increase, indicating the expanded scope may require different mitigation solutions to scope 1.

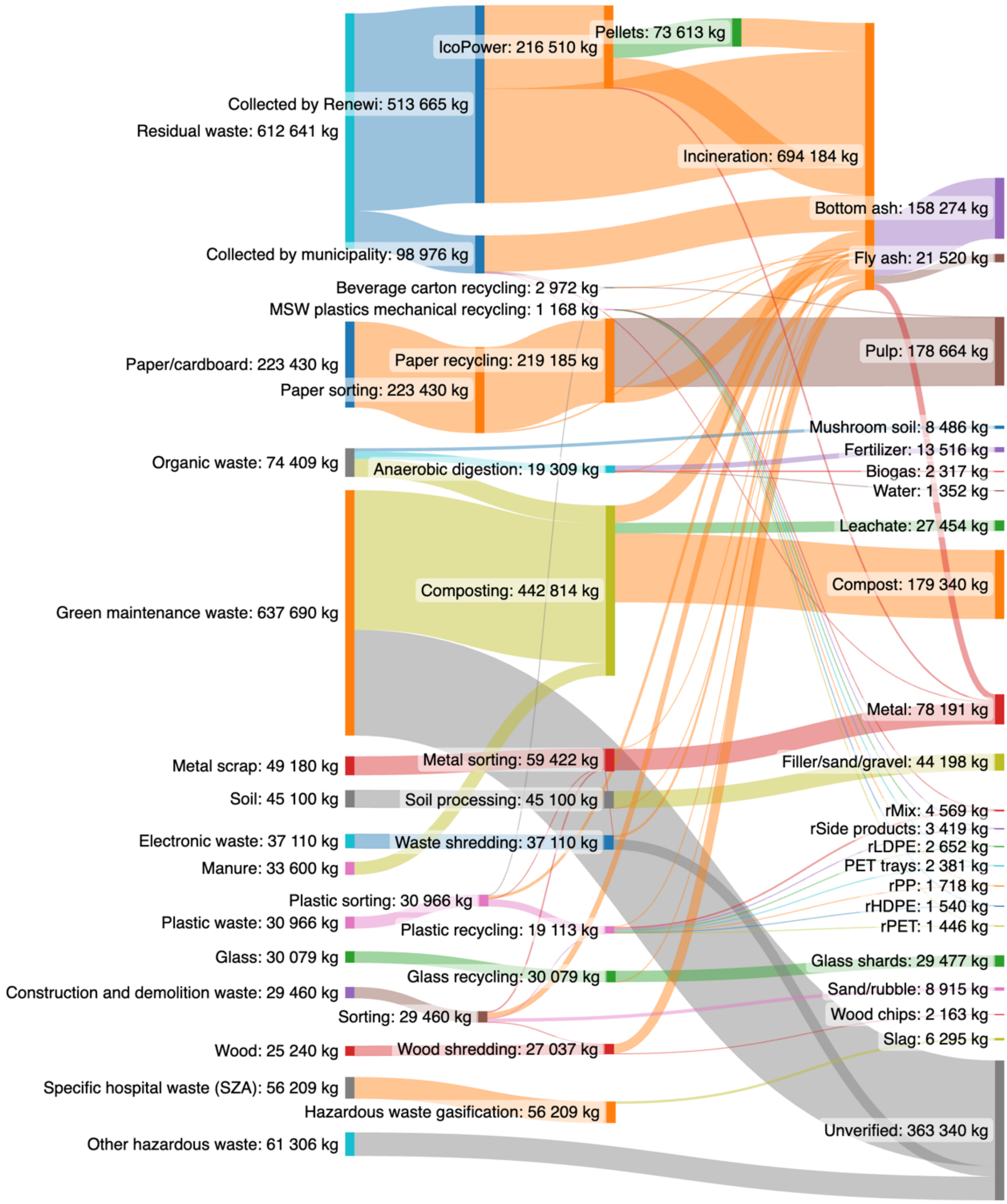

Figure 8*. Sankey diagram of Scope 2 solid waste flows. Mass flows of ICT equipment sent to reuse are not included in the figure. Emissions from processing and moisture loss to the atmosphere from the manufacture of pellets are not represented in this figure, due to which the outputs of some processes are lower than the inputs.*

The residual waste fraction that separates into two streams according to the waste collector mostly ends up in incineration. The fraction of recovered materials from post-separation of residual waste seen in Scope 1 (figure 4) decreases due to recycling process losses and dirt and moisture content (Brouwer et al., 2019). From the fraction of waste collected by Renewi and sent to Icopower, the pellets produced are sold to external parties and incinerated as the rest of the waste. Hence these pellets, which are a form of refuse derived fuels, are still considered as having an R-ladder processing level of R9. During the drying step of the production of the Icopower pellets, there is a loss of moisture, which is not portrayed in the Sankey diagram (figure 8) for simplicity. The outputs of the incineration with energy recovery include bottom ash, fly ash, metals, and emissions. The latter is not represented in the below figure as only outputs that can be inserted back into the material loop have been portrayed. While AVR claims to capture around 2% of their CO_2 emissions, the end use of this gas is unclear and not visualized on the Sankey diagram. Bottom ash, and fly ash can be used in road construction or in other construction materials. However, since the prior incineration step is on the R-ladder level R9 and there is a downcycling of materials, they are not considered under the recycled material yield on the level of R8 (recycling).

For organic waste, manure, and green maintenance waste treatment, there are losses in the form of emissions to the atmosphere during composting. This is not depicted in the Sankey diagram. Recycled outputs from composting and anaerobic digestion that can be re-inserted into the material loop include compost and fertilizer. Other process outputs include cleaned water, biogas, and leachate. It is unclear what happens with leachate, however, the water is cleaned and released into surface water and biogas is sold as an energy source. The composting and anaerobic digestion are considered as R-ladder level R8, which corresponds to recycling. Around 8 500 kg of coffee grounds are used as a substrate for growing oyster mushrooms by De Clique (De Clique, personal communication, 13 June, 2023) which is also considered as level R8 – recycling (Potting et al., 2017).

When comparing the quantity of materials going to incineration in both scopes, 85 779 kg of additional waste is incinerated in scope 2. This waste is from the sorting of different waste streams, unrecyclable fractions, or waste from recycling processes. This results in a 12.9% increase in material incineration (R9) in the expanded scope. It is assumed that energy is recovered from all waste incineration processes and the output yields are the same, unless specified in the waste stream description. The combined weight of recycled outputs from all the waste streams are 115 468 kg lower in scope 2 when compared to what is sent to sorting/recycling. This indicates a 75.7% material yield from streams sent to sorting and recycling. Most of the lost mass from sorting and recycling is sent to incineration, while some is considered "unverified" due to the lack of knowledge or available data on the waste processing. Slag from hazardous waste gasification could be used under road construction or be processed into construction materials such as bricks or tiles (Kaushal et al., 2022), however, the exact fate of the stream is unclear. It is therefore left as a separate output in figure 8 and not included with the recycled material yield. Wood and construction and demolition waste streams have the lowest amount of usable material yield. If grade-A wood could be separated from these streams at UU and processed separately by the waste handler, the recycled material yield could be increased. For other waste streams there can be a recycling limit due to the degradation of the quality of materials. For example, for paper and cardboard recycling, the fibers become shorter with each cycle and contaminants that were not removed during the processing accumulate, meaning the paper can only be recycled a certain amount of times and new virgin fibers are added to maintain the quality of paper and cardboard products (Bajpai, 2015). For metal, glass, and plastic, there is a downcycling for a fraction of the materials sent to recycling due to contamination (Haupt et al., 2017). While soil is cleaned and processed into materials used for construction, there are also recycling losses and a downcycling of material for this waste stream (Renewi, personal communication, 31 May, 2023). From waste sent to composting/anaerobic digestion in scope 1, only 205 011 kg of material is obtained as a useable output when looking further downstream in scope 2. Over 265 000 kg of the waste input is sent to incineration or lost as emissions during further processing, indicating a 43.6% material yield. Therefore, there is a yield ceiling with current recycling technologies and economic considerations. While sending materials to recycling does yield materials that can be reinserted into the loop, the losses of material from the extended scope of the MFA are significant.

In scope 2 it is evident that downstream processing has large material losses due to contamination, process inefficiencies, and material degradation. There is an increase in incineration (R9) of around 13% which is below the zero-waste requirement set by UU. Material losses from sorting/recycling and composting/anaerobic digestion (R8) in scope 2 are 24% and 56%, respectively. These losses indicate an opportunity for setting ambitions for waste reduction higher on the R-ladder and reducing the quantity of materials that require processing on level R8 (recycling) and R9 (incineration).

4.3 Waste mitigation measures

From the Sankey diagrams of both scopes, the residual waste was identified as the most problematic stream for reaching UU's definition of zero-waste due to the quantity of material going to incineration. The FSC staff determined during the team presentation that residual waste should be targeted with mitigation measures, while deeming it relevant to find improvement solutions for other waste streams as well. Interviewees also noted the large quantity of residual waste and made general suggestions to improve circularity at UU. Mitigation measures identified during the interviews and desk research have been grouped into categories which have been elaborated on in the sections below and summarized in table 5. These include limiting single use items, improving waste separation and including circularity in purchasing policies, as well as additional suggestions to increase collaboration along the supply chain to find areas for improvement.

***Table 5**. Summary of mitigation measures from interviews and desk research.*

<table>
<tr><th>General concept</th><th>Ongoing UU waste mitigation projects</th><th>Proposed mitigation measures</th><th>R-level</th></tr>
<tr><td rowspan="3">Eliminate single use dishes</td><td rowspan="3">Single use cups will be eliminated in UU buildings from January 2024</td><td>Implement UU-wide reusable dish system with deposits</td><td>R1 – Refuse</td></tr>
<tr><td>Install water dispensers in UU buildings</td><td>R1 – Refuse</td></tr>
<tr><td>Free tap water and glasses available in dining areas</td><td>R1 – Refuse</td></tr>
<tr><td rowspan="3">Increase waste separation at the source</td><td>Separate bins are available in all buildings since beginning of 2023</td><td>Improve waste bin placement
- residual waste bins should not be available by themselves
- always have the four different types next to each other</td><td>R8 – Recycle</td></tr>
<tr><td rowspan="2">Proposal to expand Milieustraat and Tankhal</td><td>Expand Milieustraat and Tankhal operations to separate more waste at UU</td><td>R8 (Milieustraat)
R3-R8 (Tankhal)</td></tr>
<tr><td>Communication on how and why to separate waste and recycle
- information campaign about how to sort trash
- consistent info on all UU platforms</td><td>R8 – Recycle</td></tr>
<tr><td rowspan="3">Require external suppliers to adopt circularity measures</td><td rowspan="3">N/A</td><td>Have partners/external parties on campus also reduce single use dishes and collaborate with any UU reusable dish systems</td><td>R1 – Refuse</td></tr>
<tr><td>Require commitments to reduce waste from catering and packaging</td><td>R1 – Refuse and
R8 – Recycle</td></tr>
<tr><td>Switching to suppliers who are circular and have sustainability certifications</td><td>R3 – R8</td></tr>
</table>

4.3.1 Eliminate single use items

One specific suggestion that originated from the research was eliminating or minimizing single-use items. The single use items that could be subject to this strategy range from dishes in canteens to lab equipment. Multiple interviewees mentioned the availability of single use cups at the university as an issue that could be solved by eliminating the single use cups and having people use their own reusable mugs or bottles (I5-8). While the single-use cups will be removed from UU buildings starting from 2024, in line with the government ban on disposable cups and containers made from plastic (Rijksoverheid, 2023a), there are still improvement opportunities at the university. The lack of water refill stations available at UU was brought up by interviewees (I6; I9); and other universities have added water refilling stations on their campuses to promote the use of reusable water bottles (University College Cork, 2022). Additionally, universities in the Netherlands and UK are stopping the sales of disposable water bottles as well as drinks and food packaged with single use plastics (University College Cork, 2022; University of Amsterdam, 2021). Single use dishes and cutlery at the UU dining facilities could be substituted by switching back to using ceramic and glass crockery or by having a UU-wide system of reusable take-away dishes that have a deposit and return scheme (I6). The latter idea could benefit from having all the dining facilities on campus give out and accept back the (unwashed) dishes (I6). The idea of switching to reusable alternatives also applies elsewhere, such as scientific labs. Replacing single use lab equipment with glass equipment or reusing the plastic equipment when possible, could reduce the amount of hazardous waste from research activities (The University of Edinburgh, 2022). Therefore, critically reflecting on different areas where single-use items can be reused multiple times or replaced with reusable items and systems can help to reduce the quantity of waste generated by UU by applying methods higher on the R-ladder such as refuse (R1) and reuse (R3).

4.3.2 Increase waste separation at the source

Improving waste separation at the source by placing waste separation bins on campus and communication on how to separate waste was identified in desk research as well as interviews as a method to direct more waste to recycling (R8). Separate waste bins for paper, plastics and drink cartons (PD), organic waste, coffee cups, and residual waste are used in many universities in the Netherlands (Dobbelsteen & Gameren, 2022; Dragtstra et al., 2023; University of Groningen, 2021) and have also been placed in UU's buildings since the beginning of 2023. While having separate bins is one step to diverting materials from going to residual waste incineration to recycling, the successful separation of waste relies on the individual knowledge and change in behavior of people (I7; I8). It is therefore important to analyze the waste bin placement and clearly communicate what waste goes into which bins. Interviewees mentioned how waste bin placement could be improved on campus by not having residual waste bins available individually and always having all separation bins together (I6). Waste bin placement at UU was noted to be inconsistent with organic and paper bins only available in few locations (I6; I9). To ensure separation opportunities, the University of Amsterdam has removed individual waste bins and placed all bins in halls with a possibility to separate waste in each location (University of Amsterdam, 2021).

Multiple universities emphasize that communication about what can go into each bin is key to obtaining better separation and have waste sorting guides available to students and staff (The University of Edinburgh, 2022; University of Groningen, 2021; Wageningen University & Research, 2023). Beyond informing people of the proper waste categories, the communication required for waste separation also involves ensuring people that the separated waste is treated differently than residual waste and sent to recycling (I7). All this information and details on waste separation need to be consistent across UU's platforms and websites, and the university could benefit from having a central waste information page that includes bin locations (I7), similarly to the University of Edinburgh's waste website managed by their Waste Office (The University of Edinburgh, 2019). This is especially important as waste separation instructions may differ at UU compared to household waste separation at home, depending on the municipal waste management policies (I9). The waste separation also applies to science labs, where the training and habits of students and staff could be monitored and improved to ensure the least amount of material possible is sent to hazardous waste and packaging and any uncontaminated materials are disposed of in separate plastic and paper bins (The University of Edinburgh, 2022). Reviewing the waste bin placement and having an information campaign about waste separation on campus as well as the fate of each waste stream could decrease to amount of waste sent to incineration (R9).

Additionally, the university could expand their Milieustraat and Tankhal operations to increase waste separation and explore opportunities higher on the R-ladder. While currently the Milieustraat and Tankhal successfully divert bulky waste from going directly to residual waste by separating it into components such as metal, wood, plastics, and EPS, and find alternative uses for materials, there is a lack of space to store the materials and a shortage in workers who could look for alternatives to recycling (I3). Currently the material streams from the Tankhal are not large enough to have agreements with parties who would regularly collect and process the streams at higher R-levels than recycling (I2). Additionally, many people are not aware of the materials they can send to the Tankhal instead of regular disposal (I2). Expanding these facilities and communication about them to the faculties could help to increase recycling (R8) and increase the material streams that have a possibility to be processed on a higher R-level.

4.3.3 Require circularity from external suppliers

In addition to UU's own activities, there is potential to improve waste management through more sustainable purchasing and requiring suppliers to collaborate with waste reduction efforts. While UU could eliminate single use items and set up dish reuse schemes in its own operations, having suppliers and external parties on campus also commit to the same circularity measures and limit single use items can help create a UU-wide system and reduce waste from free-riders (I6; I10). Switching to suppliers who are circular and have the corresponding certifications is another option to mitigate waste (I7). Evaluating the suppliers' circularity and introducing sustainability requirement to purchasing were identified in desk research as well. These could include looking at more regional suppliers (University of Groningen, 2021), identifying companies or startups that use less packaging, offer to take back the packaging, or use product-as-a-service business models (Dragtstra et al., 2023), or companies that are involved in programs like 'Too good to go' that are designed to reduce food waste (University of Amsterdam, 2021). The University of Edinburgh has identified suppliers for lab equipment and chemicals that have more circular practices and suggest using companies that use less or paper packaging and indicate material sustainability (The University of Edinburgh, 2022). TU Delft is setting up a supplier portal that includes CO_2 emissions that will be used when making purchasing decisions (Dobbelsteen & Gameren, 2022). Alternative supplier circularity levels can range from refusing waste (R1) to using products that have higher recycling yields (R8). Having specific guidelines for purchasing can help UU reduce waste as the university has direct control over the chosen suppliers and can identify products and services that create less waste.

4.3.4 Idea-level suggestions

Further ideas were identified during desk research; however, these remain at a suggestion level at other universities and have not yet been implemented according to our knowledge. This section provides descriptions to offer insights into potential future solutions used at other institutions. TU Delft has suggested creating an inventory of all materials where the input, use, and output of purchased goods is registered (Dobbelsteen & Gameren, 2022). The aim is to create an internal marketplace for products that can be accessible to people on and off-campus. A similar reuse portal for lab equipment and furniture is suggested in Edinburgh (The University of Edinburgh, 2018). Other furniture reuse programs through suppliers were identified in the US (Stanford University Office of Sustainability, 2020). The FSC also has a furniture warehouse that promotes reuse of the items by other faculties, which could be expanded to be accessible to the wider community. Additionally, storage and repair facilities are suggested by TU Delft, where various items could be repaired instead of being sent to disposal (Dobbelsteen & Gameren, 2022). Furthermore, the University of Twente proposes the introduction of incentives to prolong the use electronics for staff, limiting the purchase of new electronics if the current ones are still functional (Dragtstra et al., 2023).

4.3.5 Collaboration opportunities to generate further mitigation measures

Several interviewees suggested methods to generate additional waste mitigation ideas, which included sourcing knowledge from the UU community and collaborating with external parties such as other universities and waste handlers (table 6). Projects involving students were identified in desktop research, where universities encouraged green initiatives from student organizations and looked at initiating living labs projects around waste management (University of Groningen, 2021). In the Netherlands, a competition that aims to create circular and biobased student startups that provide alternatives to current waste management has been set up at Wageningen University (ten Napel, 2023). The project involves mentors and business partners, including waste handlers and recyclers who can share their expertise. Interviewees of this study identified student projects and competitions as sources for generating novel mitigation solutions, in addition to suggesting the integration of a sustainability course into current curriculums which could include zero-waste projects (I5; I9).

Further collaboration with waste management offices at other Dutch universities was suggested, as other institutions are also looking to improve their waste management and are facing similar issues as UU (I7). Collaboration opportunities with local communities and charities to reuse products and equipment no longer used by the university could provide material management on higher R-levels (The University of Edinburgh, 2018). Additionally, interview participants suggested direct contact with waste handlers to implement improvement measures. These can include improvements such as post-separation sorting, which could increase the quantity of waste going to recycling (R8) or understanding the current limits to recycling as well as whether UU could help in sharing knowledge and testing new recycling technologies (I8). Co-operating can help understand the waste problems and give insight into current challenges for reaching zero-waste targets. Collaboration throughout the supply chain and the generation of new ideas via student projects and competitions were found to be opportunities for UU to get closer to their zero-waste goals, as becoming more circular requires systemic changes involving both upstream suppliers and downstream waste handlers and recyclers.

Table 6. Summary of proposed collaboration ideas to generate further waste mitigation measures.

Collaboration type		**Proposed ideas**
Internal collaboration	Student involvement and community collaboration	Create a zero-waste competition for students
		Require students to take a sustainability course that involves a zero-waste project
External collaboration	Innovation projects with other universities	Communication and sharing ideas with other universities on waste reduction and waste management improvement
		Student innovation projects/competitions with other universities
	Collaboration with waste handlers to improve recycling	Discussions with waste handlers to understand what kind of possibilities there are to improve or change waste management
		Investigate possibility of recycling more plastics
		Investigate possibility of post-separation of residual waste

4.4 Barriers to proposed mitigation ideas

One of the largest barriers mentioned in the interviews was the lack of knowledge of the composition of waste streams. While the Sankey diagram provided insight into how the waste streams are managed, every interviewee indicated they were unable to suggest concrete mitigation measures due to the waste compositions being unknown. The interviewees and FSC identified residual waste as a key problematic stream but stated that a specific waste composition analysis of the stream would be necessary before they could suggest specific measures that could reduce the quantity of waste sent directly to incineration (I5-10). Further research on the composition of waste streams is recommended to choose and implement suitable solutions.

Another large barrier mentioned in the interviews was the resistance to change. If people are required to change their behavior – carry a cup or a container with them, or the convenience of using single-use items is impacted, there can be discontent. Therefore, any large change requires clear communication of why and how this is being done (I7). While there have been initiatives that aim to reduce waste or test the impact of a solution, such as SPAR not giving plastic bags for a two-week sustainability program, these initiatives can be confusing if they are not universally implemented (I10). Moreover, if the projects are only temporary, people do not have time to adjust and modify their behavior (I10). Implementing zero-waste solutions that are UU-wide, and clearly communicated can allow people to adjust.

Furthermore, participants brought out the importance of monitoring the waste streams and any changes in quantities and composition as mitigation measures are implemented. A detailed characterization of each waste stream and regular monitoring would allow to assess whether the measures are successful in reducing the waste and increasing the quantity of materials inserted back into the loop (I8; I9). If there is no change observed, then further studies may be required to understand the barriers. Interviewees suggested that poorly planned mitigation solutions, lack of knowledge, and resistance to change may hinder the mitigation measures from having the desired impact (I7; I8; I10). Surveys on the recycling behavior of students and staff in addition to information campaigns were suggested to evaluate what changes are needed to ensure people cooperate with waste measures (I6; I7). The importance of monitoring changes in waste flows was observed from desk research as was the relevance of communicating updates on progress and changes in waste flows (Dragtstra et al., 2023; The University of Edinburgh, 2018). Hence, to decide on which mitigation measures are most suitable, further research into the composition of waste streams is suggested, followed by regular monitoring of impacts to evaluate the measures. Clear communication is proposed to overcome the lack of knowledge and resistance that may be present when implementing measures that require behavioral change.

5. Discussion

Conducting MFAs provided insight into the management of UU's waste flows and expanding the scope to include downstream processing showed a lower recycled material yield as described in section 4.2. Several waste mitigation ideas that varied on the R-ladder scale were identified with the help of the MFA results and can be applied depending on the zero-waste approach. According to these results, suggestions to consider the expanded scope and a shift towards higher R-level strategies are presented in subsection 5.1. Limitations and data gaps are discussed in the following subsection 5.2. Subsections 5.3 and 5.4 discuss a case study on residual waste and recommendations for future improvements.

5.1 Shifting the zero-waste focus

From the mitigation measures identified in this research, suggestions focusing on internally implementable options may provide quick wins and deliver results on the level of scope 1. The ideas of increasing separation and requiring circularity from suppliers focus on the input side and are more directly under UU control. Understanding the residual waste composition can help determine suitable measures to divert recyclable materials from going directly to incineration. For streams where the processing chain is less clear and there is high uncertainty due to the materials being sent to multiple downstream processors, it can be beneficial to investigate the waste sources and look at site-specific waste generation to determine how the waste stream can be reduced. An approach from the input side for waste streams such as hazardous waste and electronic materials from labs can be easier to control by the university. This may make the initiatives focusing on the narrower scope more feasible to implement than measures that require collaboration efforts.

In addition to short-term wins, the necessity for long-term mitigation measures that require collaboration is demonstrated by the more complex processing chain seen in the expanded scope. Comparing the two Sankey diagrams of scope 1 and 2, it is evident that the quantity of secondary materials generated is considerably smaller than the quantity of waste initially sent for recycling. For organic matter, the recycled material yield is under half of what is sent for processing. While low, these yields are typical for composting processes (Zhang & Matsuto, 2011). Switching to more anaerobic digestion could improve the yield, however, this change requires discussions with waste handlers to understand their capacities and still results in material loss. For the other separately collected material streams sent to recycling, the material yield decreases by 24%. When investigating mitigation measures, it is crucial to consider these downstream losses and the extended scope as they give a more systemic understanding of material circularity and the impact of UU operations.

Long-term collaboration strategies identified in this research that take into account the complexities and losses observed in scope 2 of the MFA are helpful for generating new ideas, however, there is value in focusing on strategies higher on the R-ladder. While collaboration with universities and actors along the supply chain is beneficial for generating alternative recycling solutions and improving technologies, the envisioned solutions may be more difficult to implement due to the number of parties involved and require more time. The difficulties in obtaining specific data for recycling processes indicate the value on focusing on upstream solutions. Considering strategies higher up on the R-ladder theoretically reduces the quantity of materials sent to recycling (Reike et al., 2018), limiting the material loss from processing. Methods on upper levels of the R-ladder such as reducing food waste from production and consumption could prevent organic material losses associated with composting and digestion processes seen in the extended scope (Y. Wang et al., 2021). Using mitigation solutions that keep materials in the loop for longer such as eliminating single use dishes and using reusable dishes instead, can be implemented internally and have a large potential to reduce waste quantities.

While suggestions for quick wins that divert materials from incineration to recycling can help the university decrease the amount of materials processed below the current zero-waste definition, looking at the expanded scope is relevant for understanding the circularity impact of UU on a more systemic level. Since material losses in downstream processing will happen for steps lower on the R-ladder such as recycling (R8) and there are more barriers when trying to change waste management on a system level, initial focus on internally implementable solutions can yield faster results, especially when considering higher R-level strategies that reduce the quantity of waste generated by UU. This approach is also relevant for waste streams which are currently unlikely to be eliminated or diverted from incineration completely, such as hazardous waste from research activities. It can be beneficial for UU to aim higher on the circularity ladder with their overall waste mitigation strategy to reduce the total amount of materials used, instead of focusing on achieving full recycling according to the current zero-waste definition.

5.2 Limitations and data gap

There are multiple limitations to this study and data gaps in the waste stream analysis. These include the MFA only providing a snapshot of the waste flows, data reliability and accuracy issues, a constantly changing regulatory environment, and simplifications and assumptions to the scope and waste streams.

Firstly, an MFA only gives an overview of the waste flows in a specific moment in time. The nuances and variability of the waste streams over time are not accounted for. While the temporal scope of the MFA of one year accounts for the differences during the seasons due to the school year and breaks, the waste flows can vary within each year and from one year to another. These differences can become relevant when suggesting solutions where a constant stream of waste input is required or fluctuations in waste quantities are undesirable. For example, expanded on-site recycling facilities may experience a lack of capacity if waste flows are inconsistent and higher than expected in some periods. During periods when less bulky waste is generated, there may be excess capacity, leaving the recycling facility idle. This can make hiring the suitable number of employees or estimating a size for the facility difficult. Waste quantities can also fluctuate yearly, with some waste streams depending on ongoing activities at the university. Such streams are lab waste and soil, which are dependent on research projects. The specific types of experiments and equipment required can vary, which causes fluctuations in the quantity of waste generated. Therefore, it is beneficial to repeat the MFA and take into account the seasonal variability when choosing mitigation solutions.

In addition to the limited timescale, the data used in the MFA has varying accuracy and reliability. The year 2022 was still impacted by COVID-19 related restrictions so the waste figures may not fully reflect the typical operation of the university. Additionally, the data was mainly obtained via secondary sources. While the waste handlers were contacted and some of the information about the waste streams, such as the residual waste, is expected to be primary data, the measurements conducted by the companies are often unclear. Renewi was also not able to provide contact details for its downstream suppliers. The downstream companies were approached via contact info on their websites; however, no replies were received. It is known from literature that it is difficult to obtain specific data on waste processing and yield quantities from waste handlers (Viva et al., 2020). Hence, data from peer-reviewed and grey literature was used to supplement the data from waste handlers. This data, especially from peer-reviewed articles can be somewhat outdated. Several assumptions and generalizations were made during the mass balances when specific data from waste handlers or the further downstream actors was not available. Further collaboration with waste handlers and downstream processors and discussing the possibility of obtaining direct measurement results could improve the data quality and make the results more specific to UU. Transparent communication throughout the supply chain and data on recycling yields would increase the reliability and accuracy of the MFA and help implement solutions.

The constant changes in the regulatory environment, differing waste separation in regions and conflicting communication from UU sources complicate waste separation for students and staff. These changing regulations also increase the uncertainty of the MFA as literature data was used that predates certain changes in waste management. New laws on the government level such as introducing deposits for metal cans (Rijksoverheid, 2023b) and banning the use of disposable plastic cups (Rijksoverheid, 2023a) impact waste collection and composition data as well as sustainability initiatives on campus. Furthermore, people might not be aware of these changes, which can lead to confusion when waste separation signage is not updated or not available in both Dutch and English, considering the significant number international students and faculty (see figure 9). Depending on the region of residence, the waste sorting rules can differ at home compared to UU buildings. In the municipality of Utrecht plastics and drinking cartons from households are collected with residual household waste and sorted out in post-separation facilities (Gemeente Utrecht, 2023). People can incorrectly assume waste is collected and separated in the same manner at the UU buildings, which follow different waste sorting. In the 2022 waste figures, separate waste bins at UU were not yet in place in all buildings, leading to plastic and organic waste streams not being present in many buildings and paper waste possibly ending up in residual waste figures as well. Therefore, average waste composition assumptions used in the MFA and subsequent mitigation ideas are subject to uncertainty. Repeating the MFA yearly to understand the impact of waste regulation and UU policy changes and direct measurements of waste composition can improve the MFA, while clear communication on waste policy changes and progress can improve separation.

(A) (B)

Figure 9. (A) Image of waste bins on the 4th floor of the library on July 4th 2023, where organic and paper bins are not present and the label on the plastic bin still includes metal cans, which are not allowed in the PD waste stream since April 1st 2023 (Renewi, 2023b). **(B)** Image of waste bin description on the ground floor of the Vening Meineszgebouw B available only in Dutch (taken March 28th, 2023).

Several simplifications and assumptions were made to the scope of the MFA that increase the uncertainty. Firstly, the Faculty of Medicine was excluded as the faculty is intertwined with the University Medical Center (UMC). Education and research take place in UMC buildings, which is outside of the waste management scope for Utrecht University. It is noteworthy that lectures and exams are still held in UU buildings and students use libraries and other educational buildings that are within the scope of this study. This movement of students and staff between buildings that have been assigned to a specific faculty is also acknowledged. To improve the results, the actual percentages of offices per faculty in each building as well as the percentage of classrooms could be used in allocating waste per faculty. Waste from rented buildings was excluded from the scope of the MFA as UU owns most of the buildings it operates in and data for the rented buildings is limited. Additionally, waste figures for external parties operating in UU-owned buildings were excluded where possible, however, it is acknowledged that some external party waste may be combined with waste from UU. Furthermore, due to a lack of data for the three waste streams that are managed at a level higher than recycling, they were not included in the MFA. It is suggested to monitor the quantities of these waste streams and include them within the scope of the MFA in the future. The simplifications listed have been noted during the MFA and have been excluded due to limited data availability or uncertainties associated with their inclusion.

5.2.1 Data gap in waste stream composition

The material flows of UU's waste indicate the potential to reduce waste from multiple streams. While several general improvement ideas were generated via stakeholder interviews, all participants brought out the need for further information before suggesting any concrete solutions per stream. Interviewees were unsure of how their suggested ideas would impact UU waste, as they are unsure of what ends up in the waste bins. If the exact contents of waste bins were known, then an approach to reduce or replace products that are thrown away could be devised. For some waste streams, the composition is clearer and simpler, while others require separate projects or waste scans to determine the inputs.

The streams with fewer sources can be defined by contacting the respective building or lab managers and asking for the specific input details. This approach is preferred when the waste stream may contain hazardous materials or is relatively homogenous. For example, soil waste originates from only two buildings and is used in lab experiments. The contaminants and materials that end up in soil collection bins can more easily be determined from the input side and have been elaborated on in section 3.1.2. A similar approach can be taken for construction and demolition waste, which originates from only four buildings, but the composition and consistency of the stream remains unclear. For electronic waste which is largely equipment from natural sciences such as fridges, determining the state of the disposed equipment and establishing a policy that assesses the potential for repair or remanufacturing prior to disposal can prevent materials with reuse possibilities from being discarded. Another waste stream that can be better assessed from the input side is hazardous waste. Given that the waste originates from labs various buildings and the specific waste contents beyond the general categories are unknown and can be dangerous, conducting a separate assessment project would be beneficial to measure inputs from labs across the natural science faculties and identify potential hotspots for waste reduction. During the lab waste tour in the Geosciences, it was identified that hazardous and non-hazardous waste separation was limited, but further analysis of the waste composition is necessary. Measures for improvement may range from trainings and establishing best practices to avoid unnecessary waste to implementing cleaning protocols and providing bins for materials that can be recycled instead of disposed in hazardous or residual waste. The latter option requires further discussion with the downstream supply chain as limited information about allowed contamination in waste streams was obtained during this study.

Waste streams that originate from many buildings and are separately collected and recycled with current best available technologies may benefit from an approach from the purchasing side. Streams such as glass, paper and cardboard, and organic waste originate from a variety of buildings and are relatively clear streams. Since these streams are already sent for recycling, they can be targeted with more ambitious mitigation ideas from higher up the R-ladder. Purchasing policies can be reviewed to select more circular suppliers who offer alternatives to sending material to recycling. Opportunities to reduce the organic waste quantities can also be discussed with service providers that generate food waste. Additionally, there may be streams such as manure which are difficult to reduce as they are generated from university operations that are difficult to limit without impacting education and research. As animals are integral to education at the Faculty of Veterinary Medicine, accepting the manure waste stream as a part of UU's essential activities may be necessary. Other activities such as the maintenance of UU's grounds that can involve cleaning up leaves and clearing gutters at Science Park are also required.

Conducting a study on waste composition that involves direct measurements of waste bin contents can be beneficial for material streams that originate from a multitude of buildings and where the input side is less clear. These can include residual waste, plastics, wood, and metal, with focus on the first three due to their high amount of material loss in processing. As waste generation differs per faculty and building, it can be necessary to conduct residual and plastic waste scans in various building types in both the city center and Science Park. Residual waste composition from office buildings might differ from education and canteen buildings, however, further research is needed to determine the specific contents. Waste streams may also be variable and fluctuate depending on activities within the faculties. In the case of waste that is not constant or is non-recyclable, the solutions may be more related to sourcing policies. Furthermore, an analysis on the level of object components may be useful to understand the further recycling implications and to better assess alternative options that could improve management or reduce waste. Most of the metal scrap and wood streams are from the Milieustraat activities, where bulky waste is separated. Identifying whether it is possible to reuse the material on a higher R-level or recycle wood as A-grade wood are opportunities for improvement for these two waste streams that rely on further understanding of the composition of the bulky waste and activities it is generated from.

5.3 Case study on residual waste

Utrecht University is currently conducting a residual waste scan. Based on the preliminary results from the first part of the scan in May 2023, an example case study is described.

5.3.1 Waste composition

The initial scan looked at residual waste bin contents from 4 buildings in the city center region: Janskerkhof 2-3, UCN Dining Hall, University Library City Center, and Adam Smith Hall. This scan only looked at the fraction of waste that belongs in the residual waste bin, not all of the waste. It was found that about half of the waste delivered is actually considered residual waste (EcoSmart, 2023). The rest of the residual waste is incorrectly separated material, but the content is unclear and requires further assessment. At the time of this research report, the preliminary waste scans found that around 50% of the waste by weight of residual waste is tissues. Over 21% of the residual waste consisted of coffee cups. Other waste included composite packaging for food from supermarkets, office supplies such as pens, aluminum cans, wooden cutlery, various other products such as medicine packaging, aluminum foil, tights, and cleaning supplies like latex gloves, cleaning sprays and sponges.

5.3.2 Mitigation ideas

Based on this preliminary information, some improvement solutions suggested by the interviewees are applicable. Additionally, it was possible to show this case study to a few individuals during the semi structured interviews to obtain their opinion on potential solutions. Firstly, solutions that are inspired on the highest R-ladder level, refuse, are brought out. Then, solutions further down the R-ladder are emphasized.

For tissues, if they originate in the bathrooms, this could be to have alternative systems such as air dryers, which do not generate waste while in the use phase. Alternatively, using reusable cotton towel roll systems, where the towels are washed and reused could be applied (I10). For the recycling R-level, the Tork hand towel system could be expanded to include more buildings, so the paper towels from toilets get recycled. If the tissues originate from canteens or are externally brought in by building users, it can be more difficult to find mitigation solutions for the waste stream. An interviewee noted that items such as cloth handkerchiefs are an alternative to tissues but acknowledged that it is unlikely that these will be preferred by individuals (I6). At this stage, the interviewees indicated that it may not be possible to eliminate or reduce all types of residual waste (I9).

For coffee cups, while not included in the MFA due to the waste stream being under 0,1% of total waste by weight, different strategies could be used. Coffee cups from the MAAS coffee machines in the building could be removed and consumers could be forced to use their own reusable cups. This system will already be implemented in January 2024. Additionally, improved placement and information on separating waste, which was identified in section 4.3, can be implemented to increase proper separation.

5.4. Further steps

As the residual waste scan was not a part of this research methodology, solutions were not investigated in depth and can be done in a future study. Based on the results of the MFA and collected mitigations ideas as well as data gaps identified in this research, an illustrative roadmap that provides an overview of how to approach waste streams and determine strategies to get closer to the zero-waste goal is created (figure 10). The first step is to measure the waste stream composition through either direct waste scans or by looking at input data discussed in section 5.2.1. The second step is to determine solutions that focus higher on the R-ladder. Solutions can include concrete ideas identified within this research in addition to the generation of further mitigation ideas suggested in section 4.3.5. As the next step, internally implementable ideas can be preferred as they rely less on external parties. In the long-term and to address the waste problem on a systemic level, collaboration along the supply chain is needed. Fourthly, to determine whether the implemented solutions are successful, change in the waste flows requires monitoring. While the MFA from this research can be used as a basis for future MFAs, any changes in recycling or suppliers need to be updated and future MFAs can benefit from improved data from waste handlers. In addition, continued waste scans and monitoring of the composition of waste streams will help identify whether the implemented plans have the desired impact, however, not all impacts may be directly measurable. Finally, clear communication of the changes happening and why the university is pursuing zero-waste along with reporting any progress is important to address the barriers related to a lack of knowledge and resistance to change.

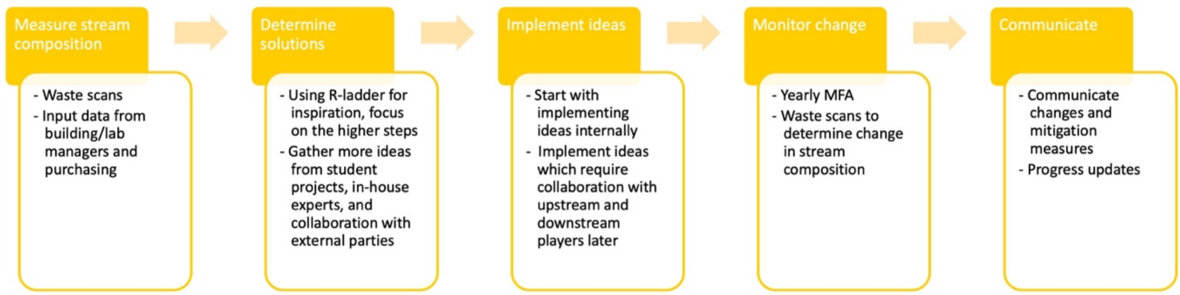

Figure 10. *Roadmap on how to approach and find improvement solutions for the waste streams.*

6. Conclusion

Utrecht University has adopted the R-ladder approach into its waste management strategy and has set a goal to become zero-waste, contributing to Dutch circular economy efforts. This research aimed to determine how UU could get closer to their waste goal by first providing an understanding of the management of the current waste flows and then identifying improvement measures. The main research question of the study was: “How can Utrecht University become a zero-waste organization while considering the impact of an expanded scope and varying R-level ambitions on waste flows?”.

To answer the question, an MFA was conducted with a narrow scope focusing on the origin of the waste and an expanded scope that included downstream processing of waste flows. Considering UU’s definition of zero-waste, which requires materials to be processed at a level of recycling or higher, the largest problematic waste streams that are below the required processing level were residual and hazardous waste. Residual waste was generated in most buildings while the hazardous waste originated from natural science laboratories in the Geosciences, Sciences, and Veterinary Medicine faculties. When considering downstream practices, a 13% increase in waste sent to incineration was identified. Recycled material yields of 43.6% and 75.7% were determined for separately collected waste streams sent to composting/anaerobic digestion and sorting/recycling, respectively. These losses occurred due to contamination of separately collected streams and inefficiencies during recycling processes. To avoid downstream losses, it is suggested to prioritize R-ladder ambitions at higher levels, aiming to eliminate the use of raw materials and maintain materials in the loop to prevent downcycling.

Measures to improve waste management were identified via stakeholder interviews and desk research. The concrete measures higher on the R-ladder included elimination of single use dishes and packaging in addition to switching to circular procurement strategies and requiring service providers on campus to collaborate with UU initiatives. Lower R-level measures involved increasing waste separation at the source by improving waste bin placement and increased communication surrounding separation. Suggestions to collaborate with other universities and actors along the supply chain to identify further areas of improvement and sourcing novel ideas from the UU community were noted. Overall recommendations drawn from the results suggest measuring the exact composition of waste streams, focusing on higher R-level strategies, starting with internally implementable solutions, monitoring progress through yearly MFAs and waste scans, and communicating information about measures and waste reduction progress.

This study provided a clear idea of the boundaries for UU’s waste strategy and presented a methodology for continued monitoring of waste flows. It showed that it is currently difficult for UU to become zero-waste according to their own definition, as a fraction of material from downstream processes will be sent to incineration. Furthermore, there are some essential research and education functions of the university that produce waste. It can be beneficial for UU to focus on and set goals to reduce waste quantities. These can be achieved by using higher level R-strategies that aim to refuse and reuse materials. As the Science Park is a distinct and separate area situated on the periphery of Utrecht, it offers a promising opportunity for conducting pilot projects for new waste management strategies. To select suitable mitigation measures, further research into the composition of waste streams, specifically residual waste and hazardous waste, is recommended. Continued communication with waste handlers is suggested to obtain more accurate and UU-specific data as well as to understand opportunities and limits to current recycling practices. Since this research focused exclusively on solid waste flows it is advantageous for future research to consider additional environmental impacts, such as CO_2 emissions, to align waste strategies effectively with UU's carbon neutrality goals.

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Appendices

Appendix A – Glossary of acronyms and translations

Afval uit onderhoud watergangen	Waterway maintenance waste
Anorganisch zuur	Inorganic acid
Anorganische loog	Inorganic lye
Artikelen verontreinigd	Contaminated articles
Beeldschermen	Monitors
Bouw & sloop	Construction and demoliton waste
CE	Circular economy
EC	European Commission
Electronicaproducten	Electronics products
Elektr(on)isch afval	Electronic waste
Folie	Film
Folie/kunststoffen	Foils and hard plastics
Gevaarlijk afval	Hazardous waste
GFT	Organic waste
Glas	Glass
Grof Afval	Bulky waste
Grond	Soil
Halogeenrijke organische vloeistof	Halogenated waste
Hout	Wood
Koel- en vriesapparatuur	Refrigeration and freezing equipment
Koffiebekers	Coffee cups
Koffiedik	Coffee grounds
Laag calorische vloeistof	Low-calorific liquid
Licht vervuild zand	Lightly polluted sand
MFA	Material flow analysis
Mest	Manure
Papier/Karton	Paper and cardboard
PMD	Plastic packaging, metal cans, drinks cartons
Restafval	Residual waste
Schroot	Metal scrap
Slib uit vetvang	Sludge from grease trapping
Snoeihout, blad, groen	Pruning wood, leaves, green
SZA (Specifiek ziekenhuisafval)	Specific hospital waste
Vertrouwelijk papier	Confidential paper
Swill	Swill

Appendix B – List of UU buildings included in the MFA

City center (Binnenstad)

Humanities

- Achter de Dom 2
- Descartes Hall (E)
- Drift 10
- Drift 13
- Drift 15
- Drift 21
- Drift 23
- Drift 25
- Drift 6-8
- Janskerkhof 13-13a
- Janskerkhof 15A
- Kromme Nieuwegracht 22/Muntstr. 2A*
- Kromme Nieuwegracht 80*
- Opleidingscentrum AZU WKZ
- Spinoza Hall
- Transcomplex*
- Witte Vrouwen 7 Bis

Law, Economics and Governance

- Adam Smith Hall (AA)
- Bijlhouwerstraat 6-8
- Janskerkhof 2-3A

Education

- Janskerkhof 30
- Locke Hall (C)
- Newton Hall
- UCN Dining Hall
- Universiteitsbibliotheek Binnenstad
- Voltaire Hal

Other

- Academiegebouw*
- Nicolaas Beetshuis*
- Parnassos
- Universiteitsmuseum

Science Park

Other

- Bestuursgebouw
- W.C. van Unnikgebouw
- Trafo/Ketelhuis
- Warmte Kracht Centrale
- FSC OS Reststoffenbeheer RA
- S.R.O.N.

Science Park

Social and Behavioural Sciences

- Martinus J. Langeveldgebouw
- Sjoerd Groenmangebouw

Geosciences

- Aardwetenschappen
- Earth Simulation Lab
- Lab GEO Princetonplein 9
- Vening Meineszgebouw A
- Vening Meineszgebouw B
- Vening Meineszgebouw C

Sciences

- Botanische Tuinen / Fort Hoofddijk
- Botanische Tuinen/Bezoekerscentrum
- Buys Ballotgebouw
- C. Bleekergebouw
- David de Wiedgebouw
- Hans Freudenthalgebouw
- Hugo R. Kruytgebouw
- Kassencomplex Botanische Tuinen
- Leonard S. Ornsteinlaboratorium
- Minnaertgebouw
- Roverokas Botanische Tuinen
- Victor J. Koningsberger gebouw

Veterinary Medicine

- Androclusgebouw
- H. Jakobgebouw
- Hondenkennel Tolakker
- Jeanette Donker-Voetgebouw
- Martinus G. de Bruingebouw
- Mesthuis
- Nieuw Gildestein
- Proefboerderij De Tolakker
- Rundveestallen
- Willem C. Schimmelgebouw

Education

- Educatorium
- Espressobar Gutenberg
- Marinus Ruppertgebouw
- Universiteitsbibliotheek USP

* Buildings where waste is collected by municipal waste handler