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Future Household Plastic Packaging Waste in Gothenburg

Master's thesis in Industrial Ecology

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Gothenburg, Sweden 2025
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Cover:
Picture from a recycling station looking out over the WtE plant in Sävenäs.

Gothenburg, Sweden 2025

Abstract

Plastics are a major source of fossil CO_2 emissions, with packaging plastics being the largest stream globally and in Sweden (SOU 2024:67; SWD/2022/384). Rising consumption and low recycling rates lead to more waste being incinerated, contributing significantly to emissions over the plastics' life cycle. Sweden and the EU have introduced regulations to reduce waste and increase recycling rates. The most recent addition is the EU's Packaging and Packaging Waste Regulation (PPWR). Emissions from Swedish waste-to-energy incineration due to plastic waste remain a key concern. To reduce incineration emissions, the focus must be on waste prevention and improved sorting to enable more recycling. However, without clear projections, municipalities like Gothenburg risk misallocating efforts and planning capacity. To plan effectively, they must assess how future packaging waste flows may develop.

This report aims to analyse future plastic packaging waste flows in Gothenburg, focusing on how PPWR will shape municipal waste management. It seeks to project how the flows of plastic packaging waste might change up until 2030 and investigate the impacts of PPWR. Furthermore, the study aims to examine how future flows of plastic packaging waste may affect the direct fossil CO_2 emissions from the WtE plant in Sävenäs. Three research questions guide the study: *What is the current flow of plastic packaging waste in Gothenburg and how is it managed? What are the projected flows of plastic packaging waste in Gothenburg in 2030 accounting for the impacts of PPWR? What would be the associated changes in direct CO_2 emissions from the Waste to Energy (WtE) facility in Gothenburg?* Methods include material flow analysis, waste projections, and lifecycle assessment, each building on the other.

Results show that, of the 16 kt of plastic packaging waste generated in 2024, 71% is incinerated, emitting 31 kt of CO_2. By 2030, plastic packaging waste can possibly increase by 6 kg/capita or decrease by 10 kg/capita. This indicates that a reduction in waste generation and achievement of associated regional and national targets is possible. The wide range of projections is due to many uncertainties, such as input data accuracy as well as how and if PPWR measures will be implemented in practice. Nevertheless, if PPWR is implemented successfully, plastic packaging waste can be reduced in Gothenburg. However, additional measures will be needed to meet ambitious targets. These may include targeted information campaigns for households in apartment buildings to increase their low sorting rates, or new building requirements to support source sorting indoors.

The study identifies several aspects of interest for further investigation, including how to prepare for shifting waste streams, potential increases in paper packaging waste, and changes in recycling station usage. Additionally, reduced plastic packaging waste may have broader system effects, such as increases in other packaging types, substitution of other materials with plastic, and unequal competition within the EU if implementation of PPWR varies between countries.

Keywords: Plastic Packaging Waste, MFA, Sensitivity Analysis, Waste Projection, PPWR, EPR, Municipal Waste Management, WtE

Acknowledgements

First of all, I would like to thank my supervisor Bo for both coming up with the idea but also for the support and cheers he has given me during this time. It was always a blast to read his comments as half of them consisted of "What!?!" and "Fun!" alongside more constructive comments. I would also like to mention my unit and unit chief at KOV for taking me in, listening to my weekly "I will continue to write" statements every Monday meeting and providing moral support whenever the process was not going as fast or good as I would have liked.

Thank you to my examinator Maria for listening, reading and commenting my, at times, incomprehensible stream of thought. You made sure the report was as good as it could be and for that I am grateful, even though I might not have felt exactly those thoughts when reading and correcting every one of your comments.

Thanks to friends who have had to listen to my rambling thoughts and complaints, never making me feel as if I am boring or annoying them, even though I am quite sure I must have been at multiple occasions. You have been essential in me keeping my sanity and positive outlook on life whenever I have felt lonely or as if the universe is out to get me. Special thanks to Emmi, Englund and Carter for giving exactly the support I needed. This extends to Isak as well, the one person who has never really had a choice in whether to answer my calls or listening to my anxiety. You have been a constant safe haven and I could not have gone through this process and finished this report without you.

Lastly, thanks to my family. Even though I proudly exclaimed that I would never work with sustainability nor engineering like them, you have never questioned me when I made 180 after 180 and ended up exactly where I was not supposed to land. You have helped me in overcoming my self-doubt time and time again, and especially this spring, when the prospect of a post-studies life seemed dark and gloomy, you have always been there for me. Thank you so much.

Lovisa Årebäck, Gothenburg, May 2025

List of Acronyms

Below one can find a list of acronyms that have been used throughout this thesis listed in alphabetical order. In parenthesis behind some expanded acronyms is their Swedish translation.

CCS	Carbon Capture and Storage	(Avskiljning och lagring av CO_2)
CO_2	Carbon Dioxide	(Koldioxid)
DfR	Design for Recycling	(Design för återvinning)
DRS	Deposit and Return System	(PANT)
EoL	End-of-Life	
EPR	Extended Producer Responsibility	(Utökat producentansvar)
ETS	Emission Trading System	(Utsläppshandel)
GDP	Gross Domestic Product	(Bruttonationalprodukt)
GWP	Global Warming Potential	(Global uppvärmningspotential)
JRC	Joint Research Center	(Gemensamma forskningscentret)
KOV	Department of Sustainable Waste and Water	(Kretslopp och Vatten)
LCA	Life-cycle Assessment	(Livscykelanalys)
MFA	Material Flow Analysis	(Materialflödesanalys)
MS	Member States	(Medlemsstater)
MRF	Materials Recovery Facility	(Förbehandlingsanläggning)
MSW	Municipal Solid Waste	(Kommunalt avfall)
NPA	Producer Responsibility of the Industry	(Näringslivets Producentansvar)
PPWD	Packaging and Packaging Waste Directive	(Förpackningsdirektivet)
PPWR	Packaging and Packaging Waste Regulation	(Förpackningsförordningen)
PRO	Producer Responsibility Organisation	(Producentansvarsorganisation)
RS	Recycling Station	(Återvinningsstation)
RC	Recycling Centre	(Återvinningscentral)
RQ	Research Question	(Frågeställning)
SA	Sensitivity Analysis	(Känslighetsanalys)
SEPA	Swedish Environmental Protection Agency	(Naturvårdsverket)
SLS	Strategic Literature Search	(Systematisk litteraturöversikt)
SMED	Swedish Environmental Emission Data	(Svenska MiljöEmissionsData)
SU	Single-use	(Engångsbruk)
TMR	Tailor Made Responsibility	
WFD	Waste Framework Directive	(Avfallsdirektivet)
WtE	Waste to Energy	(Avfall-till-Energi)
WP	Waste Program	(Avfallsplanen)

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Introduction

Plastics represent a significant source of fossil CO_2 emissions, not only through their production but also through their end-of-life incineration, posing a major challenge to climate change mitigation efforts. Plastics can be classified into a wide variety of plastic types and their numerous applications result in a significant dispersion of plastic goods throughout society. However, the largest flow of plastic in Sweden is packaging plastics (SOU 2024:67, p. 25). This is also true globally with 47% of all packaging in 2006 consisting of plastic, with an estimated doubling of plastic packaging consumption occurring between 2018 and 2040 (SWD/2022/384). An increase in consumption will naturally result in an equal increase of plastic packaging waste. To manage packaging waste is an issue all countries will face, and if the trend is not disrupted, the issue will only worsen.

To ensure proper waste management, Sweden employs a variety of rules and regulations such as extended producer responsibility (EPR), mandatory waste programs, and municipal waste responsibility. EPR relocates the responsibility for managing packaging waste from the consumer to the producer, forcing them to create, maintain and fund a packaging waste collection and recycling system (SFS 2022:1274, 4 chap. 1§). A mandatory waste program forces each municipality to set goals for waste minimisation and strive for a more environmentally friendly waste system (SFS 2011:927, 9 chap. 4§). Lastly, in 2024, Sweden introduced Municipal Waste Responsibility, which in practice means that “each municipality is responsible for the collection, transportation and recycling or disposal of municipal waste" (Swedish Waste Association, 2022a, 15 chap. 3§). This responsibility and how the tasks are carried out are critical to how much material is and can be recycled and subsequently how much is incinerated in the local waste to energy (WtE) facilities (EEA, 2024). Of all the municipalities, Gothenburg is the second largest municipality by population in Sweden and the waste originating there is considered "very similar" to the average Swedish household waste composition (Edo et al., 2024, p.7). Additionally, the department in charge of waste management, Sustainable Waste and Water (KOV) has been involved in several studies where waste prevention measures are tested as well as been a key collaborator in the newly published "Action plan to reduce plastics to waste incineration" (Sahlin and Ljungkvist Nordin, 2025). This makes Gothenburg municipality and KOV an ideal subject for studies regarding the waste generation and management systems.

WtE facilities are a crucial part of Gothenburg’s waste management as well as the energy and district heating network. It is where residual and hazardous waste is transformed into electricity and heat whilst simultaneously and successfully redirecting a waste flow which otherwise would have ended up in landfills (SFS 2011:927, 3 chap. 12§). However, a distinct disadvantage are the associated emissions which occur as a result of combustion. About 7% of Sweden's total greenhouse gas emissions come from waste incineration and 90% of this comes from the incineration of fossil plastics (SOU 2024:67, p.343). If plastics could be removed from the residual waste stream, the emissions could be reduced significantly. This would in turn make progress towards reaching the Swedish environmental goals of a 63% reduction of CO_2 emissions compared to 1990 and net zero emissions 2045 (SEPA, 2024c). Additionally, as Swedish WtE generation is included in EU ETS, a reduction of direct emissions would lower the cost of emission allowances (Hörnell, 2022).

Issues such as increased consumption of plastic packaging and low recycling rate of plastic on the market, has been raised and addressed on the European level through for example the newly adopted Packaging and Packaging Waste Regulation (PPWR) by the European Commission (Popp, 2024). The regulation sets a target of reducing the total amount of packaging put onto the market with 5% by 2030 and 15% by 2040 compared to 2018 levels (Regulation 2025/40/EC, art. 43). PPWR also encourages reuse and refill options for consumers and implements quotas for increasing recycling rates, recycled content and recycling volumes. All member states, including Sweden, are obliged to comply with EU regulations but can choose to be even more ambitious if they are so inclined (SKR, 2024b). Industry actors impacted by PPWR have been interviewed about their view on the regulation and believe it to be an important step towards lowering the negative impacts of packaging waste (E. Ahlström, personal communication, February 24, 2025). The main positive aspect was that it was applicable to all companies in all member states (C. Håkansson, personal communication, February 26, 2025). Producers in general understand that PPWR brings a collection of heavy demands but that the motivation behind it is sound.

Regarding the issue of incineration of plastic waste, there are three primary approaches to reducing emissions, of which two focuses on limiting the amount of plastic entering WtE facilities (Sahlin and Ljungkvist Nordin, 2025; Swedish Energy Agency, 2024). The first involves reducing overall waste generation, such as minimising packaging weight and size. The second approach seeks to divert recyclable plastic from the residual waste stream either by enhancing source separation efforts or by implementing materials recovery facilities (MRFs) to extract recyclables before incineration. The third approach, in contrast, involves mitigating emissions after incineration through carbon capture and storage (CCS), effectively capturing direct CO_2 emissions from combustion processes. Among these strategies, improving the separation of recyclable plastics is generally regarded as the most cost-effective and practical option from the perspective of waste management authorities (Hogg, 2024). It requires relatively minor adjustments while allowing existing waste management systems to operate with minimal disruption at no further cost for the authority in charge (consumers bear the cost of increasing their own source separation). However, correct source sorting is more difficult in practice than in theory, which is supported by the fact that of the total amount of residual waste incinerated in Sweden, over 60% is incorrectly sorted and could have been recycled (SOU 2024:67, p.343). Municipalities like Gothenburg tries to encourage households to sort better and recycle more using methods such as a fee per kilogram of residual waste/household or information about the benefits of source separation. However, they have not yielded strong enough results and have proved inadequate in redirecting waste flows to their correct destination at the levels implemented: too low waste fee, too little/inadequate information etc. (Swedish Waste Association, 2022a; The City of Gothenburg, 2024).

Historically, waste management has predominantly been a reactive process; waste is generated, and only then does the question arise: how should it be handled (Tekniska museet, 2021)? In contrast, waste prevention represents a shift toward a proactive approach, wherein public authorities such as municipalities seek to prevent the generation of waste (SFS 2011:927, 9 chap. 4§). However, these authorities have long faced structural challenges that hinder effective waste prevention and management, including planning conditions such as limited financial resources and constrained regulatory mandates. These struggles have also been echoed by A-L. Eliasson from KOV (personal communication, February 4, 2025).

A crucial tool for enhancing waste prevention strategies and overcome structural challenges would be the ability to predict future waste flows (Dyson and Chang, 2005). Accurate forecasts are impossible to achieve but they can still be a useful planning tool. Forecasting would allow authorities to allocate resources more effectively, targeting critical bottlenecks or overlooked waste streams and stakeholders with greater precision. For instance, while increased information about the packaging material from producers to consumers may intuitively seem like a key focus area, incorporating the anticipated impacts of PPWR into predictive models, where such information requirements are already mandated, could provide a more refined understanding of where intervention is most needed and limit the allocation of unnecessary resources (Regulation 2025/40/EC).

In summary, incineration of plastic packaging waste represent a significant source of fossil CO_2 emissions. Plastic packaging waste and thus also emissions are expected to increase over the years if nothing is done to prevent it. Proactive waste prevention measures are an important approach for this objective but in order for it to be effective, relevant authorities must be aware of how the waste flows might develop over time. Implementation of new packaging rules through PPWR are a welcome effort but without an estimate of its effects, municipalities like Gothenburg risks wasting time and efforts on prevention measures already accounted for. Researchers has yet to investigate the effects of PPWR, and its the effects on the second largest city in Sweden is not likely to be prioritised. The next step for Gothenburg municipality and KOV should therefore be to conduct such research, to analyse how the consequences of the new regulation may affect their operations in order to best meet the plastic packaging flows of the future. An objective echoed and undertaken in this thesis.

1.1 Research Gap

Prediction of future waste flows has been the subject of numerous research studies (Dyson and Chang, 2005; Razaviarani et al., 2025 etc.). However, a notable gap found in the literature is the integration of forthcoming legislative changes into these predictive models. While the effects of a variety legislation on waste management have been extensively studied, the recent implementation of PPWR means that no studies have yet examined its impact in conjunction with waste stream projections (Obersteiner et al., 2021; Esguerra et al., 2024). Addressing this gap could significantly enhance the precision and effectiveness of waste management strategies. This need is also echoed by the Department of Sustainable Waste and Water (KOV), which is in charge of waste management in Gothenburg.

1.2 Aim and Scope

The purpose of this report is to analyse the future flows of plastic packaging waste from households in Gothenburg, with a specific focus on how PPWR is shaping the municipal waste management. It seeks to project how the flows of plastic packaging waste might change up until 2030 and investigate the scope of impacts PPWR may cause. Furthermore, the study aims to see how the future flow of plastic packaging waste may affect the direct fossil CO_2 emissions from the WtE plant in Sävenäs.

These objectives consequently allow for a discussion about how the planning conditions for KOV's activities and their operations might change over time.

1.2.1 Problem formulation

To fulfil the aim of the thesis, three research questions has been identified. Those should be answered by the report and are as follows:

1. What is the current flow of plastic packaging waste in Gothenburg and how is it managed?
2. What are the projected flows of plastic packaging waste in Gothenburg in 2030 accounting for the impacts of PPWR?
3. What would be the associated changes in direct CO_2 emissions from the WtE facility in Gothenburg?

1.2.2 Summary of Methodology

In order to achieve the aim and answer the research questions (RQs) above, the following methods has been used: material flow analysis (MFA), waste projections and life cycle assessment (LCA). The inclusion of all three methods was in order to assess (1) how plastic packaging waste *generation* may vary based on for example impacts of legislation or local/national variations, and (2) how *emissions* may fluctuate depending on plastic packaging waste generation as well as distribution within and design of the waste management the system.

The workflow and use of the different methods are visualised in chapter 5, figure 5.1. The methods are used as building blocks where the results from one method are used as input data in the next, e.g. the MFA of the 2024 system serves as a point of departure for the waste projections. Sensitivity analysis (SA) was also integrated into the other methods to identify and check the effects of critical data.

1.2.3 System Boundaries

This thesis will have a technical boundary of only including *packaging made from plastics* (see section 3.2.2) discarded within the geographical boundary of *Gothenburg municipality*. There is also an organisational boundary of only including flows that falls within *KOV's jurisdiction*. Temporal boundaries are set to *2024* as the baseline year and *2030* as the year for future projections. *2030* is a suitable choice as a majority of the articles in PPWR goes into affect before or in *2030* as well as KOV themselves having set waste management targets to be achieved in said year (see section 4.1.1).

1.2.4 Delimitations

The pre-defined system boundaries inherently excludes all non-plastic waste as well as plastic goods that does not fall under the definition of packaging. This limitation is made to narrow the scope but will subsequently result in the full impact of PPWR, which affects all packaging regardless of material, to not be fully examined. However, since direct emissions from waste incineration is a main focus of this report, and plastic is the main culprit and focus of numerous studies for how to reduce the negative environmental impacts of waste, it is a well-motivated delimitation. Additionally, the temporal boundary of 2030 omits a limited number of articles proposed in PPWR which affects plastic packaging waste but are expected to go into effect after 2030, further limiting the scope and analysis. Finally, a notable limitation with similar consequences is that only PPWR articles with clearly quantifiable effects will be considered when assessing the future changes in mass flow.

In addition, only waste from households and co-localised businesses will be included in the study, thus excluding the waste stream from the vast majority of businesses in Gothenburg municipality. This is due to KOV not being the responsible actor, unless explicitly contracted, for collection of plastic packaging waste from businesses (B. von Bahr, personal communication, May 8, 2025). Companies, businesses and organisations are instead responsible for securing their own waste collection contracts for packaging waste (food and residual waste is still the responsibility of municipalities) (SFS 2011:927, 3 chap. 4§). Businesses are heavy users of packaging, thus will experience the effects of PPWR, but said effects will not be accounted for in this study.

A related delimitation is that household behaviour patterns will be assumed to remain the same in 2030 as they are in 2024. This excludes analysis of the effects of for example new and expanded information requirements on all packaging which might improve the sorting behaviour of people. As the effects are hard to quantify without a large-scale survey, these changes where excluded. However, a notable exception is the inclusion of kerb-side collection roll-out for villas as an effect of Swedish waste legislation. This will likely change waste sorting behaviours *but* it will be accounted for in this study to produce a representative projection of the future waste management system. Additional reasons for the inclusion is that the effects of kerb-side collection roll-out is quantifiable based on literature or case-studies in Sweden.

To only include changes in fossil emissions resulting directly from incineration of plastic packaging waste, which serves as the basis for emission allowances in EU ETS, is another main limitation. This will exclude any emissions occurring during production and transport to and from consumers as well as avoided emissions due to recycled plastic substituting virgin plastics.

Notably absent is the inclusion of a CCS facility onto the WtE facility in Sävenäs in the future projections and analysis. This exclusion was based on two key considerations: the prioritisation of CCS as a last-resort measure and the extensive construction timeline, exceeding five years, required for its implementation.

Lastly, a limitation for those who wish to remake this study or use the sources mentioned in this report is the fact that many are written in Swedish.

1.3 Declaration of Interests

This thesis has been conducted in collaboration with the Department of Sustainable Waste and Water (KOV) in Gothenburg Municipality. The department has provided substantial data and information critical to the completion of the study. However, they have not influenced the content of the thesis, nor have they altered or dictated any part of the written text. Their role was limited to that of supervisors and data providers. The author has kept in mind KOV's interest of reaching favourable results and actively ensured that aspects analysed specifically for their benefit were only included in conjunction with broader comparative and analytical evaluations to minimise the risk of biased results.

1.4 Organisation of Report

This thesis is structured so as to provide a comprehensive analysis of waste management systems and policy, with a particular focus on both the present and future plastic packaging waste generation. The report begins with introductory sections, outlining the research gap, objectives, methodology, and the scope and boundaries of the study.

The contextual framework is established in Chapter 2, which discusses the legislative landscape relevant to plastic waste, including the use of Material Flow Analysis

(MFA) and Waste Projections research relevant to the study. Chapter 3 then explores both Swedish and European waste policies, detailing responsibilities at the municipal level and analysing regulatory instruments such as the Extended Producer Responsibility (EPR) scheme and finally introduces and explains the newly published Packaging and Packaging Waste Regulation (PPWR). The thesis proceeds to a review of the waste management in Gothenburg (Chapter 4), examining the structure and functions of the local waste authority, collection methods, incineration strategies, and ongoing initiatives aimed at sustainable waste management.

Chapter 5 presents the methodology, covering data collection, MFA implementation, waste projections, LCA, and a sensitivity analysis. Chapter 6 presents the results which includes a baseline analysis of plastic flows in 2024, and projections for 2030, with emphasis on waste generation and CO_2 emissions from WtE processes. These findings are then critically discussed in Chapter 7, addressing their implications for policy, environmental impact, and urban planning. The discussion also outlines the study's limitations and identifies potential areas for further research.

The thesis concludes in Chapter 8 with a summary of key conclusions.

2

Research Context

Here follows a literature review of the research context wherein this study are located. The review aims to justify how this study contributes to the research field.

The simplest formulation of the thesis scope and aim is "the analysis of the future material flow of plastic packaging". Based on this sentence and the information provided in the introduction (see chapter 1), the following research areas where identified as of particular importance for this study and the context it is located within: *Material Flow Analysis of Waste and Waste Management*, *Projection of Future Waste Generation* and *Impacts of Legislation*. In order to understand and present these fields, two strategic literature searches (SFS's) into MFA and Legislation were conducted where the methods along with relevant boundaries and limitations are described in section 5.1.1 and appendix A.

Conclusions drawn in this chapter can be boiled down to the fact that many studies exists with any of the three topics presented in the paragraph above. The studies in question can focus on one topic or use combinations of two, but what could not be found was instances where all three topics were combined. Especially not one using the geographical boundary of Gothenburg nor the newly adopted legislation of PPWR. This gap is what this thesis aims to fill and thus contribute new and useful research to the fields described below.

2.1 Material Flow Analysis of Waste and Waste Management

The foundational methodology of this thesis is MFA of plastic waste in the waste management system. A SFS was performed on this subject of which the search strings and results are compiled in appendix A, table A.1, A.2, and A.3. The SFS showed that MFA can be done on multiple scales and on different sectors (see section 2.1.1). The subject area of plastic and plastic packaging waste is not new and multiple mappings of the Swedish flows have already been conducted (Fråne et al., 2022). The studies answered a wide range of questions spanning from simply mapping the system to understanding the effects of potential changes. Conclusions includes agreement with the waste hierarchy, a wish for increased high quality recycling and the need for inclusion of sustainability indicators not only based on mass.

What is lacking however is a focus on Gothenburg and especially the waste management system within the city. Such mapping would be useful for more than simply understanding the system and size of the flows but as a guidance for effected authorities to understand their own system and, with more precision, aim their efforts when combating waste.

2.1.1 Applications of MFA in Waste Management

Material flow analysis (MFA) as a tool for mapping materials has been used widely, with different scopes, different sectors in focus, different geographical boundaries and for different materials (Hsu et al., 2021). For mapping plastic packaging, multiple European countries has been the subjects of MFA studies, for example Spain (Lopez-Aguilar et al., 2022), Portugal (Gonçalves et al., 2024) and Italy (Lombardi et al., 2021). Similar studies has also been conducted at regional scale as for instance in Flanders, Netherlands (Thomassen et al., 2022) or at city scale in Sweden (Esguerra et al., 2024). The studies mentioned aimed to understand and quantify the material flow of waste in the municipal waste management system and often applied different metrics or indicators to assess the sustainability of the system. Metrics includes sorting, collection, and recycled content rates among others.

MFA has been increasingly utilised to evaluate the waste management systems in cities and regions. Such a study is often commissioned by stakeholders with an interest in enacting systemic change but with inadequate knowledge about where such change would be most effective. The resulting models can be used to assess the environmental and economic impacts of waste management (Albizzati et al., 2024), to quantitatively and qualitatively investigate the waste management system for certain product categories (Van Eygen et al., 2018), or simply to asses the stocks and flows (Jiang et al., 2020).

Another use of MFA is to compare the environmental effects of different waste management options, e.g. high-quality recycling versus down cycling (Ekvall et al., 2025), manual versus automatic post-consumer sorting (Pluskal et al., 2023), and reuse versus recycling (Thomassen et al., 2024). By using MFA, these articles identifies the flows and then analyses the differences between the two (or more) systems. What can be deduced is often where the largest reduction potential is located, either as an effect of flow diversion or reduction (exemplified in Tallentire and Steubing (2020)).

Regarding MFA of plastic in Sweden, the Swedish Environmental Emission Data (SMED) has created, amended and extended a report wherein the flows of plastic waste in Sweden was mapped on behalf of the Swedish Environmental Protection Agency (SEPA) (Fråne et al., 2012). SMED constructed a MFA on the plastic waste from different sectors whereof households were one of them (p.23). The report was complemented in 2019 by the same institution where the main additions was a mapping of raw materials and specific product streams that contain plastic (Ljungkvist Nordin et al., 2019). In the latter report, no MFA was constructed. Lastly, the SEPA produced their own plastic flow mapping of Sweden for the year

2020 (Fråne et al., 2022). The aim of the project was to produce a map, with as accurate information possible, which could be used to monitor developments in the field of plastics and follow the flows of raw materials, products and waste. It in turn could be used for example to identify flows where authorities need to focus their efforts in order to achieve national and international targets.

2.1.2 Challenges and Areas for Improvement

Material flow studies have met several challenges over the years. One such challenge is the complexity of waste, especially plastic waste (Kawecki et al., 2021). Waste is composed of all types of materials and the materials can be of several different chemical compositions. Materials are no longer sector specific and the dispersion of especially plastics can be seen in all sectors and comprise the entire product or a very small component. Kawecki et al. (2021) aimed to provide a basis for future impact analyses of specific polymers and thus overcome the material complexity issue. The approach they used to achieve this was dynamic probabilistic material flow analysis, a very resource and time consuming method not suitable for widespread use due to said factors.

MFA as a method has additionally been accused of providing a limited basis for analysis as it is only assesses material flows and mass-based indicators (Albizzati et al., 2024, Vadoudi et al., 2022). Only focusing on mass neglects environmental and economic impacts, reducing the usefulness of the results as a basis for policymaking and circularity assessments. Albizzati et al. argues for expansion of the typical MFA methodological framework with life cycle thinking to encompass all possible effects of the system. Vadoudi et al., which focuses on multi-layer plastic packaging, instead advocates for the inclusion of a new circularity indicator such as "intensity of re-use".

Lastly, a general challenge most articles mentioned was the lack of complete data. To solve this issue, many focused their studies on specific geographic locations or case studies where data was available (Esguerra et al., 2024). Others identified data gaps and focused their MFA studies on filling said gaps through their research results. One such example can be found in Verstegen et al. (2022) wherein a data gap regarding share of packaging present in household hazardous waste was identified and a method for identifying the share was proposed.

2.1.3 Future Directions

Future developments in MFA related to waste generation and management are essential for enhancing sustainability practices. One promising direction is the integration of MFA with planning and forecasting models to establish more effective waste management strategies, a direction that this thesis also explores (Dokl et al., 2024). This combination allows organisations to outline their future objectives and formulate actionable plans to transition from their current waste management practices toward achieving goals such as zero waste. By implementing life cycle thinking, the results can further aid the assessment of both economic and environmental consequences of systems interventions (Albizzati et al., 2024). Lastly, by increasing the use of more advanced MFA modelling approaches, such as dynamic MFA, the ever increasing complexity of the modern society can be further and more accurately captured (Luan et al., 2021).

2.2 Projection of Future Waste Generation

A second important aspect of the methodology in this thesis focuses on estimations of future waste generation amounts. For this subsection, no SFS was conducted.

This is a research field with a large focus on municipal solid waste (MSW) and where a wide range of different methods have been used. Methods range from from mathematical regression models to advanced artificial neural networks. What they all have in common is however the inherent challenge of proving the accuracy of the models, as the future for many of them have yet to come about. The literature shows the presence of a set of influencing factors such as population growth and socioeconomic status which positively or negativity affect the waste generation within a system.

2.2.1 Methods

There are multiple different methods for trying to estimate future waste generation. The most prevalent appears to be: Systems dynamics modelling (Dyson and Chang, 2005; Ng and Yang, 2023; Fontaine et al., 2024), Waste Flow Diagram (Razaviarani et al., 2025), and models using artificial intelligence (Elshaboury et al., 2021; Abbasi and El Hanandeh, 2016).

Systems dynamics modelling tries to account for multiple influencing factors which not only influence the waste but also each other. By varying certain influencing factors, the model aims to see how said variation changes the other factors (Ng and Yang, 2023). A Waste Flow Diagram is a method using MFA to map the sources and endpoints of a material and presenting the flows usually in a Sankey diagram. By adjusting individual parameters, different scenarios can be visualised (Razaviarani et al., 2025). Lastly, models using AI are increasingly becoming popular as the field develops. Models using agent based networks or artificial neural networks aims to overcome the challenge of incomplete data and uncertainties to model how the future may develop (Elshaboury et al., 2021). By using AI, many more computations can be made and many more influencing factors can be accounted for all at once.

Regardless of method, most models uses a business as usual (BaU) scenario to which results could be compared. The BaU model is based on the assumption that waste generation per capita remains constant, with population growth being the sole variable to account for (Ng and Yang, 2023; Dyson and Chang, 2005; Razaviarani et al., 2025). The reference can both be used for comparison, as in "is X better than BaU", or as a control for the developed model.

2.2.2 Influencing Factors

Through this literature search, waste generation has been found to depend on a plethora of influencing factors. Such factors include population growth, socio-economic status (income and employment status), GDP, operational condition (design of waste management system), household behaviour, and consumption pattern (Razaviarani et al., 2025; Elshaboury et al., 2021).

The waste generation is positively and substantially correlated with population and income level (Elshaboury et al., 2021). Additionally, a higher socioeconomic status indicates a higher consumption and thus a higher waste generation. The design of the waste management system is also seen to be a influencing factor as better access to recycling options increases recycling rate etc. (Westin, 2020).

2.2.3 Challenges and Areas for Improvement

Despite the advancements in forecasting methods, challenges remain. Prediction models are typically influenced by socio-economic and demographic factors, which can limit their applicability across different contexts. Fontaine et al. (2024) addresses this by creating a model which is designed to adapt to the source material and address different scenarios of data variability. Furthermore, historical data is standardised to ensure consistency in time series analysis, an issue exacerbated by changing methods for collection of similar data, rapid urban growth and insufficient budgets (Fontaine et al., 2024).

2.3 Impacts of Legislation

The implementation of new legislation inevitably affects the individuals and organizations subject to it. The effects can be modelled both before and after implementation and depending on the subject matter, different methods are used to estimate them. As the result of a SFS performed on this research field, numerous studies were found to have examined the effects of legislation and policies on plastic waste (summarised in Appendix A and table A.5).

The reviewed studies highlights that assessing the impact of legislation on plastic waste is a common research topic. However, no study has addressed the Packaging and Packaging Waste Regulation (PPWR), likely due to its recent introduction. Legislative impacts are often measured using life cycle assessment (LCA) and expressed in CO_2-equivalents, representing a different but related approach to this study's objectives.

2.3.1 Methods

The SLS results indicate that research in this field varies in both focus and choice of method. For instance, Albizzi et al. (2024) used LCA and economic analysis to evaluate the societal costs of EU waste management policies, while Castillo-Díaz et al. (2024) compared the implementation of circular economy policies across EU countries. The reviewed studies employ various methods, including LCA (Albizzati et al., 2024; Singh and Biswas, 2023), material flow analysis (MFA)(Liu et al., 2021; Hsu et al., 2021; Esguerra et al., 2024), statistical analysis (Castillo-Díaz et al., 2024; Dokl et al., 2024), case studies (Dehio et al., 2023; Esguerra et al., 2024), expert interviews (Sundqvist et al., 2024; Dehio et al., 2023) and scenario modelling (Obersteiner et al., 2021). Common themes include circular economy, progress towards meeting stipulated goals, and the relationship between consumption and waste generation.

2.3.2 Applications and Examples

The major applications for this field is to either investigate the possible scale of effects before the legislation is passed or the actual effect experienced after implementation. The latter is exemplified in Dehio et al. (2023) where the authors aims to understand the effects of Germany's Dual System (similar to the earlier Swedish waste management system where producer responsibility organisations (PRO's) handled the recyclable packaging collection and municipalities the residual and organic waste). The pre-implementation research is more difficult as most legislation goes through multiple changes between proposal and final version. However, research has been done on how legislation can be added or amended based on findings from currents systems. One such article aimed at proposing management strategies to be used by other countries based on India's approach of minimising microplastic waste (Singh and Biswas, 2023). Another article reviews the problems associated with plastic products in Europe and how the extended producer responsibility legislation could be amended to face said problems (Leal Filho et al., 2019).

Two studies were identified as of particularly relevant for this: *Carbon footprint reduction potential of waste management strategies in tourism* (Obersteiner et al., 2021) and *Characterization, recyclability, and significance of plastic packaging in mixed municipal solid waste for achieving recycling targets in a Swedish city* (Esguerra et al., 2024). The first, by Obersteiner et al. (2021), applied scenario modelling and CO_2 footprint analysis to assess how waste management policies could reduce tourism-related carbon emissions. While its focus on tourism is less directly relevant, the methodology and policy considerations align with this study. The authors analysed waste generation in ten European cities and estimated the waste reduction potential of various management strategies.

Esguerra et al. (2024) examined the role of plastic packaging in MSW concerning Sweden's 2030 recycling target of 55% (SEPA, 2024c). Their findings are particularly relevant to this thesis, as it focuses on a Swedish case city, utilises sorting analyses for MSW characterisation, and compares results to EU recycling targets. A key insight from their research is that plastic waste in municipal solid waste (MSW) is often overlooked in discussions on increasing recycling rates, despite a significant share of plastic packaging ending up in MSW. This observation highlights the importance of including plastic packaging found in residual waste in the scope of this thesis. Moreover, their use of material flow analysis (MFA) to trace plastic waste streams is methodologically aligned with the approach adopted in this study. However, they conducted a more detailed sorting analysis than mandated by municipalities, providing a more comprehensive view of waste composition.

2.3.3 Challenges and Areas for Improvement

One challenge facing this research field is cross-country as well as cross-sectorial applicability. Castillo-Díaz et al. (2024) discovered significant differences and variations in circular economy initiatives across countries. These differences are largely due to variations in national legislation, into which circular economy measures have been adapted or retrofitted. As a result, the implementation approaches vary widely, making cross-country comparability low. A conclusion drawn by the authors was that there was need for European coordinate actions to fully achieve a circular economy.

Additionally, an article comparing two possible deposit and return systems (DRS) for increased reuse and recycling of plastic packaging in Sweden based their analysis on Swedish data and public opinion (Lu et al., 2022). Said alternatives might not be applicable in a country without an already existing DRS in place.

Lastly, there is a challenge in assessing the systems implications of multiple legislations or policies. Sundqvist et al. (2024) found that policy instruments addressing packaging reuse in Finland was insufficient but addressing them all simultaneously might create tensions in applications and alignment. There is need for such methodology improvements to be able to study the effects of multiple policies at the same time.

3

Waste Policy

Structurally, Sweden is comprised of three different administrative levels, the local, regional, and national level, with the European Union being an unofficial fourth level above them all (SKR, 2021). The national level, also known as the government, decides about laws and regulations which has to be followed by both the regional and local administrations.

As a member state (MS) in the EU, Sweden has agreed to abide by the principle of the primacy of EU law. The primacy determines that EU law will prevail over national laws in case of conflict (EUR-Lex, n.d.). This principle is fundamental for the EU to be workable and effective in their pursuit of a true European community with a common goal and direction. If the primacy did not exists, countries who did not agree with any policy adopted by the Union could simply claim that their national law says otherwise and disregard it.

Both the Swedish government and the EU has enacted laws and regulation which has shaped the waste management in Sweden and Gothenburg. In this chapter, the most relevant and important laws will be presented and explained as to their subject matter and aim. The chapter is divided into two sections, EU legislation and Swedish legislation, where PPWR, which is highly relevant to this thesis, is presented in section 3.1.2. The practical aspects of implementation and enforcement of the laws presented in this chapter will be explained in chapter 4.

3.1 European Waste Legislation

With regards to the scope and aim of this study, two significant EU legislative documents are of importance to explain further:

1. The Waste Framework Directive (WFD)
2. The Packaging and Packaging Waste Regulation (PPWR)

In short one could explain their relationship as complementary to each other: the WFD sets the broad environmental and legislative context, while the PPWR implements these principles within the packaging sector through concrete, enforceable measures (Directive 2008/98/EC; Regulation 2025/40/EC).

3.1.1 The Waste Framework Directive

The WFD is a legislative document applicable to all EU Member States (MS), but must be transposed into national law in order to be legally binding. The overarching aim of the directive is:

> ...to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use (Directive 2008/98/EC, art. 1).

The WFD applies to all types of waste and lays the foundation for national regulations, such as the Swedish Waste Regulation which is explained later in section 3.2. In addition to its general objectives, the directive introduces key principles that shape EU waste legislation, such as the polluter pays principle and life-cycle thinking. These aim to shift the waste producing responsibility from consumers to producers and promote a more holistic view of environmental impact throughout a product's lifespan.

An additional requirement of the WFD is for MS to establish separate collection systems and develop national waste management plans and waste prevention programmes. Moreover, it introduces the concept of Extended Producer Responsibility (EPR), which plays a central role in implementing legislation like PPWR. This exemplifies how the WFD serves as a legal and conceptual foundation upon which more targeted regulations, such as the PPWR, are built.

3.1.2 PPWR

A central component of this study is the newly adopted packaging regulation PPWR. In this section, the regulation is summarised, relevant impacts described and a brief timeline about PPWR's implementation presented.

3.1.2.1 Scope

As stated in the introduction, the European Parliament approved PPWR 2025/40 and repealed the previous directive PPWD in 2025, 94/62/EC (Regulation 2025/40/EC). By switching from a directive to a regulation, MS must adopt the regulation as is and it cannot be changed nor adapted by MS. Nevertheless, if the regulation grants it, each MS can set more ambitious goals than the ones stated or apply for exemptions. The new regulation is also more comprehensive than the directive and covers all packaging regardless of material and all packaging waste regardless of origin and use (art. 2(1)). According to Åsa Stenmarck, Material Flow Expert at SEPA, the largest difference between the old PPWD and new PPWR is the new focus on design aspects such as regulating material contents, shape and recyclability demands (personal communication, February 18, 2025).

According to article 1(1) in PPWR, the subject matter of the regulation is the following (Regulation 2025/40/EC):

> This Regulation establishes requirements for the entire life-cycle of packaging as regards environmental sustainability and labelling, to allow its placing on the market. It also establishes requirements for extended producer responsibility, packaging waste prevention, such as the reduction of unnecessary packaging and the re-use or refill of packaging, as well as the collection and treatment, including recycling, of packaging waste.

In preparation of new EU legislation where the impacts are expected to be significant, a preparatory document in the form of an impact assessment (IA) is conducted by the Commission (European Commission, n.d.-b). The IA aims to analyse the core issue(s) of the subject matter, determine if action by the EU should be taken and if yes, estimate the social, environmental and economic effects of outlined policy options. The commission does this through synthesis of existing research, new research done by the Joint Research Centre (JRC) and inputs from external stakeholders. Stakeholders could be governmental organisations, national authorities and industry as well as individuals and experts.

In order to estimate the impacts of PPWR, the IA constructed a baseline model onto which the proposed measures could be applied (SWD/2022/384). The baseline determined that plastic packaging waste would not only increase in size but also occupy a larger market share. The total waste generation per capita was predicted to be 209 kg in 2030 of which 48.6 kg comes from plastic packaging. This approach is similar to the one used in this thesis and described in chapter 5. What is important to distinguish is that the impacts assessed in the report are measured for the entire European Union. Effects described might be proportional in each country, e.g. packaging minimisation, whilst others might not, e.g. the use of compostable plastics.

Most articles in PPWR are addressed to the MS and it is up to the MS themselves to delegate responsibility to relevant public authorities. In order to determine which responsibilities might land on or affect the municipalities, a question about it was asked to Åsa Stenmarck as SEPA represented Sweden at the PPWR negotiations (personal communication, February 18, 2025). She concluded that there are a few ambiguities regarding who the responsible authorities in question are regarding some articles but that SEPA are expecting a substantial amount of the responsibilities to fall to them. Stenmarck cannot speak about what effects might fall on the municipalities. However, they will be spending a significant amount of time and resources on harmonising Swedish law and PPWR, hopefully clarifying it further.

In the regulation, there are multiple different targets to be fulfilled. Two of which are of particular importance to this study:

1. Each Member State shall reduce the packaging waste generated per capita, as compared to the packaging waste generated per capita in 2018 as reported to

the Commission in accordance with Decision 2005/270/EC, by at least: (a) 5 % by 2030; (b) 10 % by 2035; (c) 15 % by 2040. (Regulation 2025/40/EC, art. 43(1))

2. By 31 December 2030, the following minimum percentages by weight of the following specific materials contained in packaging waste generated: (a) 55 % of plastic. (Regulation 2025/40/EC, art. 52(1d))

3.

Since this study focuses on the year 2030, only target (a) of Article 43(1) is relevant. Therefore, any reference to Article 43(1) in this context specifically refers to subparagraph (a).

3.1.2.2 Timeline

As of May 2025, not all aspects, standards, and systems presented in PPWR are finished. Up until 2030, a variety of both delegated (must consult with expert groups compiled of experts from each EU country before adoption) and implementing (must consult with all EU countries before adoption) acts are scheduled for design and adoption (European Commission, n.d.-a). Below follows a brief timeline describing important years where larger/ more impactful articles will be finalised or adopted. Note that there are more articles being adopted than the ones presented in figure 3.1.

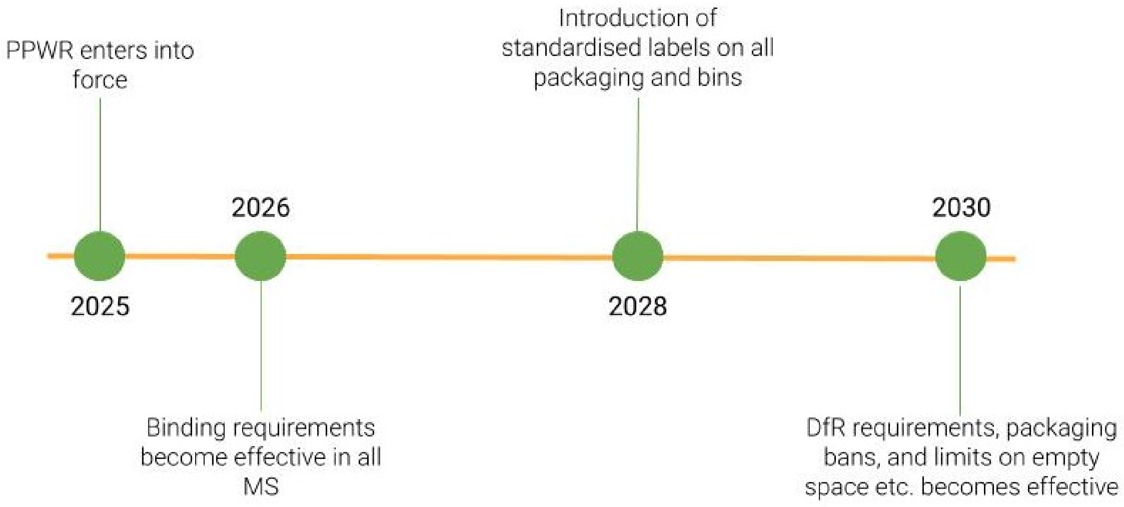

Figure 3.1: *A simplified and compressed timeline of PPWR implementation up until 2030.*

With regards to the timeline only spanning five years into the future, not everyone is optimistic about the feasibility of implementation. Karin Jawerth, packaging manager at ICA, noted two factors which makes the implementation of PPWR within the given time period difficult (personal communication, March 31, 2025). Firstly, PPWR includes a large number of measures, of which a number are not yet finalised nor even defined. One such example could be found in article 25 where a list of banned packaging formats are detailed (Regulation 2025/40/EC). In addition to the list, the article also spells out that the Commission has to publish guidelines, along with any determined *exemptions* to the list, from 2027 (art. 25(6)). For producers working with singular packaging types, the list of articles applying to them is shorter. They are also less likely to be hit by late changes caused by implementing or delegated acts. ICA, as a food retailer, deals with a plethora of types, materials and functionalities which subjects them to many of the measures in PPWR, often simultaneously. This increases the difficulty and the cost of achieving conformity with the entirety of PPWR. The second reason why fulfilment on time seems difficult is the reference year of 2018. When PPWR demands a 5% decrease of waste generation in 2030 as compared to 2018 levels, the actual reduction demanded is much higher. Packaging amounts has only grown in the seven years passed, challenging the prospect of achieving the goals on time.

Counterarguments to said points was also raised during the interviews. Nadja Dahlgren, Packaging Developer at Axfood, explained that they together with other retailers within the Swedish food retailers federation already have committed to 100% recyclable packaging, a soon mandated minimum requirement for all packaging (personal communication, March 17, 2025; Regulation 2025/40/EC, art. 6). Additionally, Swedish PRO's are already pushing their affiliated producers towards recyclable packaging through differentiated pricing (E. Ahlström, personal communication, February 24, 2025; C. Håkansson, personal communication, February 26, 2025).

3.1.2.3 Qualitative Effects of PPWR

Articles in PPWR which more directly will affect KOV are article 13(1) regarding harmonised labels on all waste receptacles, 48(5)b about source sorting availability in all public places and 63(1) regarding green public procurement requirements (Regulation 2025/40/EC). These articles will be elaborated on below and discussed in section 7.3.

Article 13(1) states that all MS shall label all waste receptacles with a harmonised labelling system which are to be determined in an implementing act at latest in August 2026. The labelling system must then be fully implemented in the MS in 2028 (see figure 3.1). This article could potentially be very impactful in both Gothenburg, Sweden and the Nordic countries as they already have such a harmonised system (EU PICTO, n.d.). In 2017, Denmark launched a pictographic system of waste symbols which Sweden, Norway and Iceland chose to adopt and implement in 2020. This system has been a great success and is mentioned in the IA of PPWR as an inspirational example of which the article was modelled after (SWD/2022/384). However, neither the IA nor PPWR indicates if the EU would adopt the Nordic system or create one of their own. That it would look exactly the same is unlikely if the process works in the way described by Christian Håkansson, Packaging & Sustainability Manager at TMR. He has heard that many negotiations do not end with the option everyone wants, but rather with the option everyone can accept (personal communication, February 26, 2025). If the commission were to construct a new system, all packaging, waste receptacles, etc., which quite recently has been labelled, must be re-labelled again to match the new system.

Article 48(5)b states that systems and infrastructures for source sorting of all packaging waste shall cover the entire Member State and consider population, waste volume, and accessibility (Regulation 2025/40/EC). They must ensure accessibility to separate collection in public spaces, businesses, and residential areas with adequate capacity. What this means is that source sorting receptacles must be expanded and cover more areas of Gothenburg. This is an important step towards decreasing littering in parks and lower the amount of packaging ending up in the residual waste (Ljungkvist Nordin et al., 2019, p. 156). This responsibility is shared with the Department of Urban Environment and *might* effect the operational planning conditions of KOV operations according to themselves (B. von Bahr, personal communication, February 21, 2025). The division of responsibility being presently unclear.

Lastly, article 63(1) states that the commission by February 12, adopt implementing acts specifying minimum mandatory requirements on public contracts in which the packaging or packaged products represent more than 30% of the estimated contract value or of the value of products used by the services that are the object of the contract (Regulation 2025/40/EC). The requirements are to be decided so as to incentivise the supply and demand for environmentally sustainable packaging and as public procurement amounts to as much as 14% of the European GDP, this article has a high probability of enacting substantial change (preamble §173). According to current guidelines for KOV regarding public procurement, packaging waste shall be minimised by prioritising re-usable and re-fillable packaging as well as purchasing products in "loose weight" and to choose the pack size according to each product (The City of Gothenburg, n.d.-c, p.3). Through correspondence with the Department of Purchase and Procurement, what article 63(1) would change is mainly dependent on what the minimum mandatory requirements would entail and how they are constructed (I. Wadman, personal communication, March 5, 2025). This regards whether Gothenburg City's current demands are higher or lower than the ones decided upon by the EU.

3.2 Swedish Waste Legislation

Swedish waste legislation can be summarised through two legal documents:

1. The Environmental Code (SFS 1998:808)
2. The Waste Regulation (SFS 2011:927)

The Environmental Code aims to

> ...promote sustainable development, which means that present and future generations are assured a healthy and good environment. Such

> development is based on the realisation that nature has a conservation value and that man's right to change and use nature is associated with a responsibility to manage nature well. (SFS 1998:808, 1 chap. 1§)

The legislation is a framework law which means that it sets out guiding principles, rather than detailed procedures, for how to behave towards the environment. Provisions regarding waste and waste management is compiled in chapter 15 (SFS 1998:808). The provisions promotes reuse and recycling as well as other management of materials, raw materials and energy so that a cycle is achieved (1 chap. 1§). The key points mentioned in the chapter relates to the waste hierarchy (which is visualised in figure 3.2), producer responsibility, permits and supervision, and environmental risk management. What chapter 15 does not include are detailed definitions and procedures for different types of waste or how the code is to be implemented. Said task instead falls to the second legal document, the Waste Regulation.

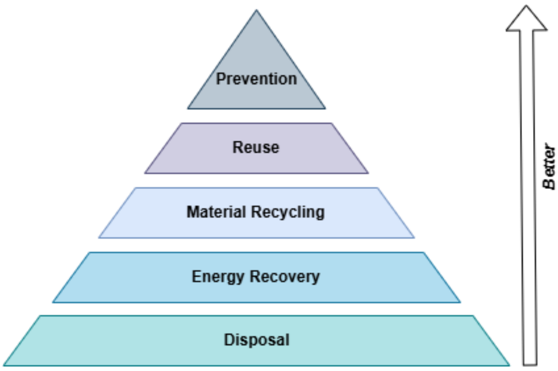

Figure 3.2: *Waste hierarchy as described in the Environmental Code (15 chap. 10§)*

The Waste Regulation is an implementing regulation with a singular focus on waste and waste management (SFS 2011:927). It specifies *how* the principles of the Environmental Code are to be implemented. It also contains detailed rules for the practical management of waste along with clear definitions for waste types and other associated terminology. This regulation is harmonised with the European WFD ensuring that the rules and definitions stay the same so as to make it easier for interpreters of the regulations.

In both the Environmental Code and the Waste Regulation, two provisions are of particular importance for this study:

- Municipal waste responsibility
- Extended Producer Responsibility (EPR)

These provisions are largely responsible for the shape of the waste management system and delegates the legal chain of custody for who is responsible for *what, when* and *where.*

3.2.1 Municipal Waste Responsibility

To manage packaging waste, Sweden has introduced Municipal waste responsibility, which in practice means that “each municipality is responsible for the collection, transportation and recycling or disposal of municipal waste in accordance with Chapter 15, 3§ and 20§, of the Environmental Code" (SFS 1998:808). Municipal waste is defined as follows:

> waste from households and waste from other sources that is similar in nature and composition to waste from households excluding waste from: production; agriculture and forestry; fishing; septic tanks, sewerage networks and wastewater treatment; construction and demolition; End-of-Life vehicles" (SFS 1998:808, 15 chap. 3§).

In summary: municipalities are responsible for collection and transport of municipal waste from households and co-localised businesses and has been the responsible actor since January 2024 (SFS 2011:927, 3 chap. 4§). Co-localised businesses are businesses which share waste collection facilities with households, for instance a hair dresser on the bottom floor of an apartment building.

The collection and transport responsibility comes with an operational and administrative cost of which the producers, through so called producer responsibility organisations (PRO’s), must reimburse municipalities (SEPA, 2024a). However, they must inly cover the cost of collecting the separately sorted packaging waste, not residual nor food waste and the fee is determined by SEPA. PRO’s are authorised by SEPA and are defined as "a legal person that prevents or manages waste from producers’ products" (SFS 1998:808, 15 chap. 9§). Currently only two PRO’s are authorised in Sweden: Tailor-Made Responsibility (TMR) and Producer Responsibility of the Industry (shortened NPA based on their Swedish acronym) (The Swedish Environmental Protection Agency, 2023).

In Gothenburg, it is the responsibility of KOV, to collect and transport the waste regardless of waste collection type (see figure 4.2) to the correct destination. How the waste management is performed is of high importance due to the influence of contamination on the output quality of the recycled materials (SOU 2024:67). KOV must take great care to run a high quality operation to ensure as much material as possible can be recycled and subsequently lower the reject amount which subsequently has to be incinerated. An aspect which will be explained further in chapter 4.

3.2.2 Extended Producer Responsibility (EPR) for packaging waste

In 1994, Sweden adopted the concept of producer responsibility for newspapers and packaging (Swedish Waste Association, 2022b). This meant that producers were responsible for the collection and recycling of said product categories and together they constructed a system which as of 2024 covers about 5 800 recycling stations and all of Sweden. The aim was to raise the sorting and collection rate through increased availability and thus hopefully transform them into new products.

In 2023, the regulation on EPR entered into force (SFS 2022:1274). This regulation aimed to further enable sorting at source and thus make the waste management system more efficient (The Swedish Environmental Protection Agency, 2023). The regulation was seen as an addendum to the European directive 94/62/EC which earlier this year was replaced by PPWR. In article 3 of PPWR, packaging is defined as follows:

> An item, irrespective of the materials from which it is made, that is intended to be used by an economic operator for the containment, protection, handling, delivery or presentation of products to another economic operator or to an end user, and that can be differentiated by packaging format based on its function, material and design (Regulation 2025/40/EC).

Packaging can be divided into five types as defined further in article 3 of PPWR and compiled in table 3.1 (Regulation 2025/40/EC). (The § noted behind each definition regards the paragraph in question under article 3).

What the new EPR regulation entailed was that stakeholders like municipalities and producers received new roles and responsibilities, for example: all municipalities are obliged to introduce kerb-side collection of packaging waste for all types of households by 2027 (The Swedish Environmental Protection Agency, 2023). In addition, all producers must be affiliated with an authorised PRO before beginning operations and placing packaging on the market.

This legislation also includes an obligation for all producers to report the amount of packaging they place on the Swedish market and how the collected packaging waste is handled. In 2023, producers placed 265 762 tonnes of plastic packaging (excluding plastic deposit bottles) on the Swedish market of which 153 961 tonnes were collected (Landerdahl et al., 2024, p.18). However, an important note is the fact that the amount probably is an underestimation due to the presence of free riders or distance purchases with a sales point outside of EU (Landerdahl et al., 2024). Free riders are producers that avoids taking producer responsibility or are not affiliated with any PRO. New EPR rules requiring PRO affiliation should hopefully minimise this issue (The Swedish Environmental Protection Agency, 2023).

Type	**Definition**	**Example**
Sales	Packaging conceived so as to constitute a sales unit consisting of products and packaging to the end user at the point of sale (5§)	A bottle containing soda
Group	Packaging conceived so as to constitute a grouping of a certain number of sales units at the point of sale, irrespective of whether that grouping of sales units is sold as such to the end user or whether it serves as a means to facilitate the restocking of shelves at the point of sale or to create a stock-keeping or distribution unit, and which can be removed from the product without affecting its characteristics (6§)	Wrapping surrounding a six-pack of soda
Transport	Packaging conceived so as to facilitate the handling and transport of one or more sales units or a grouping of sales units, in order to prevent damage to the product from handling and transport, but which excludes road, rail, ship and air containers (7§)	A box containing multiple six-packs of soda
Service	An item that is designed and intended to be filled at the point of sale in order to dispense the product (1§)	A mug to be filled with soda at a dispenser
E-commerce	Transport packaging used to deliver products in the context of sale online or through other means of distance sales to the end user (5§)	A padded envelope containing a soda purchased online

Table 3.1: *Definition and examples of the five different packaging types as described in article 3 in PPWR (Regulation 2025/40/EC)*

4

Waste Management in Gothenburg

Below follows information regarding the waste management of Gothenburg which is necessary for understanding the report. This includes the structure of the Swedish government and public authorities as well as the role of the department of Sustainable Waste and Water (KOV) within it.

4.1 The Department of Sustainable Waste and Water in the City of Gothenburg

Gothenburg Municipality is the second-largest municipality in Sweden according to population, with approximately 290 000 households. Its organisation follows a hierarchical structure, see figure 4.1, with the Municipal Council as the highest governing body (Statistics Sweden, 2023; The City of Gothenburg, n.d.-d). The Council is elected by the inhabitants of Gothenburg which in turn, appoints the Municipal Board (SKR, 2024a). Together, they govern the municipality, which in practice involves delegating responsibilities and setting objectives for relevant subdivisions within the organisation. These subdivisions can be broadly categorised into four different branches, as illustrated in figure 4.1. One of the branches is the Departments (sv. "Förvaltningar och Nämnder") whereof one is KOV.

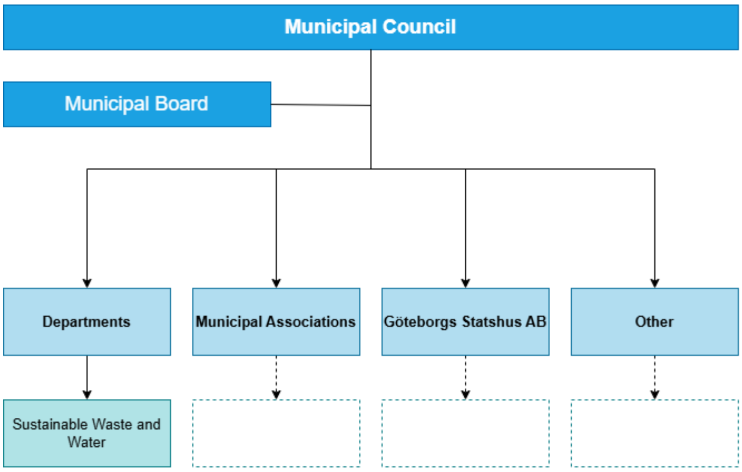

Figure 4.1: *Organisational structure of Gothenburg Municipality*

As a department, KOV is tasked with ensuring the supply of clean water, collection and treatment of sewage water, as well as the waste management of MSW (The City of Gothenburg, n.d.-e). MSW is comprised of all types of solid waste which people discard of anywhere within the city, excluding waste from businesses. Since all 290 000 households generates waste daily, this task is no small feat. Waste being defined as "any substance or object which the holder discards or intends or is required to discard" by the EU (Directive 2008/98/EC). KOV and its operations are mainly funded by costumer fees with some minor missions being tax-funded or funded by producer responsibility fees (see section 3.2.2). A part of KOV's mission is to help Gothenburg Municipality reach their climate goals and one of these are about lowering the amount of generated waste, as well as moving the nonetheless generated waste up the steps of the waste hierarchy (see figure 3.2) (The Gothenburg Region, 2021).

As a subdivision of the local level of Swedish governance, KOV alongside the municipality are as stated, subject to laws and regulations dictated by the Swedish government and the EU. One of those laws states that each municipality shall have a program for waste management, a responsibility given to KOV by the Municipal Council and explained further in section 4.1.1. In addition to this law there is the Waste Regulation (sv. Avfallsförordningen) which deals with the topic of waste and its management as well as chapter 15 in the Swedish Environmental Code (SFS 2011:927; SFS 1998:808), all of which have been explained more thoroughly in chapter 3. One of the articles in the Waste Regulation stipulates that no combustible nor food waste should be landfilled (SFS 2011:927, 3 chap.). This regulation is largely responsible for the design and structure of waste management systems in Sweden.

4.1.1 The Waste Program

Gothenburg and surrounding municipalities have together formulated a Waste Program (sv. Avfallsplanen) with the aim of preventing unnecessary waste and to develop the management of waste nevertheless generated (The Gothenburg Region, 2021). The Waste Program is a statutory guidance document decided by the Municipal council where *statutory* refers to the fact that there legally has to be a planning document for waste management according to the Environmental Code (SFS 1998:808, 15 chap. §41). The code states that a Waste Program must contain information on for example measures to reduce the quantity of waste generation in the municipality. The term *guidance document* means that whatever is written in the program is a goal to strive for but no legal repercussions will be administered if the goals are not met. In the program, one goal is of special significance to this study:

> The plastic waste from households shall decrease by 50% per citizen (The Gothenburg Region, 2021)

Despite the fact that the sentence uses the definition "plastic waste", only plastic *packaging* waste is tracked. The progress towards achieving the goal is measured continuously by summing all plastic packaging waste which is either source sorted or present in the residual waste stream, and dividing by population. The goal is based on the reference year of 2019 and are set to be achieved in 2030 (The Gothenburg Region, 2021). The reference value for 2019 was 33.3 kg/cap, meaning that for the goal to be achieved, the value in 2030 must be equal to or less than 16.65 kg/cap.

4.2 Waste Management

The type of management and treatment used for waste are determined by its classification and composition. Residual waste are directed to a waste incineration facility located in Sävenäs owned by Renova AB, of which Gothenburg Municipality is a majority stakeholder, for WtE generation. Packaging materials, on the other hand, should be delivered to one of two authorised PRO's for material recycling, ensuring that no packaging waste enters the residual waste stream and vice versa. However, in practice, significant amounts of packaging waste are found in the residual waste stream, while some non-packaging materials are inadvertently sent to PRO's. Which waste belongs in each fraction is marked via both images and text as defined in the Nordic pictographic system (see section 3.1.2.3).

As already mentioned, inhabitants of Gothenburg generated approximately 33.3 kg plastic packaging waste per capita in 2019. This is substantially higher than the Swedish average of 26.2 kg/capita based on data of plastic packaging placed on the Swedish market in 2022 but slightly lower than the EU average of 36.1 kg/capita (Landerdahl et al., 2024; Eurostat, 2024). Gothenburg municipality therefore has to manage more waste than other municipalities not only due to size difference.

The information provided in the following subsections can also be considered background information for the systems mapping performed in section 6.1.1, a step towards answering RQ1.

4.2.1 Waste Collection

As stated above, only waste originating from households and co-localised businesses falls under municipal responsibility. According to an employee at KOV, there are currently four main collection methods for the disposal of packaging waste: recycling centres, recycling stations, residual waste bins, and kerbside collection (for images, see figure 4.2) (E. Hilmersson, personal communication, January 21, 2025). There is a very small fraction of packaging in the food waste but as it is less than 1% it is excluded from the analysis (Ljungkvist Nordin et al., 2019, p.72). The collection activities are based on the concept of source separation where people sort their waste *before* it enters the waste management system rather than having a facility that sorts the waste after it has been collected (Swedish Waste Association, 2023). Source sorting has been used in Sweden since the 1980s and is the foundation of Swedish waste management (NSR, n.d.).

Recycling centres are large facilities where households enter (usually by car) and discards waste not covered by EPR, hazardous waste, and bulky waste that cannot fit in the smaller recycling stations (Sopor.nu, 2024). Through any of the 11 centres in Gothenburg, visitors sort the waste into larger fractions like wood, plastics, gardening waste and hazardous waste and there is personnel present to help whenever necessary (The City of Gothenburg, n.d.-a). Recycling stations are as mentioned smaller than recycling centres and only manage packaging waste, newspapers and small batteries, all of which are covered by EPR (Sopor.nu, 2024). In Gothenburg there are 310 recycling stations (The City of Gothenburg, n.d.-b). Of these, KOV estimates that 20–40 will likely close in the coming year(s) due to acute traffic issues, dumping, or general health and safety concerns for workers (E. Eliasson, personal communication, January 24, 2025). A few are also made redundant by the construction of recycling rooms in the vicinity and as kerb-side collection for villas roll-out, more are expected to close due to lower demand.

Kerb-side collection is the name for waste sorted at or near residential buildings, usually in recycling rooms in basements of apartment complexes or small outdoor houses nearby. Kerb-side collection of packaging is presently only available for apartment buildings but will be expanded to villas with initial roll-out in spring 2025 and full scale roll out by 2027 (SFS 2022:1274, 6 chap. §4). Through kerb-side collection, all households discards their residual waste and as of 2027 their packaging waste as well. This will entail a change for villas which will transition from from two regular sized bins, one for residual and one for food waste, to three slightly larger bins with two compartments in each. Each compartment handles one of the following categories: residual waste, food waste, plastic packaging, paper packaging, metal packaging and glass packaging. Anything bulky can still be thrown at a nearby recycling station or, if the waste does not apply to any of those categories, at a recycling centre.

Figure 4.2: *Collection activities, starting top left: Recycling centre, kerb-side collection (apartments), recycling station, kerb-side collection (villas) (The City of Gothenburg, 2025c)*

Regardless of preferences, source sorted packaging waste which enters the waste management system gets transported to one of two re-sorting facilities managed by external subcontractors. Re-sorting is the process where the plastic packaging waste is tipped out, compressed and re-loaded into larger transport vehicles and in theory thus returned to the producers via their affiliated PRO. TMR and NPA collects 15.5% and 84.5% respectively and the plastic is sent for advanced sorting (SEPA, 2024b). Afterwards, different private actors purchase the sorted fractions and recycles them for different purposes. Unsold fractions and sorting reject (~30% of input) is sent to incineration according to Swedish Plastic Recycling (R. Jansson, personal communication, March 19, 2025).

All of the aforementioned collection methods for plastic packaging waste are based on intentional, source-separated disposal. Ideally, plastic packaging should be discarded exclusively through these designated pathways. In practice, however, a significant portion of plastic packaging is instead disposed of via the residual waste stream (Edo et al., 2024). This misdirection can be attributed to a variety of factors, including—but not limited to—uncertainty or confusion regarding the appropriate sorting category or the material composition of the packaging, contamination with food residues leading to unpleasant odours during storage, limited access to or space for source-sorting infrastructure, misconceptions that the packaging will ultimately be incinerated regardless of sorting, and a general lack of motivation to comply with sorting guidelines (Mielinger and Weinrich, 2024; Mosslind, 2022). Irrespective of the underlying cause, the outcome remains consistent: residual waste is incinerated for energy recovery, a process carried out in Gothenburg at Renova AB's WtE facility in Sävenäs.

4.2.2 Waste incineration

The means of disposing of waste through incineration had been used in Sweden since at least 1948 when the first district heating facility was constructed in Karlstad (Bjarnehag, n.d.). If the process generates power, the waste serves as a substitute for another fuel material (e.g. oil and coal), and the process achieves high enough energy efficiency it is considered recycling according to Swedish law (SFS 2011:927, Appendix 1 R1; SFS 1998:808, 15 chap. 6§).

Regarding waste incineration in Gothenburg, the Sävenäs WtE facility was established in 1972, and in 1998, Renova AB was founded, assuming responsibility for waste incineration on behalf of its 10 municipal owners (Renova AB, n.d.). This development marked the inception of Gothenburg's modern waste management system, which today includes four incineration furnaces, along with an additional unit for hazardous waste, collectively capable of processing up to 550 000 tonnes of waste per year (Bjarnehag, n.d.; Mark och Miljödomstolen mål nr M 3543-04 dom 2005-06-28; Renova AB, n.d.). Sävenäs alongside all other WtE facilities in Sweden are responsible for about 7% of Sweden's total greenhouse gas emissions of which 90% comes from the incineration of fossil plastics (SOU 2024:67, p.343). These emissions represent a significant financial burden for each facility, as Sweden, Denmark, and

Lithuania are currently the only countries that include waste incineration in the EU Emissions Trading Scheme (ETS). For Renova AB, this results in an annual cost of approximately 125 million SEK, a figure expected to rise as the price of emission allowances continues to increase (Hörnell, 2022; Påsse, 2024). Negotiations are currently ongoing whether to include all European incineration plants in EU ETS 2 with an inclusion from 2028 and onwards (Hörnell, 2022).

The waste management operations of Sävenäs begins with reception of waste into their facility where it is poured almost directly into their grate furnaces (Renova AB, 2020). They incinerate approximately 10 000 tonnes of waste every week and the generated heat provides 5% of the electricity use in Gothenburg and district heating to about one third of Gothenburg residents. The output is generated by combustion which after initiation, burns of its own accord. The amount of heat a WtE process can recover depends on its composition. Due to this, the range of heating value is wide but appears to range between 10-24 MJ/kg MSW (Themelis and Mussche, 2014; Ivanovski et al., 2023). Plastic waste has an average heating value of 35.7 MJ/kg and the main factor which lowers the heating value of MSW is the fraction of organic waste (Themelis and Mussche, 2014).

The heat and power contributions of Sävenäs are an essential part of Gothenburg's heat and power generation, but it is associated with two significant drawbacks: generating emissions and destroying future resources. Waste incineration of MSW has been determined to produce a variety of compounds relevant for the climate, mainly CO_2, N_2O, NO_x, NH_3 and organic C, which exits the facilities through the flue gas (Johnke, 2003). Sävenäs cleans and filters its flue gas in many different processes which they claim results in mainly CO_2 being released into the environment (Renova AB, 2020). On their website, they claim that one kilo of waste results in about 1 kg CO_2 emissions if using the present waste composition. However, by sorting and removing 1 kg of fossil plastics from the waste it saves about 2.7 kg of CO_2 emissions (Vanderreydt et al., 2021). The previously mentioned compounds released into the environment all contribute to global warming and all except organic C is counted towards their total CO_2 emissions which by extension creates a higher cost through the EU ETS.

The use of waste incineration remains a topic of debate, with perspectives varying significantly between countries. In Sweden, public and political attitudes toward WtE generation are generally positive, whereas in other nations, opposition is more pronounced. For instance, in the United Kingdom, a political movement advocates for restricting waste incineration and implementing stricter environmental standards. However, according to an article from the Energy from Waste Network, "restricting Energy-from-Waste capacity will not in itself drive reductions in material use, nor increases in reuse and recycling" (Paul Winter, 2025).

Sweden's reliance on WtE has also led to increased waste imports to sustain energy production. In 2009, Renova AB acknowledged in a newspaper interview with *Expressen* that it had begun importing and incinerating waste from Norway due to a

20% decline in local waste volumes, attributed to reduced consumption during a period of economic hardship (Elfström, 2009). By 2018, waste imports had continued to rise as domestic waste generation declined. Said year, Sweden imported approximately 3 030 000 tonnes of waste, the majority of which was allocated for energy recovery through WtE facilities (SEPA, 2020). The primary exporting countries were Norway and the UK, with a smaller fraction originating from the Netherlands.

The import of waste plays a crucial role in maintaining stable heat and power production in Sweden. Additionally, from an environmental perspective, utilising waste for energy recovery is often considered a more sustainable alternative to landfill, which would otherwise be the disposal method in the waste-exporting countries (P4 Gothenburg, 2011). Public opinion about waste import for incineration remains generally negative in spite of the aforementioned reasons as determined by a study performed by KOV (Sahlin et al., 2013).

The import of waste plays a crucial role in maintaining stable heat and power production in Sweden. Additionally, some sources frame energy recovery from waste as a more sustainable alternative to landfill, particularly when the exported waste would otherwise be landfilled in the country of origin (P4 Gothenburg, 2011). However, this perspective can be problematic, as it often overlooks the broader environmental implications of incineration, such as greenhouse gas emissions etc., and may serve to justify continued waste exports rather than incentivising upstream waste reduction or improved recycling infrastructure in the exporting countries (Zero Waste Europe, 2019).

Figure 4.3: Renova AB's WtE plant in Sävenäs

4.2.3 Alternative Approaches

In recent years, a few municipalities have opted for constructing so called materials recovery facilities (MRF's) in order to lower the emissions and recycle more waste. This method is already being used in Europe with the UK being the largest user with over 100 facilities in operation as of 2023 (Matthews, 2023). Other countries such as Norway and the Netherlands uses MRF's as a way to complement existing source sorting systems (Maile, 2019; Thoden van Velzen et al., 2021). Presently, with two MRF's up and running in Brista and Högdalen and one under construction in Gärstad, the latter option is true for Sweden as well (Sörab, 2024; Stockholm Vatten och Avfall, 2024; Tekniska verken, n.d.).

A MRF is a sorting facility built adjacent to a waste incineration facility where bags of residual waste are opened and sorted through different automated or mechanical processes (Thoden van Velzen et al., 2021). Which waste fractions are sorted depends on the capacity of each facility and economic considerations. Even if the facility has the capacity of sorting paper, is anyone willing to receive it and recycle it for a profitable enough margin? The MRF in Brista sorts plastics, metals and organic matter whilst the MRF in Gärstad (which is under construction) will be able to sort paper and cardboard as well (Sörab, 2024; Tekniska verken, n.d.). Important to note is that organic matter is only possible to sort when they are in specialised plastics bags (Sörab, 2024). Gothenburg, which uses paper bags, would not have the same opportunity.

“Sorted fractions from MRFs are generally considered to be of lower quality than source-sorted fractions, as they tend to be more contaminated, less pure, and may pose workplace hazards due to odours, mould, and other factors, according to Swedish Plastic Recycling (R. Jansson, personal communication, March 19, 2025). This could impact the quality of output which makes the sorted residual waste fractions less attractive for recycling companies. Additionally, the share of plastic being rejected is also higher than in the source sorted fraction.

An employee at KOV explained that Renova AB and all the stakeholder municipalities discussed constructing an MRF a few years ago, but the proposal was rejected due to uncertainties about whether the sorted waste would even be recyclable (B. von Bahr, personal communication, March 20, 2025). In addition, even though the MRF sorts out materials covered by EPR, municipalities presently have no legal rights for reimbursements from the producers (Udd and Ridfeldt, 2025). In most cases, municipalities instead has to pay a high fee to the sorting facilities to accept their sorted waste (B. von Bahr, personal communication, May 13, 2025). Calls from municipalities to the Swedish government advocates for an amendment of the current waste legislation reform to make MRF's profitable. The opinion piece written by executives at two municipalists states that, in order for Sweden to reach a fossil free WtE generation, construction of MRF's are necessary. This opinion is mirrored by the Swedish Waste Association who has conducted an intervention study to see how the WtE generation can reach net zero (Swedish Waste Association, 2021).

Lastly, article 48(4) in PPWR states that MS "may ensure that packaging waste that is not collected separately is sorted prior to disposal or energy recovery operations to remove packaging designed for recycling" (Regulation 2025/40/EC). Since the article is a *may* statement, the use of a MRF is not mandatory, but the inclusion of the article in the regulation shows that MRF's are an acceptable tool to use for increased sorting.

5

Methodology

The following chapter describes the methods used in order to achieve the aim of the study. The primary methods are material flow analysis (MFA), waste projections, and life cycle assessment (LCA). The inclusion of all three methods was in order to assess (1) how plastic packaging waste *generation* may vary based on for example impacts of legislation or local/national variations, and (2) how *emissions from incineration* may fluctuate depending on plastic packaging waste generation, as well as distribution within and design of the waste management the system.

The workflow and use of the different methods is visualised in figure 5.1 below. Starting with data collection and MFA, the first RQ can be answered. Then, said results are used to perform waste projections and answer RQ2 which later can be used in LCA calculations for RQ3. Sensitivity analysis (SA) was also integrated into the other methods which is why SA is not included in the figure.

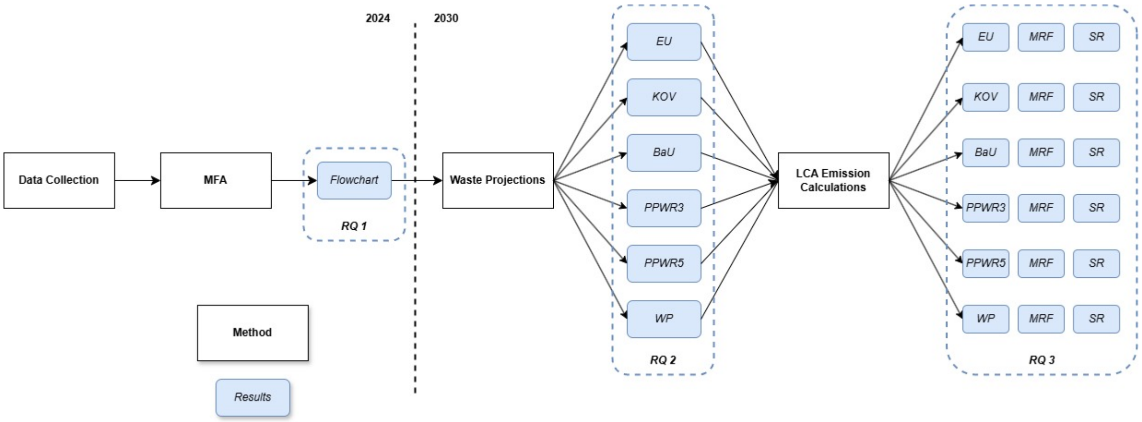

Figure 5.1: *Visualisations of the workflow going from left to right. Methods in white boxes and results to each RQ in blue.*

5.1 Data Collection

As seen i figure 5.1, the first step is data collection. Apart from the general search for data, two data collection methods were used, interviews and strategic literature search (SLS). A literature search was conducted early on to gain a theoretical understanding of the research context and system, with topics of interest including

MFA, waste projections and relevant laws and regulations, with a particular focus on PPWR. Interviews were used as a complementing data collection method.
A major requirement of this study and to be able to maintain a high degree of primary sources was the ability to speak and read Swedish. Public authorities in Sweden are not required to use any additional language to Swedish and the working language at KOV is Swedish (SFS 2009:600). This results in most public sector documentation being written in Swedish.

Both the data collection methods, sources and quality are expanded upon below.

5.1.1 Strategic Literature Search

The literature search was performed during March 2025 in the database ScienceDirect. It was done iteratively and with two main topics: "Material Flow Analysis" and "Legislation". The search result was limited to articles written in English as well as articles published during the last ten years. The full search strategy is included in appendix A and results were presented in chapter 2.

The database searches were complemented with a few key sources not discovered during the SLS, such as reports from SEPA, which are considered relevant to the subject area as well as this report.

5.1.2 Interviews

In order to properly map the waste management system and fully understand the impacts of PPWR, interviews with relevant stakeholders was necessary. Relevant stakeholders were integral both for the understanding of the current system and as a source of information. Due to the uncertain future, stakeholders with industry insights aided the interpretation of the effects of PPWR, provided arguments for inclusion or exclusion of projection parameters, and provided a more solid foundation onto which interpretations and assumptions had to be made. However, interviews were not the main method of data collection but rather acted as a supportive tool in the process.

The interviews was semi-structured where questions were prepared in advance but not strictly adhered to (Esaiasson et al., 2017). Opportunities for follow up questions presented during the interview was taken and revealed otherwise unnoticed information. This is a main advantage of the semi-structured interview method according to Esaiasson et al. (2017). For ease of transcribing and revisitation, a request regarding recording permission was made and in accordance with current GDPR regulations (Regulation 2016/679/EC). The transcribing process was of the type "Intelligent transcription" where an initial version was done using the dictation function of Microsoft Word, which was then manually adjusted in order to remove unnecessary text such as filler words and repetitions (Semantix, n.d.). This was done in order to get a concise text whilst still capturing and presenting what the interviewee said and meant. Lastly, in the case were either directs quotes or information gathered during the interviewees was used, the text section was be sent to the interviewee for approval before publishing.

The interviewees was contacted by the author and most were discovered organically as the study progressed. An important aspect to the study was to include informants from stakeholders which would be affected by PPWR, either as a producer or a public authority such as SEPA. In addition to SEPA, the two PRO's were interviewed both for their opinions as packaging experts but also as spokespersons for their affiliated producers. Additionally, the two largest grocery retailers ICA and Axfood was interviewed since a majority of household waste comes from the food sector (Esguerra et al., 2024). Lastly, a producer of paper packaging was interviewed to get their view on the possible shift from plastic to paper as well as their opinion on the plastic reduction potentials.

The interviewees and relevant information about them are compiled in table 5.1 below and the interviews took place during February and March 2025 and lasted approximately 30-45 minutes each.

Table 5.1: *Summary of interviewees*

Name	**Title**	**Org.**	**Type**
Åsa Stenmarck	Material flow expert	SEPA	Public Authority
Einar Ahlström	Material specialist	NPA	PRO
Christian Håkansson	Packaging & Sustainability Manager	TMR	PRO
Nadja Dahlgren	Packaging Developer	Axfood	Producer
Emelie Karlsson	Structural Designer & Innovation Specialist	DS Smith	Producer
Jessica Eliasson	Customer Engagement Manager	DS Smith	Producer
Karin Jawerth	Packaging Manager	ICA	Producer

More informal interviews with personnel at KOV was continuously conducted to understand the organisation and the data produced by KOV. Those are not compiled in the table above and the duration varied between 10 minutes to one hour.

5.1.3 Data sources

Different methods require different data types. LCA requires data on emissions whilst MFA requires data on amounts of materials being processed in the system. However, all methods benefit from as up to date and accurate data as possible.

One of the major data sources used in the MFA are sorting analyses (also referred to as compositional or picking analyses). KOV conducts sorting analyses every two years to assess the contents of residual waste and results from previous sorting analyses can be accessed from many years back. These studies follow standardised methodologies from the organisation Swedish Waste Management and involve sampling from various districts with homogenous housing types, either apartments or villas. The outcomes are presented both in absolute terms (kg/household/week) and as a share of total residual waste (%). Results of one such sorting analysis is included in appendix B.

When conducting waste projections, different future pathways needs to be analysed and they include on both trends, projections and estimated legislative impacts of, in this case, PPWR. Sector-specific trend analyses will need to be reviewed as this work extends over several years. This may include historical waste generation and/or the estimated demand for plastic packaging in the EU. Some of the material is readily available at KOV whilst an additional literature search will be needed for the material that does not. Secondary material can and will be used to verify the accuracy of data points or calculated values.

When reviewing legislative impacts, quantification will first and foremost be based on research conducted by the EU Commission or related institutions. If such data cannot be found, additional literature or information provided through interviews will be identified to ensure that the quantification of its effects is well founded.

5.1.4 Data Quality

The data required to conduct an MFA can come from primary, secondary, or tertiary sources. Depending on the purpose and data quality, secondary or tertiary sources may sometimes be preferable. Examples of data include total and source-separated flows of recyclables, overall residual waste streams, and sorting analyses of waste samples. If provided by KOV, these would constitute primary sources in this context. The study benefits from as up to date and as locally applicable data as possible(Brunner and Rechberger, 2004). Data from Gothenburg will be prioritised and if that does not exist, Swedish and then European data will be used instead.

The aim of data collection is to use as much primary data as possible with secondary and tertiary data being used to fill knowledge gaps. Nevertheless, if a data point could be considered of low impact, quality could be reduced in favour of effective time management as determined by the author.

The quality of sorting analysis data is a debated subject. Regardless, it is the only source of data on residual waste composition available as well as being used by KOV for their internal investigations and studies. Therefore it will be used in this thesis in spite of the inherent issues but the consequences will be discussed further in section 7.3.2.

5.2 Material Flow Analysis

Material flow analysis (MFA) according to Brunner and Rechberger is "a systematic assessment of the flows and stocks of materials defined in space and time" where materials could be "both substances or goods" (Brunner and Rechberger, 2004, p.3). The method is based on the law of conservation of mass which allows for the following formula to be true in each process within the system:

$$\sum_{i=1}^{m_i} x_{input,i} = \sum_{j=1}^{n_j} x_{output,j} + \Delta stock \tag{5.1}$$

This principle makes it possible to estimate potentially missing data based on the mass balance and works on both the process and system scale.

The steps necessary to follow when performing a MFA are the following (Brunner and Rechberger, 2004):

1. Problem definition
2. System definition
3. Determination of mass flows
4. Balancing of goods
5. Determination of concentrations
6. Balancing of substances
7. Illustration and interpretation

MFA is a versatile method as it can be carried out on both individual and groups of materials and at all organisational levels, from company value chains to global trade flows. Areas where MFA is widely used include e-waste (electronics), urban mining, and strategic planning of corporate value chains. In Brunner and Rechberger (2004), waste management and MFA has a dedicated subsection where the benefits of application is discussed and described (p.17).

In this study, MFA is used to quantify the current flows and stocks of packaging plastic waste in the municipality of Gothenburg and create a flowchart as shown in figure 5.2 (stocks will be shown to be negligible in the results and thus not addressed further). Problem and system definition are the same as for the entire study, where a good, plastic packaging, are to be followed through the waste management system of KOV. No substances or concentrations of specific polymers will be investigated in this thesis, making steps 5 and 6 redundant.

The flowchart depicted in figure 5.2 is constructed based on the systems mapping described in section 6.1.1. The flows (arrows) are named and all boxes represents an activity/process and mass balance as described in equation 5.1 is true for each individual box as well as the entire system. One flow not explicitly shown in figure 5.2, but still essential for the calculations, is the total residual waste flow, denoted as capital B. This flow includes all material types, not just plastics, and serves as the basis for estimating the share of plastic packaging in residual waste.

Figure 5.3 is a detailed view of how the use phase is structured according to different variables. The Use Phase consists of either apartments or villas and they can be presented either as number of people, number of households, or number of waste subscriptions. Multiple people can live in one household and multiple households can be included in one waste subscription (e.g. one waste subscription for a 30 household apartment complex). Number of households are the most common reference unit found in the data.

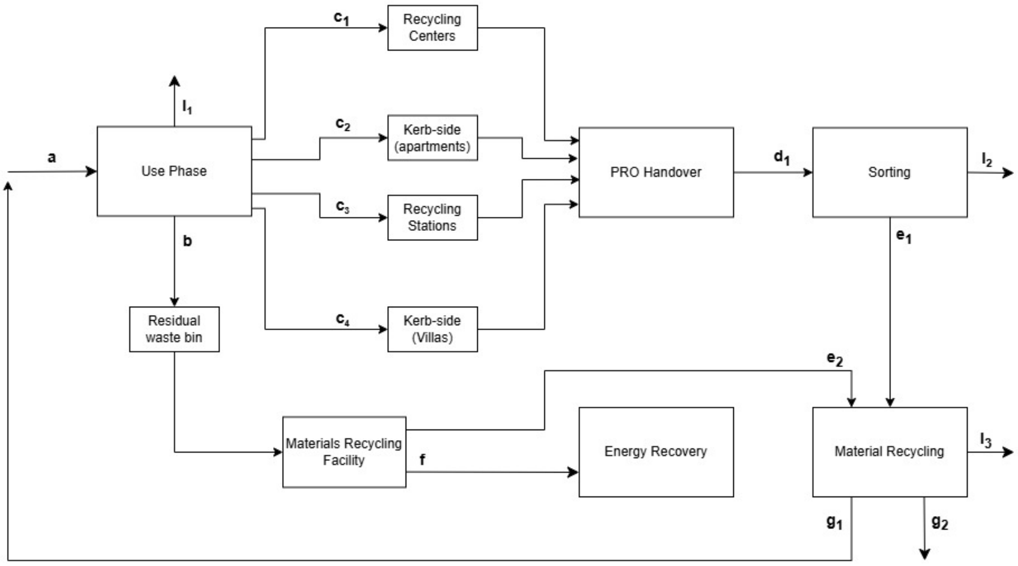

Figure 5.2: *Flowchart with named flows and processes, correlating to flowcharts created in the results. Used for equations and calculations described in the following sections.*

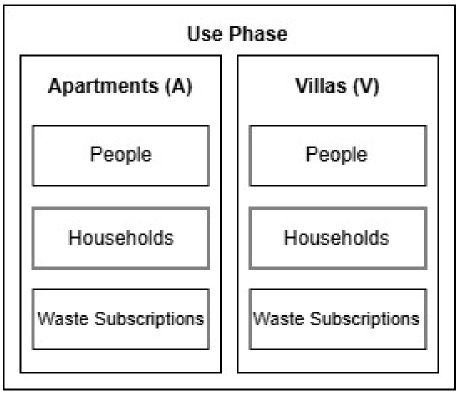

Figure 5.3: *A close-up of the Use Phase depicted in figure 5.2 including the different variables used for describing it*

5.2.1 Assumptions of the Study

In this study, a number of assumptions have been made. These are compiled in the list below in no particular order.

1. The measures published in PPWR as of May 2024 is assumed to be implemented in 2030.
2. Kerb-side collection from villas will result in less packaging waste in the recycling stations and the residual waste bin. The sum of those reductions will instead end up in the kerb-side collection bins, correctly sorted.
3. Shares of plastic packaging to be turned over to PRO's in Q4 are assumed to be true for the entire year.
4. Household behaviour patterns will not change over time.
5. Inhabitants of Malmö and Gothenburg exhibit the same sorting behaviour.
6. A MRF in Gothenburg will have the same sorting efficiency as the MRF in Brista, Stockholm (Sörab, 2024).
7. No losses (nor stock) from the Use Phase: l_1=0

5.2.2 Associated Calculations

Unsurprisingly, data on the amount of plastic packaging waste in each flow is not always easy to acquire. As a consequence, the principle of mass balance together with mentioned assumptions are used to determine the missing values. Each calculation are explained below with results to be found in chapter 6.

As revealed in figure 5.3, data regarding the use phase is often divided between apartments and villas with number of households as the reference unit. This is true for the following sections as well.

5.2.2.1 Data processing - sorting analyses

In order to find the value for b, plastic packaging present in the residual waste, a data processing step was necessary, primarily regarding sorting analyses as described in section 5.1.3 and in appendix B. A quality review of the data indicated that the most robust and consistent metric was the percentage-based format ([% of total residual waste]), which was therefore used for further calculations.

The 2024 sorting analysis included detailed breakdowns of specific plastic types, such as styrofoam and non-deposit beverage packaging (von Bahr, 2025). From this, the proportion of plastic packaging subject to EPR within each housing area was estimated. These shares were weighted by the number of households in each area (as outlined in equations 5.2 and 5.3) to determine the average residual waste composition of plastic packaging for both household types across Gothenburg municipality. As apartment dwellings make up the majority of housing in Gothenburg, an additional weighting step (eq 5.4) was used to estimate the city-wide average. This final weighted share was then multiplied by the total volume of residual waste collected in 2024, B, yielding an estimate of how much plastic packaging remains in unsorted municipal waste.

$$\frac{b_A}{B_A} = \frac{\sum_{i \in a} s_i * n_i}{a} \, [\%] \tag{5.2}$$

$$\frac{b_V}{B_V} = \frac{\sum_{i \in v} s_i * n_i}{v} \, [\%] \tag{5.3}$$

$$b = \frac{\frac{b_A}{B_A} * A + \frac{b_V}{B_V} * V}{A + V} * B \tag{5.4}$$

Where:

i = geographical area
a, v = number of Apartments/Villas within each geographical area i
A, V = Total amount of Apartments/Villas in Gothenburg
s = share of plastic type in residual waste [%]
n_i = number of households in area i

The same equations were used on historical results of sorting analyses and only minor adjustments had to made to facilitate previous reporting standards.

5.2.2.2 Kerb-side collection rollout

An operational change which will occur in Gothenburg is the new mandatory requirements for all municipalities to ensure kerb-side collection for all households in 2027 (SFS 2022:1274, 6 chap. 4§).

An assumption stated in section 5.2.1 was "Kerb-side collection from villas will result in less packaging waste in the recycling stations and the residual waste bin. The sum of those reductions will instead end up in the kerb-side collection bins, correctly sorted". The share of plastic packaging waste shifted from residual waste to kerb-side collection ($s_{b \to c_4}$) has been estimated both by the Swedish Waste Association and KOV. The share shifted from recycling stations ($s_{c_3 \to c_4}$) has not been investigated in the same manner and must instead by estimated using a reference case.

Malmö rolled out kerb-side collection for villas in 2019 and since Malmö is the third largest municipality in Sweden and has a similar household composition to Gothenburg, with more apartments than villas (84% vs. 83%), the cities were assumed to behave the same (City of Malmö, 2025). By further assuming that the relationship between total source sorted waste and waste sorted by villas into kerb-side collection bins are the same in Malmö and in Gothenburg, the equations below (eq. 5.5, 5.6, 5.7) can be used to find the amount of waste shifted from recycling stations to kerb-side.

$$c_4 = s_{b \to c_4} * b + s_{c_3 \to c_4} * c_3 \tag{5.5}$$

$$\frac{c_4}{c_{tot}} = \frac{c_4(malmö)}{c_{tot}(malmö)} \tag{5.6}$$

$$s_{c_3 \to c_4} * c_3 = \frac{c_4(malmö)}{c_{tot}(malmö)} * c_{tot} * (s_{b \to c_4} * b) \tag{5.7}$$

5.2.2.3 Collection rate

An important distinction is the difference between collection versus recycling rate of plastic packaging waste. The recycling rate (RR) is usually the topic of interest but as the system in focus in this study, Gothenburg and KOV only conducts collection not recycling, a conversion is necessary. With the flows described in figure 5.2, and the definition being somewhat ambiguous in PPWR (Regulation 2025/40/EC, art. 53), the recycling rate can be calculated in two ways:

1. Total input a divided by total recycling output g.
2. Total input a divided by total recycling input e.

These definitions can be extended to equation 5.8 and 5.9 below.

$$RR_1 = \frac{d}{a} * \frac{e}{d} * \frac{g}{e} \tag{5.8}$$

$$RR_2 = \frac{d}{a} * \frac{e}{d} \tag{5.9}$$

Further down in this chapter (see section 5.4), one of the parameters to be analysed with regards to changes in emissions is the achievement of a recycling rate of 55% for plastic packaging waste (Regulation 2025/40/EC, 52(1d)). This value, with the factor $\frac{e}{d}$ being known, can be used in equations 5.8 and 5.9 to determine the two collection rates ($\frac{d}{a}$) which has to be achieved in order to reach a RR of 55%.

5.2.2.4 Materials Recovery facility

Another calculation necessary to describe regards the construction of a MRF in Gothenburg with an equal sorting rate ($\frac{e_2}{b}$) as a MRF in Brista (Sörab, 2024). Through a combination of data publicly available on their website and email correspondence with the facility manager Stellan Höglund, equations 5.10 and 5.11 could be used in order to estimate a sorting rate ($\frac{e_2}{B}$) for a MRF in Gothenburg (personal communication, March 3, 2025).

$$\frac{e_2}{B}(gbg) = \frac{e_2}{B}(brista) \tag{5.10}$$

$$e_2 = \frac{e_2}{B}(gbg) * B \tag{5.11}$$

5.3 Waste Projections

In order to answer the second RQ, the method of waste projections was used. The constructed MFA of the waste management system in 2024 served as a baseline for projecting future plastic packaging waste flows in 2030 as can be seen in figure 5.2. For ease of comparison, a business as usual (BaU) projection was constructed based on the assumption that waste generation per capita remains constant, with population growth being the sole variable. This is a common method used for this type of study (Ng and Yang, 2023; Dyson and Chang, 2005; Razaviarani et al., 2025). As discovered in the literature review and presented in section 2.2.2, future waste streams depends on more parameters than population growth. The main parameters found in the literature was population growth, socio-economic status, GDP, operational conditions (design of waste management system), household behaviour, and consumption patterns (Razaviarani et al., 2025; Elshaboury et al., 2021).

As stated in section Delimitations (1.2.4) and Assumptions (5.2.1), behavioural changes has already been excluded from this study. Or more accurately, they are assumed to remain unchanged until 2030.

Regarding GDP and socio-economic status, research shows that GDP is positively correlated with socio-economic status, which in turn correlates with increased waste generation (Dyson and Chang, 2005). However, higher socio-economic status is also associated with greater participation in recycling efforts. These relationships are complex and interdependent and thus requires a dynamic model to fully account for them, something this study does not include. Therefore, both GDP and socio-economic status have been excluded as variables in this study.

Population growth was determined to be seen as a constant and all projections accounts for it. That leaves operational conditions and consumption patterns as the parameters that may influence the waste flows in 2030. Whilst Siew Ng and Yang only varied which component of the residual waste stream where recycled, this study conducts a broader sensitivity analysis as is described more in detail in the subsection below to construct the full scope of future developments.

In table 5.2 below, a complete list of future plastic packaging waste generation projection parameters can be found. Each parameter is denoted with a name which is used in resulting figures and a description of what each parameter is based upon. In column "Value", the equation for calculating the value for each specific inflow a are reported. How the values were calculated can be found in appendix C. The two measures regarding PPWR are separated using the number 3 and 5, indicating the related reduction of a.

Table 5.2: *Parameters for waste generation projections*

Name	Description	Value	Source
BaU	Consumption per capita in 2024 remains the same in 2030	$a(BaU) = \frac{a}{Gbg_{population}(2024)} * Gbg_{population}(2030)$	KOV
EU	Consumption corresponds to market prognosis of plastic packaging consumption in the EU	$a(EU) = a * 1.28$	IA of PPWR
KOV	Waste generation continue to follow the trends as determined by KOV	$a(KOV) = c_i * 1.173 + b * 0.801$	KOV, personal communication
PPWR3	Only a set of individual measures from PPWR has an effect	$a(PPWR3) = a(BaU) * 0.968$	PPWR
PPWR5	Gothenburg fulfils the targeted waste prevention of 5% as stated in PPWR	$a(PPWR5) = 0.02383 * Gbg_{population}(2030)$	PPWR, art. 43(1)
WP	Gothenburg fulfils the targeted waste prevention of 50% as described in the Waste Program	$a(WP) = 0.01665 * Gbg_{population}(2030)$	The Waste Program

The parameters were chosen in order to visualise the full scope of future waste generation possibilities. *EU* can be considered a worst case scenario based upon the possible future described in PPWR if no action is taken. In contrast, *WP* represents a best case scenario where the ambitious goal of 50% reduction of plastic packaging waste is achieved by KOV and the inhabitants of Gothenburg. The parameter *KOV* takes into account the trends in historical waste generation as determined internally for long term economic planning. Lastly, the effects of PPWR is divided into two possibilities, *PPWR3* (3% reduction of a) accounts for if individual measures goes into affect but the waste reduction targets of *PPWR5* is not met (see table 5.4). Instead, *PPWR5* (5% reduction of a, Regulation 2025/40/EC, art. 43(1)) which accounts for the reduction target being achieved through *PPWR3* and any additional necessary measures.

The possibility of achieving *PPWR5* has been questioned by the interviewees. Einar Ahlström, NPA, raised article 43(1) (the full article as described in section 3.1.2) as the hardest article in PPWR to achieve (personal communication, February 24, 2025). He claimed that " historically, packaging volumes have never gone down except in severe recessions" and since 2018, the amounts had only increased more.

Other interviewees were asked about article 43 as a consequence of Ahlström's statement and they all agreed. Christian Håkansson, TMR, added that to reach such an ambitious target, a massive behavioural change must occur first (personal communication, February 26, 2025). He did add however that the other measures presented in PPWR may help the progress towards the reduction target.

5.4 LCA Emission Calculations

In order to answer the third RQ, a method for estimating the emissions was necessary. Based on the literature there emerged two main methods: (1) a full LCA study which includes the complete life cycle of both production, use, and end-of-life treatments (Vanderreydt et al., 2021), (2) single focus on the end-of-life treatment options (Vlasopoulos et al., 2023).

In order to estimate the full impact of reduced plastic in the residual waste the first option is preferable. However, considering the geographical and organisational boundaries of this study, only the emissions from waste transport and incineration occurs within them. Option 2 was therefore chosen as the quantitive method of choice, but a qualitative discussion regarding other indirect emissions and impacts will still be conducted. Another argument in favour of option 2 is the fact that Renova AB only pays for emission allowances covering the direct fossil emissions, not accounting for the life cycle nor regardless of the fact that it generates heat and power as a useful bi-product (B. von Bahr, personal communication, April 3, 2025). This aligns with the potential use of the results as a basis for estimating costs of future EU ETS emission allowances.

Vlasopoulos et. al. performs a comparative analysis of the emissions from two different waste treatment options, landfill and incineration, where transport to the facilities were accounted for (2023). Another article instead focused on comparing two different waste incineration facilities, one in Denmark and one in Italy, using a "gate to chimney" LCA (Turconi et al., n.d.). Both articles used the impact category of Global Warming Potential (GWP) as the category of comparison with the unit [ton CO_2-eq/tonne plastic waste]. Since waste transport lorry's in Gothenburg are exclusively propelled using either HVO, biogas or electricity, emissions from transports were determined to be negligible and excluded from the calculations. Additionally, Vanderreydt stated that indirect emissions from "necessary auxiliaries" (e.g. heating or air conditioning of the facility) were determined to be "almost negligible compared to the direct emissions and are estimated at 0.05–0.10 tonnes of CO_2-eq/tonne of plastic waste" (2021, p.24). These auxiliaries were therefore also excluded from the study.

The direct fossil emissions were calculated was based on Vanderreydt et al. (2021), where emissions from incineration where calculated separately from the other steps in the plastic life cycle. The emission factor used by Vanderreydt et al. (2021) was 2.70 ton CO_2-eq/tonne which is consistent with emission factors determined by Edo et al. (2024) which analysed factors for different plastic types, ranging from

2.2 to 2.8 kg CO_2-eq/kg (p.36). The emission factor was multiplied with the total amount of plastic waste entering the WtE facility in Sävenäs (f) to determine total direct CO_2 emissions.

How f will vary depends on the total plastic packaging waste generation a (see table 5.2), and what share of a enters the WtE facility (f). The waste distribution within the system have been determined to be varied in three ways: (1) Same collection rate as in 2024, (2) a MRF is constructed and sorts the waste after it has entered the residual waste bin, or (3) the targeted recycling rate of 55% in PPWR is achieved.

In table 5.3 below, a complete list of future emission projection parameters can be found. Each parameter is denoted with a name which is used in resulting figures and a description of what each parameter is based upon. The name "NoChange" is only used in this table and the already established names in table 5.2 will instead be used. In column "Value", the equation for calculating the value for each specific inflow f are reported. The values for the two parameters *MRF* and *CR1* has been calculated as described in section 5.2.2.3 and 5.2.2.4.

Table 5.3: *Parameters for emissions projections*

Name	**Description**	**Value**	**Source**
NoChange	The Collection rate of 2024 is true in 2030	$f(NoChange) = a(2030) * 0.71$	
MRF	KOV constructs a MRF	$f(MRF) = b(2030) * 0.554$	SÖRAB
CR1	The target of 55% plastic recycling rate (RR_1) in PPWR is fulfilled	$f(CR1) = b(2030) * 0.141$	PPWR, art. 52 (1)

It was decided to not combine parameters *MRF* and *SR* due to it not being economically feasible nor necessary to construct a MRF if the collection rate was above 80% and if a MRF was built then the recycling rate would double to 61%. That the collection rate would double is also why the recycling rate as calculated according to equation 5.9 (RR_2) is excluded. RR_2 results in a collection rate of 68%, which makes an additional projection, with approximately equivalent values, unnecessary.

5.5 Sensitivity Analysis

Any attempt at predicting the future involves assumptions and decisions with varying degrees of uncertainty. This results in a less and less exact prediction the further into the future one aims to project. To account for this and determine the full scope of the future variations, sensitivity analysis (SA) was chosen as the method of choice. Sensitivity analysis can be defined as a method to "assesses how variations in input parameters, model parameters or boundary conditions affect the model output" (Bennett et al., 2013)

As described briefly in the chapter introduction, an SA was conducted to assess (1) how plastic packaging waste generation may *vary* based on different factors, and (2) how emissions may *fluctuate* depending on the waste generation and distribution. The resulting parameters have already been presented and explained in table 5.2 and 5.3, all except *PPWR3*.

Apart from varying different parameters for the waste generation and WtE emissions, a more in depth SA was performed on the specific parameter named *PPWR3*. Said parameter represents a set of individual measures from PPWR, excluding the article covered by Parameter *PPWR5*. This distinction was made to assess the extent to which Gothenburg and KOV achieve reductions inherently, thereby determining whether additional, non-PPWR measures are required to meet the targets outlined in parameters *PPWR5* and *WP*.

The selection of articles in PPWR to analyse followed a two-step process: (1) identification of measures with potentially quantifiable effects on the system and (2) an attempt to quantify these effects. Measures that could not be quantified in step (2) were excluded, and for those where a value was derived, any uncertainties were accounted for by calculating an associated range of uncertainty. The articles included after step 2 was concluded are compiled in table 5.4 and the data and calculations used to determine the impact of each measure can be found in Appendix D. Important to note is that each "WG decrease" is meant as a reduction of the inflow a.

The resulting subset of measures is comprised of a number of articles which will affect the amount of waste generated into the system. In the first column, *Type*, the type of measure is noted. Ban essentially means that the packaging format in question is forbidden from entering the European market. Compostable means that the material in the packaging format must be compostable. DfR is short for Design for Recycling and means that the packaging format must follow the design requirements in question. Requirement is the last type and simply means that said measure is a requirement for each MS. DRS is short for "deposit and return system".

Table 5.4: *Individual articles included in the waste generation projection parameter PPWR3 described through type, affected packaging format as well as a longer explanation.*

Type	**Art.**	**Packaging Format**	**Explanation**
Compostable	9(1)	Sticky labels affixed to fruit and vegetables	Must be compatible with the standard for composting in industrially controlled conditions in bio-waste treatment facilities
Compostable	9(1)	Tea, coffee or other beverage bags intended for single use	A permeable tea, coffee or other beverage bag, or soft after-use system single-serve unit that contains tea, coffee or another beverage, and which is intended to be used and disposed of together with the product, must be compatible in line with sticky labels
Ban	25(1)	Single-use (SU) plastic grouped packaging	Single-use plastic packaging at the point of sale that groups products like bottles, cans, and packets to encourage multiple purchases, excluding packaging needed for handling
Ban	25(1)	Single-use (SU) plastic packaging for unprocessed fresh fruit and vegetables	Single-use plastic packaging for less than 1,5 kg pre-packed fresh fruit and vegetables.
Ban	25(1)	Very lightweight plastic carrier bags (VLWPB)	Plastic bags thinner than 15 micrometers, exceptions when the bag is required for hygiene reasons or provided as sales packaging for loose food when this helps to prevent food wastage.
DfR	10(1)	"Unneccessary" packaging	The packaging placed on the market is designed so that its weight and volume is reduced to the minimum necessary to ensure its functionality, taking account of the shape and material from which the packaging is made.
DfR	24(1)	Grouped, transport, or e-commerce packaging	The maximum empty space ratio, of grouped packaging, transport packaging or e-commerce packaging shall ensure that, is 50 %
DfR	24(4)	Sales packaging	Empty space in sales packaging is reduced to the minimum necessary for ensuring the packaging functionality, including product protection.
Requirement	50(1)	DRS of beverage bottles	Ensure the separate collection of at least 90% per year of SU plastic beverage bottles with a capacity of up to three litres

6
Results

This chapter presents the results obtained throughout this study which were conducted as described in chapter 5. The information provided in chapter 3 and 4 is necessary to fully understand the information presented below.

The structure follows the hierarchical structure visualised in figure 5.1, starting with Plastic Flows in 2024, and building upon it with Waste Generation and WtE Emission Projections for 2030.

6.1 Plastic Flows in 2024

This section is dedicated to answering RQ 1: *What is the current flow of plastic packaging waste in Gothenburg and how is it managed?* In order to do so, MFA was used as described in section 5.2.

The first subsection hereafter uses the problem and system definition defined in chapter 1, information presented in chapter 4, and interview results, to map the waste management system in Gothenburg. The second subsection uses the mapping in combination with additional data to determine and balance the mass flows, resulting in an illustrated flowchart of the flow of plastic packaging waste in Gothenburg 2024.

6.1.1 Systems Mapping

A flowchart representing the waste collection operations for plastic packaging waste in Gothenburg was constructed in cooperation with employees at KOV, with results in figure 6.1 below. The map could be considered step 2 in the MFA procedure (see section 5.2).

As can be seen below, the map includes both system boundaries defined in the introduction, Gothenburg municipality and KOV jurisdiction. This is in order to include the Use Phase, a process not within the jurisdiction of KOV. The figure starts with an inflow of plastic packaging consumption entering Gothenburg municipality into the Use Phase. Households and co-localised businesses discard their plastic packaging waste which crosses the boundary of KOV jurisdiction into one of four collection activities (extending to five in 2027). A small fraction might exit the use phase through another path as would be the case of littering or disposal in public waste bins etc., both of which are not managed by KOV. Once the plastic packaging waste has entered the waste management system, KOV has full responsibility for ensuring the proper handling and transporting to the next actor in the chain of command described in section 3. KOV collects the waste and then relinquishes the source sorted fraction to the PRO's, which as soon as the handover is complete, KOV is no longer the legal responsible actor. Residual waste is transported to Sävenäs for WtE generation. This explains why material recycling is located outside the system boundaries whilst energy recovery is located within.

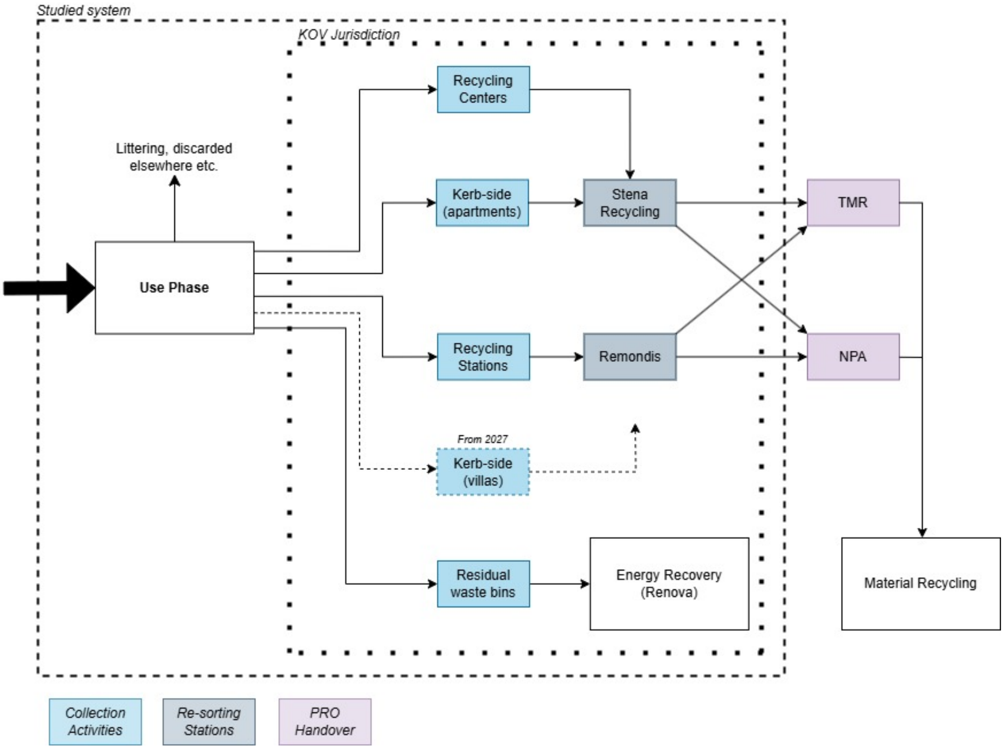

Figure 6.1: *Flowchart of the waste management system within the scope of this study*

6.1.2 MFA 2024

Based on the operations of KOV, the next step was to construct the MFA flowchart through step 3-7 as listed in section 5.2 (excluding step 5 and 6). The result of MFA can be found in figure 6.2.

Data on how much plastic packaging has been collected by KOV originates from two different sources:

1. Data on source sorted waste provided by subcontractors and compiled for annual reporting to SEPA (Avfall Web, 2025)
2. Sorting analyses on household waste ordered by KOV and performed by an external subcontractor (Edo et al., 2024)

The source sorted data could be used as is whilst the sorting analyses required further processing as described in section 5.2.2.1. Important to note is that the MFA does not contain any kerb-side collection for villas as it has not yet been rolled out.

Data from one sorting analysis of one geographical are shown in appendix B for reference. By using equations 5.2, 5.3 and 5.4 and results from sorting analysis, it was determined that residual waste from apartments consists of approximately 13.4% plastic packaging whilst the corresponding value for villas is 14.5%. The weighted sum resulting from eq. 5.4 is 11 553 tonnes. One could instead calculate the residual waste generation per person in each household type without affecting the results from eq. 5.4. On average, there are more people on average living in a villa (2.4 people/villa) compared to people living in apartments (1.7 people/apartment) (SCB, 2024). When accounted for, the residual waste generated by a person living in a villa is comprised of 6% plastic packaging waste whilst the residual waste from a person living in an apartment is comprised of 8% plastic packaging.

The calculated weight of plastic packaging in the residual waste together with data on source-sorted waste provided by KOV resulted in a total plastic packaging waste generation a of 16 217 tonnes whereof 4 664 tonnes enters the source sorting waste streams in 2024 (see fig 6.2). By using the relationship of 1 kg plastic waste equals 2.7 kg CO_2 after incineration, approximately 31 200 tonnes of CO_2 were emitted by the WtE facility in Sävenäs in 2024 (Vanderreydt et al., 2021).

The re-sorting facilities are obliged to turn over the packaging waste to PRO’s in a pre-defined share which differs between materials. The shares are determined by SEPA for each quarter and for each material (SEPA, 2024b). Shares of plastic packaging in Q4 were set to 15.5% for TMR and 84.5% for NPA and said numbers were assumed to be true for the entire year.

The resulting MFA showed no accumulation of stock anywhere in the system. This is reasonable as approximately 99% of the goods bought becomes waste within 6 months according to the UN Habitat (UN News, 2018). As the MFA covers a full year, even the non single-use packaging will have had ample time to be discarded. The total amount into the system is determined to be 16 217 tonnes of plastic packaging, or 26.6 kg/cap. This is slightly higher than the national average of 22.3 kg/cap (Landerdahl et al., 2024). By dividing the amount of plastic packaging waste collected through any of the three source sorting options by the total input, the collection rate for Gothenburg is calculated to be 28.8%

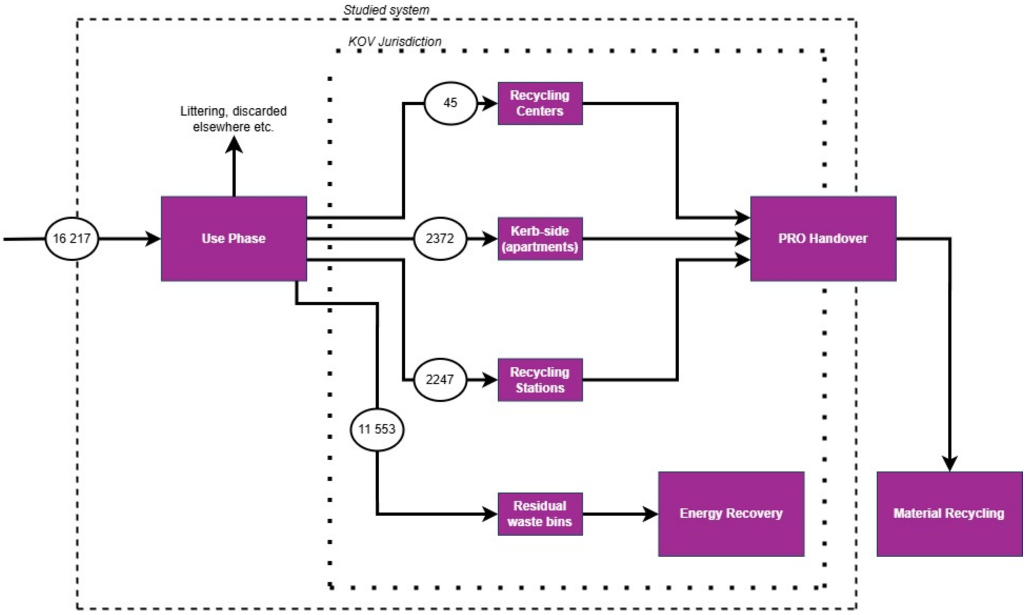

Figure 6.2: *MFA of plastic packaging waste in Gothenburg 2024 [tonnes]*

6.1.3 Predetermined Future Operational Changes

As previously mentioned and seen in figure 6.1, kerb-side collection of source sorted packaging waste for villas will be mandatory from 2027 and onwards (SFS 2022:1274, 6 chap. 4§). This operational change is assumed to alter the waste sorting behaviours of villas and cause a redistribution of plastic packaging waste in three of the waste flows described in figure 6.2. Through the equations described in section 5.2.2.2, said redistribution could be calculated.

It is estimated that kerb-side collection reduces the amount of residual waste by approximately 40% (Edo et al., 2024, p.46). However, based on trial studies done in Gothenburg, the effect could be significantly lower at 23% (Hilmersson, 2019). The first study is based on a larger sample size whilst the second is smaller but focused specifically on villas in Gothenburg. For the MFA, the lower value was chosen as it both gives a conservative estimate and is more specific to plastic packaging rather than all packaging materials. An additional argument for choosing the lower value is a corroborative result from a report by the organisation Swedish Waste Management, which found that the residual waste from villas decreases by 26% (Westin, 2020, p.5). Regardless, 23% decrease is significant reduction resulting from a single action. However, since villas only comprise 17% of the households in Gothenburg, the net decrease of the total residual waste stream, $s_{b \to c_4}$, is expected to be approximately 4%.

The amount of plastic packaging waste previously thrown in the recycling stations, which in 2030 would instead be thrown in the kerb-side collection bins, has unfortunately not been defined for villas by any actor. Therefore another city, in this instance Malmö, was used as a comparable case study with citizens behaving similarly regarding the collection rate of plastic packaging waste.

Equation 5.6 resulted in the flow denoted as c_4 accounting for approximately 24% of the total waste generated a, this includes both $s_{b \to c_4}$ and $s_{c_3 \to c_4}$ (eq. 5.5). Since $s_{b \to c_4}$ is already known, equation 5.7 can be used to find $s_{c_3 \to c_4}$. The results determined that 26% of the waste thrown into the recycling stations by villas will shift to the new kerb-side collection bin. The changes in waste distribution are visualised in figure 6.3 below.

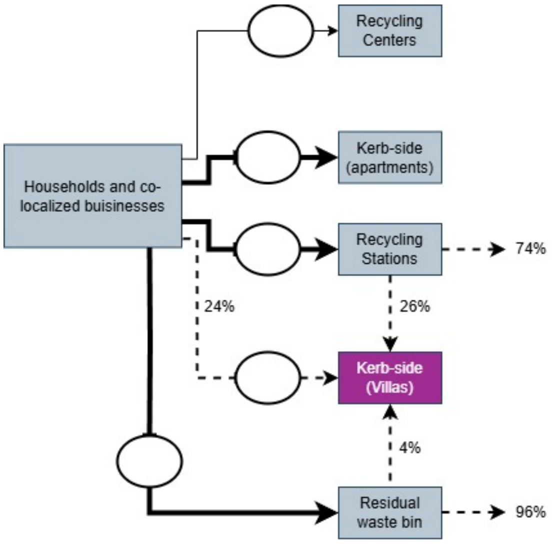

Figure 6.3: *Shares of waste previously thrown by villas into other waste collection activities which will, after full scale roll-out, be thrown into the kerb-side collection bin.*

6.2 Projections for 2030

In the following sections, projections about future developments in waste generation and direct fossil emissions will be presented in order to answer RQ 2 and 3. Each section focuses on a different area of the system and each focus will be presented for ease of understanding.

Each scenario will be adjusted for population growth as based on data from Statistics Sweden (SCB) and forecasts from Gothenburg municipality. Gothenburg is projected to grow approximately 4.4% between 2024 and 2030, increasing the population from 608 993 to 635 961 (The City of Gothenburg, 2025a; The City of Gothenburg, 2025b).

6.2.1 Future Waste Generation

Waste generation projections will be based in the parameters presented in table 5.2 in the section 5.3. Each parameter is associated with a waste reduction value as compared to the 2024 value of a.

6.2.1.1 Focus of Analysis

In figure 6.4 below, the relevant flow of this section is highlighted. When projecting the change in waste generation, it is the inflow of plastic packaging (a) into the Use Phase which is altered. The method used for this section is waste projections as described in section 5.3.

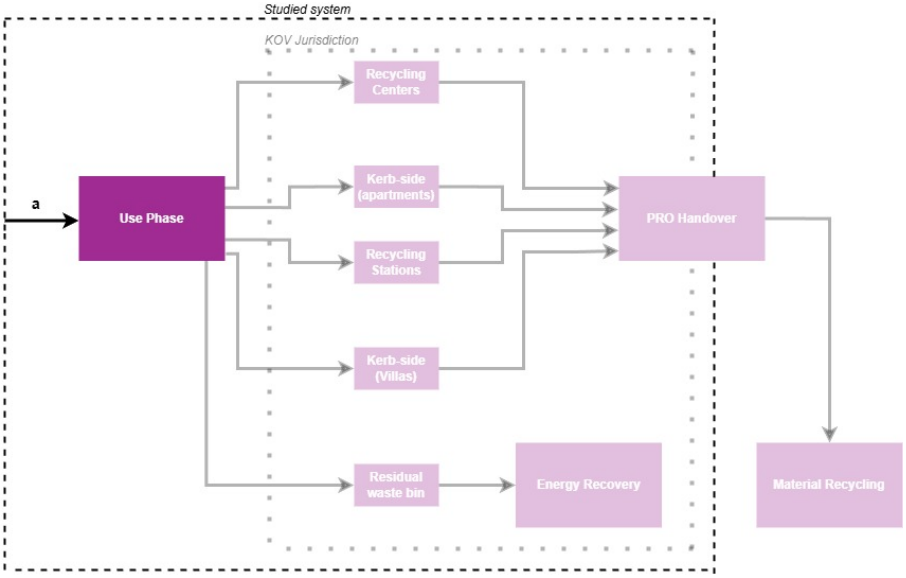

Figure 6.4: *Section focus: Total waste generation a. Only non-transparent parts are relevant.*

6.2.1.2 Calculations of Parameters - waste generation

The parameter referred to as *PPWR3* is further elaborated in section 5.5 and detailed in table 5.4. Each article listed therein corresponds to a specific expected reduction of the inflow a due to changes in either waste composition (e.g. switch from plastic to another material) or waste generation (e.g. ban on plastic products). The effect of each measure has been modelled relative to *BaU*, and is expressed as a projected percentage reduction in total waste generation a. An overview of these measures, including their most probable impact and estimated range of potential outcomes, is presented in figure 6.5. While certain measures, such as forcing certain packaging types to be compostable, will likely result in negligible effects (approaching 0% reduction), others, such as bans targeting SU grouped packaging for fruit and vegetables, are expected to lead to measurable decreases in waste generation regardless of best or worst case scenario. The cumulative effect of the *PPWR3* parameter was estimated by aggregating the most likely values of each individual measure, resulting in a projected total reduction of 3.08% relative to the *BaU* projection.

Although the *PPWR3* scenario could potentially be integrated with both the *EU* and *KoV* projections, it has been applied solely to *BaU* within this analysis in order to isolate and highlight its independent impact.

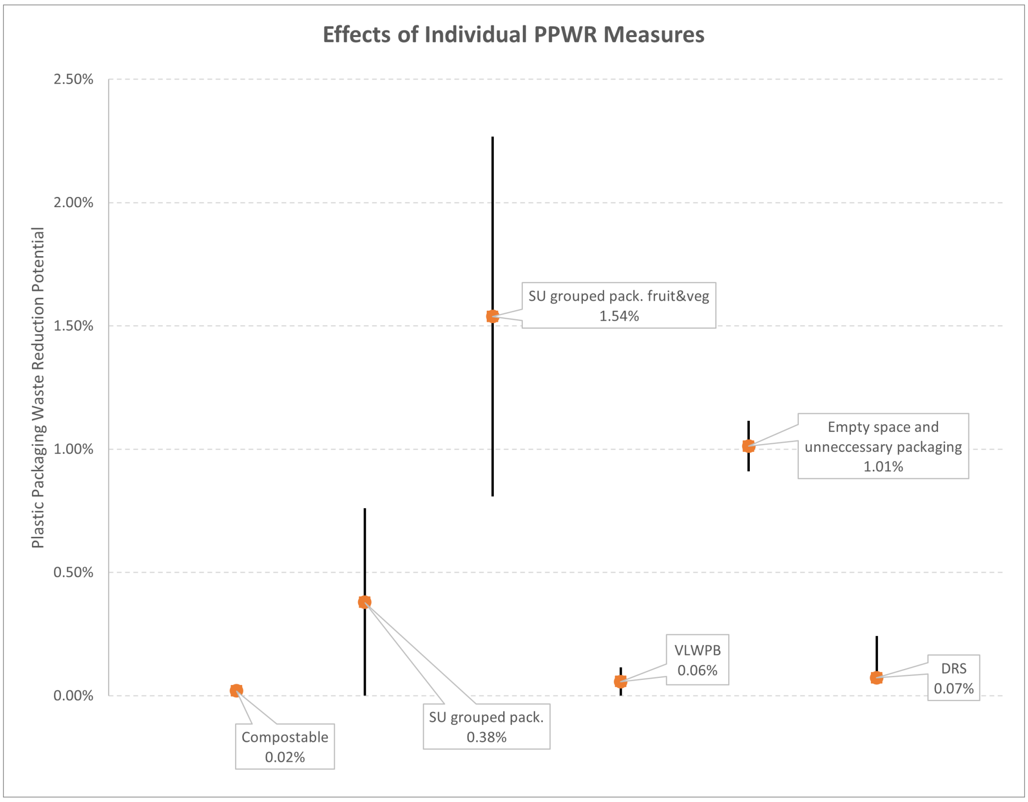

Figure 6.5: *Potential impact ranges for PPWR3 measures*

6.2.1.3 Projections

Once the change in waste generation was determined for the *PPWR3* projection, the next step was to compare the impacts between all parameters in table 5.2 with historical developments. Figure 6.6 shows the range of future projections compared to historial data. The historical data is calculated using the same method of processing sorting analyses results as described in section 5.2.2.1 applied on historical results, which together with old reports on source separated waste (both provided by KOV), revealed the historical amounts of plastic packaging waste in Gothenburg (källa).

The maximum waste generation shows an increase of plastic packaging waste per capita by +6 kg/cap (*EU*) whilst the minimum waste generation shows a reduction of -10 kg/cap (*WP*) as compared to 2024 levels. Apart from *EU*, all projections falls below *BaU*. This could indicate that the future waste generation may become lower than today.

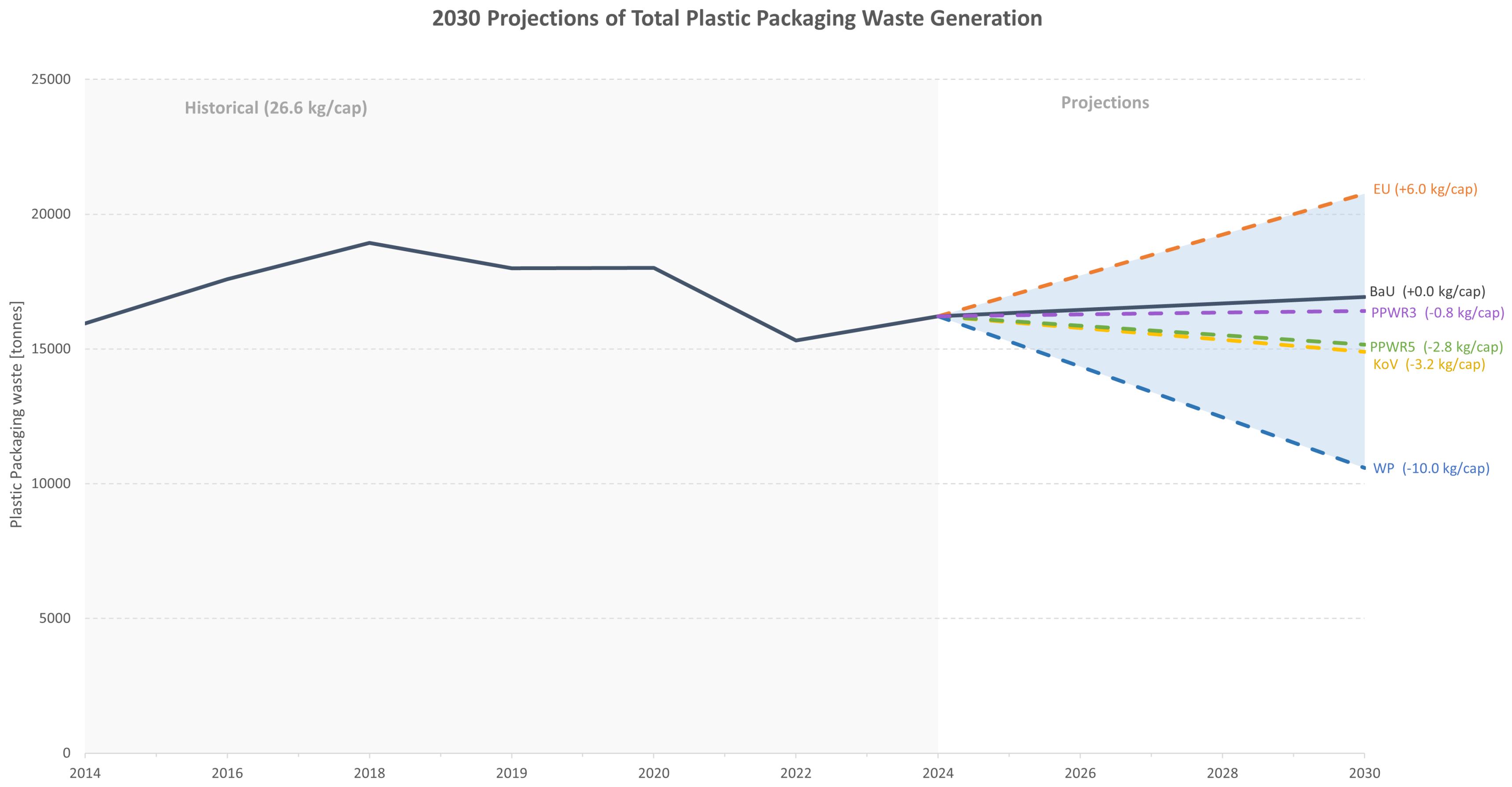

Figure 6.6: *Visualisation of historical developments and future projections of waste generation.*

6.2.2 Future Direct CO_2 Emissions

Emission projections will be based in the parameters presented in table 5.3 in section 5.4. Each parameter is associated with a change in waste distribution within the system which results in different amount of plastic entering the WtE facility (f) and subsequently being incinerated. The resulting projections are constructed through multiplying the amount of plastic packaging waste entering the residual stream (f) by 2.7 CO_2-eq.

6.2.2.1 Focus of Analysis

In figure 6.7 below, the flow in question is highlighted. When projecting the change in emissions resulting from waste incineration, the flow in question is the amount of waste entering the WtE facility denoted as f. Said flow is dependent in the distribution of waste within the system as more waste being source sorted equals less waste in the residual waste (assuming a remains constant). If Renova were to construct a materials recycling facility (MRF) it would divert waste from the process box "residual waste bin" directly into the process box "material recycling" (e_2) as the PRO's are only the responsible actor regarding source sorted flows.

The method used for this section is LCA as described in section 5.4.

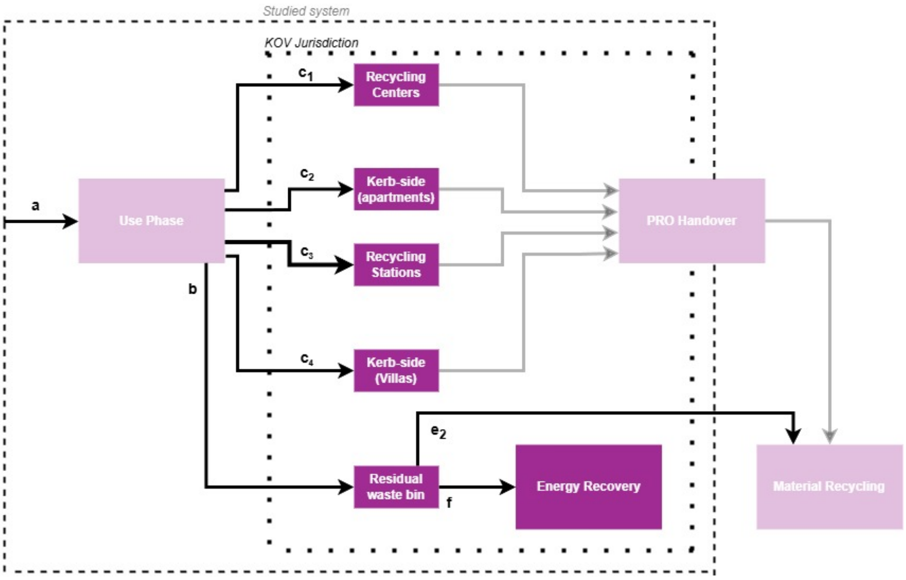

Figure 6.7: *Section focus: Waste distribution. Only non-transparent parts are relevant.*

6.2.2.2 Calculations of Parameters - emissions

The first parameter to calculate is the necessary collection rate if the PPWR target of a 55% recycling rate is to be achieved.

To determine the collection rate $\frac{d}{a}$, equation 5.8 in section 5.2.2.3 was used. The flow named d equals the sum of flows exiting the collection activities *RS*, *RC*, and *Kerb-side* (villas and apartments) whilst a equals the total input to the system. The contribution of a MRF is excluded in this calculation as it is assumed not have been constructed in this scenario. Since PPWR states that the recycling rate should be 55% in 2030, and both the sorting and recycling efficiencies reside at 80% each, the collection rate must be 85.9% or higher to reach the target according to Swedish Plastic Recycling (Regulation 2025/40/EC, art. 52; R. Jansson, personal communication, March 19, 2025).

The second parameter regards the construction of a MRF in Gothenburg with the same sorting rate as the MRF in Brista.

Brista processes 100 000 tonnes of residual waste each year and last year they sorted 7 300 tonnes of plastic whereof 83% were plastic packaging (Sörab, 2024; S. Höglund, personal communication, March 3, 2025). Höglund had no information regarding how much of the waste originates from businesses or households, but since all the waste is considered household-like, the sorting rate could be assumed to be identical between households and businesses. This results in a sorting rate of 6% of the total residual waste stream B when using equation 5.10.

Gothenburg generated 85 0000 tonnes of total residual waste (B) from households and co-localised businesses in 2024 (KOV, 2025). If a MRF were to be constructed, this would result in 5 100 tonnes of plastic packaging waste being diverted from incineration to recycling (e_2) according to equation 5.11 and flows named in figure 6.7. To find the sorting rate of b (plastic packaging in residual waste) instead of B (total residual waste), one has to divide e_2 with b. With b equal to 11 553 tonnes in 2024 (see figure 6.2), that would result in a plastic packaging sorting rate, $\frac{e_2}{b}$, of 41%. A rate assumed to remain constant in 2030.

6.2.2.3 Projections

Once the changes in waste distributions as a consequence of the parameters presented in table 5.2 was determined, the next step was to compare the impacts. Figure 6.8 shows the range of future emission projections compared to historial data. The full lines represents the parameter NoChange (the collection rate $\frac{d}{a}$ remains the same as in 2024) with each colour corresponding to a waste generation parameter (*EU*, *WP*, etc.). Dashed lines corresponds to the parameter of *CR1* (55% recycling rate) and dotted lines to the parameter *MRF*, with the colour of the lines indicating which waste generation parameter it is applied upon.

The maximum emission increase is associated with the *EU* projection with an increase of +22.3% whilst the maximum emission reduction was -88.2% based on waste generation from *WP* in combination with *CR1*. If neither *CR1* nor *MRF* parameter are applied, half of the projections results in increased emissions whilst the other half results in emission reductions.

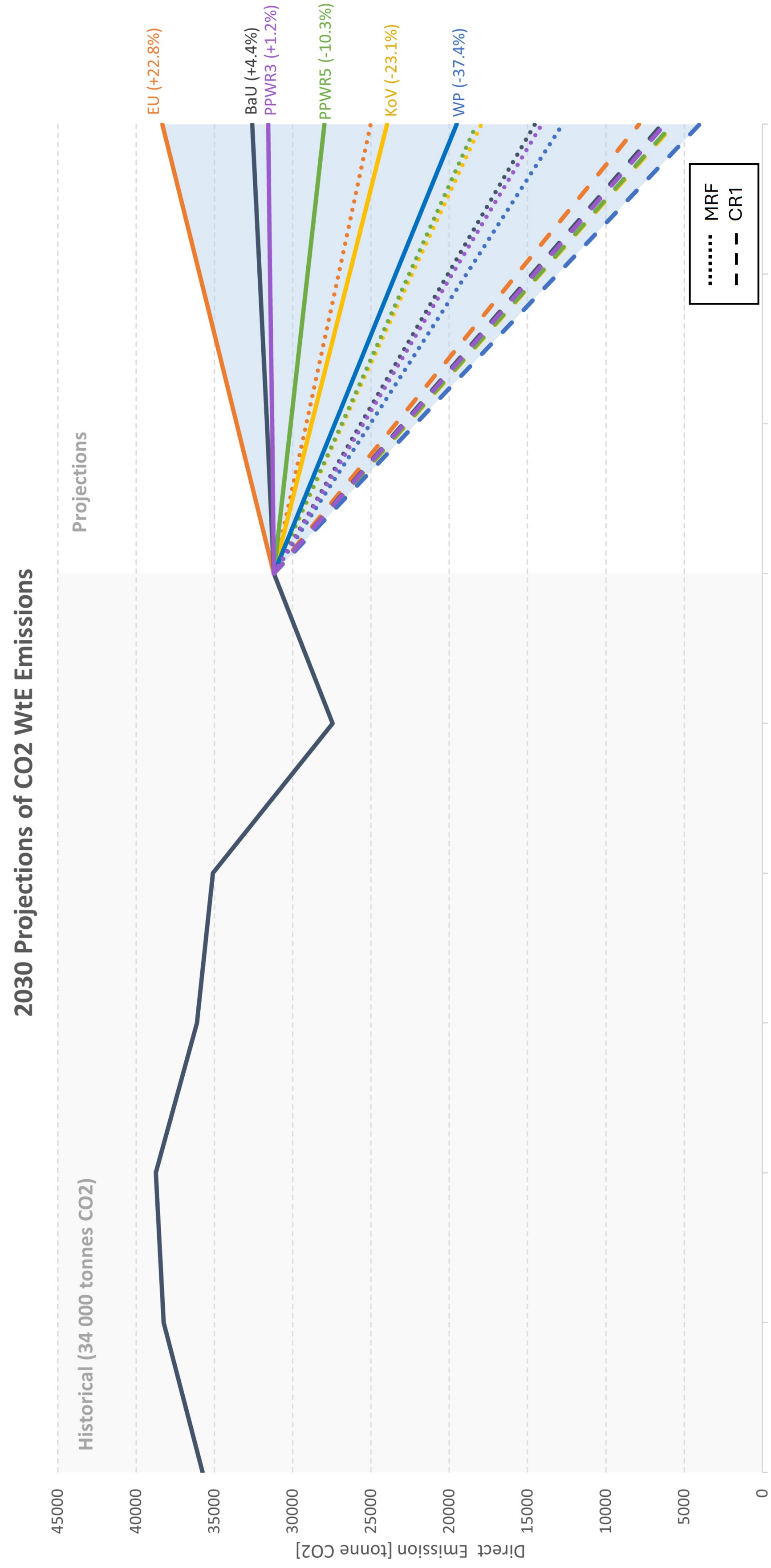

Figure 6.8: *Visualisation of historical and future developments in waste generation.*

For ease of comparison, figure 6.9 shows only the change in emissions in 2030 as compared to 2024 for each of the projections.

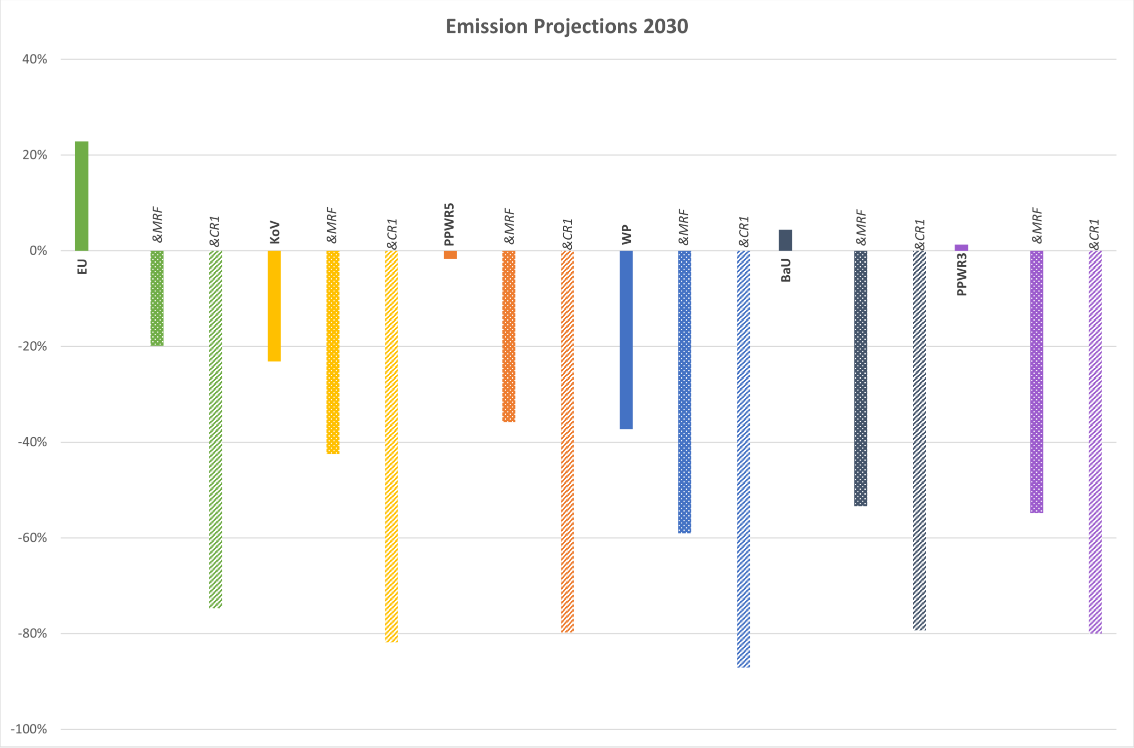

Figure 6.9: *A comparison of 2030 emission changes as compared to 2024 Baseline.*

Lastly, one aspect which would not change the amount of plastic packaging being incinerated but would reduce the emissions massively is stated in article 8(2) but has yet to be decided upon (Regulation 2025/40/EC). In said article, the European commission has reserved the option to allow for the recycled content target of article 7(1) to be fulfilled by exchanging virgin plastics to bio based plastics instead (Regulation 2025/40/EC). The article states that 30-35% of almost any plastic packaging must be recycled post consumer plastics. If said recycled post-consumer plastics were allowed to be exchanged for bio-based plastics, that would reduce the fossil based emissions by a third. Since EU ETS does not count non-fossil emissions, the cost would also be reduced. The decision of whether to approve of the substitution or not will be made in 2028 and presented as a legislative proposal.

7

Discussion

The aim of this report has been to understand the future flows of plastic packaging waste in Gothenburg with a specific focus on how the implementation of PPWR is shaping the municipal waste management. This has been done through a MFA of the current waste management system, waste projections of how said system might develop, and a LCA emissions calculation of future direct CO_2 emissions from WtE generation in Sävenäs. The results can be found in chapter 6 and contains answers to the research questions posed in section 1.2.1.

To facilitate a comprehensive and nuanced discussion which fulfils the aim, the discussion is separated into three main themes, (1.1) Waste Generation and Distribution, (1.2) WtE Emissions, and (1.3) Operational Planning Conditions. With this division, overarching themes and issues can be highlighted while keeping the results of the different research questions in mind.

7.1 Waste Generation and Distribution

The first and second research questions regards the determination of current and future flows of plastic packaging waste in Gothenburg. These questions were answered in section 6.1 and 6.2.1 and the results are discussed in the following section.

7.1.1 Current System

As discovered in the MFA of 2024, the total plastic packaging waste generated in Gothenburg is 16 217 tonnes. This is equal to 26.6 kg/capita, a value higher than the national average of 22.3 kg/capita (Landerdahl et al., 2024). There exists multiple explanations, of which one is that inhabitants of Gothenburg simply consumes more plastic packaging than average. Gothenburg is of relatively high socio-economic status (a factor which influences the waste generation as mentioned in the Method chapter) compared to many municipalities which makes this a probable explanation (Statistics sweden, 2023). Another explanation concerns the fact that Gothenburg is a major employment hub, with an estimated 122,000 people commuting from neighbouring municipalities into the city for work in 2023 (Region Västra Götaland, 2023, p. 23). These individuals spend a large part of their day in Gothenburg and discard waste there, even though they are not counted as residents when waste generation is calculated on a per capita basis. The last possible explanation regards the presence of free-riders and international sales points, as mentioned in section 3.2.2 (Ljungkvist Nordin et al., 2019). The average plastic packaging waste generation is based on the amount of packaging placed on the Swedish market, which in turn is based on reported values from producers and PRO's. If a producer wanted to save money, they might decide to not register the product with SEPA. Additionally, international sales points (ex. online marketplaces) might only report on the transport packaging and not the sales packaging of the product you have purchased. The difference between the national average waste generation and Gothenburg's, could therefore be ascribed to both or any of these three occurrences. Regardless, the most likely explanation is probably a combination of all of the above.

Based on the results, the collection rate of plastic packaging for recycling in Gothenburg 2024 falls slightly below 30%. This is despite the fact that the people in Gothenburg has access to sorting facilities at a short distance, with a majority having it inside their apartment complexes. Compared to villas, households living in apartments are currently slightly better at correctly sorting plastic packaging waste. This is however projected to change with the introduction of kerb-side collection for villas. If, instead of waste generation per household, waste generation per capita were used as the unit of assessment, it becomes evident that people living in villas are actually already better at sorting their waste than those living in apartments. The residual waste being comprised of 6% vs. 8% of plastic packaging per person in villas and apartments respectively. This is due to the fact that there are more people on average living in a villa compared to people living in apartments (2.4 people/villa vs. 1.7 people/apartment) (SCB, 2024). Why people living in apartments are worse at sorting can be explained by many of the factors presented in section 4.2.1 and a study of the sorting behaviours is necessary to understand it. However, two factors that would seem to provide partial explanations, (1) no space for sorting infrastructure inside apartments and (2) people living in villas paying for their own waste collection and thus being more mindful of how they can lower the amount of residual wast by for example throwing plastic packaging at the free recycling stations instead. This last factor will still remain true when villas receive kerb-side collection as they still will only pay for amount of residual and organic waste and not the recyclables (B. von Bahr, personal communication, April 28, 2025).

7.1.2 Future Projections

The results of the plastic packaging waste projections shows a maximum generation of +6.4 kg/cap (*EU*) whilst the minimum generation was -11.8 kg/cap (*WP*) compared to 2024 levels. Neither extreme scenario seems likely based on both the historical trends but also due to there not being any current plans from KOV nor the City of Gothenburg for how to practically lower the plastic packaging waste generation and reach the stipulated goals (Lirell, 2025). The goal of 5% reduction in waste generation assumed to be fulfilled in *PPWR5* require actions not included in *PPWR3* since the lines do not overlap. Irrespective of what those actions would be, it is not impossible to achieve as the waste generation was around the correct levels both in 2022 and 2014 (Regulation 2025/40/EC, art. 43(1); von Bahr, 2025). *PPWR3* seems to counteract the increased waste generation due to population growth accounted for in *BaU*. This might however not be true in other countries where less articles of PPWR, compared to Sweden, has been fulfilled already. In said countries, PPWR3 would contain more articles and have a greater waste reducing effect than it has in Sweden.

Of the six articles relevant for Sweden accounted for in *PPWR3* and visualised in figure 6.5, only one and a half run the risk of having zero effects. This includes the single-use (SU) grouped packaging and the mandated compostable packaging for tea and coffee. SU grouped packaging includes both plastic film used for grouping products during transport and smaller packaging such as a plastic bag of individually wrapped candy. Why the effect may have zero effect of the waste generation can be found within both of these examples. Firstly, the film used for grouping products during transport is not considered consumer packaging, as it never reaches the use phase or the end consumer. Therefore, it does not affect household waste generation, neither at present nor after its potential future ban or removal. Thus not affecting households waste generation, neither now nor after its future ban/removal. Secondly, packaging such as the bag of candy are also subjects to strict hygiene requirements, a fact which PPWR accounts for by adopting article 25(6) in conjunction with the ban. The article states that by 2027, "the Commission shall publish guidelines, in consultation with Member States and the European Food Safety Authority, which explain Annex V in more detail, including examples of the packaging formats in scope, and any exemptions from the restrictions...". This means that food articles may be excluded from the ban. Additionally, Axfood spokesperson Nadja Dahlgren mentioned during an interview that there is room for discussions as to why certain packaging such as SU grouped packaging is necessary (personal communication, March 17, 2025).

Why only half of the compostable articles could have zero effect is due to the fact that there appears to be almost no packaging containing tea, coffee or similar which are made of plastics today. Most are made of paper or a type of textile, with only one actor (Lipton) being observed to still use plastic tea bags. This would suggest that even if they became compostable, the product was not made from plastic from the beginning, thus not affecting the system in this report.

Another article to discuss is the effect of banning SU grouped packaging for fruit and vegetables (Regulation 2025/40/EC, Annex V). This is the article with the highest possible effect. To clarify, the ban does not include individually packaged fruit and vegetables such as a cucumber but only when they are grouped with the purpose of selling more products. Regardless, this ban could very well remove almost all plastic from the greens section as a consequence of stores having to dedicate a section in their store to refill (Regulation 2025/40/EC, art. 28(5)). If costumers bring their own bags for the fruits, that might count as refill and could be an easy solution for many grocery retailers to fulfil both requirements simultaneously according to Karin Jawerth, packaging manager at ICA (personal communication, March 31, 2025).

7.1.3 Broader Systems Implications

One important aspect to discuss is the broader systems implications changes in waste generation could cause. This study concludes that a decrease in plastic packaging waste generation is achievable. However, such a reduction does not necessarily translate into a decrease in the overall generation of packaging waste across all material categories. A potential material substitution effect may occur, whereby packaging producers replace plastic with alternative materials such as paper or metal. Given that these substitute materials typically exhibit higher densities and weights compared to plastic, the total mass of packaging waste could, paradoxically, increase despite reductions in plastic usage. Additionally, producers might switch from pure plastic packaging to composite materials like paper packaging with a plastic lining. Composite material is more difficult to recycle than monomaterial packaging, with the plastic lining usually being lost in the process, which would lower the recycling rate by increasing the losses from the recycling system (Tetra Pak, n.d.).

There is also a risk of plastics manufacturer shifting their target markets from packaging to others, causing the total amount of *plastics* in society to remain the same. As stated in the introduction, the largest flow of plastics in Sweden is in packaging (SOU 2024:67). If the demand for plastics gets dramatically lowered, as is the prerogative of PPWR, the producers will want to find an alternative market which can purchase their product. Said new market might bring about new problems such as microplastic pollution of both humans and the environment or increased products of single use purposes.

If one broadens the perspective, packaging in the EU might decrease whilst the packaging might increase or stay the same in other countries. Packaging producers seldom only sell to producers within the EU, and they might keep the old design for non-EU markets instead of the new design. Additionally, a point raised by Christian Håkansson at TMR, some countries within the EU might not even care if they receive a fine for not achieving certain aspects of PPWR, rather taking the fine and continuing with business as usual (personal communication, February 26, 2025). This would skew the competition between countries and negatively affect the market.

7.2 WtE Emissions

The third and last research question regards the subsequent changes in direct CO_2 emissions from the WtE facility in Gothenburg when accounting for the results of RQ 2. This question was addressed in section 6.2.2 and the results are discussed in the following section.

7.2.1 Emission Changes

The results shows that the maximum direct emissions increase comes from the *EU* projection of +22.3% whilst the minimum direct emission decrease is -88.2%. The latter corresponds to the waste generation from *WP* combined with *SR1*. This shows that there is much higher potential for reduction than for an increase of emissions. Most of the future projections are showing a decrease, with the number being 50% if removing all *SR1* and *MRF* projections. The results seems to be in favour of a decrease of future direct emissions, not accounting for any feasibility nor cost aspects.

Another factor that could influence emissions is whether the Commission permits the use of bio-based plastics to meet recycled content quotas. While switching to bio-based plastics has a high potential to reduce *fossil* emissions, this outcome depends on both decisions made by the Commission, and the supply of sustainably made bio-based plastics (SEPA, 2021, p.21). Bio-based plastics face significant supply constraints due to growing demand across multiple sectors and are often priced 20 to over 100% higher than their fossil-based counterparts (Union, 2022). If the packaging industry gains limited access to these materials, strategic allocation would be necessary, prioritising use in products most likely to end up in incineration could maximise emission savings, assuming that is the goal.

Because bio-based plastics are derived from renewable sources, their recyclability is less critical from an emissions standpoint. However, it is essential that their production adheres to sustainable forestry and agricultural practices to ensure a genuinely lower environmental footprint (SEPA, 2021). If the Commission approves this substitution and supply can meet demand, it may enable the continuation of existing consumption patterns while lowering fossil emissions. Still, such a shift would not reduce overall waste generation, an important target of the PPWR.

Replacing virgin plastics with bio-based alternatives can help cut emissions but may not stimulate demand for recycled plastics to the same degree. Although recycled bio-based plastics could eventually form part of the market, technical challenges, such as the incompatibility of fossil and bio-based plastics, make this difficult. If PPWR allows bio-based plastics to count toward recycled content quotas, the incentive to develop robust markets for secondary (recycled) materials may weaken. Therefore, this substitution could be viewed as a transitional measure rather than a long-term solution.

Additionally, Näslund (2025) claims that the climate goals established by Gothenburg Municipality are unrealistic. Said article focuses mostly on the goals relating to decreasing the territorial emissions where the interviewee believes that the municipalities should focus on what they have control over. One such factor which KOV have at least part control over is the emissions from the WtE facility in Sävenäs. KOV could try to convince the other shareholder municipalities of Renova AB to build a MRF or they could construct one of their own. The results in figure 6.8 shows that a materials recovery facility (MRF) have substantial impact on the emissions and the diverted waste can be handled by the advanced sorting facility in Motala, thus ensuring that at least 70% of it is recycled (see section 4.2.1). A MRF could also help Gothenburg to achieve the recycling rate of 55% mandated in PPWR (Regulation 2025/40/EC, art. 52).

7.2.2 Broader Systems Implications

As stated in Delimitations and RQ 3, the emission calculations only accounts for the direct fossil emission occurring at the WtE facility in Sävenäs. This was a conscious choice as the main concern for this study was to provide a basis for future EU ETS costs. However, does the future projections of plastic waste generation and management actually decrease emissions?

Regarding direct emissions, the main factor influencing if emissions from Sävenäs would be lowered is their need to compensate for the lost fuel with waste from other countries in order to provide the necessary power and district heating. As described in section 4.2.2, the WtE process provides approximately 5% of the electricity use in Gothenburg and district heating to about one third of Gothenburg residents. It is the plastic fraction, with its high heating value, that increases the heating value of the mixed MSW. If the plastic fraction were to be lowered or disappear entirely, Renova AB would have to burn a larger amount of waste in total if they are to produce the same output. Said additional input could either be in the form of higher amounts of other waste fractions or higher import of international waste. In theory, the direct emissions from WtE generation at Sävenäs attributed to waste from Gothenburg would decrease, although the total direct emissions from Sävenäs as a whole might remain unchanged.

If emissions from the entire plastic packaging lifecycle were considered, instead of just the direct emissions from a single end-of-life process, the projected changes would likely differ from those shown in figure 6.8. Achieving a net reduction in lifecycle emissions depends on several key factors: that a substantial portion of collected plastic is effectively recycled, that emissions from increased transport (from collection to recycling and production) do not outweigh the benefits, and that recycled plastics meaningfully displace virgin feedstock.

For instance, if a MRF was built and diverted the plastics from the residual waste stream to material recycling, the following statement is true according to development engineer Rickard Jansson from Swedish Plastic Recycling: the diverted plastics are more contaminated, less pure and is a workplace hazard due to smells and bacteria than the source sorted waste streams (personal communication, March 19, 2025). This could result in a higher fraction of the waste being rejected and sent back to incineration, resulting in more energy use for cleaning and longer transport for a share which ends up incinerated anyway.

The second assumption regards transportation. Whenever recycling or reuse is introduced into a lifecycle, the transport usually increases. Material which before had to be transported from raw material extraction to production, consumer, and then to WtE generation, now has to be transported from consumer to sorting, recycling, re-production, back to consumer and so forth. One has to use lifecycle assessment and determine of the avoided emissions of production and incineration outweighs the emissions from increased transport and the sorting/recycling processes.

Lastly, replacing virgin feedstock with recycled plastics would contribute significantly to reducing emissions. This is aided by article 7 in PPWR as it states that a certain share of the material has to come from post-consumer recycled plastics, artificially creating demand for secondary plastics. However, recycled plastics are today much more expensive than virgin plastics and many waste flows can not be recycled to equal or higher quality due to either contamination or the recycling process in itself. Additionally, article 7 retains the option for the Commission to amend the article and lower the minimum required shares if compliance with the article is deemed "excessively difficult" (Regulation 2025/40/EC, art. 7(13)).

To simply replace plastics with other materials is not necessarily environmentally beneficial. Returning to the example of a possible transition from plastic packaging to composite packaging made of paper with a plastic lining, this shift presents both opportunities and challenges for recycling and material recovery. The plastic lining can be separated through soaking in water but it is seldom economically viable to recycle the plastic and it is then burned (Tetra Pak, n.d.). If the entire packaging had been made of plastics, the material could have been recycled in its entirety. This exemplifies why design for recycling is imperative when transitioning to a more circular society. Through measures such as article 6 which demand that all packaging shall be recyclable at scale, more packaging can be recycled with less losses through the system (Regulation 2025/40/EC).

7.3 Operational Planning Conditions of KOV

The last sentence of the aim declares a need for a discussion regarding how the planning conditions for KOV's activities and their operations might change over time as a consequence of the changing waste generation, distribution, and direct emissions of the waste management system. This section will tackle said topic and discuss both the quantitative effects, how changes in waste generation and distribution might affect their operations, and qualitative effects, changes not due to mass flows or similar.

During the course of this thesis, several statements have been encountered suggesting that the Packaging and Packaging Waste Regulation (PPWR) will have little to no impact on municipal departments. However, given that the regulation explicitly addresses both packaging and *packaging waste*, an area in which municipalities are directly involved, such a conclusion is premature. Even if the anticipated effects on municipal operations are relatively limited, it remains important to examine them systematically and to gather as much empirical evidence as possible to understand their scope and implications.

7.3.1 Quantitative Effects

As can be seen in the resulting figures (see 6.6 and 6.8) the amount of plastic packaging waste and where said waste ends up will most likely change from today. Even if the total waste generation remains the same (*BaU*), the introduction of kerb-side collection for villas will decrease the amount of plastic packaging waste in the recycling stations by 24%. Such a change would lead to the recycling stations not have to be emptied as often or have as many stations in operation. However, as was discussed earlier, a decrease of plastic packaging won't necessarily mean a decrease of all packaging. Paper and metal packaging takes up more space and is less compressible than plastic packaging which would require larger collection bins at the recycling stations. Regardless, KOV must investigate how the current recycling stations can be adjusted to fit future needs.

Changing waste flows will also change the flow of money coming from households and SEPA. If households discards less plastic waste in the residual waste bin, they will pay less to KOV for waste collection as it is based on weight. However, since producers pay for the waste collection of packaging, KOV should get more more from SEPA to compensate. Whether the compensation will be sufficient to cover the *additional* costs remains unclear. This concern is reinforced by the fact that current compensation levels already fail to fully cover existing waste collection operations according to an employee at KOV (A-L. Eliasson, personal communication, February 4, 2025). Finally, a reduction in the amount of plastic within the residual waste stream would result in lower CO_2 emissions from the Sävenäs WtE facility, subsequently decreasing expenditures related to EU ETS and emission allowances. Here, it is important to acknowledge that the price of emission allowances is projected to increase over time (Påsse, 2024, p.5). As a result, the total cost associated with emissions may remain comparable to current levels despite reductions in plastic incineration, effectively stabilizing costs rather than allowing them to rise further. If a MRF were to be built, costs would decrease further, an investment that several municipalities have already considered worthwhile. Now that it is known that waste sorted in MRF's can be sorted by advanced sorting facilities and that they accept the stream, the planning conditions has changed since the alternative was last brought up for discussion (see section 4.2.3). Perhaps a new discussion is therefore in order.

The last thing to touch upon is the relationship between collection rate and recycling rate. The parameter used for the projections can be seen as the worst case, when there is no other changes than the collection rate. As already mentioned, article 6 in PPWR mandates that all packaging shall be fully recyclable at scale in 2030, which should reduce the losses in both the sorting and recycling processes (Regulation 2025/40/EC). If PPWR would reduce the losses, denoted as $\frac{e}{d}$ and $\frac{g}{e}$ in figure 5.2, the collection rate ($\frac{d}{a}$) would not need to increase from the current 30% to nearly 90%. Instead, a more moderate increase to approximately 60% would be sufficient to achieve the targeted outcomes.

7.3.2 Qualitative Effects

First and foremost, how can KOV use the results of this study as a basis for coming operational planning? By monitoring which projected line of waste generation Gothenburg follows, the study could be a tool to see if the projected path is a desirable one, if it requires further actions, and how large an action is then needed. By knowing the impacts of PPWR and what subject matter it tackles, KOV can focus their efforts on smaller areas but with large effects, such as mandating dedicated space in every apartment to waste separation, or other actions KOV have the authority to implement. As apartments are worse at source sorting than villas, said group should be the focus of such efforts.

Such actions will most likely be necessary to achieve the goals in *PPWR5*. Due to Sweden already having fulfilled many of the articles in PPWR, for example as a maximum yearly consumption of 40 plastic carrier bags/capita, authorities must find and implement other measurers to reach the goals. A country with a higher waste generation and less rules will benefit from other articles than those in *PPWR3*, articles such as mandated DRS and the introduction of a common labelling system (Regulation 2025/40/EC, art. 50 and 12). KOV needs to figure out where reductions can be found and how to go beyond PPWR.

With regards to PPWR, there are not many articles which directly affects KOV but there remains challenges nonetheless. As expressed by interviewed industry actors, the timeline to implement the measurers in PPWR is quite short (see section 3.1.2.3). SEPA is currently working on exactly how PPWR will be introduced to and harmonised with Swedish waste legislation but until it is finalised, it is hard to accurately predict the influence of PPWR on KOV (Å. Stenmarck, personal communication, February 18, 2025). The articles presented in the mentioned section has been deemed, by the author, as probable to affect KOV, especially the introduction of a common European pictographic system (Regulation 2025/40/EC, art. 13(1)). With the labels being determined by August 2026, the department will have to re-label all existing waste receptacles, including the new kerb-side collection bins for villas, regardless if they have been distributed or not. This would involve a significant cost for the department, which they have already incurred once when the Nordic pictographic system was adopted in 2020 (EU PICTO, n.d.).

The pictographic system will have to become common knowledge through information provided by KOV. Said information campaign could be the perfect opportunity to also inform more about the environmental benefits of source sorting and to dispel disinformation about how valuable the actions of individuals actually are. Christian Håkansson, TMR, emphasised that the most important contribution the public sector can provide is to increase the knowledge of the public (personal communication, February 26, 2025). The PRO's are working on changing the mentality of the producers, which is an important step, but what will really make a difference is when the consumers also take part in the sustainability transition. PPWR partly addresses this issue, for example by strengthening consumer information requirements, but the extent to which it will influence behaviour is difficult to estimate and falls outside the scope of this report.

To increase the awareness and the participation of the public, information is not the only option. One can also increase it by making sure all apartments have adequate space for indoor sorting, an issue many blame for their historical lack of sorting (see section 4.2.1), or to assess the sorting behaviour of individual households. By adding to or extending the current sorting analyses to assess and provide the share of correctly vs incorrectly sorted waste of each individual household, everyone can actually see how well or how poorly they are doing. Such data could be incentive enough for many people to change their behaviour and if complementary tips for more correct sorting was included in the results, the campaign could result in substantial change. The downside is the large cost of such an operation but one has to weight the advantages against the disadvantages. To investigate if the benefits outweighs the costs, a trial project could be conducted and the results used to make a decision about full-scale implementation. To further lower costs and to avoid any integrity issues, analysis on the shared recycling rooms for apartments complexes could be made to both catch multiple households in one go and to not single out any individuals.

Sorting analyses have been criticized as unreliable because they only reflect waste from one or two weeks out of the year. Their quality also depends on the subcontractor used, which became clear when some municipalities changed subcontractors in 2024 (Swedish Waste Association, 2024). To minimise the issues, the trade organisation Swedish Waste Management has taken steps to further standardise the methodology and asked municipalities to perform quality controls during the process. An additional issue to address is the difference in results which occur depending if one bases their analysis on the data in percentages or in absolute numbers. A quality control was performed on results based on either variable to ensure the highest possible quality which revealed that one variable gave significantly more reasonable results. The opinion of the author was echoed by KOV. Due to there not being any better source of data, and that sorting analyses are used by all Swedish municipalities, this possible weak point in the result was thoroughly considered throughout the process, ensuring usability of the results.

7.4 Limitations of the Results

Delimitations of the study were presented early in the report to provide the reader with a picture of what was and was not included in the analysis (see section 1.2.4). What follows below is what impacts and consequences said limitations might have had on the results.

The focus of this study was on plastic packaging waste, a limitation which excludes all other types of plastic waste as well as other types of packaging materials. This narrows down the scope of the study while at the same time limiting the conclusion one can draw about the entire waste system. A discussion was nonetheless conducted with broader system implications on other materials, mainly paper, to provide as a complete picture as possible with the limitations in mind. Packaging as a product is very complex as they can vary in size and shape deciding on what it is supposed to contain. This means that measures such as a maximum empty space ratio is very hard to quantify as it affects all packaging vary in size, shape and purpose. Other measures which might have a large impact on the system but isn't possible to quantify, has been excluded from the analysis. This indicates that the results of *PPWR3* might be a conservative estimate.

By limiting the use phase to only include households and co-localised businesses, all waste originating from industries etc. are excluded. While this could significantly impact the overall waste management system, business residual waste accounts for only 9% of KOV's waste subscriptions, suggesting minimal impact on the plastic packaging generation and WtE emissions estimates in this study (KOV, 2025). However, if businesses generate a higher proportion of plastic packaging in their residual waste, the effect could be more substantial.

On the other hand, by assuming that behaviours remains the same from now until 2030, a factor which arguably has the largest impact on waste generation and management was excluded. It is people who consume packaging and it is the same people who decides its end-of-life fate. The exclusion was necessary to narrow the scope but people's attitudes towards waste management is also important knowledge for waste management authorities such as KOV. If behaviours were to be included, it would probably have a large effect on the results, but in which direction is more difficult to predict.

Another limitation regards the temporal boundary. The study is limited to 2030, at which point not all delegated and implementing acts have been decided upon nor all measures having gone into effect. The results reflects the information as given in 2025 and speculation about which articles might be changed and how has neither been done nor included. This is a strength rather than limitation as the subjective opinions of the author or industry stakeholders have been discussed rather than used in the results.

The last limitation is the decision to only include direct emissions from Sävenäs. This reduces the usefulness of the results in terms of assessing the sustainability of the effect of PPWR as other systems implications might negate the reduced emissions included in the study. A limitation once again reflected upon in the discussion so as to minimise its impact.

7.5 Further work

Further work to be performed after the conclusion of this study could either broaden the analysis to include all packaging waste types consumed by households (paper, metal, glass, etc.) or continue to only include plastic packaging waste but include waste generated by businesses as well. Optimally both studies should be performed in order to fully grasp the impacts of PPWR on the flows of packaging waste, an opinion echoed by Åsa Stenmarck at SEPA (personal communication, February 18, 2025).

Another study that should be performed and probably will be performed by relevant authorities as a follow-up on how the progress towards reaching the goals are progressing and subsequently a hot-spot analysis on which aspects are lagging behind and how to mitigate it. The follow-up is mandated in PPWR whilst the hot-spot analysis is crucial to avoid missing targets and potential penalties.

Lastly, one aspect which was not studied in this report but was brought up by almost all interviewed stakeholders was the need for consumer behavioural changes. As inspired by Nadja Dahlgren of Axfood, a study focused on how to reach consumers with information which they will actually read and take in would be beneficial for all involved actors (personal communication, March 17, 2025). Do QR-codes on the products actually reach costumers or what is a worthwhile alternative approach? If people knew why a change was enacted and how much impact it entails, they might be more willing to accept it which in turn might make business more willing to enact changes in their products.

8

Conclusion

The waste management system of Gothenburg in 2024 shows that a majority of plastic packaging ends up in the residual waste stream. Of the total 16 kt plastic packaging waste generated by households and co-localised businesses, 71% is incinerated and results in 31 kt of fossil CO_2 being emitted to the atmosphere.

Through the use of material flow analysis, waste projections and LCA, this study concludes that, in 2030, a decrease in plastic packaging waste generation is possible. That would indicate a decrease in direct fossil emissions from incineration or at least a stabilisation. However, there are many possible future paths for the waste system, and high uncertainty makes it difficult to consider any one scenario more likely than another. Uncertainties includes the accuracy of the input data (sorting analyses), actual effects of individual measures in PPWR and even an uncertainty regarding the feasibility of the entire regulation.

It can be concluded that the PPWR may contribute to a reduction in plastic packaging waste generation in the municipality of Gothenburg. The regulation could aid authorities in achieving environmental goals, but it is not enough in and of itself. Due to Sweden already having fulfilled or nearly fulfilled many of the demands and requirements of PPWR, the magnitude of reductions as an effect of PPWR may not be as large in Sweden as it may be in other EU countries. Sweden and its municipalities have to work beyond PPWR and find additional measures to achieve the ambitious targets set forth, such as a plastic packaging recycling rate of 55% in 2030 or a decrease in waste generation of 5% compared to 2018 values. PPWR is also working with a tight schedule where many targets are to be met in the short timespan of five years and where individual measures needs to be implemented in as little as three years. Sweden and KOV must in addition to the above mentioned objectives, plan for shifting waste streams such as a possible increase in paper packaging waste as well a decrease in waste disposed of at recycling stations.

Finally, of special importance since plastic packaging waste generation may decrease over time but that may not be true for the other packaging materials. Shifts from plastic to other materials could even increase the amount significantly. But, as long as the amount of plastic packaging is reduced in the residual waste stream, the direct emissions from WtE in Sävenäs will decrease.

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A

Appendix 1

In this Appendix, the Strategic Literature Searches (SLS) conducted in chapter 2 are described in detail. As mentioned in section 5.1.1 in the Method, all search strings were limited to the last 10 years as well as being written in English and the databased used was ScienceDirect.

The resulting articles from the search were screened for relevance through analysis of key words, title and abstract and then compiled in a final table of literature to review. No citation criteria or similar, was used to further sort the literature as this SLS was focused on finding what types of studies has ben made in each field, not how well regarded the studies were in the scientific community.

A.1 Strategic Literature Search - "MFA"

Since one of the main methods in this study was MFA on plastic packaging flows, one search string was focused on this. Below in table A.1 and A.2, two versions were created.

Table A.1: *Summary of SLS results regarding "MFA" literature (1)*

String	**Hits**
"material flow analysis" AND legislation	812
"material flow analysis" AND legislation AND plastic	473
"material flow analysis" AND legislation AND plastic AND waste	468
"material flow analysis" AND legislation AND plastic AND packaging AND waste	269
"material flow analysis" AND legislation AND "plastic packaging" AND waste	72
"material flow analysis" AND legislation AND "plastic packaging" AND waste AND Sweden	18

Table A.2: *Summary of SLS results regarding "MFA" literature (2)*

String	**Hits**
"material flow analysis" AND "plastic packaging"	216
"material flow analysis" AND "plastic packaging" AND waste	214
"material flow analysis" AND "plastic packaging" AND waste AND EU	122
"material flow analysis" AND "plastic packaging" AND waste AND EU and "sensitivity analysis"	28
"material flow analysis" AND "plastic packaging" AND waste AND EU and "sensitivity analysis" AND Sweden	3

When adding "Sweden" to the search string in the last step, only three articles remained. Of these three, only one was considered relevant which led to the conclusion to backtrack one step and stop the SLS at the next to last string in table A.2 above.

The resulting 28 and 18 articles were screened for relevance where words such as "material flow analysis", "plastic packaging", and "waste" was seen as obligatory factors to deem an article relevant. The screening determined 13 and 4 unique articles to be reviewed and they are presented in table A.3 below:

Table A.3: *Literature for review regarding topics related to MFA*

Title	**Source**
A model to assess the environmental and economic impacts of municipal waste management in Europe	Albizzati et al., 2024
Assessment of Plastic Stocks and Flows in China: 1978-2017	Jiang et al., 2020
Characterization, recyclability, and significance of plastic packaging in mixed municipal solid waste for achieving recycling targets in a Swedish city	Esguerra et al., 2024
Circular economy of plastic packaging: Current practice and perspectives in Austria	Van Eygen et al., 2018
Comparing a material circularity indicator to life cycle assessment: The case of a three-layer plastic packaging	Vadoudi et al., 2022
Development and application of a predictive modelling approach for household packaging waste flows in sorting facilities	Kleinhans et al., 2021
Dynamic material flow analysis of plastics in China from 1950 to 2050	Luan et al., 2021
Estimated material metabolism and life cycle greenhouse gas emission of major plastics in China: A commercial sector-scale perspective	An et al., 2022
Estimating the packaging share in household hazardous waste: Methodology proposal and case study application	Verstegen et al., 2022
Extended producer responsibility: How to unlock the environmental and economic potential of plastic packaging waste?	Andreasi Bassi et al., 2020
How circular are plastics in the EU?: MFA of plastics in the EU and pathways to circularity	Hsu et al., 2021
Incineration economy: Waste management policy failing the circular economy transition in Norway	Mattson et al., 2024
Material flow analysis and recycling performance of an improved mechanical recycling process for post-consumer flexible plastics	Lase et al., 2022
Polymer-specific dynamic probabilistic material flow analysis of seven polymers in Europe from 1950 to 2016	Kawecki et al., 2021
Post-consumer plastic sorting infrastructure improvements planning: Scenario-based modeling of greenhouse gas savings with sustainable costs	Pluskal et al., 2023
The environmental benefits of improving packaging waste collection in Europe	Tallentire and Steubing, 2020
The environmental impacts of reusable rice packaging: An extended comparative life cycle assessment	Thomassen et al., 2024

A.2 Strategic Literature Search - "Legislation"

Another main topic of this study regards impact assessment of legislation, especially on plastic flows. Therefore one search string was focused on this, with results presented in table A.4 below.

Table A.4: *Summary of SLS results regarding "Legislation" literature*

String	Hits
legislation AND plastic AND waste AND EU	6 210
(legislation OR regulations OR laws OR directives) AND plastic AND waste AND EU	16 196
(legislation OR regulations OR laws OR directives) AND "plastic packaging" AND waste AND EU	1 497
(legislation OR regulations OR laws OR directives) AND "plastic packaging waste" AND EU	338
(legislation OR regulations OR laws OR directives) AND "plastic packaging waste" AND EU AND (effect OR impact)	332
(legislation OR regulations OR laws OR directives) AND "plastic packaging waste" AND EU AND (effect OR impact) AND Sweden	97

The resulting 97 articles were screened for relevance where words such as "Legislation" (or synonyms) and "plastic packaging" was seen as obligatory factors to deem an article relevant. The screening determined 13 unique articles to be reviewed and they are presented in table A.5 below:

Table A.5: *Literature for review regarding topics related to*

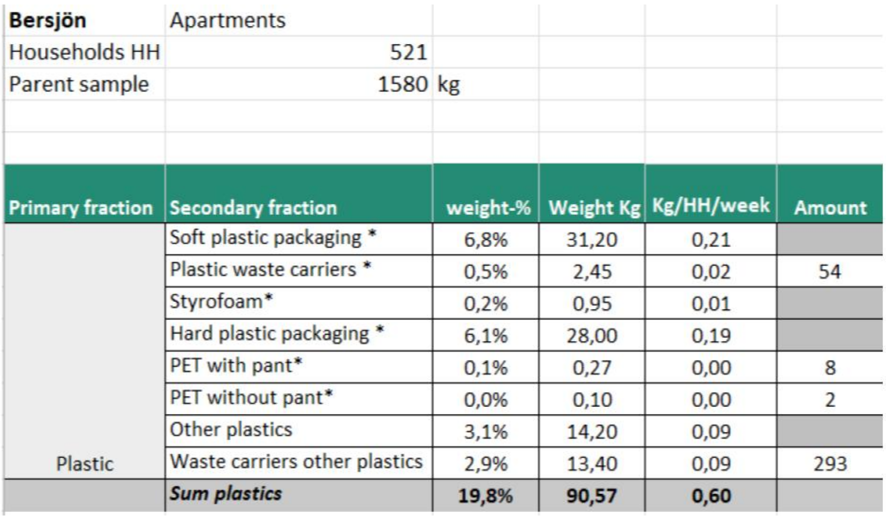
Title	**Source**
A model to assess the environmental and economic impacts of municipal waste management in Europe	Albizzati et al., 2024
Management practices for compostable plastic packaging waste: Impacts, challenges and recommendations	Cristóbal et al., 2023
Challenges and perspectives of the circular economy in the European Union: A comparative analysis of the member states	Castillo-Díaz et al., 2024
Management strategies for single-use plastics: lessons to learn from Indian approach of minimizing microplastic waste	Singh and Biswas, 2023
Global projections of plastic use, end-of-life fate and potential changes in consumption, reduction, recycling and replacement with bioplastics to 2050	Dokl et al., 2024
Regulating markets for post-consumer recycling plastics: Experiences from Germany's Dual System	Dehio et al., 2023
From niche support to system building—Perceptions of the transformation potential of policy measures on packaging reuse	Sundqvist et al., 2024
Cost-benefit analysis of two possible deposit-refund systems for reuse and recycling of plastic packaging in Sweden	Lu et al., 2022
Characterization, recyclability, and significance of plastic packaging in mixed municipal solid waste for achieving recycling targets in a Swedish city	Esguerra et al., 2024
How circular are plastics in the EU?: MFA of plastics in the EU and pathways to circularity	Hsu et al., 2021
An overview of the problems posed by plastic products and the role of extended producer responsibility in Europe	Leal Filho et al., 2019
Carbon footprint reduction potential of waste management strategies in tourism	Obersteiner et al., 2021
How does the global plastic waste trade contribute to environmental benefits: Implication for reductions of greenhouse gas emissions?	Liu et al., 2021

B

Appendix 2

In figure B.1 below, the results from one sorting analysis performed on one geographical area can be found. In bold at the top of the sheet, the name of the housing area (Bergsjön) is stated alongside the type of households (apartments), number of households (521) and the weight of the parent sample (1580 kg). The parent sample is divided into equal piles of which equal portions of each pile is extracted to form a total sample of 500 kg (von Bahr, 2025). What follows is the actual sorting. The sample is first sorted into 10 different primary fractions (e.g. biowaste, glass packaging and metal packaging). The primary fractions are then sorted into 23 secondary fractions (e.g. plastics are sorted into four different secondary fractions: polystyrene, hard plastic packaging, soft packaging and other plastics). Each pile is weighted as is, no cleaning occurs, and the result of which is compiled in Excel sheets as figure B.1 illustrates.

The analysis of the results are performed by an employee at KOV and not by the subcontractor. The results are compared to previous years and any anomalies are excluded. In 2024, areas which used a single rubbish chute, for both residual and food waste, were excluded as food waste was assumed to have been absorbed by the materials and thus inflated the weight of the other waste fractions.



Bersjön	Apartments	
Households HH	521	
Parent sample	1580	kg

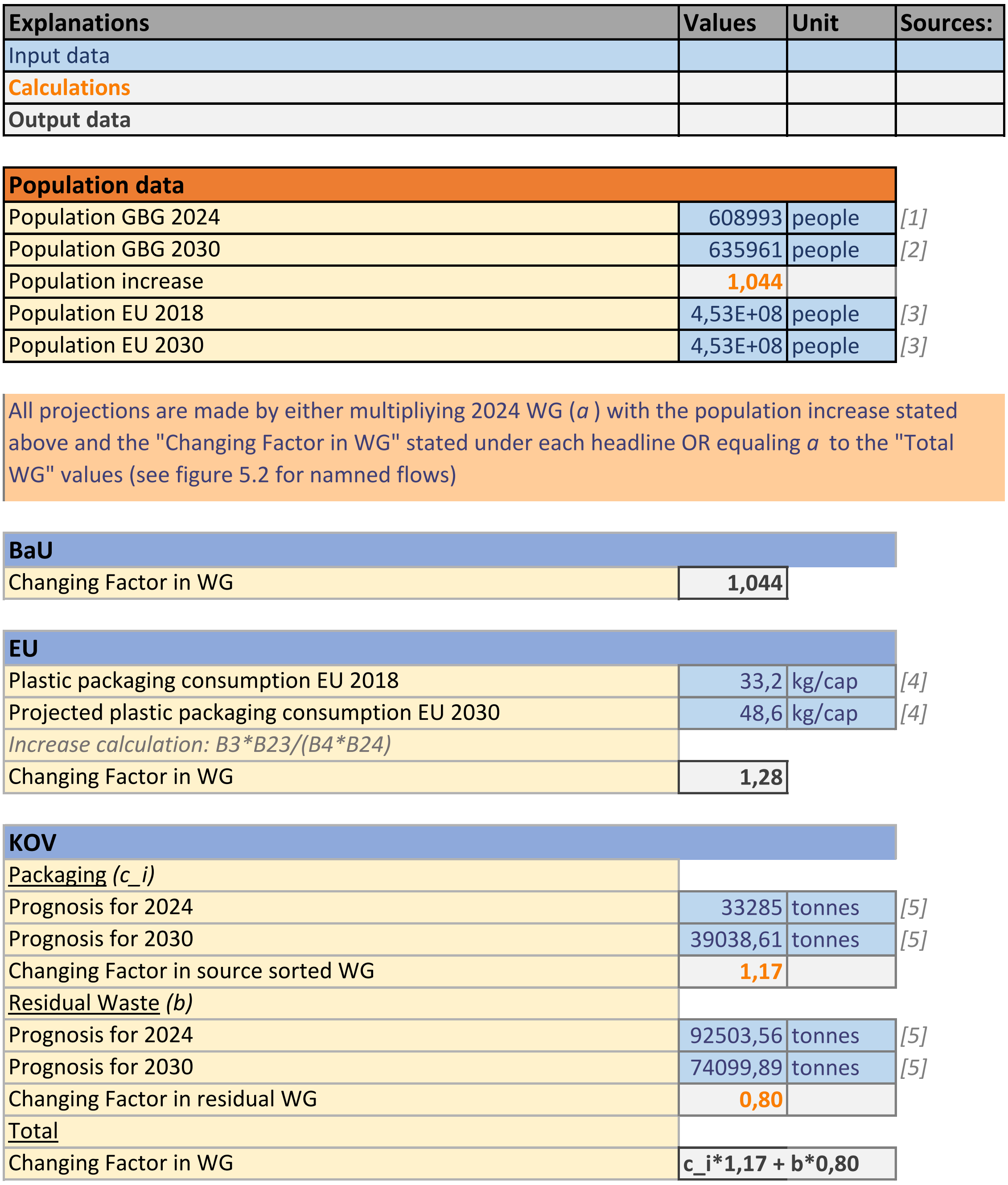
Primary fraction	Secondary fraction	weight-%	Weight Kg	Kg/HH/week	Amount
Plastic	Soft plastic packaging *	6,8%	31,20	0,21	
	Plastic waste carriers *	0,5%	2,45	0,02	54
	Styrofoam*	0,2%	0,95	0,01	
	Hard plastic packaging *	6,1%	28,00	0,19	
	PET with pant*	0,1%	0,27	0,00	8
	PET without pant*	0,0%	0,10	0,00	2
	Other plastics	3,1%	14,20	0,09	
	Waste carriers other plastics	2,9%	13,40	0,09	293
	Sum plastics	**19,8%**	**90,57**	**0,60**	

Figure B.1: *The reporting format of sorting analyses, exemplified for one geographical area (von Bahr, 2025).*

C

Appendix 3

Excel sheet compilation of how values in table 5.2 were calculated.



Explanations	Values	Unit	Sources:
Input data			
Calculations			
Output data			

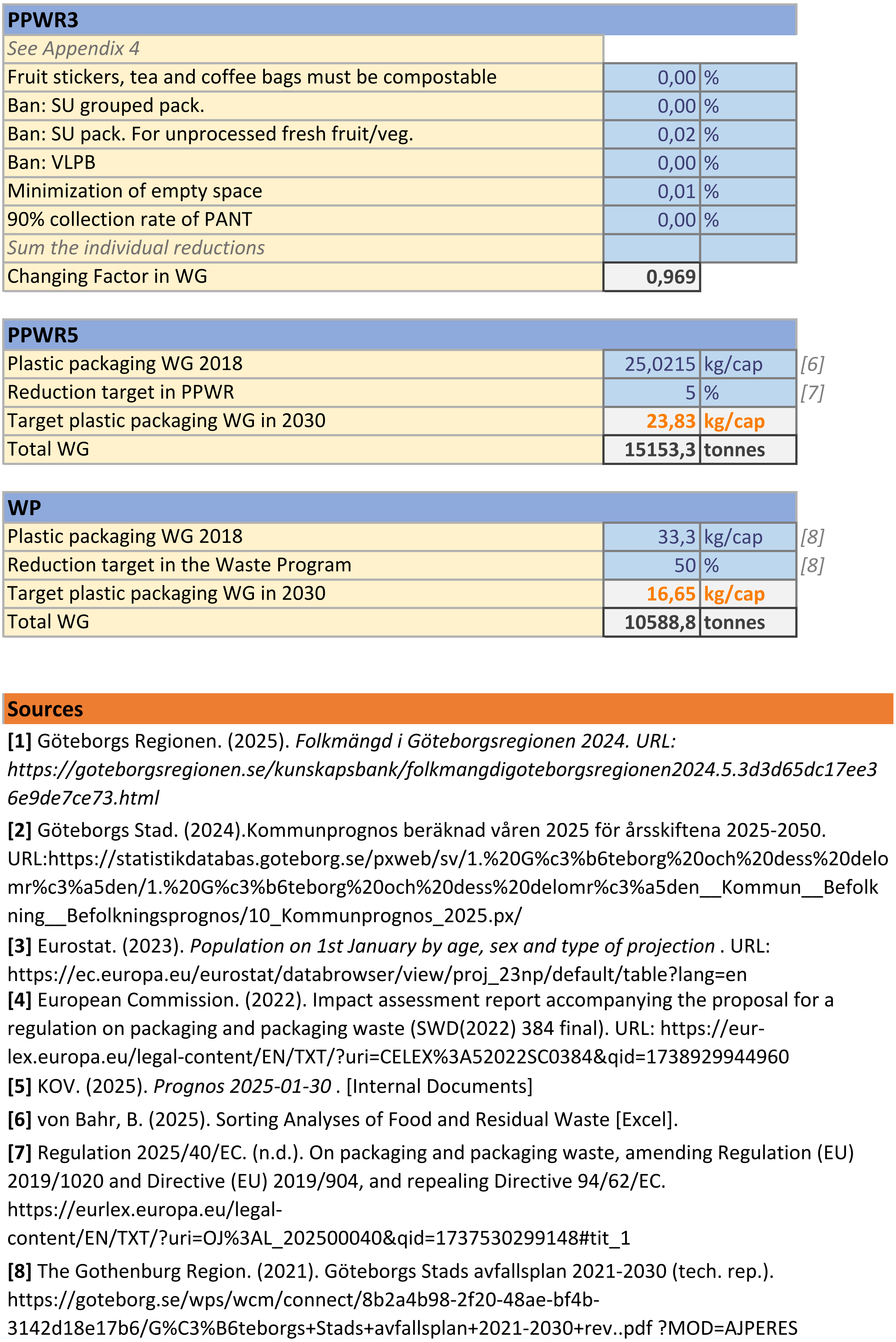
Population data			
Population GBG 2024	608993	people	[1]
Population GBG 2030	635961	people	[2]
Population increase	1,044		
Population EU 2018	4,53E+08	people	[3]
Population EU 2030	4,53E+08	people	[3]

All projections are made by either multipliying 2024 WG (*a*) with the population increase stated above and the "Changing Factor in WG" stated under each headline OR equaling *a* to the "Total WG" values (see figure 5.2 for namned flows)

BaU			
Changing Factor in WG	1,044		

EU			
Plastic packaging consumption EU 2018	33,2	kg/cap	[4]
Projected plastic packaging consumption EU 2030	48,6	kg/cap	[4]
*Increase calculation: B3*B23/(B4*B24)*			
Changing Factor in WG	1,28		

KOV			
Packaging *(c_i)*			
Prognosis for 2024	33285	tonnes	[5]
Prognosis for 2030	39038,61	tonnes	[5]
Changing Factor in source sorted WG	1,17		
Residual Waste *(b)*			
Prognosis for 2024	92503,56	tonnes	[5]
Prognosis for 2030	74099,89	tonnes	[5]
Changing Factor in residual WG	0,80		
Total			
Changing Factor in WG	c_i*1,17 + b*0,80		



PPWR3			
See Appendix 4			
Fruit stickers, tea and coffee bags must be compostable	0,00	%	
Ban: SU grouped pack.	0,00	%	
Ban: SU pack. For unprocessed fresh fruit/veg.	0,02	%	
Ban: VLPB	0,00	%	
Minimization of empty space	0,01	%	
90% collection rate of PANT	0,00	%	
Sum the individual reductions			
Changing Factor in WG	**0,969**		

PPWR5			
Plastic packaging WG 2018	25,0215	kg/cap	*[6]*
Reduction target in PPWR	5	%	*[7]*
Target plastic packaging WG in 2030	**23,83**	**kg/cap**	
Total WG	**15153,3**	**tonnes**	

WP			
Plastic packaging WG 2018	33,3	kg/cap	*[8]*
Reduction target in the Waste Program	50	%	*[8]*
Target plastic packaging WG in 2030	**16,65**	**kg/cap**	
Total WG	**10588,8**	**tonnes**	

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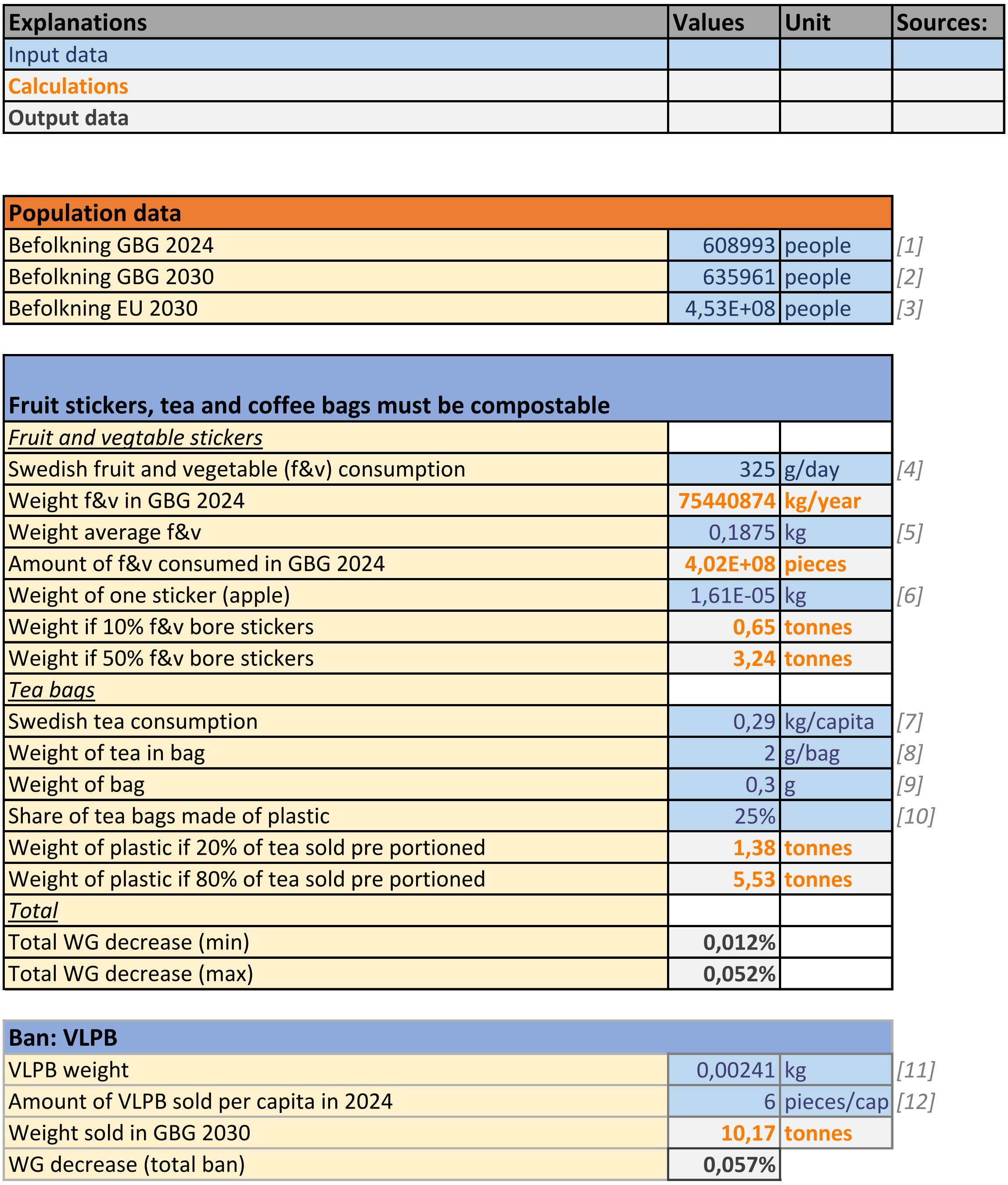
D

Appendix 4

Excel sheet compilation of *PPWR3* impact calculations.



Explanations	Values	Unit	Sources:
Input data			
Calculations			
Output data			

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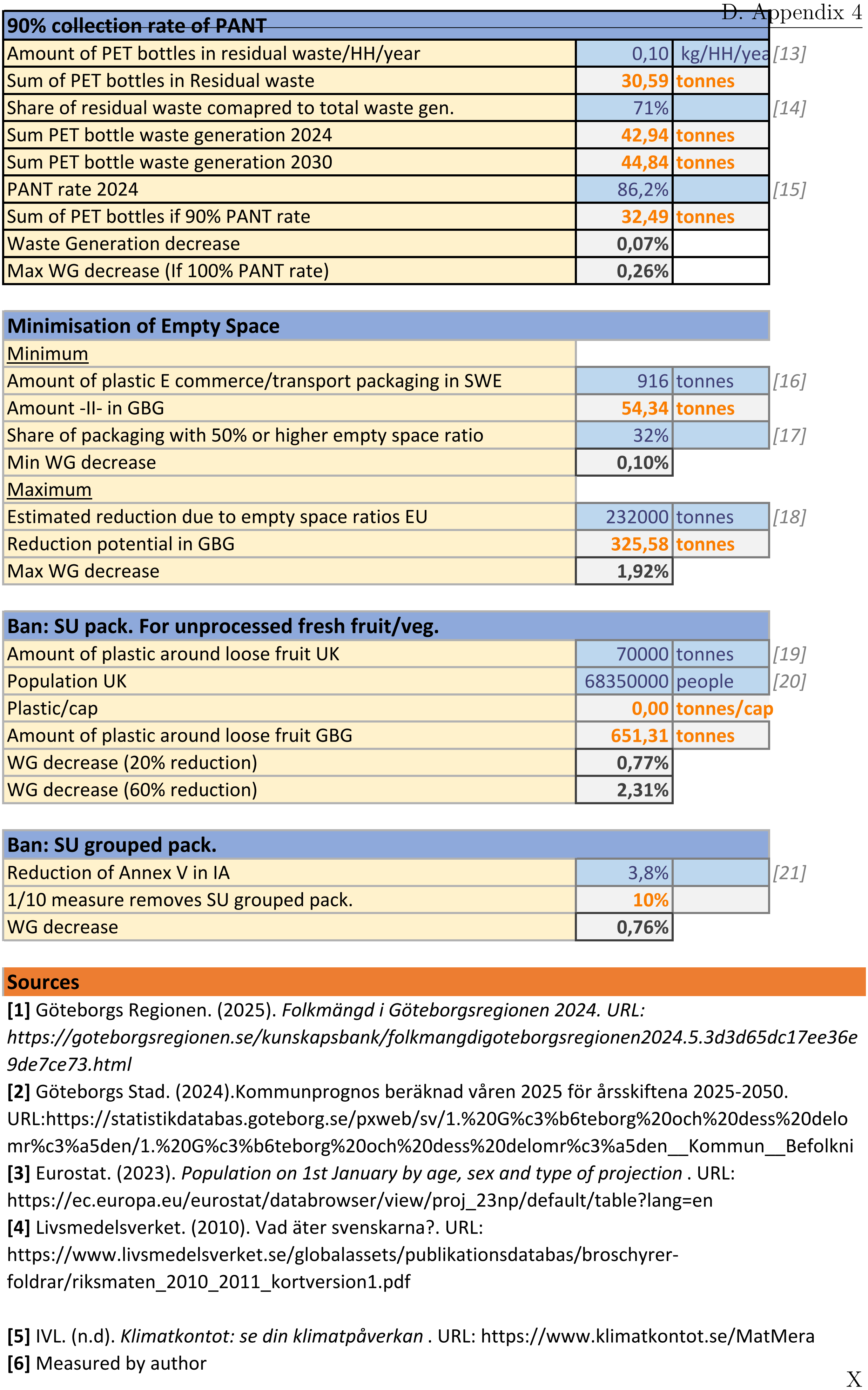
Befolkning GBG 2024	608993	people	*[1]*
Befolkning GBG 2030	635961	people	*[2]*
Befolkning EU 2030	4,53E+08	people	*[3]*

Fruit stickers, tea and coffee bags must be compostable			
Fruit and vegtable stickers			
Swedish fruit and vegetable (f&v) consumption	325	g/day	*[4]*
Weight f&v in GBG 2024	75440874	kg/year	
Weight average f&v	0,1875	kg	*[5]*
Amount of f&v consumed in GBG 2024	4,02E+08	pieces	
Weight of one sticker (apple)	1,61E-05	kg	*[6]*
Weight if 10% f&v bore stickers	0,65	tonnes	
Weight if 50% f&v bore stickers	3,24	tonnes	
Tea bags			
Swedish tea consumption	0,29	kg/capita	*[7]*
Weight of tea in bag	2	g/bag	*[8]*
Weight of bag	0,3	g	*[9]*
Share of tea bags made of plastic	25%		*[10]*
Weight of plastic if 20% of tea sold pre portioned	1,38	tonnes	
Weight of plastic if 80% of tea sold pre portioned	5,53	tonnes	
Total			
Total WG decrease (min)	**0,012%**		
Total WG decrease (max)	**0,052%**		

Ban: VLPB			
VLPB weight	0,00241	kg	*[11]*
Amount of VLPB sold per capita in 2024	6	pieces/cap	*[12]*
Weight sold in GBG 2030	10,17	tonnes	
WG decrease (total ban)	**0,057%**		



90% collection rate of PANT			
Amount of PET bottles in residual waste/HH/year	0,10	kg/HH/yea	[13]
Sum of PET bottles in Residual waste	30,59	tonnes	
Share of residual waste comapred to total waste gen.	71%		[14]
Sum PET bottle waste generation 2024	42,94	tonnes	
Sum PET bottle waste generation 2030	44,84	tonnes	
PANT rate 2024	86,2%		[15]
Sum of PET bottles if 90% PANT rate	32,49	tonnes	
Waste Generation decrease	0,07%		
Max WG decrease (If 100% PANT rate)	0,26%		

Minimisation of Empty Space			
Minimum			
Amount of plastic E commerce/transport packaging in SWE	916	tonnes	[16]
Amount -II- in GBG	54,34	tonnes	
Share of packaging with 50% or higher empty space ratio	32%		[17]
Min WG decrease	0,10%		
Maximum			
Estimated reduction due to empty space ratios EU	232000	tonnes	[18]
Reduction potential in GBG	325,58	tonnes	
Max WG decrease	1,92%		

Ban: SU pack. For unprocessed fresh fruit/veg.			
Amount of plastic around loose fruit UK	70000	tonnes	[19]
Population UK	68350000	people	[20]
Plastic/cap	0,00	tonnes/cap	
Amount of plastic around loose fruit GBG	651,31	tonnes	
WG decrease (20% reduction)	0,77%		
WG decrease (60% reduction)	2,31%		

Ban: SU grouped pack.			
Reduction of Annex V in IA	3,8%		[21]
1/10 measure removes SU grouped pack.	10%		
WG decrease	0,76%		

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