Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Energy and Process Engineering

Zsófia Miklós

Systems analysis of waste management opportunities at ReMidt IKS

Focusing on the circular economy

Master's thesis in Industrial Ecology
Supervisor: Helge Brattebø
Co-supervisor: Ida Plassen Limi and Sigrun Jahren

June 2021

NTNU
Norwegian University of
Science and Technology

ReMidt

Zsófia Miklós

Systems analysis of waste management opportunities at ReMidt IKS

Focusing on the circular economy

Master's thesis in Industrial Ecology
Supervisor: Helge Brattebø
Co-supervisor: Ida Plassen Limi and Sigrun Jahren
June 2021

Norwegian University of Science and Technology
Faculty of Engineering
Department of Energy and Process Engineering

NTNU
Norwegian University of
Science and Technology

Master thesis work

for

student Zsófia Miklós

June 2021

Systems analysis of waste management opportunities at ReMidt IKS: Focusing on the circular economy

Background and objective

This master thesis is a follow up of the TEP5100 Industrial ecology project work written during Fall 2020.

Information collected from ReMidt will be updated for year 2020 as well as the generic municipal solid waste management model developed by Pieter Callewaert (2017) that has been used to quantify and model a baseline scenario representing the current performance of ReMidt. In addition, various scenarios will be defined and modelled to test the feasibility and effectiveness of waste management measures based on technological, economic, and environmental criteria.

The overall objective of this MSc thesis is to contribute to the understanding of how municipal waste management companies operate in Norway and the role they play in implementing the circular economy. The work is linked to NTNU's Industrial Ecology Programme's research focus on Circular Economy and Resources. ReMidt will act as partner contributing with inventory and guidance when feasible. Ida Plassen Limi, Business Developer at ReMidt IKS will act as contact person.

The following tasks are to be considered:

1. Update datasets for the year 2020 with special focus on transport and waste composition data
2. Define and model relevant scenarios for ReMidt
3. Conduct an uncertainty and sensitivity analysis
4. Suggest recommendations to ReMidt on basis of the study
5. Discuss strengths and weaknesses of the work, and suggestions for follow-up research.

Preface

With this report I conclude my master's degree in Industrial Ecology at the Norwegian University of Science and Technology in June 2021. The work is linked to the Industrial Ecology Programme's research focus on Circular Economy and Resources.

This study is the outcome of one year of work, starting with a 2-month REdu summer internship at ReMidt IKS in Orkanger. During this time, I developed a simplified scenario model with Power BI visualization tool. The model allowed users to explore the impact of improved source separation of residential waste on material recycling rates. Due to the short timeframe of the internship, the model remained at a preliminary stage. However, Torbjørn Evjen, Head of quality and development, and Arne Kristian Mo, System developer at ReMidt were interested in my results and encouraged me to continue working on my model. Furthermore, the internship inspired me to learn more about the role Norwegian municipal solid waste management (MSWM) companies have in the circular economy.

Therefore, within the framework of the TEP5100 Industrial Ecology project work (Autumn 2020), I continued collaboration with ReMidt. My project report, titled as *Targets and reality: Feasibility assessment on how local waste management actors can help implement the circular economy*, included a literature review on waste legislative frameworks and the definition of circular economy in the European and Norwegian contexts. Furthermore, I collected relevant primary and secondary data to map and quantify the different waste streams in the MSWM system. I chose the material flow analysis (MFA) methodology to conduct a systematic assessment of the waste, energy, and emission flows. By reviewing relevant literature, I discovered that a former NTNU Industrial Ecology student Pieter Callewaert (2017) had already developed a generic MFA model close to what I intended to work on. Therefore, I utilised his tool to quantify and model a reference scenario for the year 2019.

Due to the limited timescale, scenario modelling, sensitivity and uncertainty analysis were not carried out in my project work. Therefore, my TEP4930 Industrial Ecology Master's Thesis (Spring 2021) represents a work that goes more in depth and addresses these research gaps. To provide a comprehensive overview on the work I have carried out during the past year, this thesis includes improved parts from my project work (literature review, model, and case study descriptions) combined with new chapters on scenario modelling, sensitivity and uncertainty analysis, and the presentation and discussion of the results.

I would like to thank Helge Brattebø at NTNU and co-supervisors, Ida Plassen Limi, Business Developer at ReMidt, and Sigrun Jahren at NTNU for guidance and assistance throughout this work. I am also grateful for all the help and support I have received from my family and friends.

Abstract

Background: Political and public interest in the end-of-life faith of products and associated environmental impacts have been growing during the past years. Circular and sustainable resource use is key to implement the circular economy in European countries like Norway, which has a very low degree of material circularity. Increasing the amount of *municipal waste* prepared for reuse and recycling has become a key target in European waste and resource policies. The EU Waste Framework Directive stresses the vital role of municipal solid waste management actors in ensuring efficient waste collection and treatment that leads to more re-use and recycling. However, there is a lack of comprehensive overview on to what extend local waste management actors can help implement the circular economy. This study aims at addressing this research gap by answering the following research questions:

- What is the current performance of the studied municipal solid waste management (MSWM) system?
- How do new waste management measures affect system performance?
- What are the most important measures that influence system performance?
- Is it feasible to achieve the 65% target for preparing municipal waste for recycling by 2035?

Method: The multi-layer material flow analysis (MFA) methodology was used *to conduct a systematic assessment of different waste flows* through the Norwegian case study of ReMidt. The aim is to understand how the collection and treatment of municipal waste can influence material, energy, and emission flows *within a MSWM system.* Five indicators were chosen to measure system performance: *collection, material recycling and energy efficiencies, rate of preparing municipal waste for recycling (excluding re-use) and associated climate change impact*. The indicators were calculated based on the total amount of recyclable waste fractions. A generic municipal solid waste management model developed by Pieter Callewaert (2017) was used to quantify and model the current MSWM system and future scenarios.

Results and conclusions: The current collection efficiency of the system is 31.7%, material recycling efficiency is 16.9%, and energy efficiency is 61%. ReMidt's overall rate of preparing municipal waste for recycling is at 17.4%, which is below the 50% target set for 2020. The low collection and recycling efficiencies and preparation rates are the results of the lack of source separation of food waste in ReMidt municipalities and the low sorting rate of plastic packaging. In addition, poor fraction quality, low market value of recycled materials and energy intensive treatment processes have a significant contribution to low system efficiencies. The overall climate change impact of the MSWM system is net positive. Waste incineration with heat recovery contributes the most to both generated energy and GHG emission. The scenario analysis shows that to improve system efficiencies and to achieve the 65% target by 2035 the following waste management measures should be considered:

- Source separating food waste and glass and metal packaging waste.
- Introducing a “Pay for what you throw” scheme in the kerbside and bring collection systems to improve the sorting rate of recyclables, especially plastics.
- Central sorting of residual waste.
- Investing in state-of-the-art sorting and recycling technologies to recover more residual, organic, and plastic fractions.
- Reducing rejects during sorting and recycling processes, especially for food waste and plastics.
- Changing legislations regarding biogas production, bio-waste feedstock and biogas vehicles.
- Designing products for recycling.

Sammendrag

Bakgrunn: Politisk og offentlig interesse for «end of life»-sikkerheten til produkter og tilhørende miljøpåvirkninger har vokst de siste årene. Sirkulær og bærekraftig ressursbruk er nøkkelen til å iverksette en sirkulær økonomi i europeiske land som Norge som har en veldig lav grad av materiell sekularitet. Å øke andel *husholdningsavfall og lignende næringsavfall forberedt til ombruk og materialgjenvinning* har blitt et sentralt mål i europeisk avfalls- og ressurspolitikk. EUs rammedirektiv for avfall understreker den viktige rollen som kommunale avfallshåndteringsaktører har for å sikre at innleverte produkter behandles på en riktig måte og at alle de resirkulerbare fraksjonene blir levert til gjenbruk eller materialgjenvinning. Det mangler imidlertid omfattende oversikt over i hvilken utstrekning lokale avfallshåndteringsaktører kan bidra til å iverksette en sirkulær økonomi. Denne studien tar sikte på å løse dette forskningsgapet ved å svare på følgende forskningsspørsmål:

- Hva er den nåværende ytelsen til det studerte kommunale avfallshåndteringssystemet?
- Hvordan påvirker nye avfallshåndteringstiltak systemytelsen?
- Hva er de viktigste tiltakene som påvirker systemytelsen?
- Er det mulig å oppnå 65% forberedelsesgrad for husholdningsavfall og lignende næringsavfall til materialgjenvinning innen 2035?

Metode: Flerlags materialstrømsanalyse (MFA) brukes for å gjennomføre en systematisk vurdering av avfallsstrømmene gjennom den norske casestudien av ReMidt. Målet er å forstå hvordan innsamling og behandling av de forskjellige avfallsstrømmene kan påvirke material-, energi- og utslippsstrømmer i et kommunalt avfallshåndteringssystem. Indikatorene som brukes til å måle systemytelsen er *innsamlings-, gjenvinnings-, og energieffektivitet, forberedelsesgrad for husholdningsavfall og lignende næringsavfall til materialgjenvinning (unntatt ombruk), og tilhørende klimapåvirkninger*. Indikatorene ble beregnet ut fra den totale mengden resirkulerbare avfallsfraksjoner. En generell modell for kommunal avfallshåndtering utviklet av Pieter Callewaert (2017) er basisen for modellen som brukes til å kvantifisere og modellere dette systemet og framtidsscenarier for ReMidt.

Resultater og konklusjoner: Den nåværende innsamlingseffektiviteten til systemet er 31,7%, gjenvinningseffektiviteten er 16,9% og energieffektiviteten er 61%. ReMidt sin forberedelsesgrad for gjenvinning er 17,4%, noe som er langt under 50% -målet som er satt for 2020. De lave innsamlings- og gjenvinningseffektivitetene og den lave forberedelsesgraden for gjenvinning skyldes i hovedsak mangelen på kildesorteringen av matavfall i ReMidt-kommuner og den lave sorteringsgraden på plastemballasje. I tillegg har dårlig fraksjonskvalitet, lav markedsverdi av resirkulerte råvarer og energiintensive behandlingsprosesser et betydelig bidrag til lav systemeffektivitet. Systemet har nettopositiv klimapåvirkning. Avfallsforbrenning med varmegjenvinning bidrar mest til både generert energi og klimagassutslipp. Scenarioanalysen viser at for å forbedre systemeffektiviteten opp mot 65% -målet innen 2035, bør følgende avfallshåndteringstiltak vurderes:

- Kildesortering av matavfall og glass- og metallemballasjeavfall.
- Å introdusere et "Betal for det du kaster-system" for hente- og bringeordninger for å forbedre sorteringsgraden for gjenvinnbare produkter, spesielt for plast.
- Sentral sortering av restavfall.
- Å investere i moderne sorterings- og gjenvinningsteknologier for å utnytte mer rest, organiske og plast fraksjoner.
- Å redusere rejekt under sorterings- og gjenvinningsprosesser, spesielt for matavfall og plast.
- Endring av lovgivning om biogassproduksjon, bioavfall som råstoff og biogasskjøretøy.
- Å designe produkter for gjenvinning.

Abbreviations

CE	Circular economy
C&D	Construction and demolition waste
EC	European Commission
EoL	End of Life
FW	Food waste
G&M	Glass- and metal packaging
G&P	Garden and park waste
IE	Industrial Ecology
IKS	Interkommunalt Selskap (In English: inter-municipal company)
LCA	Life cycle assessment
LHW	Lower heating value
MFA	Material Flow Analysis
MSWM	Municipal solid waste management
P	Plastic packaging
P&C	Paper and cardboard packaging
RW	Residual waste
TC	Transfer coefficient
WEEE	Waste electrical & electronic equipment
WFD	Waste Framework Directive

Table of Contents

List of Figures

List of Tables

1. Introduction

Climate change, environmental degradation and natural resource scarcity have been common challenges for European countries during past decades. To mitigate these challenges while securing economic prosperity, regional cooperation is necessary. Therefore, the European Commission presented the European Green Deal in December 2019. It is an action plan to support efficient resource use, biodiversity restoration and emission reduction efforts while transitioning to a clean, circular economy (European Commission, 2020). Increasing the circularity of resources by improved material recycling rates is one of the first steps to facilitate such transition.

As the Circularity Gap Report indicates, over 97% of Norway's consumed materials are not recycled back into the economy (Circle Economy and Circular Norway, 2020). This accounts for 235 million tonnes of materials that is equivalent to ~64 times the size of the Norwegian private passenger vehicle fleet[1]. To tackle these challenges at a national level, the Norwegian government announced in January 2019 that "Norway will be a pioneer in the development of a green, circular economy that makes better use of resources, and develop a national circular economy strategy" (Statsministerens kontor, 2019).

In September 2020, a study[2] on this national strategy was published by Deloitte on behalf of the Norwegian Environmental Agency (Miljødirektoratet). The report emphasizes the role of *waste-, sewage,- and recycling industries* in "triggering the potential for a circular economy by facilitating higher levels of sorting, re-use and material recycling, and by offering secondary raw materials on the market" (Deloitte, 2020). Since then, the waste management sector has been closely working with relevant governmental agencies to define concrete measures and instruments for increasing the circularity of materials.

In Norway, there is a mandatory reporting scheme in place – called KOSTRA - that requires municipalities to report on their waste accounts, including accounting on the collection, recycling and final treatment of municipal waste (SSB, 2018). This gives an indication on where Norway stands regarding End-of-Life (EoL) waste volumes and treatments compared to other European countries. The effectiveness of national waste management systems is measured through binding targets defined in the Waste Framework Directive (de Römph and Cramer, 2020). One of these targets is to increase the *preparation of municipal waste for re-use and recycling to a minimum of 50% by 2020, 55% by 2025, 60% by 2030 and 65% by 2035* (European Parliament and Council of the European Union, 2018). It is the responsibility of national governments to devise their own laws on how to reach these levels.

In 2019, 45% of household waste was sent to material recycling in Norway which falls behind the 50% EU target set for 2020 (Fostervold, 2021a). Norwegian authorities have developed a national waste plan for the period 2020-2025, which defines a specific strategy on how municipal solid waste management (MSWM) actors could measure their performance in accordance with the EU targets. However, incomplete information on material and waste streams and the lack of use of analytical methods for evaluating the environmental impact of these services create barriers to measure and increase the circularity of the Norwegian economy

---

[1] Basis for calculations: the average weight of a conventional passenger car is assumed to be 1300 kg. In 2019, 2 816 038 private cars were registered in Norway based Statistics Norway estimates. Available at: https://www.ssb.no/en/bilreg (Accessed: 29.10.2020)

[2] The study is currently (15th February 2021) under review by stakeholders and the final national strategy will be presented during the first half of 2021.

(Avfall Norge, 2019; Eggen, 2020; Olbergsveen and Knagenhjelm, 2021). In this master thesis the multi-layer material flow analysis (MFA) methodology is used *to address these issues by measure the performance of a Norwegian MSWM through the case study of ReMidt.*

Five main indicators are chosen to measure system performance: collection, material recycling and energy efficiencies, rate of preparing municipal waste for recycling and climate change impact. The following research questions will be addressed:

- What is the current performance of the studied MSWM system?
- How do new waste management measures affect system performance?
- What are the most important measures that influence system performance?
- Is it feasible to achieve the 65% target by 2035?

The aim is to understand how the collection and treatment of different waste streams can influence material, energy, and emission flows within a MSWM system. The overall goal of this study is to gain a deeper understanding of the complexity of MSWM in Norway, and to assess how waste management actors can help implement the circular economy.

2. Literature review

2.1. Circular economy and circularity

The notion of circular economy (CE) has gained momentum during the past decade. It offers a strategy to meet the continuously growing material demand by “designing out waste and pollution, keeping products and materials in use, and regenerating natural systems” (Ellen MacArthur Foundation, 2020). Still, there is no unified consensus on the definition of CE neither within academia (Merli, Preziosi and Acampora, 2018; Calisto Friant, Vermeulen and Salomone, 2020), nor in the government and corporate sectors (Kirchherr, Reike and Hekkert, 2017).

Various reviews of scientific literature (Kirchherr, Reike and Hekkert, 2017; Merli, Preziosi and Acampora, 2018; Calisto Friant, Vermeulen and Salomone, 2020) demonstrate that studies on CE are usually published in journals focusing on environmental sustainability. Most of them present a practical approach to apply industrial ecology methods and tools (LCA and MFA) to support decision-making at micro level. Since CE has a strong foundation in the industrial ecology (IE) discipline; increasing re-use, recycling and recovery rates have received more attention in the reviewed literature, than the role of social and cultural aspects (Cullen, 2017; Fellner *et al.*, 2017; Kirchherr, Reike and Hekkert, 2017; Merli, Preziosi and Acampora, 2018; Calisto Friant, Vermeulen and Salomone, 2020). Therefore, the academic definition of CE is commonly formulated as *an economic system in which resources are kept in circulation while waste generation and emission are minimalised*.

Measuring circularity is a common method to indicate the effectiveness and efficiency of circular resource use in the economy. According to Haas et al (Haas *et al.*, 2015) and Mayer et al (Mayer *et al.*, 2019) circularity is commonly discussed as either closing the socioeconomic loop though recycling; or closing the ecological loop by utilising renewable biomass. Haas and his colleagues (2015) conducted a study assessing the circularity of material flows globally and, in the EU-27. They found that due to ambitious policies and advanced recycling technologies, the EU-27 was above the global average in many of the measured indicators. For instance, while the overall global EoL recycling rate was 28%; the EU-27 stood at 41%. However, the *degree of circularity* (the share of recycled material in total processed materials) was low both at global and EU-27 levels; 6% and 13% respectively. Besides improved material recycling rates, in-use material stock stabilisation, fossil material use reduction, and the extension of product lifetime through eco-design are all necessary measures to improve the degree of circularity of the economy (Haas et al., 2015).

Similar conclusions were made by Mayer et al. (2019) in their economy-wide material and ecological loop assessment. They identified a set of indicators to measure the scale and circularity of materials and waste flows in the EU-28 economy. Results show that the *socioeconomic cycling* (referred to as degree of circularity by Haas et al.) of the EU-28 was at 9,6% in 2014. This is lower than what Haas et al (2015) found. Most importantly, similar to Cullen's (2017) arguments, Mayer et al. suggest that by *improving the quality of waste statistics, a more comprehensive overview could be gained on the material and energy flows in the economy*. It is especially important to have an overview on the amount of EoL products that can be recycled back to the economy through effective waste management operations.

MSWM is heavily regulated by EU directives and national laws and regulations. Therefore, the following two chapters will briefly describe the legislative framework for MSWM in Europe and Norway.

2.2. Legislative framework for municipal solid waste management in Europe

Improving the circularity of the European economy has been a core strategy of the European Commission (hereafter: EC) since the adaption of the First Circular Economy Package (CE Package I) in 2015 (European Commission, 2015). It merged existing EU waste policies into a CE policy framework to support long-term and short-term aspirations of a circular economic transition. In 2018, as part of aligning sustainable intentions with practical actions, the EC adopted the CE Package II (European Commission, 2018b). This includes the review and amendment of the three major framework laws on circular resource use: Eco-design Framework Directive, the Waste Framework Directive and the Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation.

The *Waste Framework Directive*[1] and its amendment[2] (hereafter: WFD) establish a legislative framework for handling waste in the Union by; i. defining key concepts and obligations related to waste management; ii. prioritising the 4R principles (reduce, re-use, recycle, recover) in the waste hierarchy (Figure 1); and iii. setting re-use and recycling targets. As Römph and Cramer (2020) point out, one of the core principles of circular economy is to maintain the value of resources while securing environmental and human well-being. Consequently, the WFD redefines **waste as a resource** that can reduce the resource dependency of the Union, while facilitating the transition to *sustainable resources management* and the *circular economy*. To reflect this ambitious role of sustainable resource management, the WFD sets new targets *for preparing for re-use and recycling of municipal waste*. Before elaborating on the targets, it is important to define waste management, municipal waste, and the activities of preparing for re-use and recycling.

---

[1] Directive 2008/98/EC on waste and repealing certain directives [2008] OJ L 312/10

[2] Directive 2018/851 of 30 May 2018 amending Directive 2008/98/EC on waste [2015] OJ L 150/10

Figure 1 - Waste hierarchy defined in the WFD. Source: ec.europa.eu

Municipal waste is defined in the WFD as:

a) Mixed waste and separately collected waste from households, including paper and cardboard, glass, metals, plastics, bio-waste, wood, textiles, packaging, waste electrical and electronic equipment, waste batteries and accumulators, and bulky waste, including mattresses and furniture.
b) Mixed waste and separately collected waste from other sources, where such waste is similar in nature and composition to waste from households.
c) <u>It does not include</u> waste from production, agriculture, forestry, fishing, septic tanks and sewage network and treatment, including sewage sludge, end-of-life vehicles or construction and demolition waste.

Waste management refers to

> "the collection, transport, recovery (including sorting) and disposal of waste, including the supervision of such operations and the after-care of disposal sites, and including actions taken as a dealer[1] or broker[2]".

While municipal waste only accounts for 10% of the total waste generated in the Union, it receives significant political attention due to its complexity (Eurostat, 2020). Both the WFD and Christensen (2011) argue that municipal waste is challenging to manage because:

- it contains highly complex, mixed compositions;
- it is directly linked to citizens, thereby its complexity is further increased;
- it has a high public visibility (odours, flies, blowing litter etc.) if it is not managed appropriately, which can have an impact on intrinsic values and health of the local environment;
- it can have negative impact on public health if the waste management system is not effective, leading to the spread of insects, animals, pathogens etc.

According to the WFD, in a sustainable resource management system these characteristics of municipal waste can be reduced if:

- efficient and effective collection and sorting schemes are implemented;
- the waste streams are traced;
- the infrastructure is adjusted to the specific waste composition;

---

[1] Dealer refers to those that purchase and subsequently sell waste, including those that do not take physical possession of the waste.

[2] Broker refers to those that arrange the recovery or disposal of waste on behalf of others, including those that do not take physical possession of the waste.

- active engagement of citizens and businesses are encouraged;
- an elaborate financing system is in place.

Preparation for re-use and recycling can be divided into two activities in accordance with the WFD.

1. *Re-use means*

   > "any operation by which products or components that are not waste are used again for the same purpose for which they were conceived".

   Thereby, *preparing for re-use* includes

   > "checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing."

2. *Preparing for recycling* means

   > "any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations".

Calculations for preparing for recycling can include home composting, composting, and digestion (biogas production) of bio-waste and the recovery of metals from bottom ash and fly ash from incineration.

To improve *high level resource efficiency* in the Union, the WFD sets the following **targets for the Member States**:

by 2020, the preparing for re-use and recycling of waste materials from households[1], shall be increased to a minimum of overall 50 % by weight.

by 31 December 2023, bio-waste[2] is either separated and recycled at source or is collected separately and is not mixed with other types of waste.

by 2025, the preparing for re-use and recycling of municipal waste shall be increased to a minimum of 55 % by weight.

by 2030, the preparing for re-use and recycling of municipal waste shall be increased to a minimum of 60 % by weight.

by 2035, the preparing for re-use and recycling of municipal waste shall be increased to a minimum of 65 % by weight

The WFD specifies that *targets for re-use shall be calculated* as the weight of "products or components of products that have become municipal waste and have undergone all necessary checking, cleaning or repairing operations to enable re-use without further sorting or pre-processing".

Targets for recycling shall be calculated either as the weight of waste that "enters the recycling operation whereby waste materials are actually reprocessed into products", or as measured output of any sorting operation provided that "the weight of materials or substances that are

---

[1] As the underlined terms indicate, the 50% target set by the end of 2020 is for household waste, while the following targets refer to municipal waste, which is household waste and similar, commercial waste.

[2] "bio-waste" means biodegradable garden and park waste, food and kitchen waste from households, offices, restaurants, wholesale, canteens, caterers and retail premises and comparable waste from food processing plants.

removed by further operations preceding the recycling operation and are not subsequently recycled is not included in the weight of waste reported as recycled”.

The current target system for measuring the efficiency of waste management relies on collection and recycling rates. According to Haupt et al. (2018) the assumption that material recycling is favourable regardless of local conditions, available technologies and decreasing marginal benefits of collection transport and recycling processes can be misleading. Especially, when the EC’s Circular Economy Action Plan heavily relies on ambitiously high recycling rates in the transition towards a more circular economy.

2.3. Norwegian municipal waste management

The following chapter gives an overview on the current waste management status of Norway. Thereby, describing the legal and structural basis for defining the system boundary, and identifying relevant parameters that will be used for scenario modelling.

2.3.1. Waste statistics in Norway

Figure 2 illustrates that the total amount of waste generated in the Norwegian economy has gradually increased between 2012-2019. Waste from private households, which takes up approximately 21% of total waste generated, has a relatively stable annual rate at ~2.5-million-tonnes. This amount also includes construction and demolition (C&D) waste generated by households.

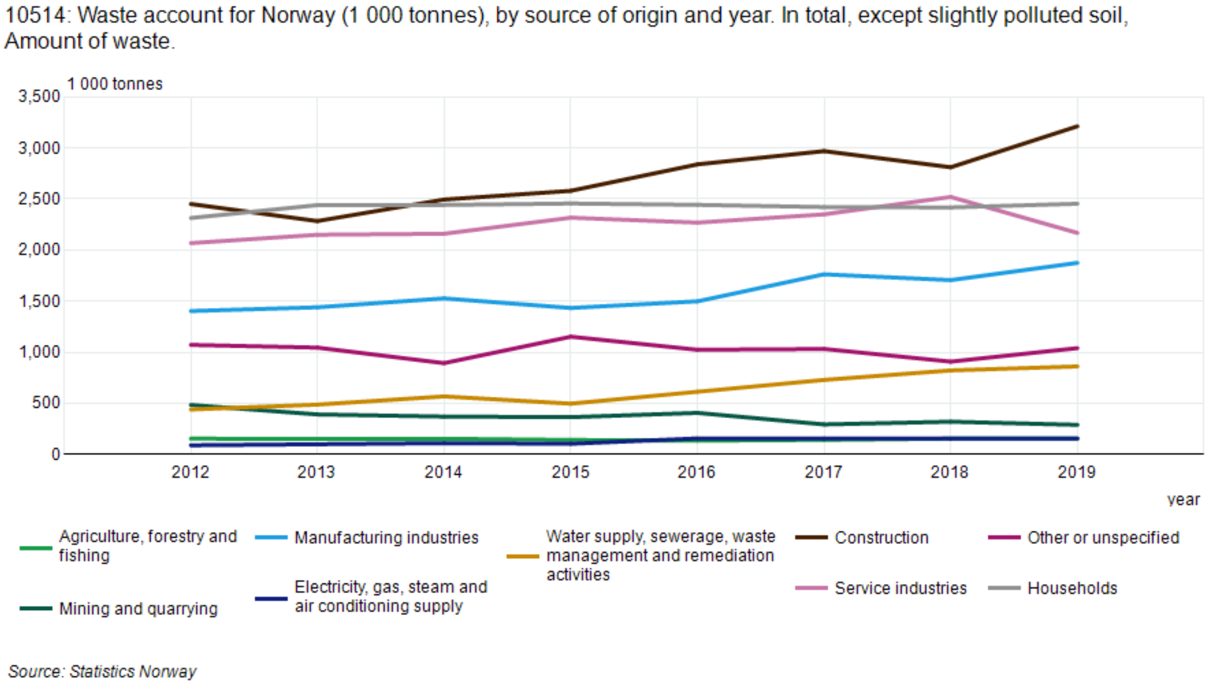


Figure 2 - Development of generated waste in Norway between 2012-2019[1].

---

[1] Source: SSB (2020) 10514: Waste account for Norway, by source of origin and material (1 000 tonnes) 2012 - 2019. Available at: https://www.ssb.no/en/statbank/table/10514/ (Accessed: 28.04.2021)

In 2019[1], the per capita generated household waste was 427 kg, which was 1,5% more than in 2018 (SSB, 2020c). Even though household consumption has been increasing, per capital waste production has remained relatively stable. One of the reasons is that households are consuming more digital media instead of newsprint (Olbergsveen, 2019).

Statistics (SSB, 2020b) on the composition of municipal waste in 2020 show that 48% of household waste was residual waste, while recyclable waste accounted for 52%[2] (Figure 3). Residual waste is the waste that is left once recyclables have been separated.

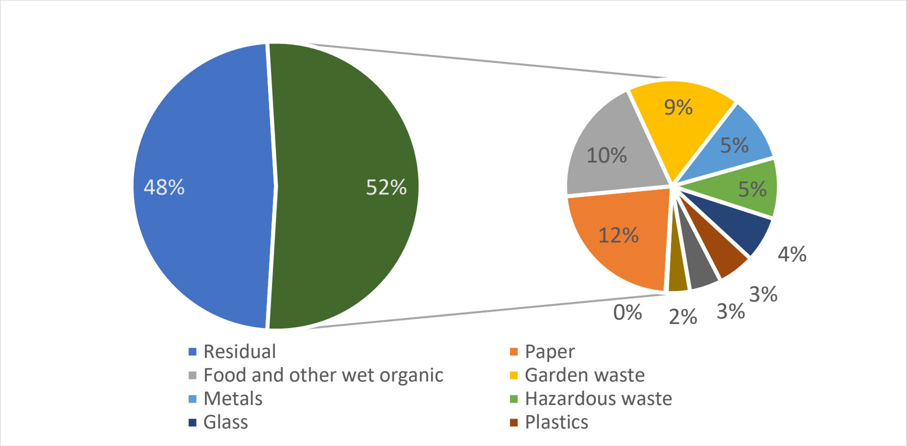


Figure 3 - Composition of sorted municipal waste in 2020[3].

Regarding waste treatment in 2020 (SSB, 2020b); 52% of municipal waste was sent to incineration, 46% to material recovery (incl. material recycling, biomass production and composting) and 2% to landfill (Figure 4). As the numbers indicate, not all source separated waste was delivered to material recycling.

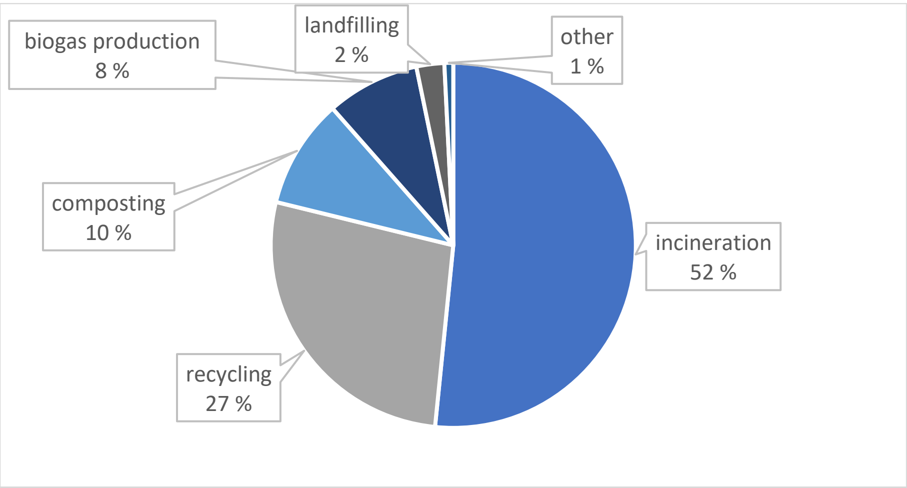


Figure 4 - Household waste by treatment

---

[1] Note: Statistics Norway will publish waste statistics for the year 2020 on 6th July 2021, which is after this master thesis is handed in. Therefore, 2019 estimates are used.

[2] Excluding: Plaster, tree, construction waste, polluted masses and car tires generated by households and but not considered as municipal waste.

[3] Source: SSB (2020) 12313: Household waste, by material and treatment (M) 2015 – 2019. Available at: https://www.ssb.no/en/statbank/table/12313/ (Accessed: 29.10.2020).

By comparing Norway with other European countries, Figure 5 shows that in 2019, Norway had the third highest per capita municipal waste generation rate (776 kg/capita) after Denmark (791 kg/capita) and Luxemburg (844 kg/capita). The EU-27 average is 502 kg/capita. However, due to differences in framework conditions and waste management systems, it is challenging to provide accurate statistical comparison of European countries. Furthermore, as it was highlighted by Avfall Norge[1] (2019), Statistics Norway included C&D waste in its Eurostat reporting since 2016. This could be a reason why Norway has such a high per capita waste generation rate compared to the average. By underlining these differences in how countries report their waste statistics to Eurostat, one can raise the question; how accurate it is to measure and compare the performance of national MSWM across Europe?

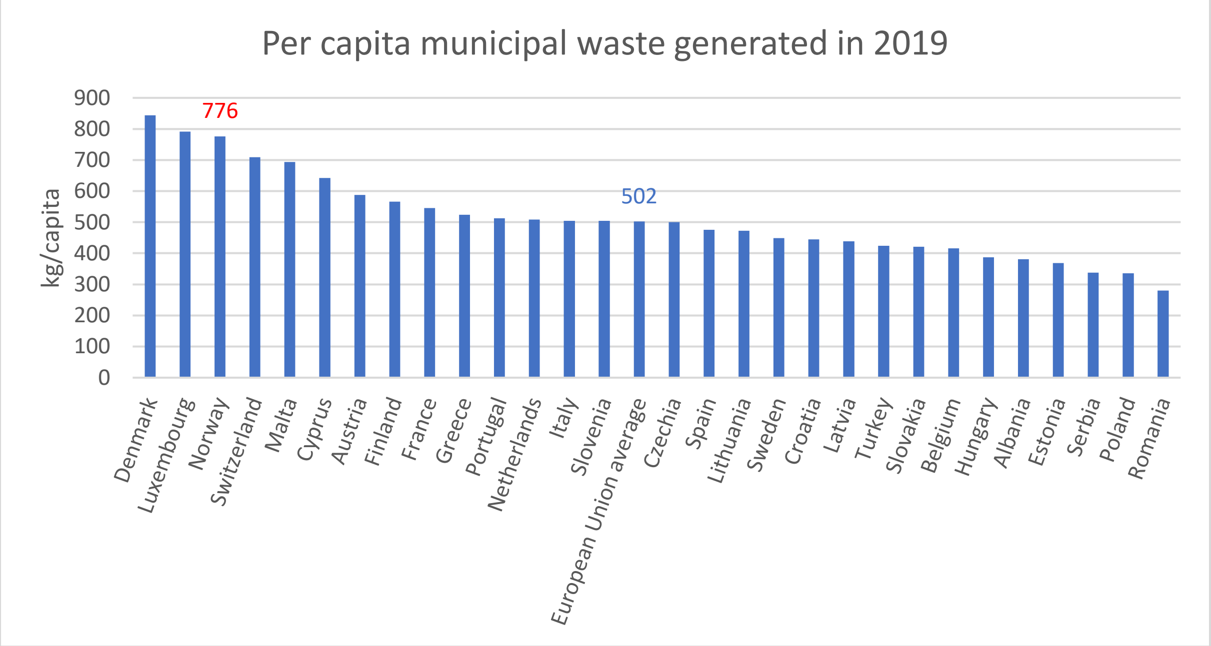


Figure 5 - Per capital municipal waste generated in the European Economic Area in 2017[2].

2.3.2. Municipal waste management in Norway

In Norway, the Pollution Control Act (Forurensningsloven)[3] gives a monopoly to municipalities on the collection of municipal waste. However, private actors can apply for municipal permission to operate. These actors usually collect residual waste from housing associations (borettslag) and from private renovation activities. Collected waste amounts are not reported in national statistics. Municipalities have the authority to decide the format of the MSWM system, either at the individual or inter-municipal level. Due to low population density, human settlements are spread across big territories which makes inter-communal waste management more resource effective (Olbergsveen, 2019).

Currently, four main waste types are under municipal waste management (Figure 6). The Pollution Control Act defines *household waste*, as waste from private households, including larger objects such as furniture. *Commercial waste* is defined as waste from public and private

---

[1] Branch organisation of waste and recycling industries in Norway.

[2] Source: Eurostat (2020) Generation of municipal waste per capita. Available at: https://ec.europa.eu/eurostat/databrowser/view/env_wasmun/default/table?lang=en (Accessed: 29.10.2020)

[3] Lov om vern mot forurensninger og om avfall (forurensningsloven). LOV-1981-03-13-6. Available at: https://lovdata.no/dokument/NL/lov/1981-03-13-6 (Accesses: 20.10.2020)

enterprises and institutions, *similar in nature and composition* to household waste. Together they count as **municipal waste,** as it is defined in the WFD. *Construction and demolition waste*, (originated from both households and commercial activities) includes waste from construction activities as well as materials and objects from demolition or rehabilitation of buildings. C&D waste does not count as municipal waste, but it is part of the MSWM system.

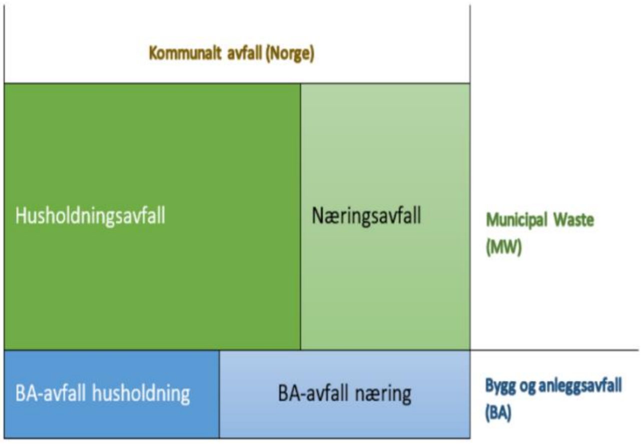


Figure 6 –Distribution of municipal waste in Norway[1].

MSWM actors are obligated to report the amount of waste they collect and deliver to treatment in the annual KOSTRA reporting scheme. Prior to 2021, there were some waste accounting and reporting inconsistencies regarding municipal waste. This has been resolved by unifying the accounting system, which entails that household and similar commercial waste must be reported separately per waste and treatment types. Eventually this would establish an administrative framework for keeping waste accounts based on municipal waste. Thereby ensuring that EU targets are calculated on an equal basis.

Regarding the amount of waste prepared for re-use, Norwegian statistics are lacking clarity. First, there is no national reporting scheme in place to register EoL products that are directly delivered to re-use or are prepared for re-use by repairing, controlling, or cleaning them. These could be reported together with other waste fractions in KOSTRA. Even though most of the reusable EoL products originate from households, they are not directly under municipal management. There are various organisations that collect reusable and recyclable textiles, shoes, and other products. Collectors bare the responsibility of preparing these products for re-use or recycling. They only make agreements with municipalities to place their containers out at recycling stations (Avfall Norge, 2019).

To address this issue, the European Commission has decided to implement a new measurement to promote re-use in Member States by laying down a common methodology and format for reporting on re-use (Klima- og miljødepartementet, 2021). It is proposed that from 2021 onwards the re-use activity shall be measured and reported on a yearly basis for products, such as textiles, electrical and electronic equipment, furniture and building materials. The national strategy for adopting such a reporting scheme in Norway is still a work in progress.

---

[1] The figure was adopted from Avfall Norge (2019). Explanation of the figure: Kommunalt Avfall (Norge) = Municipal Waste (Norway); Husholdningsavfall = Household waste; Næringsavfall= Commercial waste similar to household waste, BA-avfall husholdning = Construction and demolition waste from households; BA-avfall næring = Construction and demolition waste from commercial activities

Returning to waste accounting; *tracing material flows based on statistical data is challenging and associated with high level of uncertainties*. The reported amounts of waste delivered to recycling are not corrected for contamination, rejects due to quality issues, and failed sorting in other types of waste. This adjustment could be done by conducting regular *waste analysis* on municipal waste collected from different source (households, vacation homes, municipal and commercial institutions, recycling stations etc.) (Avfall Norge, 2019). As it was outlined in Section 2.2, targets for recycling shall be calculated either as the weight of waste that enters recycling operation or as the recyclable output of sorting operations. However, the lack of information from downstream actors makes it challenging to estimate material recycling rates with lower levels of uncertainty.

2.4. Analysis of solid waste management systems

Modern MSWM systems utilise various location and waste type specific technologies during collection and treatment operations. This not only influences logistics and operation costs but also the sustainability performance of management alternatives. Therefore, it is necessary that local and national level decision-makings are supported by analytical tools that can tackle such complexities. This is done by assessing the current performance and potential effectiveness of future waste management measures (Turner, Williams and Kemp, 2016). Material flow analysis (MFA) and life cycle assessment (LCA) are popular methodologies to evaluate the environmental performance of complex and multi-waste stream MSWM systems.

Brunner and Rechberger (2004) define MFA as “a systematic assessment of the flows and stocks of materials within a system defined in space and time”. It delivers a complete and consistent overview on all the inflows, outflows, and stocks of materials within a defined system based on the mass balance principle. Meaning that inflows must equal to the sum of the stocks and outflows. In a multi-layer MFA model, flows are first quantified as masses of materials, then the associated energy requirements and emission are calculated for each flow.

LCA is similar in nature to MFA in a sense that it also quantifies the inflows and outflows of materials within a defined system boundary. The main difference between these two methodologies is that MFA accounts for the total amount of material flows and stocks within a defined system, usually over a one-year period. LCA calculations are based on one unit of input/output, (commonly called as the function unit) across all the lifecycle stages of a defined product system. The main goal of an LCA study is to quantify the environmental impact associated with the material and energy requirements of a product system per functional unit. In MSWM LCA studies the functional unit is often defined as 1 tonne waste that must be treated.

There have been two main studies conducted in the European context using the combined MFA/LCA method for analysis of MSWM systems (Turner, Williams and Kemp, 2016; M. Haupt, Kägi and Hellweg, 2018). A common structure of these studies is that first a static MFA approach is applied to quantify the mass balance of the existing MSWM system. This is followed by the quantitative assessment of the environmental impacts, usually climate change impact, by utilising information from life cycle inventory datasets and literature. Finally, different future scenarios are modelled to compare the existing system efficiencies with alternatives. This approach has a strong focus on comparing different waste treatment alternatives and substituted products from an environmental perspective. This process requires detailed local and site-specific inventory data.

This study aims at analysing the performance of a MSWM based on material use, recycling rates and associated GHG emission in line with shifting to more circular material use in the economy. The multi-layer MFA framework offers a methodology to capture these indicators.

Similar to the combined MFA/LCA approach, the waste management system and downstream treatment and product systems are linked by waste flows and associated emission (de Sadeleer, Brattebø and Callewaert, 2020a). However, in a multi-layer MFA, GHG emission are calculated by gathering information from LCA literature and applied on the quantified material or energy layers.

In the Norwegian context, one of the most comprehensive studies on using the multi-layer MFA method for *Analysing the sustainability performance and critical improvement factors of urban municipal waste systems* was conducted by Pieter Callewaert (2017). He used RoAF, a Norwegian IKS, as a case study. Overall, he aimed to analyse the environmental performance of RoAF based on three relevant circular economy indicators: *material recycling efficiency, energy efficiency and generated/avoided GHG emission*. Callewaert developed a generic MSWM model in Microsoft Excel and MATLAB, and wrote a guideline for using his open-source multi-layer MFA model for assessing other Norwegian MSWM systems (Callewaert, 2017b). de Sadeleera, Brattebø and Callewaert (2020b) also used this model when conducting a study on waste prevention, energy recovery and recycling of food waste.

Overall, the main goal of this study is to evaluate the system efficiencies of a Norwegian MSWM system and analyse how the efficient management of such systems can improve the material circularity in the economy. Since this current study is similar in scope to the two mentioned above, instead of developing a new modelling approach, the *multi-layer MFA model developed by Pieter Callewaert (2017) will be used to calculate the system efficiencies of a MSWM system*. ReMidt serves as a case study.

3. Case study

The previous chapters gave an overview on the legislative basis for municipal waste management in Europe and Norway. Furthermore, uncertainties associated with reporting waste flows and calculating recycling rates have been outlined. It was pointed out that the multi-layer MFA methodology can be used as an effective tool to address these issues. In the following chapter, the case study of ReMidt will be presented to understand how these aspects impact MSWM at an inter-municipal level.

3.1. ReMidt

ReMidt is a Norwegian inter-municipal company owned by 17 municipalities in parts of Trøndelag and Møre and Romsdal counties. It was established in January 2020 by the merging of Hamos, NIR and Envina IKSs together. Since then, ReMidt is responsible for managing the household waste of approximately 130.000 inhabitants (ReMidt IKS, 2019).

The company’s ambition is to promote sustainable resource use by providing solutions for quality source separation, re-use, and recycling of various waste types, and by cooperating with a range of downstream actors. Thereby, keeping EoL materials in circulation. ReMidt is also involved in different projects and initiatives to strengthen cooperation with stakeholders both up- and downstream of the EoL waste value chain. For instance, ReMidt Skole is an educational initiative where 4th graders learn about sustainable resource use and the environment. ReMidt is member of SeSammen and CIVAC (Circular Values Cluster). Both of which are regional initiatives aiming to strengthen cooperation, knowledge- and technology-sharing between waste-, sewage, - and recycling industries in Central Norway.

As Figure 7 and Figure 8 indicate, ReMidt operations are covering a geographically and demographically diverse region, where both urban and rural populations are provided with waste management services. Overall, 58% of inhabitants live in *urban settlements*[1] and the remaining 42% in rural settlements (SSB, 2020a). This high level of diversity makes it challenging to implement unified waste management practices across the whole ReMidt region. This challenge has been addressed by the company which is planning to unify its waste collection system between 2021 and 2023 (Limi and Evjen, 2020).

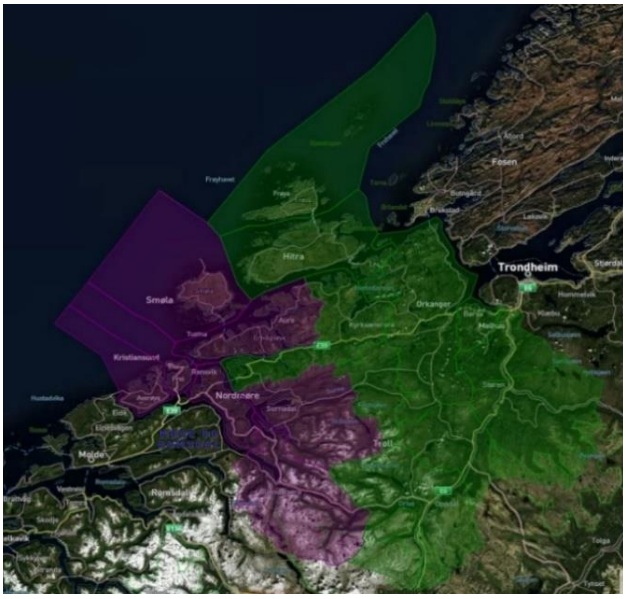


Figure 7 – Geographic variations across ReMidt municipalities[2].

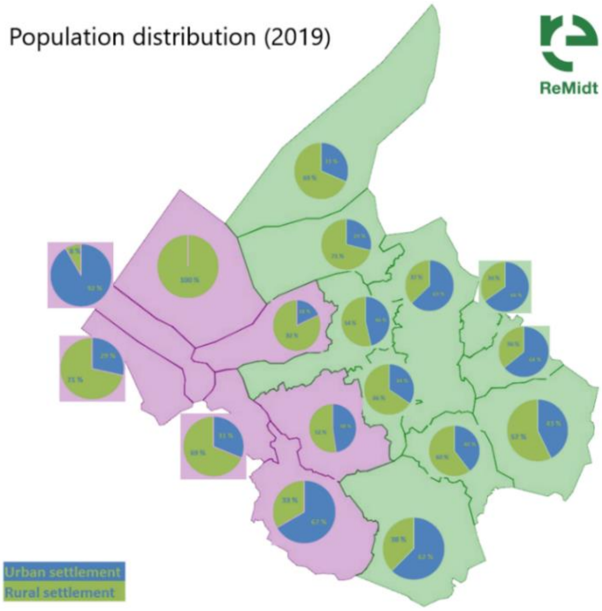


Figure 8 - Population distribution of ReMidt municipalities[3].

---

[1] Densely populated area or urban settlement denotes an area where at least 200 people live and where (with some exceptions) there is no more than 50 meters between the houses (SSB, 2020a).

[2] Map was made with an online tool developed by Norkart AS/EEA CLC2006, Mapbox, OpenStreetMap. Available at: https://kommunekart.com/ Accessed: 29.10.2020.

[3] Source: SSB (2020) 05212: Population in densely and sparsely populated areas, by sex (M) 1990 – 2020. Available at: https://www.ssb.no/en/statbank/table/05212/ (Accessed: 29.10.2020.)

3.2. Waste sorting and collection

Municipal waste can be sorted at source and at sorting facilities. Source sorting means that municipal waste is sorted by type at the point of waste generation, thereby helping to generate cleaner waste streams. Sorting facilities are responsible for separating recyclable fractions from mixed waste streams. Currently, paper and cardboard, plastic, and glass and metal packaging are sent to sorting facilities operated by downstream actors in Norway and abroad. Sorting solutions for residual waste is currently not available in Central Norway. However, a central sorting facility - Project SESAM - is expected to be built in the region in the upcoming years.

There are four main systems for collecting source separated municipal waste: kerbside collection system (henteordning), home composting, bring collection system (bringeordning) and deposit-refund system (panteordning). There are *nine main waste types* collected via these collection systems: residual waste; bio-waste; paper and packaging of paper & cardboard; plastic packaging; glass packaging; metal packaging; hazardous waste; waste electrical & electronic equipment (WEEE) and textiles. Bio-waste refers to food waste and garden and park waste.

These waste types can be further divided into different waste fractions. A detailed description of this division can be found under Appendix A.1.

Within the **kerbside collection system** *five different waste containers* are emptied by waste trucks at regular frequencies, throughout the year. Traditional waste bins, that can vary between 80 - 660 litres[1], are used for residual waste (RW), paper and cardboard packaging (P&C), glass- and metal packaging (G&M) and food waste (FW) (Figure 9). Special brown bags are provided for FW collection to keep the bin clean. Plastic packaging (P) is collected in plastic bags.

Figure 9 - Traditional waste bins (FW, G&M, P&C, RW) and plastic packaging bag (P). Source: remidt.no

As it was mentioned in the previous section, not all ReMidt municipalities have the same collection system. Figure 10 summarises the kerbside collection system each municipality had in 2020. Those municipalities with similar collection schemes are compiled together. All municipalities had a container for RW and P&C and plastic bag for P. Four (Smøla, Kristiansund, Sunndal, Oppdal) out of 17 municipalities had kerbside G&M collection. There was only one municipality (Tingvoll) where FW collection was in place. In the 16 other municipalities food waste fractions were sorted in the RW bin and delivered to incineration. To unify the kerbside collection system and to increase material recycling rates, from 2023 onwards all ReMidt municipalities will have the same five container system, described above.

---

[1] In addition to the traditional containers, waste is also collected in bottom-emptying (bunntømt) containers.

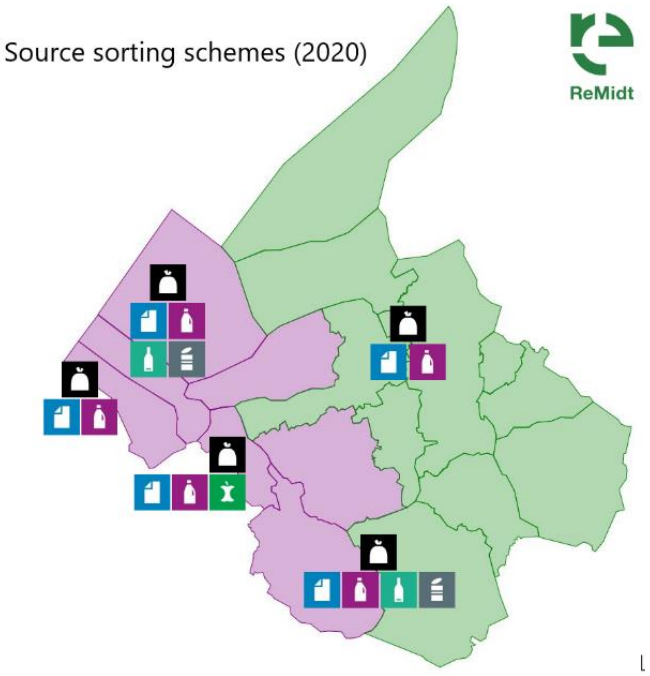


Figure 10 - Municipal waste separation scheme[1].

In addition to kerbside collection, 14 out of 17 municipalities have introduced **home composting schemes.** This means that households can make an agreement with ReMidt on collecting and utilising bio-waste as compost. In return they pay a reduced waste fee. ReMidt also offers courses and subsidises the equipment needed for home composting (ReMidt IKS, 2020). Home composting can be included in material recycling rate calculations according to the WFD.

Garden and park (G&P), wood, hazardous, WEEE and textile waste are collected within the **bring collection system**, which includes collection points (returpunkt) and recycling stations (gjenvinningsstasjon). MSWM companies are responsible for collecting garden and hazardous waste by law. In 2020, 923.48 tonnes garden and park waste were collected and delivered to composting by ReMidt. Currently, ReMidt does not have a kerbside collection system for garden and park waste. Customers must deliver them to recycling stations. In Okland and Melhus+MG regions customers can order a waste taxi free of charge which collects various waste types, including garden and park waste. In addition, G&M packaging is also collected withing the bring system. In 2020, 13 out of 17 municipalities did not have G&M kerbside collection. In these municipalities, glass and metal packaging was collected at collection points operated by external actors (Figure 11).

Producer responsibility organisations are responsible for collecting and delivering WEEE and textile waste to treatment. This is the same order for the **deposit-refund system** for plastic bottles and aluminium beverage containers. Other types of waste[2] and reusable articles can be delivered to recycling stations or second-hand stores (bruktbutikk). There are 23 recycling stations and one second-hand store (in Melhus) under ReMidt jurisdiction (see Figure 12). 11

---

[1] Municipalities with similar sorting schemes are compiled together. Source: Sortere (2020) Available at: https://sortere.no/ (Accessed: 29.10.2020)

[2] Three NTNU students, Karlsen, Medeiros and Solheim who were interning at the Trøndelag county office during summer 2020, summarised the types of waste collected at recycling stations in Trøndelag (see: Appendix A.2)

out of the 23 recycling stations in Kristiansund, Orkland, Sunndal and Tingvoll municipalities have set up containers where re-usable products can be picked up, free of charge.

Figure 11 - Surface containers for G&M. Source: remidt.no

According to Tøybleietilskudd.no, 9 out of 17 ReMidt municipalities offer cloth diaper grants (tøybleietilskudd). This means that residents of these municipalities can apply for refund from ReMidt for buying reusable cloth diapers. ReMidt is also responsible for collecting sewage sludge, C&D and various other types of household waste. However, as it was quoted from the WFD in Section 2.2, municipal waste does not include "waste from production, agriculture, forestry, fishing, septic tanks and sewage network and treatment, including sewage sludge, end-of-life vehicles or construction and demolition waste".

Figure 12 - Recycling station and second-hand store locations. Source: remidt.no.

3.3. Waste collection and treatment

Each of the five main waste types collected within the kerbside system has its own either on-ground bin or underground container system. These are emptied in various frequencies. Waste collection trucks can be equipped with different chamber technologies. Two-chamber technology means that the waste truck can collect two waste types separately at the same type. Thereby, reducing transport distances and fuel consumption. Waste types, that are outside of the kerbside collection scheme are either collected at collection points or customers deliver them directly to recycling stations.

Household waste is collected by 31 waste trucks owned by ReTrans AS, a daughter company of ReMidt and other subcontractors (Limi and Evjen, 2020). G&M is collected by Veglo AS from collection points. Transport distances and associated transport fuel use are influenced by the chamber technology and collection frequencies.

ReMidt operations are divided into seven regions (Table 1).

Table 1 - Division of ReMidt municipalities

Hitra	Orkland	Surnadal	Kristiansund (city)	Kristiansund (rural)	Oppdal	Sunndal	Melhus+MG
Hitra Frøya	Heim Rennebu Orkland Rindal Skaun	Surndal Tingvoll	Kristiansund	Aure Averøy Smøla	Oppdal	Sunndal	Melhus Midtre Gauldal

Table 2 outlines the differences in kerbside collection systems and collection frequencies. Two-chamber technology is used to collect two waste types during a collection round. As the table indicates, in most of the municipalities waste containers with paper and cardboard packaging were collected with plastic packaging bags in 2020. In Oppdal, residual waste was collected either with glass and metal packaging or with plastic packaging in every 13 weeks.

Table 2 - Kerbside collection systems and collection frequencies, 2020

Collection frequency (route/region/year)	RW	G&M	P&C	P	FW	Types collected together*
Hitra	26		13*			P&C + P
Orkland	26		13*			P&C + P
Surnadal						
Surnadal	*26*		*13**			P&C + P
Tingvoll	*26*		*13**		*13*	P&C + P
Kr.Sund_city	13		13*			P&C + P
Kr.Sund_rural						
Aure	*26*		*13*	*6*		
Averøya	*26*		*13**			P&C + P
Smøla	*26*	*6*	*13*	*6*		
Oppdal	13*		26	13*		RW+G&M and RW+P
Sunndal	26	6	13*			
Melhus	26		13*			P&C + P

After collection, residual waste is sent to reloading and then further to incineration (with energy recovery) to Statkraft Varme in Heimdal and Tafjord Kraft AS, in Ålesund. According to Morten Einar Nyrø Fossum from Morten Fossum, Statkraft Varme AS, about 100-115 kwh electricity per tonne waste is needed for the incineration processes at their facility which runs with 85% efficiency. Information from Tafjord Kraft AS was not collected.

After kerbside collection, source separated waste types are transported to the nearest reloading station before being sent to further sorting or treatment. From reloading, *paper and cardboard and plastic packaging* (Figure 13 and Figure 14) are sent to the sorting facility at Retura TRV in Heimdal to remove contamination and prepare clean fractions for further sorting and treatment. According to Per Inge Engan, Quality and Development Director at Retura TRV, the annual energy use of sorting and preparing one tonne of waste is ~16.98 kwh electricity and ~1,38 litre diesel.

Paper and cardboard are sorted and pressed before being sent to Norske Skog Saugbrugs AS paper mills in Halden, Norway. Paper recycling is an energy intensive process which requires ~ 2944 kwh electricity to recycle paper and cardboard waste into new cardboard packaging products. In some cases, materials are heavily contaminated, and therefore cannot be recycled but are sent to incineration (Norsk Resy, 2018). Based on Grønn Punkt Norway estimates (2019), on average 55.8% of cardboard packaging is sent from sorting to final recycling and the rest is incinerated.

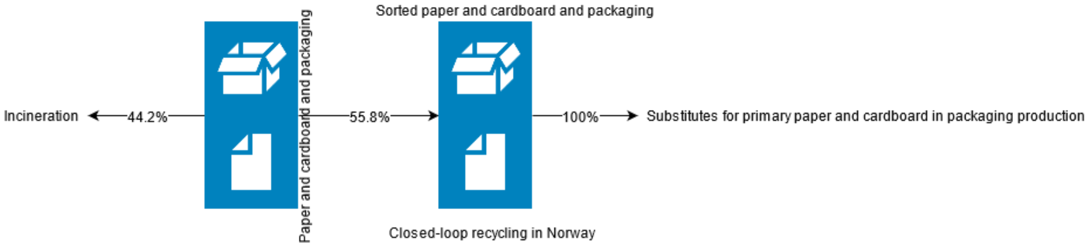


Figure 13 – Downstream flows of paper and cardboard and packaging waste

Grønn Punkt Norway is responsible for preparing *plastic packaging* for recycling by sorting it into different polymer types that are suitable for recycling. This happens in Germany now but if the sorting facility is built in Central Norway this could be done regionally. RoAf is operating one of the biggest central sorting facilities in Norway. This CS facility sorts out LDPE-folie, HDPE, PP, PET bottles but not PET boxes (salat boxes, some of the meat packaging etc.) because the chemical complexities of such products or due to contaminations. Non-recyclable fractions are sent to incineration. After sorting, the plastic ballets with 95-97% clearness are sold to recyclers, that process and sell them as granulates to the market (Watnebryn and Fredriksen, 2018). Based on Ecoinvent data on German average polyethylene production, the recycling of 1 tonne plastic packaging waste into pellets used to produce new packaging requires 489 kwh electricity. 76.67 kwh from natural gas and 0.03 kwh from propane. According to estimates from Grønn Punkt Norway (2021), of all source separated plastic packaging from households that go into sorting plants abroad, 65.7% is sent to material recycling but only 33.5% is actually recycled as secondary raw material. This means that both sorting and recycling processes operate with low efficiencies. The quality of plastic products and the low market price of virgin plastic are important factors that lead to the low level of circularity of EoL plastics.

Figure 14 - Downstream flows of plastic packaging waste

Glass and metal packaging (Figure 15) is transported by external actors to Sirkel AS in Fredrikstad for sorting and treatment. According to Espen Sandsdalen (2021), Factory and development manager at Sirkel Glass AS, the incoming G&M packaging contains 83% glass, 10% metal and 7% other fractions (ceramics, porcelain, plastic, paper and other organic materials). Materials are first separated manually and then automatically. The annual energy consumption per tonne of G&M packaging sorted by Sirkel AS can be summarized as follows: 17 kwh / ton electricity per finished product and 3.5 Nm^3 biogas / tonne in the drying process. Drying of moist goods is necessary for sorting accurately (Sandsdalen, 2021). Clear, green, and brown glass fractions between the dimensions of 5-45 mm, make up ~75% of glass inflows. These are exported to glassworks in Europe for recycling as glass packaging (bottles). Fractions between 0-5mm, ~25% of the total inflow, are used as raw materials by Glasopor building material production in Skjåk, Norway. According to Svein Lund, Development Manager at Glasopor AS, the production process requires ~1015 kwh energy / tonne material which can be divided into 50% electricity and 50% propane. The remaining 7% of G&M packaging waste is considered as contamination and is delivered to landfill. According to Ylva Eline Erbach, CEO of Norsk Metallgjenvinning AS, metal packaging that was sent to recycling in 2020 contained 80% steel and 20% aluminium. Steel is recycled by Metalco in Norway and aluminium is sent to Hydro in Germany for recycling.

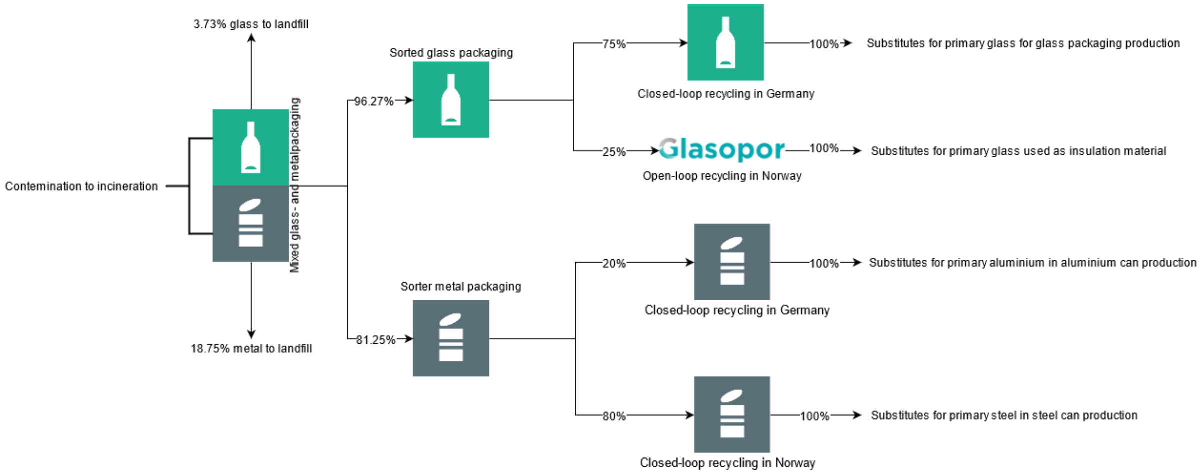


Figure 15 - Downstream flows of glass and metal packaging waste

As it was mentioned previously, PET-bottles and aluminium beverage cans are collected via deposit-refund scheme (Infinitum), which is outside of this study's system boundary.

Bio-waste can be divided into three value chains. Food waste (Figure 16) is collected from kerbside and at recycling stations and transported to Ecopro in Verdal for sorting and biogas production. Sorted contaminants are delivered to incineration at Statkraft Varme in Heimdal, while the remaining organic fractions are utilised as biogas. The organic by-product of the biogas production process is utilised as fertiliser. According to Tore Fløan, CEO of Ecopro, ~100Nm^3 biomethane can be recovered from 1 tonne of organic waste, which corresponds to 1000 kwh energy or 100 litre diesels. This process requires ~30% of the energy generated at the facility and an additional 80 kwh electricity / tonne organic waste. This energy is used for high pressure cooking to remove contaminations. Garden and park waste is collected at recycling stations and sent to downstream actors in Trondheim and Kristiansund. It was assumed in this study that 100% of garden and park waste is utilised as fertiliser without any losses. The same assumption was made for bio-waste utilised as home compost by households.

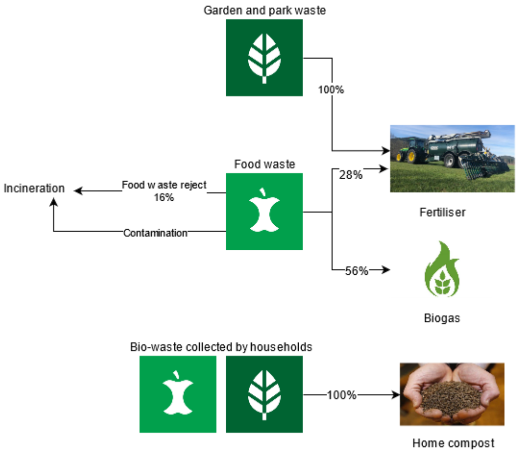


Figure 16 - Downstream flows of bio-waste

4. Method

To capture and model the complexity of a MSWM system, the multi-layer MFA methodology is used in this study which will be further explained in the following section.

4.1. Data collection and quality

The research methodologies used in this study can be divided into methods for literature review, data collection and data modelling. For the literature review section, EU Directives, peer-reviewed scientific literature, and industry/company reports served as main sources of information. Primary data for the specific case study was collected from personal communication with ReMidt employees, Ida Plassen Limi and Torbjørn Evjen. Additional information on the incineration processes at Statkraft Varme was gathered from email conversation with Morten Einar Nyrø Fossum and Sissel Hunderi. Per Inge Engan, Quality and Development Director at Retura TRV provided useful information on paper and cardboard and plastic packaging sorting in the region. Information on the biological treatment processes was provided by Tore Fløan from Ecopro. Data on G&M sorting and recycling processes was gathered from Espen Sandsdalen, factory and development manager at Sirkel Glass AS, Svein Lund, Development and Factory Manager at Glasopor AS and Ylva Eline Erbach, CEO of Norsk Metallgjenvinning AS.

Additional information, detailed calculations of the various model input parameters and model results are outlined in the Appendix. When it comes to the modelling methodology, this study is based on the work of Pieter Callewaert (2017). His *Documentation for a generic municipal solid waste management model* served as a step-by-step guide to run the model with case study specific data.

4.2. Multi-layer MFA model

As it was outlined in the introduction section, the aim of using the multi-layer material flow analysis (MFA) methodology is *to understand how the collection and treatment of different waste streams can influence material, energy, and emission flows within a MSWM system.*

As Figure 17 taken from Brunner and Rechberger (2004) shows, the first step of conducting an MFA study is problem definition, which is followed by the determination of the system boundary. This includes the selection of all the relevant flows and processes. When the system boundary is defined, the flows should be quantified. This entails the quantification and balancing of the material flows as well as transfer coefficients. Transfer coefficients (TC) describe the partitioning of a substance/material in a process. Therefore, it is a material-specific value used only in the material layer. The TC gives the percentage of the total throughput of a material that is transferred into a specific process. Finally, when all the flows and stocks are calculated then results should be interpreted, validated and uncertainties should be evaluated.

In a multi-layer MFA, when all the material flows and TCs are quantified, the energy layer is calculated. The energy layer focuses on the energy requirements and outputs of the system based on the quantified material flows. Finally, the generated and avoided emission are calculated from the quantified material and energy requirements, multiplied with GHG emission factors gathered from relevant literature. As it was highlighted in Section 2.4, no comprehensive LCA analysis was conducted, which increases the uncertainty of emission results calculated in this study.

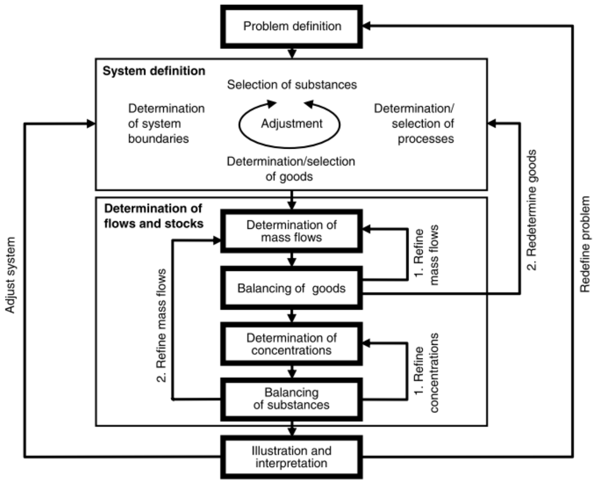


Figure 17 - MFA methodology steps, source: Brunner and Rechberger (2004)

4.3. Model

In the following section the steps of a multi-layer MFA of a waste management system will be explained through the case study of ReMidt IKS.

4.3.1. System definition

Figure 18 illustrates all waste flows and processes that are involved in the management of RW, P&C, P, G&M, FW and G&P collected by ReMidt IKS in 2020. The broader system boundary includes collection, sorting, and treatment processes. Treatment processes entail material recycling, incineration with energy recovery, thermal treatment of residues (biogas and fertilisers production), incineration bottom ash treatment, metal recovery from bottom ash, and the final disposal of residual fractions (landfill).

The system was divided into two system boundaries; one that covers only flows and processes that are under direct influence of ReMidt (orange), and a broader system boundary of the MSWM system (black). The processes are divided into five main categories: collection processes (1,2,3,19), reloading (4), sorting (5), treatment (6, 7, 8, 9, 10, 11, 17, 20) and final material markets (12, 13, 14, 15, 16, 18). Collection processes include:

- the collection of bio-waste (food and garden waste) for home composting
- the kerbside collection of RW, P&C, P, G&M and FW
- the bring collection of G&M at collection points
- the bring collection of RW, P&C, P, G&M, FW and G&P at recycling stations

Due to value-chain complexities and lack of accurate information on waste volumes, sources separated hazardous, WEEE, textile and wood waste are excluded from the system boundary. Hazardous, WEEE and textile fractions appear in relatively large quantities in residual waste, therefore these fractions will be included in the system boundary as contaminations.

From collection, waste types are transported either directly to treatment (X2-17, X1-8), or to reloading stations (X1-4) and sorting facilities (X1-5, X3-5, X19-5). From reloading, recyclable fractions are sent to sorting (X4-5). The sorting process includes the sorting of P&C and P at TRV in Heimdal and the sorting of G&M at Sirkel in Fredrikstad. From sorting, clean fractions are sent to final recycling (X5-6) and contaminations are sent to incineration (X5-8) or landfill (X5-10). From reloading FW is sent to biological treatment (X5-7), where contaminations and food waste rejects are removed, and biogas is produced from the clean FW fractions. The process generates organic by-products that can be sold as fertiliser. G&P waste is sent from reloading to composting (X4-20) and then sold on the fertiliser market. Residual waste is sent directly to incineration (X1-8; X4-8). After incineration, metals are recovered from the bottom ash (X9-11) that can be sold to the metal market.

When it comes to recycling and material substitution the picture is more diverse. The concept of circular economy assumes that closed material cycles are preferred to improve material circularity in the economy. However, a study conducted by Haupt, Kägi and Hellweg (2018) shows that open-loop recycling can yield to higher environmental credits. In this study it is assumed that some waste types are treated in a closed-loop and others in an open-loop recycling system. This division is based on whether primary information could be gathered directly from downstream actors or not. For paper and cardboard (Figure 13) and plastic packaging (Figure 14) closed-looped recycling is assumed because of lack of primary data. Meaning that the recovered secondary materials will be utilised again as packing. For glass packaging (Figure 15) the combination of open- and closed loop recycling is assumed: ~75% of the glass inflows are recycled as glass packaging abroad (closed-loop), while ~25% is utilised as Glasopor building material in Norway (open-loop). Regarding metal packaging (Figure 15), both aluminium and steel are recycled in a closed-loop system to make new beverage cans. For bio-waste (Figure 16), the generated biogas from food waste substitutes for fossil diesel and the fertiliser substitutes for synthetic fertiliser. Mixed bio-waste collected by households replacing the need of new soil. The composting of garden and park waste substitutes for fertilisers.

Regarding incineration, the generated heat from burning waste at the incineration plant at Statkraft Varme and Tafjord Kraft substitutes for the use of 46.2% electricity, 45.5% LPG and 8.3% fuel types with biological origin (calculations are found under Appendix A.10.4). Since none of these incinerators generated power, only heat generation will be substituted with the energy recovered from waste. Specific information was not gathered from Tafjord Kraft.

Regarding GHG emissions calculations, results were not adjusted for bio-carbon. Landfill emission was excluded because accurate information on the how much GHG emission is coming from the disposal of bottom ash after metal recovery could not be found.

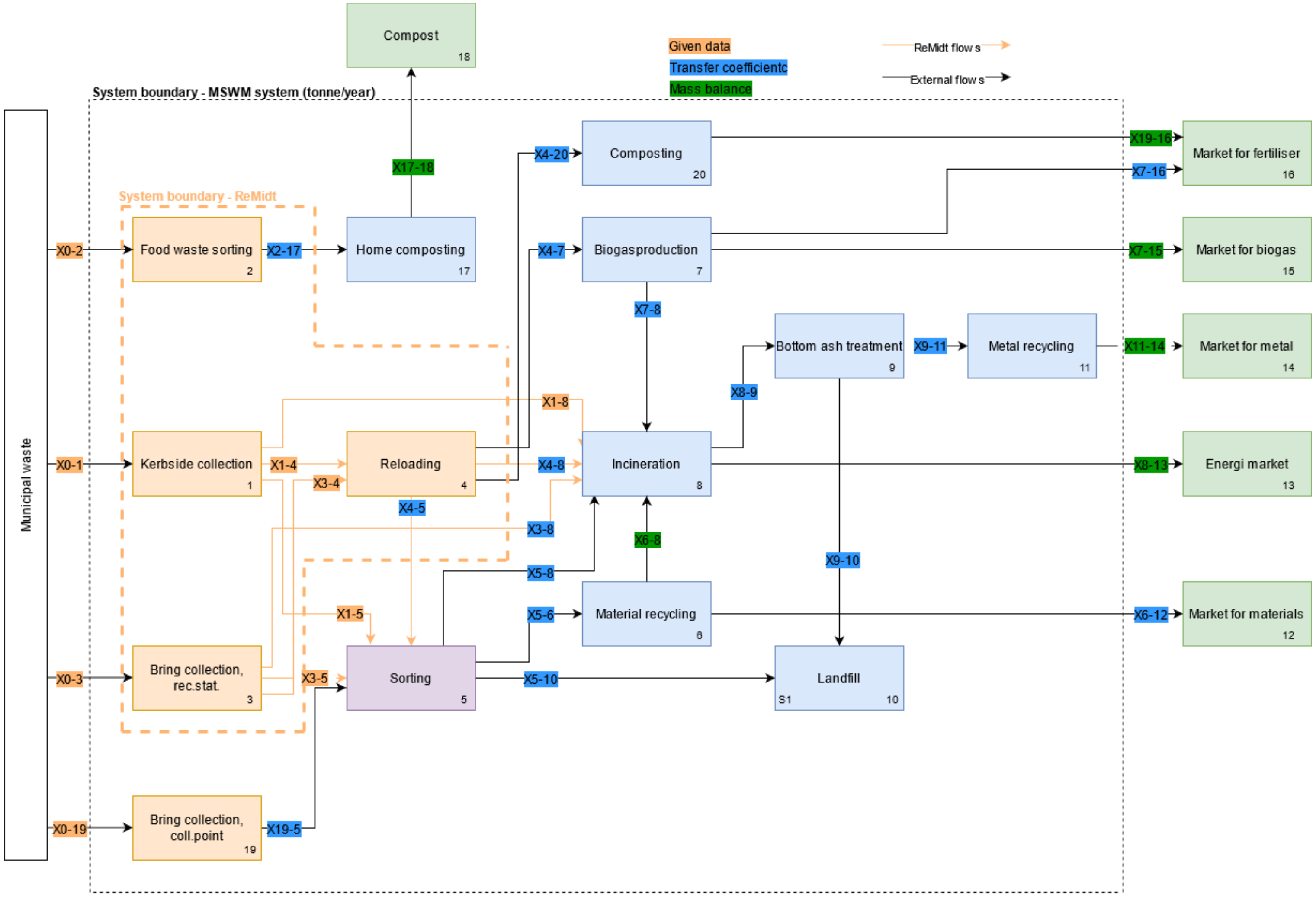


Figure 18 – Municipal waste management system, Baseline 2020

4.4. System efficiency parameter estimations

4.4.1.1. Material layer

To quantify the material layer, the input of known waste flows and TCs are needed. The detailed list of sources and calculations are listed under Appendix A.4.1-A.4.2.

The performance of the material layer is measured by the *collection efficiency, material recycling efficiency and the rate of preparing waste for recycling.*

Collection efficiency

Collection efficiency measures the amount of waste collected correctly over the total amount of municipal waste generated each year and is calculated by:

$$\eta_{coll} = \frac{\sum_j \sum_a X_{0a,i=j}}{\sum_j \sum_i \sum_a X_{0a,ij}},$$

where vector a represents all the collection processes, and i determines the correct collection bin for fraction j.

If a company has high rate of collection efficiency, it means that the different waste fractions are sorted in the correct waste container. It is important to highlight that collection efficiency calculations do not account for waste quality. Therefore, the assumption is that all recyclables should be separately collected at source and rejects would be removed during sorting and recycling operations. Since waste collection is the only process that ReMidt was directly involved in 2020, collection efficiency can serve as a useful indicator to measure the performance of ReMidt operations.

Callewaert (2017) refers to the type of bin or container solution in MSWM systems as collection technologies, which can influence collection efficiency. To evaluate the effectiveness of such technologies it is necessary to conduct regular waste analysis. Such analysis has not yet been carried out by ReMidt. There is a limited number of studies (Saxegaard and Hansen, 2013; Syed and Hovland, 2018) focusing on the impact of collection technologies on improved collection efficiency in Norway. The study carried out by Saxegaard and Hansen (2013) indicates that neither underground waste containers nor vacuum systems[23] yield to cleaner waste streams. It is because incorrect source sorting influences the most the quality of waste streams. However, these state of the art solutions are considered to be advantegous, especially in bigger cities with dense population because they hinder the spread of litter around the collection sites.

Due to lack of information, this study does not consider collection technologies in collection efficiency calculations. This could be adjusted in the future when more specific data is acquired.

Material recycling efficiency

The *material recycling efficiency* refers to "the amount of municipal waste recycled over the total amount of municipal waste generated". It is an important circular economy indicator which shows how much of the generated waste is utilised as secondary raw material in the economy (Section 2.1).

---

[23] The main difference between the underground container and vacuum systems is that in the first one each waste type has its own container. While in the vacuum solution, the different waste types are all thrown into the same bin which is the entrance of a tube system that creates a vacuum to transport the bags to a common underground collection site.

It is calculated by;

$$\eta_{rec} = \frac{\sum_j \sum_i (\sum_c X_{xc,ij} + \sum_d X_{xd,ij})}{\sum_j \sum_i \sum_a X_{0a,ij}},$$

where *c* vector represents the material market and *d* vector the bioenergy market.

Material markets include all the paper and cardboard, plastic, glass- and metal packaging that is recycled, bio-rests from biogas production and garden and park waste utilised as fertilisers, metal recovered from incineration bottom ash, and compost generated from food waste at household level. According to the WFD, biogas production should be accounted for as a material recycling process, because it generates fuel as end-product.

When it comes to FW treatment, the model allows to calculate material recycling rates based on the dry matter content of FW. The formula for calculating the dry matter adjusted recycling efficiency rate is the following:

$$\eta_{rec\_adj} = \frac{\sum_j \sum_i \sum_{c(} X_{x'c,ij} + \sum_y ((X_{yc,ij} + X_{yz,ij}) * f_y))}{\sum_j \sum_i \sum_a X_{0a,ij}},$$

where *y* vector represents all the biological treatment processes and vector *z* their biological energy/fertiliser markets. f_y is the dry matter factor which is calculated by dividing the dry matter in the input with the dry matter in the output. The dry matter content of both the incoming food waste and output are assumed to be 35% (Arnøy, Modahl and Lyng, 2013). This formula was only applied to biogas production and not for composting.

Rate of preparing for recycling

The third system efficiency indicator measures the *rate of preparing for recycling* (hereafter referred as preparation rate). Summarised in Section 2.2, the WFD defines common targets for the activity of preparing waste for re-use and recycling. Due to lack of accurate information on the total amount of municipal waste delivered to re-use, in this study only recycling is considered as a treatment alternative to recover materials from municipal waste. In the model, the following formula is used to calculate the preparation rate:

$$\eta_{prep\_rate} = \frac{\sum_j \sum_i \sum_{gj} X_{xgj,ij}}{\sum_j \sum_i \sum_a X_{0a,ij}},$$

where g_j is the vector that shows the recycling process to which ReMidt sends waste type j.

The main difference between the *material recycling efficiency* and the *rate of preparing for recycling* is that according to the WFD the preparation activity should be measured at the point where material flows leave the sorting operations with the intend to be recycled. This means that losses occurring during final recycling processes are excluded. Material recycling efficiency measures the amount of waste that is recycled back to the economy as secondary raw materials. Losses occurring during recycling are reflected on the material recycling efficiency.

4.4.2. Energy layer

The energy layer is created from the energy requirements and outputs of the system which are divided to two categories: energy needed for collecting, sorting, and treating waste (transport and process energy) and energy generated by treating waste (generated energy).

Transport energy

The first step is to calculate the energy requirement of the transport processes. This includes both waste collection as well as the transportation of waste to sorting and further treatment. Primary data was collected on annual diesel consumption and kilometrage of the waste trucks operated by former ReMidt companies in 2019. Information on the downstream transportation coordinated by external actors is based on various secondary sources that are summarised in Appendix A.4.3.

The main formula used to calculate transport energy requirements is the following:

$$\boldsymbol{Transport\ energy}_{\boldsymbol{ab,i,f}}\left(\frac{\boldsymbol{kWh}}{\boldsymbol{yr}}\right) = Energy\ intenisty_{ab,i,f}\left(\frac{kWh}{tkm}\right) * Weight_{ab,i}\left(\frac{t}{yr}\right) * Distance_{ab,i}(km) * S_f$$

where *f* is the specific fuel type used by the waste trucks.

As the equation shows, transport energy is based on the material layer and calculated by multiplying each flow with its energy intensity and transport distance. The energy intensities are calculated differently for kerbside collection and downstream transport. For kerbside collection route distances are used, while for downstream processes it would be the distance between two processes. For instance, the distance between the sorting and recycling facilities. Route distance refers to the amount of km a waste truck drives during a collection round. Route distances differ by municipality and/or regions but are the same for all the waste types. As it was pointed out in the previous section, there is a regional difference in whether various waste types are collected together or by itself. For instance, a truck with two-chamber technology can pick up two waste types at the same time which reduces the need to drive around more. This eventually leads to lower energy consumption per waste type. The energy intensity of the waste types collected within the kerbside collection system are calculated by the following equation:

$$\boldsymbol{Energy\ intensity}_{\boldsymbol{f,t,i}}\left(\frac{\boldsymbol{kWh}}{\boldsymbol{yr}}\right) = \frac{Energy\ consumption_{f,t,i}\left(\frac{kWh}{yr}\right)}{Weight_{f,t,i}\left(\frac{t}{yr}\right) * route\ distance_{f,t,i}(km)}$$

Where *f* is the specific fuel type, *t* refers to the region/municipality and *i* for the waste type.

Process energy

Process energy for process *p*, waste type *i* and energy carrier *f* is calculated by:

$$\boldsymbol{Process\ energy}_{\boldsymbol{p,i,f}}\left(\frac{\boldsymbol{kWh}}{\boldsymbol{yr}}\right) = Weight_{p,i}\left(\frac{t}{yr}\right) * energy\ requirement_{p,i,f}\left(\frac{kWh}{t}\right)$$

The process specific energy requirements were outlined in Section 3.3.

Recovered energy

Energy form waste can be recovered via incineration and biogas production.

Recovered energy from incineration refers to the energy output of the incineration process for waste type *i* and fraction *j* and is calculated by:

$$\boldsymbol{Recovered\ energy}_{\boldsymbol{i,j}}\left(\frac{\boldsymbol{kWh}}{\boldsymbol{yr}}\right) = Waste\ inflow_{i,j}\left(\frac{t}{yr}\right) * LHV_j\left(\frac{kWh}{t}\right) * Energy\ efficiency$$

The waste fraction specific lower heating values (LHV) gives a theoretical estimate on how much energy can be recovered through combustion. LHV is the energy content of waste (higher heating value) minus the energy needed to evaporate all water, which contributes to the energy output in the form of water vapour (Christensen, 2011). Energy efficiency refers to the maximum energy recovery potential of Statkraft Varme incinerator plant which is ~85% (Fossum, 2021).

The actual recovered energy potential of the incineration plant is calculated by multiplying the maximum energy recovery potential (energiutnyttelsesgrad) with the energy efficiency rate (virkningssgrad): 85%*80%=68% (Arnøy, Modahl and Lyng, 2013). In this study the maximum energy recovery rate is used to make it comparable to the material recovery rates. Due to lack of information about waste specific material recovery rates at recycling facilities, it was assumed that 100% of the source separated fractions sent to recycling are recycled (exception is plastic packaging and food waste).

Energy recovery through biogas generation from food waste is calculated by multiplying the waste flow with the methane yield of the waste type, the energy efficiency of the biological treatment plans and the LHV of methane:

$$\boldsymbol{Biogas\ out}_i\left(\frac{\boldsymbol{kWh}}{\boldsymbol{yr}}\right) = Waste\ inflow_{i,j}\left(\frac{t}{yr}\right) * Methane\ yield_i\left(\frac{Nm^3}{t}\right) * Energy\ efficiency * LHV\left(\frac{kWh}{Nm^3}\right)$$

The methane yield at Ecopro biological treatment facility is approximately 100 Nm^3/tonne food waste (Fløan, 2020).

The overall energy efficiency of the system can be calculated by:

$$\eta_{energy} = \frac{Energy\ from\ biogas\ out + Recovered\ energy}{Transport\ energy + Process\ energy + Calorific\ value\ waste\ input}$$

In addition to the three material efficiency indicators, the *energy efficiency* of the system can give an indication about how the different waste management solutions influence the amount of required and generated energy to operate the MSWM system. It is important to point out that energy recovered from waste does not consider as part of the energy supply in Norway. The prior function of waste incineration is to treat waste that cannot be recycled or landfilled.

4.4.3. Emission layer

The emission layer is estimated based on material outputs and energy requirements quantified in the material and energy layers.

The climate change impact of the different processes is calculated in two ways. First the environmental load of using energy during the various processes are calculated by multiplying the energy requirement of these processes (energy layer) with fuel specific emission factors. All the emission factors used in this study are summarised under Appendix A.10.3-A.10.4.

Second, direct emission from waste treatment processes is accounted for based on the material layer. This means that the flows of the different waste types and fractions which were quantified in the material layer are multiplied with the global warming potential (GWP) measured in CO_2-equivalent, specific for that treatment process. GWP is a measure of how much energy is absorbed by the emission of 1-unit of a greenhouse gas, relative to the emission of 1-unit of CO_2 (Liu, 2020). GWP is the common measurement of climate change impact and was chosen due to its importance for policy makers in Norway and Europe.

To evaluate the net climate impact of the system, not only generated but also avoided emission should be accounted for. Both incineration with energy recovery and material recycling are waste treatment processes that substitute for the use of primary resources. Multiplying the amount of a specific fraction that has been incinerated or recycled with its avoided emission factor, yields to net avoided emission. The overall net environmental impact is calculated by adding all the generated and avoided emission.

As it was explained in Section 4.3.1, the calculation of avoided emission from recycling is based on the type of product that the recovered secondary materials are substituting for as result of open- and closed loop recycling.

4.5. Scenarios

Five main scenarios are compared with the current system (Baseline scenario) for the year 2025 and 2035 to evaluate the impact of waste management alternatives. These scenarios are the following:

- S1: New kerbside collection scenario
- S2: Central sorting scenario
- S3: Improved kerbside collection scenario
- S4: Perfect sorting and collection scenario
- S5: Preparing municipal waste for recycling scenario

S1, S2 and S3 are divided into sub-scenarios (S1a+b, S2a+b, S3a+b) to test the sensitivity of system efficiencies for specific parameters.

An assesment on the development of generated waste amounts carried out by Bjørnerud et al (2019) shows that future waste generation will not increase due to expected population growth. The same assumption was made in this study (Figure 19). Future population estimates were calculated through the linear interpolation of population prognosis data published by Statistics Norway for the period 2020-2050 (SSB, 2021). While population estimates show a growing trend, there are variations between the different municipalities, as indicated on Figure 20. This entails future changes in the number of collection subscriptions which would influence waste logistics. However, these factors were not considered in this study.

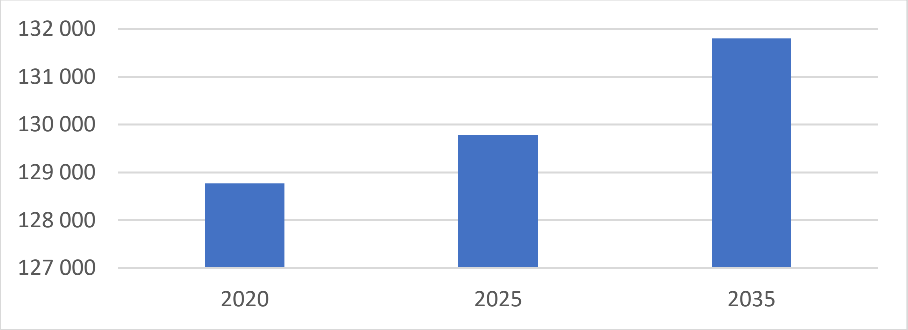


Figure 19 - Population growth, ReMidt total

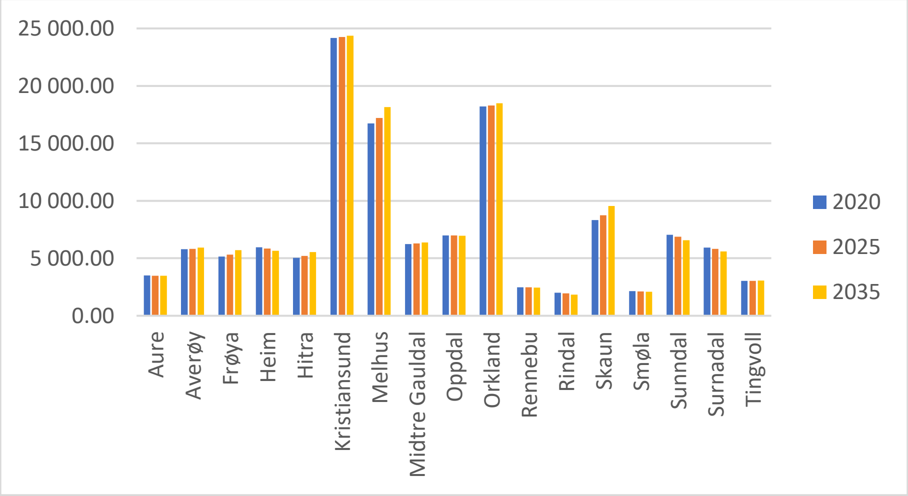


Figure 20 - Population prognosis per ReMidt municipality

Due to the limited timeframe, waste prevention efforts were not considered. Therefore, the per capita waste amounts are based on 2020 Baseline estimates. Parameters changed in the different scenarios are summarised in Appendix A.3.

S1, S2, S3b and S4 are forecasting scenarios showing the impact of various MSWM alternatives considered by ReMidt. S3a and S5 are back casting scenarios testing the feasibility of achieving future targets.

At the end of April 2021, the Norwegian Environmental Agency published an impact study for 22 different measures targeting improved preparation for re-use and recycling rates (Olbergsveen and Knagenhjelm, 2021). These measures were grouped into five main categories:

1. waste prevention and preparation for re-use
2. improved waste sorting from households
3. increased waste sorting from holiday homes
4. improved material recycling of residual waste from households
5. improved waste sorting from the municipal and commercial actors

Figure 21 shows the different waste management measures suggested by the Norwegian Environmental Agency. The size of the circles illustrates the relative effect on EU target achievement and the position in the diagram illustrates cost-effectiveness. The different colors demonstrate where in the value chain the measures should be taken (households, municipal and commercial actors, or holiday homes). The waste flows in this master thesis include all municipal waste and are not divided by origin. Measures suggested by Norwegian Environmental Agency are specific to municipal waste origins as indicated in the group titles. However, the sub-measures assigned to the different groups are identical. For instance, the source sorting of glass and metal packaging is suggested in both group 2, 3 and 5.

The introduction of kerbside garden and park waste collection tend to have the biggest influence on preparation rates. However, this is one of the costliest measures a MSWM company can introduce. Improved recycling rates of residual waste collected by private actors has the second biggest impact on preparation rates. Since ReMidt is a MSWM company this measure is not applicable. The third most important measure is the introduction of the “Pay for what you throw system” for households and municipal and commercial actors.

The goal of this analysis was to see how these measures influence the EU targets, which aligns with the research focus of this master thesis. Therefore, the scenarios defined below incorporate relevant measures from group 2-5. Re-use is outside of the scope of this study.

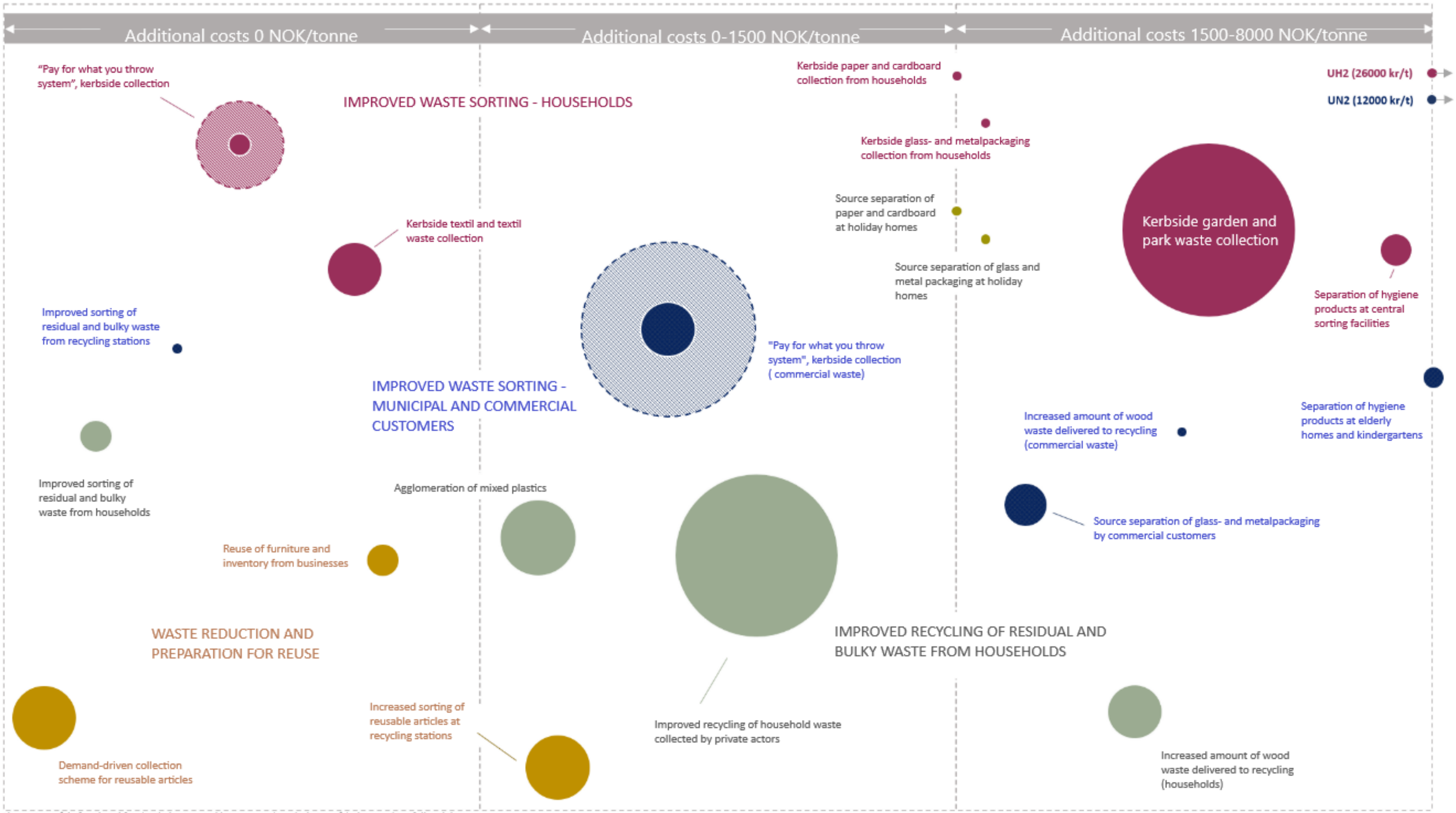


Figure 21 - Measures suggested by the Norwegian Environmental Agency, illustrated with effect, and cost in 2035.[24].

---

[24] Adopted from *Olbergsveen and Knagenhjelm (2021)* by translating headings from Norwegian to English.

Baseline scenario

The baseline scenario replicates the MSWM as it is described in the case study chapter. Only generated waste amounts were changed for year 2025 and 2035. It is important to highlight that waste accounting from 2020 might show deviations compared to previous years due to the outbreak of the COVID-19 pandemic. Comparable historical waste accounts could not be gathered because the three prior waste management companies that ReMidt emerged from had different accounting systems. Further comments on data quality and model result uncertainty will be made in a later section. Model inputs and calculations are summarised under Appendix A.4.

New kerbside collection scenario (S1)

Overall, S1 is a scenario which tests the impact of planned measures by ReMidt.

To achieve the EU target in 2025 (55%), the National Waste plan 2020-2025 (Olbergsveen, 2019) states that high proportion of wet organic waste must be sorted at source, Furthermore, glass and metal packaging must become part of the kerbside collection scheme. Therefore, ReMidt has set an ambitious goal to unify its kerbside collection system and to increase the amount of waste prepared for re-use and recycling.

As it was pointed out earlier, by 31 December 2023 bio-waste *should either be utilised as home compost or collected separately from other waste types*. This system is already in place for garden and park waste which is collected at recycling stations. However, ReMidt must offer solutions for source separating food waste for both households, municipal and commercial actors, and holiday homes. It is expected that ReMidt would collect ~55 kg/per/yr of source separated food waste in all of its municipalities, except Tingvoll that has already had kerbside food waste collection (Watnebryn and Fredriksen, 2018). As a result, less food waste will be discarded in the residual waste bin. Therefore, both the total generated residual waste and food waste amounts, and the fraction distribution of the residual waste (RW) bin had to be adjusted.

Regarding the collection of G&M packaging, prior experience from ReMidt municipalities shows that the amount of collected G&M packaging can grow by 30-50% through kerbside collection (Limi, 2021). This amount is coming from collection points, operated by external actors. Compared to the Baseline scenario, in all the alternative future scenarios it is assumed that G&M waste is only collected within the kerbside system and at recycling stations. It was assumed that about 11.6 kg/per/yr (average of Kristiansund, Smøla, Oppdal, Sunndal municipalities) will be collected via the kerbside system in municipalities that did not source separate G&M before. This new system could lead to a 3% decrease in G&M fractions in residual waste (Hamos Forvaltning IKS, 2018).

The flow chart, calculations and changes in parameters are summarised in Appendix A.5.

The introduction of the new kerbside collection scheme entails both an increase in the number of bins at household level, as well as the unification of collection methods and frequencies. It is assumed that all waste types are collected with trucks equipped with two-chamber technology. This has an influence on transport distances and energy use. As indicates, food waste is collected with either residual waste or with paper and cardboard during every 2nd week. G&M is collected with plastic during every 6th week.

Table 3 - Collection frequency, ReMidt IKS 2021-2022

Waste type	Collection frequency
Residual waste	Every 4. week
Cardboard and paper	Every 4. week
Glass and metal	Every 6. week
Food waste	Every 2. week
Plastic	Every 6. week

The introduction of the two new bins can be problematic for some customers due to lack of space. Therefore, ReMidt incentivises cooperation between its customers by introducing the neighbour-sharing (nabodeling) subscription scheme (ReMidt IKS, 2021). This means that customers pay lower waste collection fee by sharing waste bins with their neighbours. This might lead to lower demand for new waste bins and reduces collection time by emptying a smaller number of waste containers.

The climate impact of replacing fossil diesel with biogas trucks is also tested in this scenario. Currently, biogas vehicles are not considered as zero-emission vehicles, such as electric and hydrogen ones. This means that biogas trucks are subject to road tolls and other financial charges. This makes it less advantageous for waste management actors to replace their vehicle fleet (Samferdselsdepartementet, 2016). However, it is likely that regulations regarding biogas production and vehicles will change the new National Transport Plans (2022-2033) which is currently under review[25]. The new regulations would support both increased biogas production as well as the use of biogas in heavy transport (Fostervold, 2021b).

S1 is divided into two sub-scenarios for the year of 2025. While the system boundary is the same, in S1a all waste trucks are run by fossil diesel fuel. In S1b, it is assumed that due to changes in the National Transport Plans (2022-2033) it would be economically more beneficial for ReMidt to replace part of its vehicle fleet with biogas trucks. Orkland and Melhus+MG were chosen because currently these regions contribute the most to the annual fuel use.

Central sorting scenario (S2)

S2 tests the impact of central sorting on system efficiencies. See Appendix A.6 for further details.

This scenario has the same collection processes as S1 but includes an additional central sorting (CS) process, therefore the system boundary is adjusted accordingly. Recyclable fractions sorted out at central sorting facilities are not included in material recycling estimates in Norway. The Norwegian Environmental Agency is currently[26] working on a proposal to add a new chapter to the *Regulations on recycling and treatment of waste*[27] that would address this issue. In this scenario it assumed that by 2035 regulations will change. Therefore, all fractions that are suitable for recycling can be part of EU target calculations, whether they were source or post-sorted.

As it was mentioned in Section 3.2, a central sorting facility - Project SESAM - is expected to be built within the upcoming years. This facility would take in residual waste from municipalities operating in Central Norway to improve waste sorting and material recycling rates. As a result, the amount of municipal waste delivered to incineration is expected to

---

[25] 23.05.2021

[26] 27.05.2021

[27] https://lovdata.no/dokument/SF/forskrift/2004-06-01-930

decrease significantly. The transfer coefficients between the CS facility and treatment processes were calculated from data presented in the SESAM project report (Watnebryn and Fredriksen, 2018). See Appendix A.6.2 for further details.

There are two existing central sorting facilities in Norway, operated by RoAF and IVAR. According to RoAF (2020) the prerequisite of operating such a facility effectively is that residual waste must not contain wet organic and textile fractions. Organic fractions reduce the quality of recyclables. Textiles are problematic because articles such as Bhs and tights can get stuck and damage the equipment. Since textile recycling is outside the scope of this study, it will be assumed that all the textiles found in residual waste are sorted out for incineration.

There are two sub-scenarios defined in S2. In S2a residual waste only from the kerbside collection system is sent to central sorting. In S2b, residual waste collected both from kerbside and recycling stations are included. This distinction was made to see how the sorting of all the recyclable fractions in residual waste influence system efficiencies. Furthermore, the Norwegian Environmental Agency also suggests improved sorting of residual waste and bulky waste collected at recycling stations from 2025 onwards. This could be achieved by implementing innovative technologies at sorting facilities. In S2b it is assumed that the SESAM central sorting facility is equipped with state-of-the-art grinding and robot sorting technologies which make it possible to recover all recyclable fractions from residual waste.

Improved kerbside collection scenario (S3)

S3 tests the impact of improved source separation on system efficiencies. See Appendix A.7 for further details.

This scenario is similar to S1a but parameters influencing collection efficiency are changed. S3 is divided into two sub-scenarios. In the improved collection scenario (S3a), 70% collection efficiency rate is chosen for 2035. Other Norwegian MSWM companies, such as RoAF and IVAR, have set similar targets, 70% and 75% respectively. S3b represents the perfect kerbside collection scenario in which all recyclable fractions (P&C, P, G&M and FW) are source sorted with 100% accuracy.

The Norwegian Environmental Agency proposes the introduction of a “Pay for what you throw system” (“Betal for det du kaster-system”) to improve waste collection rates both in the kerbside and bring collection systems. This means that the collection of residual waste would have a higher per kilogram subscription price than recyclables. Containers would be measured at the point of collection by trucks equipped with specific weighing technologies. In addition, radio-frequency identification (RFID) solution would be used to register and assign weight information to individual containers. Thereby, waste collection fees could be tailor-made to customers, which would provide an economic incentive for correct source separation. At recycling stations, a weighing system for bulky waste is already implemented, but this could be further improved in the future. It is assumed in S3 that these measures will be introduced by 2035 to improve collection efficiencies.

Perfect sorting and recycling scenario (S4)

S4 tests the impact of improved sorting and recycling on system efficiencies. See Appendix A.8 for further details.

This scenario is comparable to S3b; with the same system boundary and collection efficiency but recyclable fractions are sorted with 100% efficiency (P5; P9). Furthermore, it is assumed that all the recyclable fractions are suitable for material recycling with 100% recycling rate, without any loss or rejection.

Preparing municipal waste for recycling scenario (S5)

S5 tests what it takes to achieve the 65% target for preparing municipal waste for recycling. See Appendix A.9 for further details.

Improved sorting of biological waste and plastic is necessary for Norway to come closer to the target. The national goal is that at least 70% of these fractions should be prepared for recycling by 2035 (Mepex and Østfoldforskning, 2018).

Currently, organic residues found in the residual waste are not separated and utilised in biogas production. However, growing interest in using biogas in heavy truck transport will likely result in improved bio-waste recovery rates. As it was mentioned in S1, Norwegian authorities have considered ensuring equal treatment of biogas vehicles with zero-emission vehicles from 1 January 2022 onwards. Therefore, it is assumed that legislations will change in the future and biological waste fractions will be recovered at central sorting facilities.

This could be achieved in different ways. According to the SESAM project report (Watnebryn and Fredriksen, 2018) currently about 30% of the incoming residual waste at central sorting facility are residues between size 0-55 mm. 70% of these residues contain organic materials which can be utilised in biogas production. According to the Norwegian Environmental Agency (2021), around 6% of residual waste sent to central sorting in Norway are hygiene products, such as diapers. These contain a significant amount of recyclable organic and plastic fractions. There are various projects focusing on the recycling of hygiene products in Europe and it is expected by the Norwegian Environmental Agency that from 2027 onwards these solutions will be more mature and implemented on a broader scale.

The SESAM project report also mentions that the remaining 70% of residual waste could be utilised as Solid Refuse Fuel (SRF). Currently the heating value of mixed residual waste (including bio-waste) sent to incineration is between 10-12 MJ / tonne. The residual fraction alone has a heating value of about 13-15 MJ/ tonne. The heating value could be increased up to 15-20 MJ/tonne by reducing the size to <80 mm. In this size and form residual waste could be sold as SRF in Sweden. Currently SRF is not included in EU target calculations. To further improve system efficiencies, this study assumes that by 2035, residual waste fractions will be sorted out at central sorting facilities and accounted as materials prepared for recycling. Furthermore, due to better product design and treatment technologies; sorting (Process 5 and 9) and recycling efficiencies (Process 7 and 6) will increase by 2035.

System variables must be changed to achieve the minimum 65% rate of preparing municipal waste for recycling:

- Aggregated collection efficiency is increased to 80% by improving source sorting both within the kerbside (X01) and bring (X03) collection systems.
- The sorting efficiency for paper and cardboard packaging at both sorting facilities (Process 5 and 9) are improved to 80%.
- The sorting efficiency for plastic packaging at both sorting facilities (Process 5 and 9) are improved to 80%.
- 30% of bio-waste fractions found in residual waste are sorted at the CS facility and sent to biogas production (Process 7).
- 30% of residual fractions found in residual waste are sorted at the CS facility and sent to SRF production (Process 6).
- Plastic packing recycling efficiency is increased to 80% (Process 6).
- Organic fraction reject generated during biogas production (Process 7) is reduced from 16% to 10%.

Alternative scenarios considered in this study are presented under Discussion.

4.6. Sensitivity

Sensitivity analysis was performed to investigate how the reduction of recyclable fractions found in residual waste influence collection and material recycling efficiencies and preparation rate. Sensitivity was tested for Scenario 1, which gives the basis for all the other future scenarios defined in this study.

4.7. Uncertainty

A simplified uncertainty analysis was conducted to show the uncertainty of model result for certain parameters. The uncertainty of the generated recyclable waste amounts and associated emission were tested because company specific data associated with these variables were lacking. As it was explained in Section 4.3.1, the weights of the different waste steams depend on the total generated waste amounts and their waste fraction distributions. Waste accounting carried out by ReMidt could provide data with relatively low uncertainty on generated municipal waste amounts. However, not all waste analysis results used in this study are specific for ReMidt; most of them were gathered from other Norwegian MSWM companies. The waste fraction distribution assigned for each of the waste types is important in calculating the system efficiency indicators and quantifying the emission layer.

It was assumed that the uncertainty of the recyclable waste types collected in the kerbside and bring collection systems are +/-5%. Due to lack of measurements on the amount of food waste utilised as compost, a higher +/-30% uncertainty was assigned to the amount food waste collected as home compost.

The fraction distribution of the different waste types collected at kerbside and recycling stations were assigned with the following uncertainties:

Waste type	RW Kerb.	RW Rec. stat	P&C Kerb.	P&C Rec. stat	P Kerb.	P Rec. stat	G&M Kerb.	G&M Rec. stat	FW Kerb.	FW and GP Rec. stat	FW Compost
RW	+/-10%	+/-1%	+/-5%	+/-5%	+/-5%	+/-5%	+/-5%	+/-1%	+/-5%	+/-5%	0%
P&C	+/-10%	+/-1%	+/-5%	+/-5%	+/-5%	+/-5%	+/-5%	+/-1%	+/-5%	+/-5%	0%
P	+/-10%	+/-1%	+/-5%	+/-5%	+/-5%	+/-5%	+/-5%	+/-1%	+/-5%	+/-5%	0%
G&M	+/-10%	+/-1%	+/-5%	+/-5%	+/-5%	+/-5%	+/-5%	+/-1%	+/-5%	+/-5%	0%
FW	+/-10%	+/-1%	+/-5%	+/-5%	+/-5%	+/-5%	+/-5%	+/-1%	+/-5%	+/-5%	0%

The uncertainty range of the different emission factors used in GHG emission calculations are the following:

Waste type	Avoided recycling, material	Avoided recycling, energy	Avoided incineration	Generated recycling	Generated, Incineration
PC	+/-15%	+/-0%	+/-5%	+/-5%	+/-5%
P	+/-5%	+/-0%	+/-5%	+/-5%	+/-5%
Glass abroad	+/-30%	+/-0%	+/-5%	+/-5%	+/-5%
Glass NO	+/-30%	+/-0%	+/-5%	+/-5%	+/-5%
Metal abroad	+/-30%	+/-0%	+/-5%	+/-5%	+/-5%
Metal NO	+/-30%	+/-0%	+/-5%	+/-5%	+/-5%
FW	+/-5%	+/-5%	+/-5%	+/-5%	+/-5%
Garden and park	0%	+/-0%	+/-5%	+/-5%	+/-5%

5. Results

Results presented in this chapter were generated with Pieter Callewaert's (2017) generic MSWM model in Microsoft Excel and MATLA. All the scenario results and model inputs are found in the supplied "Supplementary materials" folder.

5.1. Baseline scenario 2020

5.1.1. Material layer

In 2020, ReMidt collected 54045.14 tonnes of municipal waste from its customers. 78% was residual waste and 22% source separated recyclables (Figure 22). Figure 23 shows the percentage of the different waste fractions in the total generated waste. Residual waste fractions account for 31%, followed by bio-waste (26%), paper and cardboard (18%), plastic (11%), glass (6%), textiles (4%), metal (3%) and electronic and hazardous fractions (1%). Bio-waste is divided into food waste (23%), garden and park waste (2%), and home compost (1%). Interestingly, textiles have higher share than metals in the system, even though separately collected textiles are excluded from the system boundary. This means that textile flows found in RW are bigger than the sum of all metals in the system.

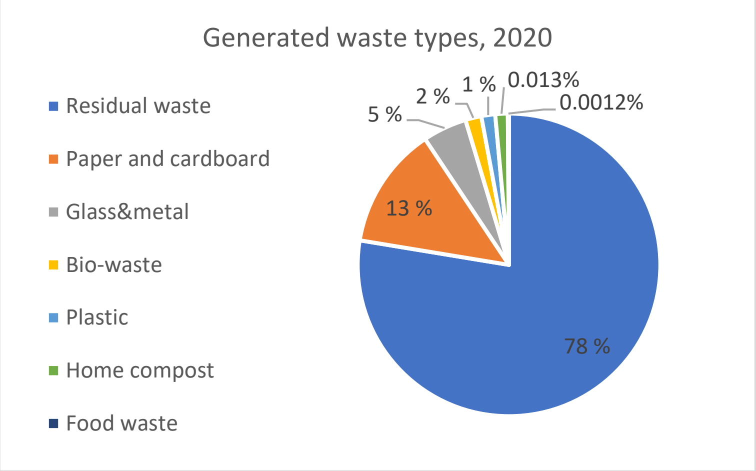


Figure 22 - Generated waste types, Baseline

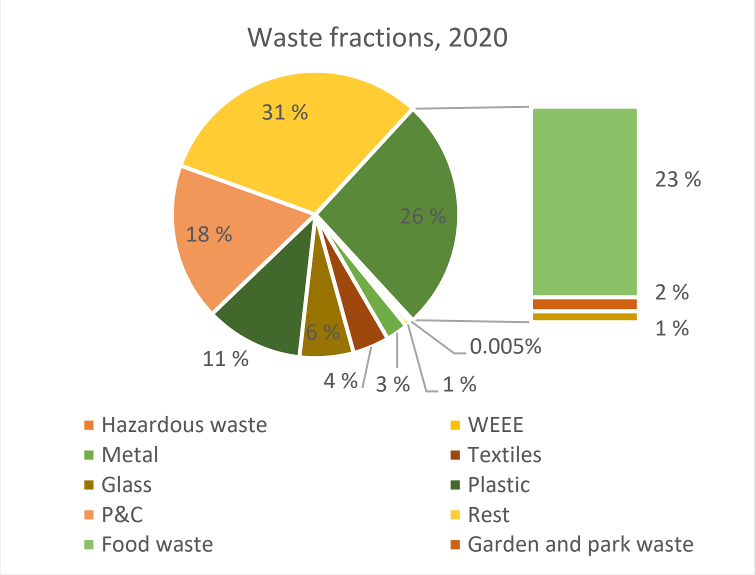


Figure 23 - Generated waste fractions, Baseline

The comparison of the figures reveals that not all waste fractions are collected in the right waste container.

The performance of the material layer shows that in 2020, 31.7% of the municipal waste was sorted correctly, 16.9% was prepared for recycling and 17.4% was recycled (Figure 24). As the red line indicates, in 2020 the 50% rate of preparing municipal waste for recycling could not be achieved.

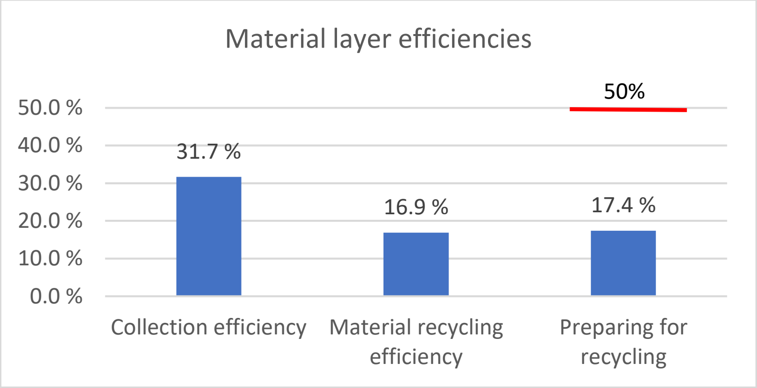
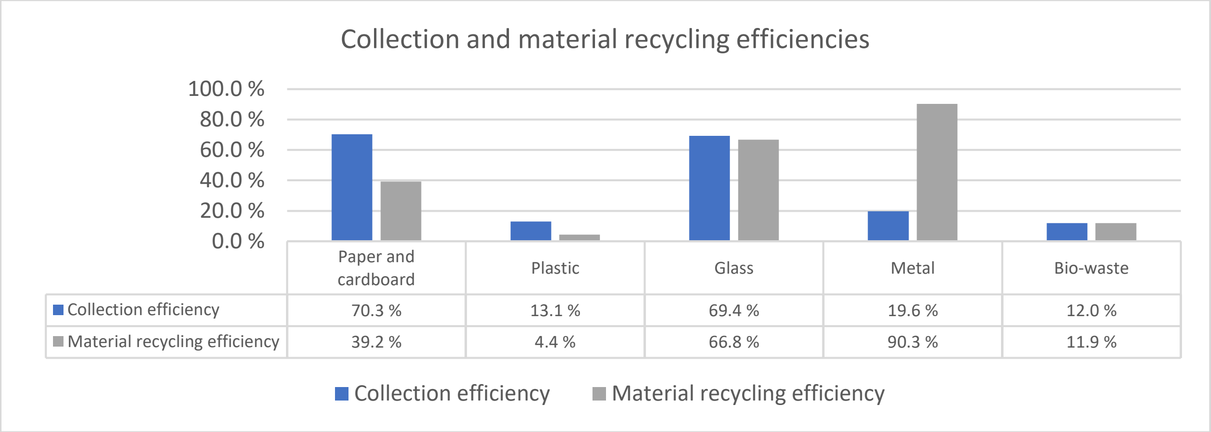


Figure 24 - Material layer efficiencies, 2020

There are variations in the collection and material recycling efficiencies of the different waste fractions. While paper and cardboard fractions had a relatively high collection efficiency rate (70.3%); only 39.2% was recycled due to contamination and quality issues. Plastic had both the lowest collection (13.1%) and material recycling efficiencies (4.4%). This is because majority of the plastics were either thrown into the residual waste bin or a significant portion of the source separated plastic fractions waste was not suitable for recycling. Results for glass fraction show that only 2.6% of the collected source separated glass fractions were not recycled. The collection efficiency of metal fractions was only 19.6%, however the recycling rate was quite high (90.3%). This is due to the efficient recovery of metals from incineration bottom ash. The collection efficiency for all bio-waste was ~12% and almost all was recycled. When only looking at food waste fractions, results show that only 6% of the generated food waste was separately collected in 2020. Losses during biogas production are low (16% reject of organic fractions), thereby the remaining 84% is recycled.



	Paper and cardboard	Plastic	Glass	Metal	Bio-waste
🟦 Collection efficiency	70.3 %	13.1 %	69.4 %	19.6 %	12.0 %
⬜ Material recycling efficiency	39.2 %	4.4 %	66.8 %	90.3 %	11.9 %

Figure 25 - Collection and material recycling efficiencies, 2020

5.1.2. Energy layer

Results from the energy layer are divided into: i. energy requirements of transportation, sorting and treatment processes; ii. feedstock energy from the waste itself; and iii. generated energy from incineration and biogas production (Table 4). Transportation is divided into energy required by the waste trucks operated by ReMidt and external actors.

The energy efficiency of the system was 61% in 2020, which means that the generated energy from waste incineration and biogas production compensated for 61% of the energy needed to operate the MSWM system.

Table 4 - Energy efficiency, 2020

Energy efficiency	61 %
Feedstock E. (kwh)	1.03E+08
Transport E. (kwh)	8.48E+06
Transport - ReMidt (kwh)	1.90E+07
Transport - Other (kwh)	7.96E+07
Process E. (kwh)	5.00E+06
Generated E. (kwh)	3.65E+06

61% of the energy used for transport is consumed by ReMidt operations and the rest is associated with external actors. Transport fuel use for the kerbside collection and transportation of residual waste to incineration takes up the biggest share of the transport energy requirements (Figure 26). The downstream transportation of bottom ash has the highest energy demand.

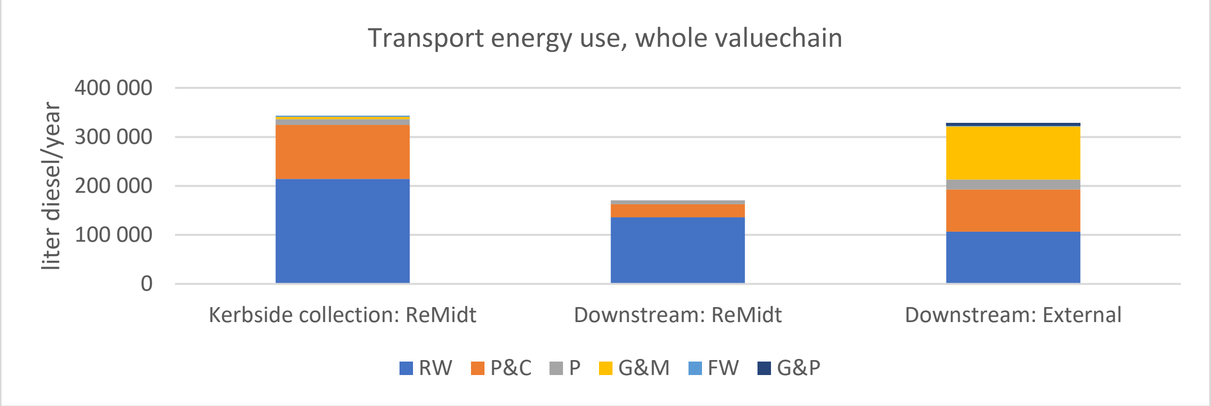


Figure 26 - Transport fuel use, whole value chain, 2020

At regional level, Orkland and Melhus+MG regions had the highest total kerbside collection fuel use, 97 073 and 81 133 litres, respectively. Sunndal and Oppdal regions had the lowest rates, 15 000 litres for each. Per tonne fuel consumptions show a different pattern. Here Kristiansund rural region had the highest rate per tonne fuel consumption rate (138.31 litre diesel per tonne waste collected), followed by Surnadal (108.22 litre/tonne), Hitra (67.01 litre/tonne), Melhus+MG (65.74 litre/tonne), Sunndal (53.32 litre/tonne), Kristiansund city (31.43 litre/tonne), Oppdal (30.34 litre/tonne), and Orkland (27.65 litre/tonne) regions. This difference emerges from the variation in collection frequencies, chamber-technologies, waste amounts and transport distances.

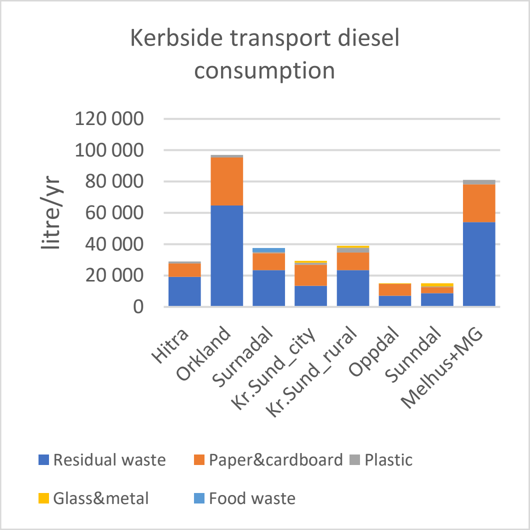


Figure 27 - Kerbside diesel consumption 2020

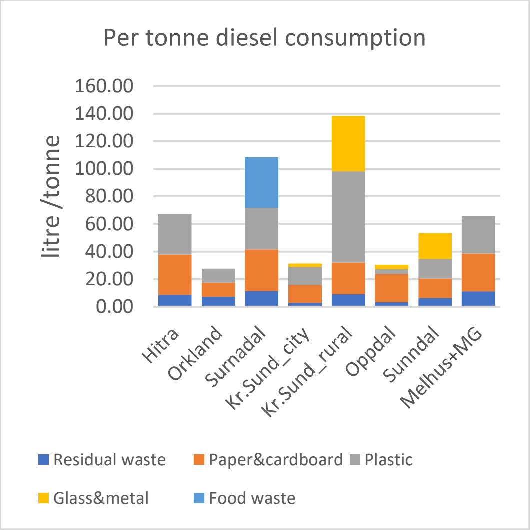


Figure 28 - Per tonne diesel consumption, 2020

5.1.3. Emission layer

The generated and avoided GHG emission are presented below. In 2020 the MSWM system had a net positive climate change impact. This means that emission occurring during waste transport, process energy use, and recycling and incineration processes could not be compensated with the avoided emission from material recycling and energy recovery.

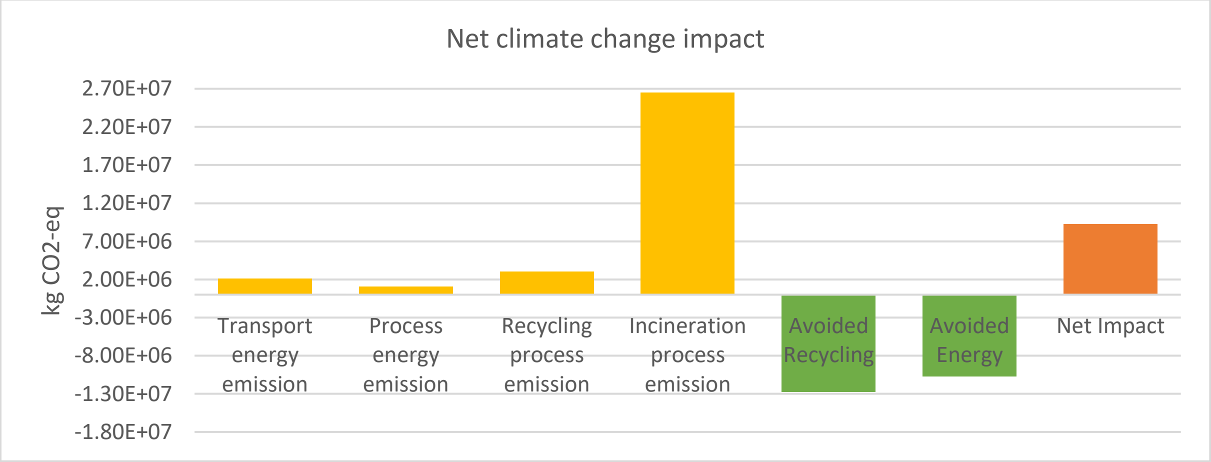


Figure 29 - Net climate change impact, 2020

Waste incineration had the biggest climate change impact in the system. The incineration of plastic and residual waste fractions generated the most GHG emission and the recovered energy from these fractions was not enough to compensate for them (Figure 30). Therefore, both plastic and residual waste fractions have a net positive climate impact (Figure 31). For the other fractions, avoided emission from recycling and energy recovery processes could compensate for the generated emission.

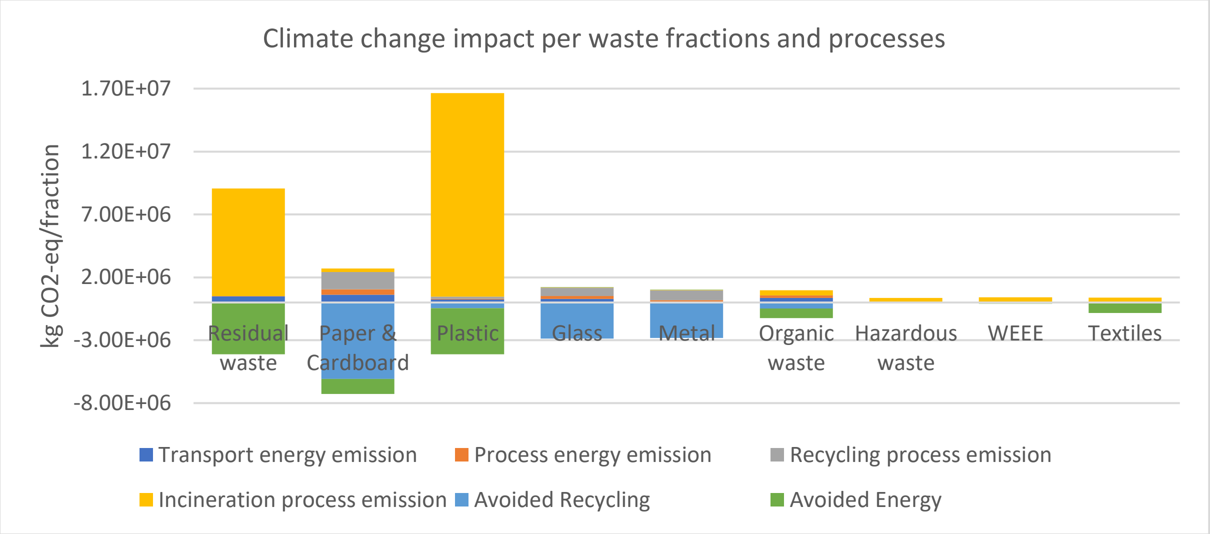


Figure 30 - Contribution of the different processes in the climate change impact of waste fractions

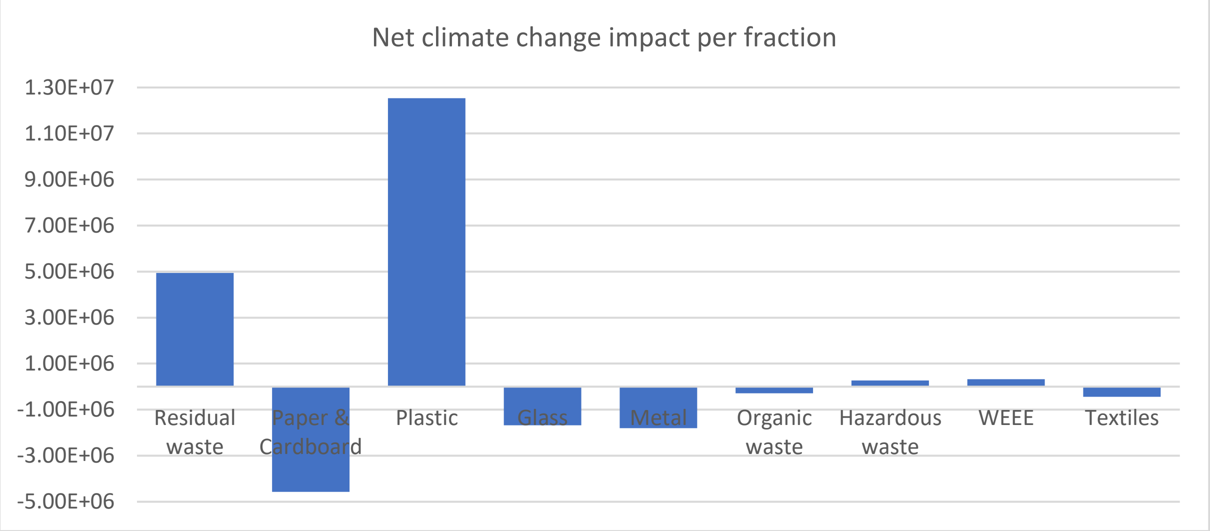


Figure 31 – Net climate change impact of the different waste fractions

Year 2025

5.1.4. Material layer

The total generated waste amount remains the same in 2025 but the size of the various waste types will change (Figure 32). RW is reduced by 17% due to improved source sorting of food waste and G&M fractions. As a result, source separated food waste and G&M amounts are expected to grow.

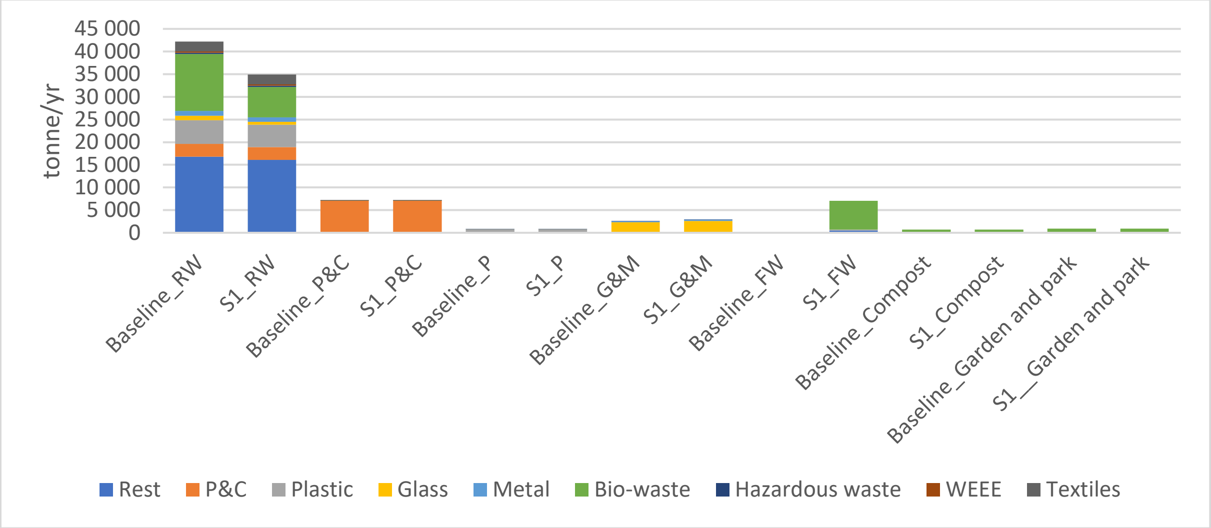
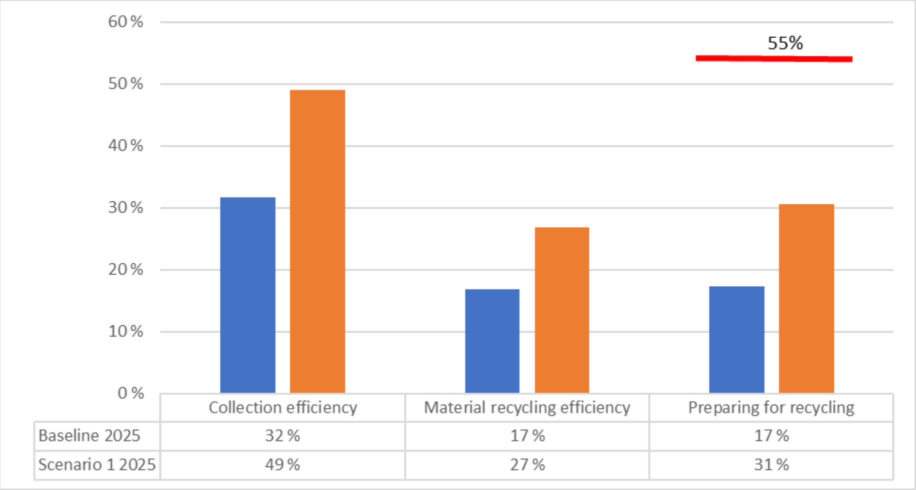


Figure 32 - Generated waste amounts in 2020, Baseline vs S1

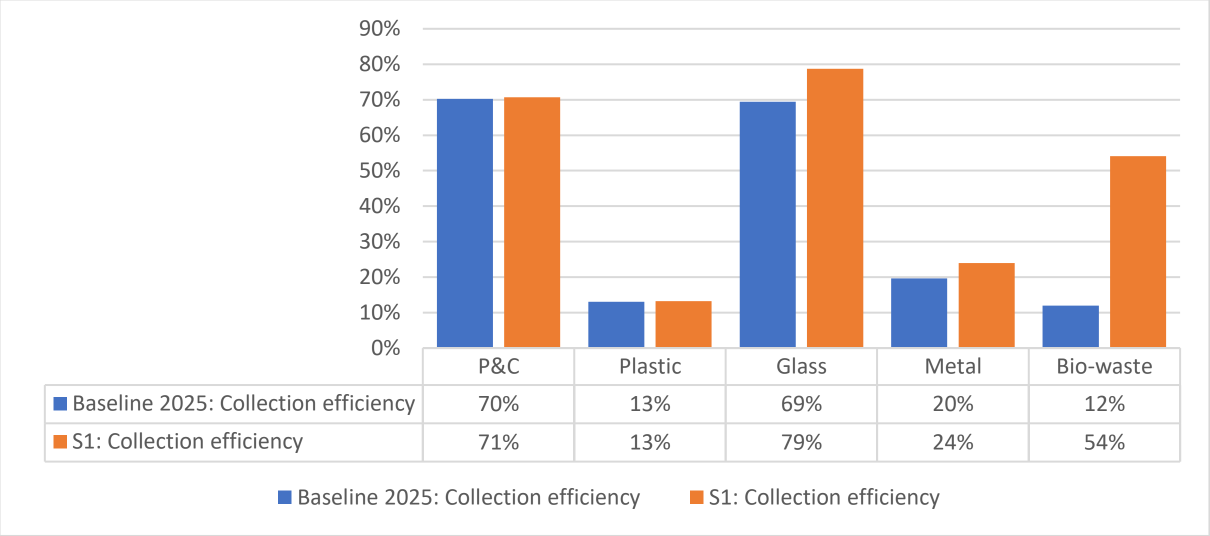
Figure 33 demonstrates the performance of the material layer, regarding collection and material recycling efficiencies, and the rate of preparing municipal waste for recycling. S1 scores higher in all the indicators, however it is still not enough to reach the 55% target by 2025 (red line).



	Collection efficiency	Material recycling efficiency	Preparing for recycling
Baseline 2025	32 %	17 %	17 %
Scenario 1 2025	49 %	27 %	31 %

Figure 33 - Material layer efficiencies, 2025

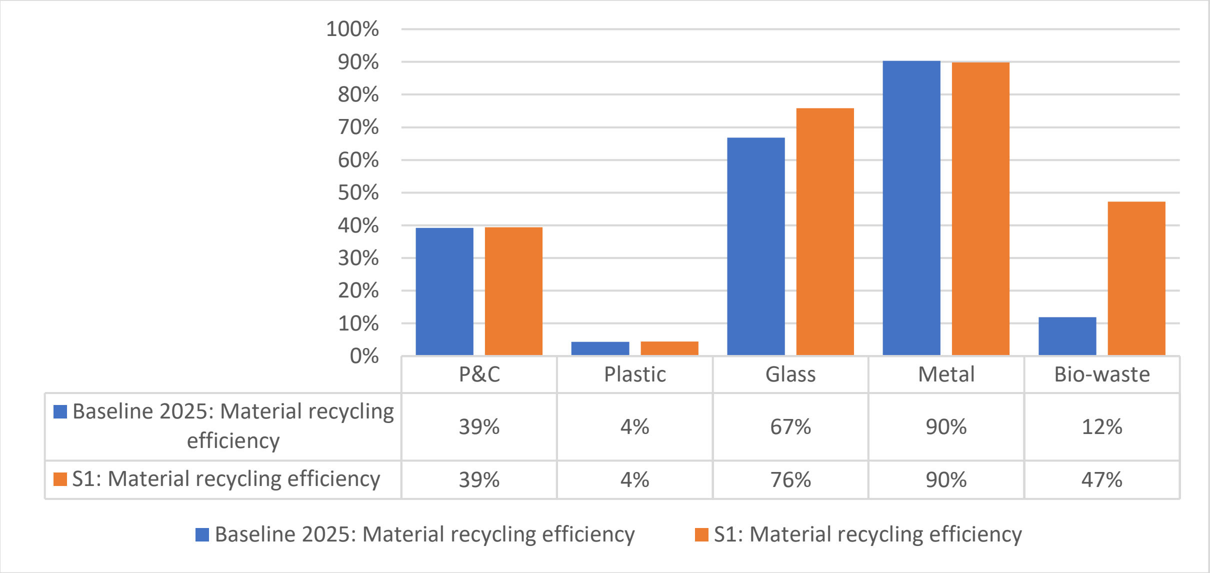
The collection efficiency of bio-waste progresses from 12% to 54% (Figure 34). The introduction of kerbside food waste collection improves all the material efficiency indicators. However, review of relevant waste analysis reports (Mepex, 2016; Bjørnerud and Syversen, 2017; Innherred Renovasjon, 2019) and literature (Syversen, Hanssen and Bratland, 2018) show that even with the food waste collection scheme in place, around ~30% of the residual waste bin content still remains food waste. Glass and metal packaging increase by 10% and 4% respectively.



	P&C	Plastic	Glass	Metal	Bio-waste
■ Baseline 2025: Collection efficiency	70%	13%	69%	20%	12%
■ S1: Collection efficiency	71%	13%	79%	24%	54%

Figure 34 - Collection efficiency, 2025

The material recycling efficiencies show similar trends to collection efficiencies (Figure 35). However, the extended kerbside collection of glass and metal has not improved metal recycling efficiency. Metal fractions are recovered from incineration bottom ash too, therefore the improved source separation of metal fractions does not have a significant impact on material recycling rates.



	P&C	Plastic	Glass	Metal	Bio-waste
■ Baseline 2025: Material recycling efficiency	39%	4%	67%	90%	12%
■ S1: Material recycling efficiency	39%	4%	76%	90%	47%

Figure 35 - Material recycling efficiency, 2025

5.1.5. Energy layer

Table 5 shows that the introduction of the new kerbside collection system leads to 1% increase in energy efficiency. It is because more energy is generated by producing biogas than burning bio-waste at the incineration facility. Fuel used in collection transport operated by ReMidt decreases by 6 percentage points, while downstream energy use increases with 3 percentage points in S1.

When the energy requirements of collection, sorting, and treatment operations are considered then results indicate that transportation under direct control of ReMidt contributes to 17% of all consumed energy in the MSWM system. 13% is coming from external transport providers, and the remaining 70% is associated with sorting and treatment processes.

Table 5 - Energy efficiency, 2025

	Baseline	S1	Change
Energy efficiency	61 %	62 %	1 %
Feedstock E. (kwh)	1.03E+08	1.03E+08	-1 %
Transport E. (kwh)	8.55E+06	8.49E+06	-1 %
Transport - ReMidt (kwh)	5.03E+06	4.72E+06	-6 %
Transport - Other (kwh)	3.68E+06	3.78E+06	3 %
Process E. (kwh)	1.92E+07	1.96E+07	2 %
Generated E. (kwh)	8.02E+07	8.06E+07	1 %

S1 has two sub-scenarios to test the impact of increasing the number of biogas waste trucks in the kerbside collection system. The transportation of RW requires the most energy in all scenarios especially during kerbside collection and delivery to incineration (ReMidt downstream). Due to the low weight of plastic packaging, this waste type has a relatively low transport energy requirement. The downstream transportation of glass and metal packaging dominates because the sorting and recycling plant for G&M is located more 600 km away from ReMidt reloading stations. Because more food waste is source separated and transported to further treatment, transport energy requirement for bio-waste fractions will increase significantly. As the Figure 36 illustrates, the replacement of part of ReMidt's vehicle fleet with biogas alternatives have a limited impact on transport energy use.

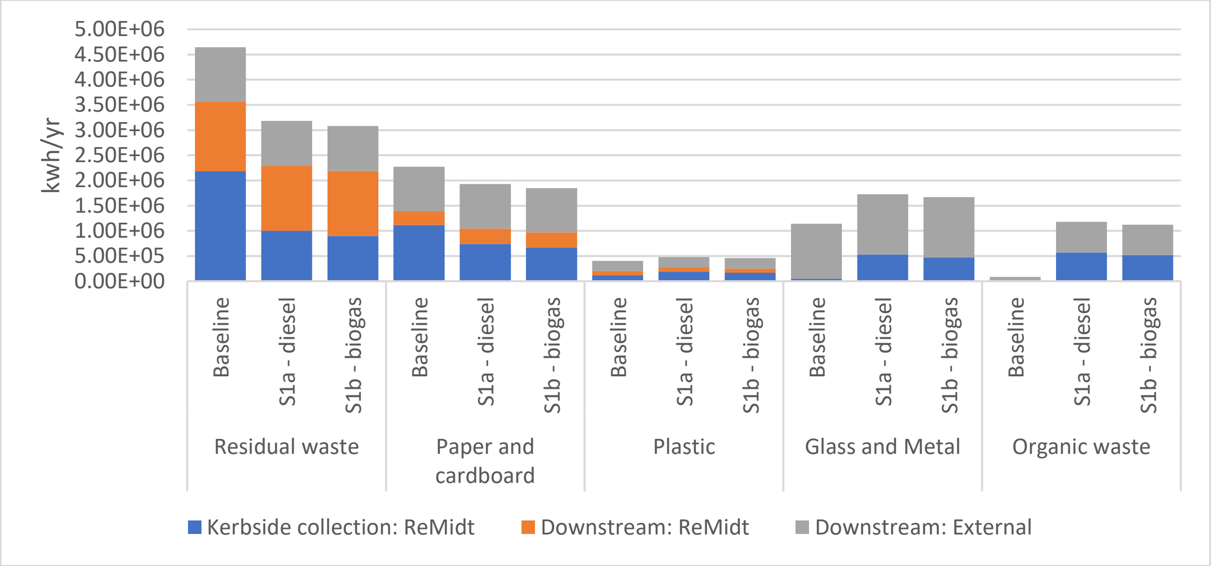


Figure 36 - Transport fuel use at different waste types and transport stages

By narrowing down the focus to the different regions (figures below), it can be observed that in both scenarios Orkland and Melhus regions have the highest transport energy consumption, while Oppland and Sunndal regions requires less energy for waste transport. This is in line with the population estimates and associated waste generation amounts presented on Figure 20. Interestingly, Kristiansund region with the highest population has a relatively low transport energy consumption compared to Orkland and Melhus+MG. This can be explained by shorter transport distances across this more densely populated, urban region.

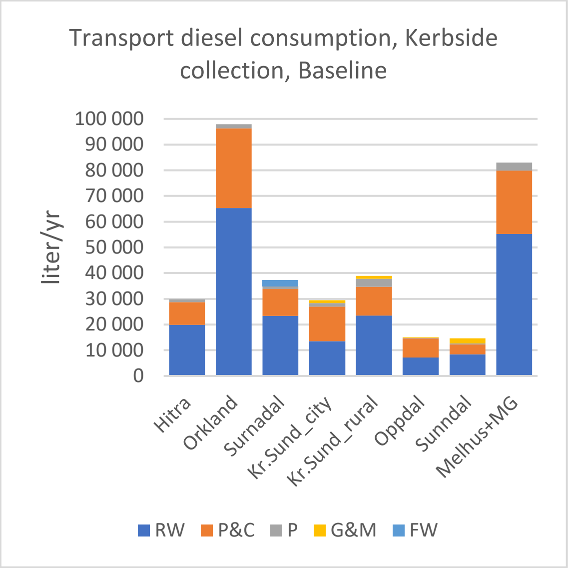


Figure 37 - Diesel consumption, Baseline

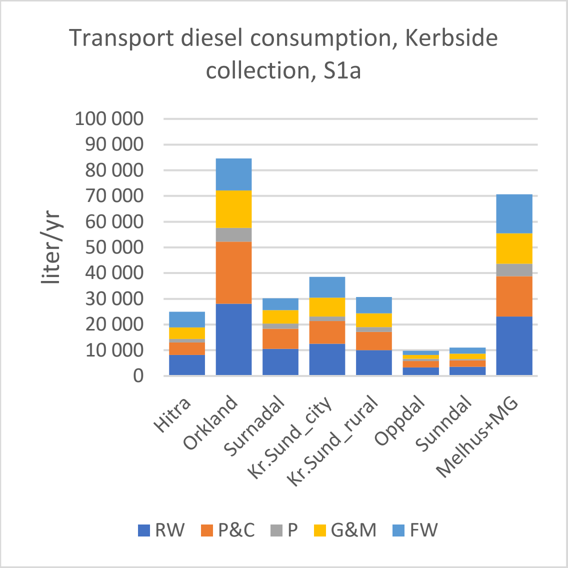


Figure 38 - Diesel consumption, S1

Considering the per tonne fuel requirement of the kerbside collection system, differences between the Baseline and S1 are more visible. In S1, fuel consumption increases in all regions. Plastic and G&M packaging are collected during the same collection round by two-chamber trucks. These waste types weight less than RW, P&C and FW. In the model it was assumed that the kerbside collection route distances are the same for all waste types. Weight and transport distances are important parameters in calculating transport energy requirements. This can explain why the kerbside collection of plastic and G&M waste contributes the most to the per tonne fuel consumption (Figure 39), while have relatively low impact on total energy consumption (Figure 38).

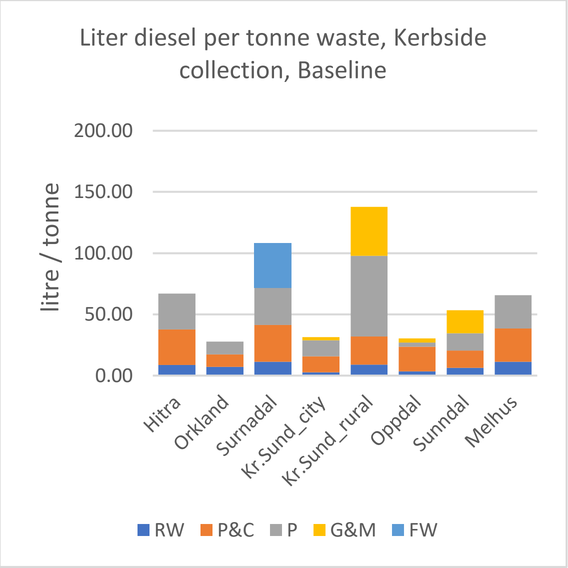


Figure 39 - Per tonne diesel consumption, Baseline

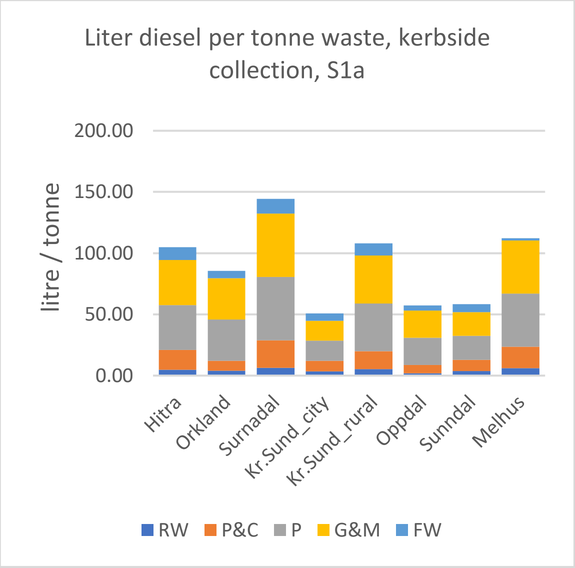


Figure 40 - Per tonne diesel consumption, S1

5.1.6. Emission layer

The introducing the new kerbside collection system results in net GHG emission reduction: -1.8 percentage points in S1a and -2.1 percentage points in S1b. This indicates that the replacement of the waste trucks in Orkland and Melhus+MG regions contribute to slightly bigger emission reductions. The overall net climate change impact of S1 is positive.

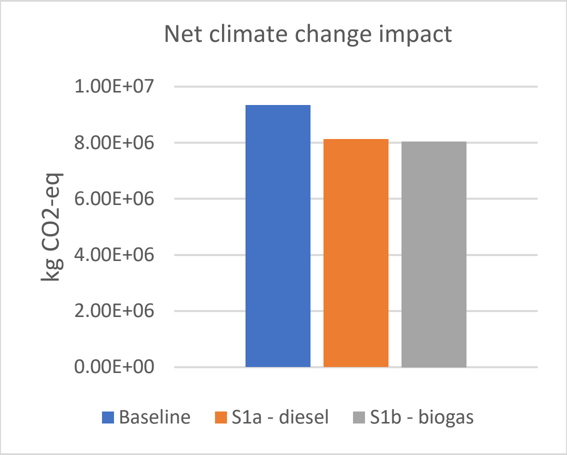


Figure 41 - Net climate change impact, Baseline, S1a, S1b

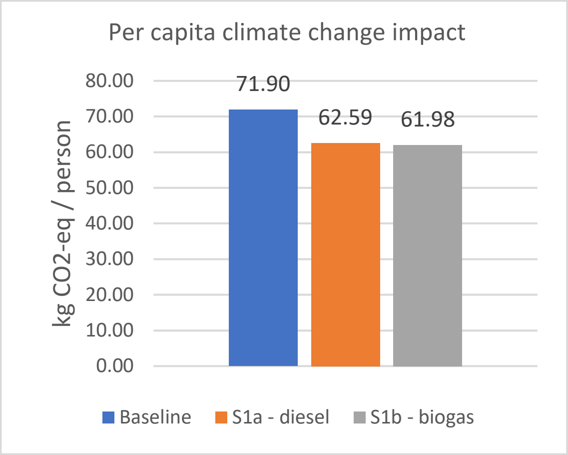
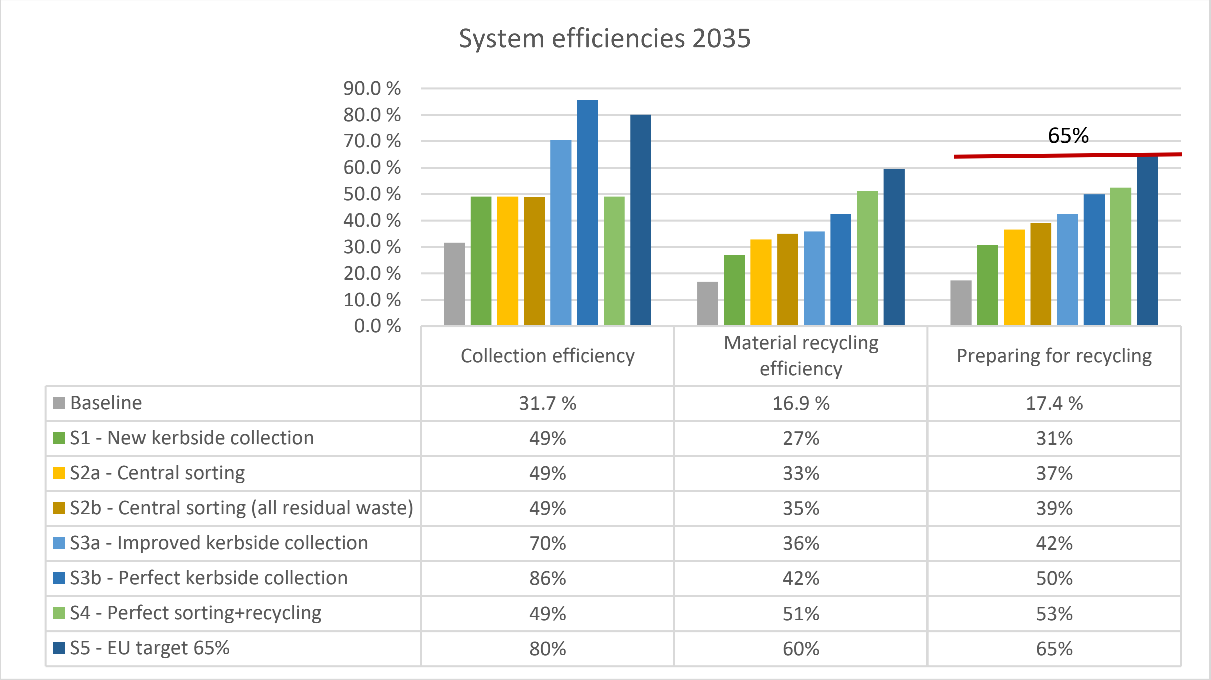


Figure 42 - Per capita climate change impact, Baseline, S1a, S1b

5.2. Year 2035

5.2.1. Material layer

In this section, material efficiency results from S1, S2, S3, S4 and S5 are compared with the Baseline scenario in year 2035. Changes in model parameters are shown under Appendix A.5-A.9.



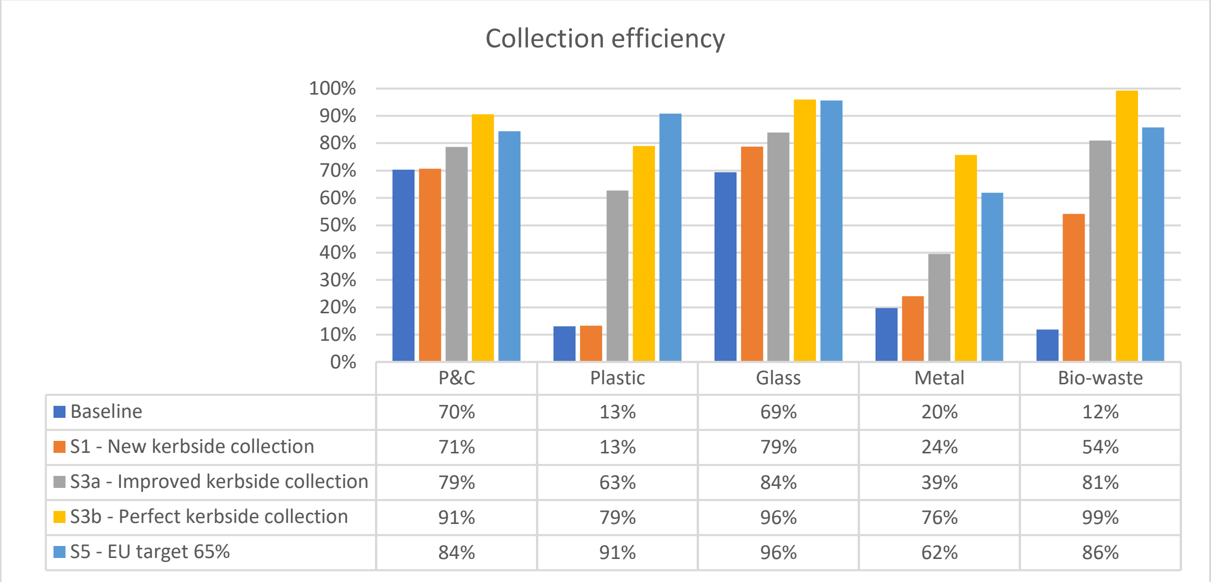
	Collection efficiency	Material recycling efficiency	Preparing for recycling
■ Baseline	31.7 %	16.9 %	17.4 %
■ S1 - New kerbside collection	49%	27%	31%
■ S2a - Central sorting	49%	33%	37%
■ S2b - Central sorting (all residual waste)	49%	35%	39%
■ S3a - Improved kerbside collection	70%	36%	42%
■ S3b - Perfect kerbside collection	86%	42%	50%
■ S4 - Perfect sorting+recycling	49%	51%	53%
■ S5 - EU target 65%	80%	60%	65%

Figure 43 - System efficiencies, 2035

Figure 43 demonstrates the performance of the material layer, regarding collection and material recycling efficiencies, and rate of preparing municipal waste for recycling. The scenarios can be divided into two categories. The so-called realistic scenarios (S1, S2a and S3a) model the impact of realistic waste management measures. Improved scenarios (S2b, S3b and S4) model the theoretical impacts of the perfect implementation of measures considered by ReMidt. S5 tests what it takes to reach the 65% preparation rate for recycling by 2035.

The introduction of the new kerbside collection system increases collection efficiency from 32% to 49%. This is the result of increasing the collection efficiency of glass packaging fractions by 10%, metal packaging fractions by 4% and bio-waste waste fractions by 42% (Figure 44). To achieve the ambitious 70% target set by ReMidt (S3a), the collection efficiency of all waste fractions must improve significantly. For instance, plastic packaging collection should improve from 13% to 63% and over 80% of bio-waste fractions (mostly food waste) should be separated at source. The highest collection efficiency that a perfect kerbside collection system (S3b) could yield to is 86%. This could be further improved if clearer waste streams enter the bring system.

To achieve the 65% preparation rate for recycling by 2035 (S5), the aggregated collection efficiency should grow to 80%. This includes the improvement of source sorting both in the kerbside and bring systems, leading to 84% collection efficiency of all paper and cardboard packaging, 91% for plastic packaging, 96% for glass, 62% for metal and 86% for bio-waste. S2a, S2b and S4 are excluded from this analysis because they have the same collection system as S1.

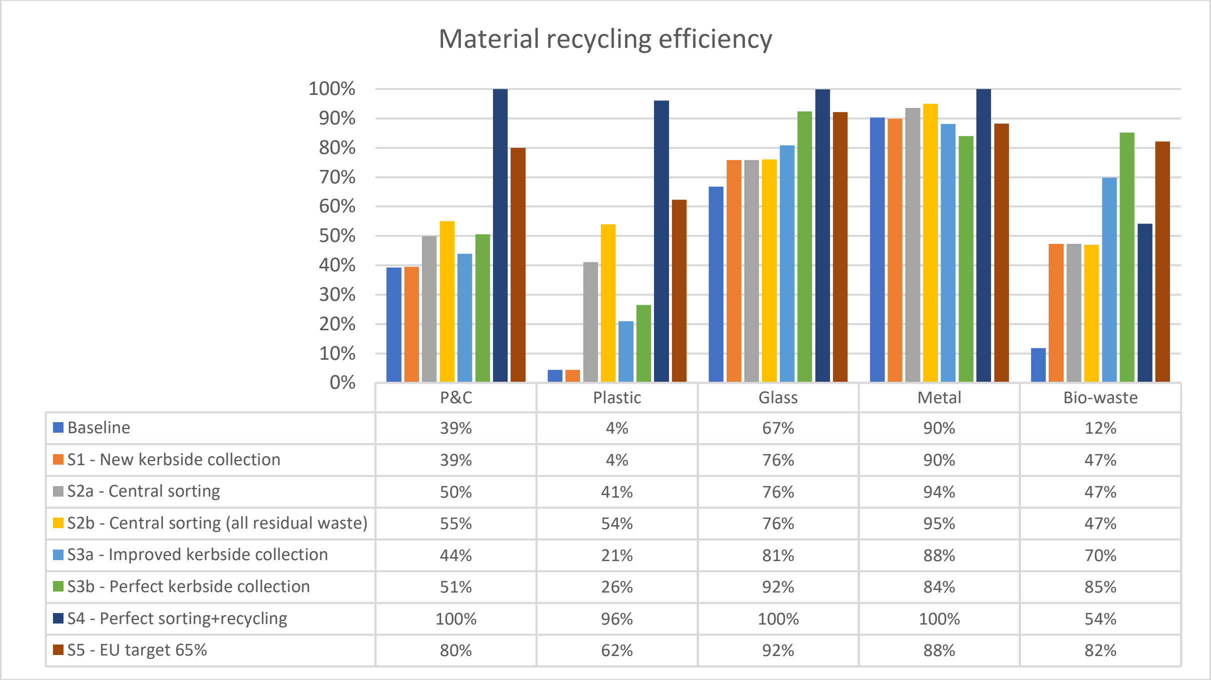


	P&C	Plastic	Glass	Metal	Bio-waste
■ Baseline	70%	13%	69%	20%	12%
■ S1 - New kerbside collection	71%	13%	79%	24%	54%
■ S3a - Improved kerbside collection	79%	63%	84%	39%	81%
■ S3b - Perfect kerbside collection	91%	79%	96%	76%	99%
■ S5 - EU target 65%	84%	91%	96%	62%	86%

Figure 44 - Collection efficiency, 2035

Material recycling efficiency results show (Figure 43) that S5 yields to the highest rate at 60%. This is a 43 percentage points increase compared to the Baseline scenario. This means that while 65% of municipal waste is prepared for recycling, only 60% is recycled back to the economy as secondary raw materials. With the introduction of the new kerbside collection system and the building of a central sorting facility, the material recycling efficiency could improve from 17% to 27% (S1), 33% (S2a) and 35% (S2b).

Comparing the impact of improved kerbside collection versus improved sorting and recycling, results show that perfect kerbside collection (S3b) yields to 42% and perfect sorting and recycling (S4) yields to 51% material efficiency. Figure 45 shows changes in fraction specific material recycling efficiencies.



	P&C	Plastic	Glass	Metal	Bio-waste
■ Baseline	39%	4%	67%	90%	12%
■ S1 - New kerbside collection	39%	4%	76%	90%	47%
■ S2a - Central sorting	50%	41%	76%	94%	47%
■ S2b - Central sorting (all residual waste)	55%	54%	76%	95%	47%
■ S3a - Improved kerbside collection	44%	21%	81%	88%	70%
■ S3b - Perfect kerbside collection	51%	26%	92%	84%	85%
■ S4 - Perfect sorting+recycling	100%	96%	100%	100%	54%
■ S5 - EU target 65%	80%	62%	92%	88%	82%

Figure 45 - Material recycling efficiency, 2035

The distributions of the different waste treatment alternatives vary in the different scenarios (Figure 46). Better waste sorting leads to more material recycling and less energy recovery. Evaporation loss occurs during the central sorting of residual waste containing bio-waste fractions.

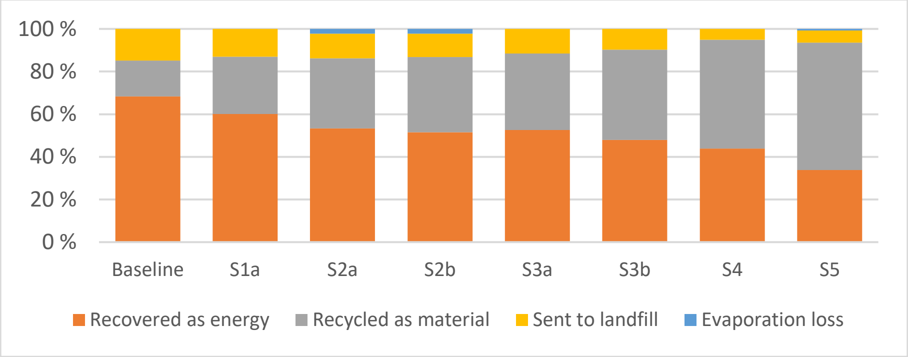


Figure 46 - Treatment per scenario, 2035

By focusing on bio-waste, Figure 47 shows how changes in improved food waste collection and sorting influence material and energy recovery rates in the MSWM system.

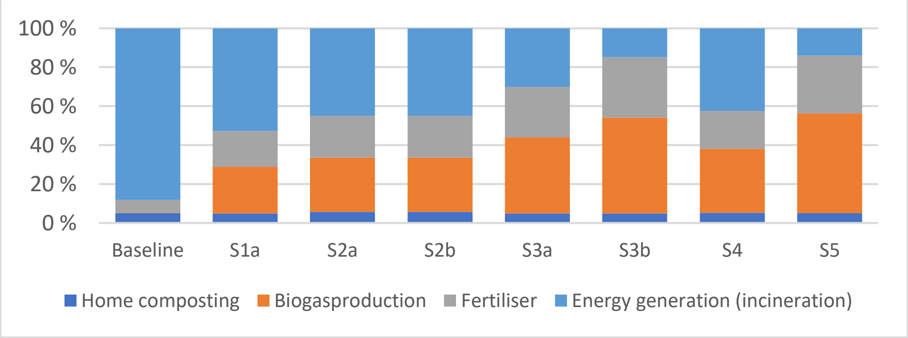


Figure 47 - Food waste treatment, 2035

5.2.2. Energy layer

Table 6 shows a decreasing trend in energy efficiencies across the scenarios. By reducing the amount of recyclable waste fractions in residual waste, less municipal waste is treated by incineration. This means that less energy is recovered from waste and more conserved in the form of secondary raw materials.

Table 6 - Energy efficiency, 2035

	Baseline	S1a	S2a	S2b	S3a	S3b	S4	S5
Energy efficiency	61 %	62 %	51 %	47 %	57 %	54 %	31 %	34 %
Feedstock E. (kwh)	1.05E+08	1.04E+08	1.04E+08	1.04E+08	1.04E+08	1.04E+08	1.04E+08	1.04E+08
Transport E. (kwh)	8.68E+06	8.63E+06	9.31E+06	9.66E+06	9.74E+06	9.24E+06	1.02E+07	1.21E+07
ReMidt (kwh)	5.07E+06	4.80E+06	4.75E+06	4.75E+06	5.43E+06	4.44E+06	4.66E+06	6.13E+06
Other (kwh)	3.75E+06	3.84E+06	4.56E+06	4.91E+06	4.31E+06	4.80E+06	5.56E+06	6.01E+06
Process E. (kwh)	1.95E+07	1.99E+07	2.25E+07	2.37E+07	2.24E+07	2.51E+07	3.46E+07	3.44E+07
Generated E. (kwh)	8.13E+07	8.17E+07	6.92E+07	6.49E+07	7.70E+07	7.50E+07	4.68E+07	5.13E+07

The introduction of the different waste management measures leads reduced kerbside collection energy use, while downstream energy requirements increase (Figure 48). This is because less waste is sent directly to incineration (reduced weight of RW), and more is transported to further sorting or treatment (increased weight of P&C, P, G&M, FW).

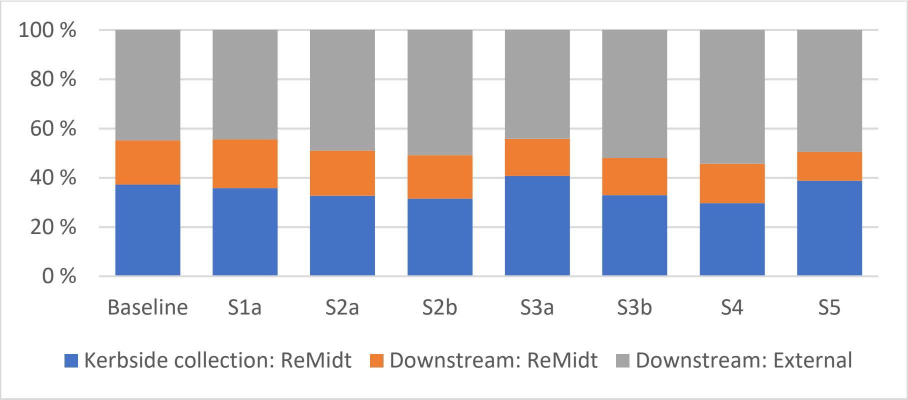


Figure 48 - Transport energy distribution, 2035

5.2.3. Emission layer

All scenarios yield to reduced net climate impact (Figure 49). However, only S2b, S4 and S5 have net negative climate change impact. The baseline scenario has the highest per capita climate change impact (71.73 kg CO_2-eq/cap.) and S4 has the lowest (121.91 kg CO_2-eq/cap.) (Figure 50).

Figure 51 shows the contribution of the different waste fractions to the climate change impact in the various scenarios. Besides S4, residual and plastic fractions contribute the most to the generated GHG emission, and paper and cardboard packaging takes the biggest share of avoided GHG emission.

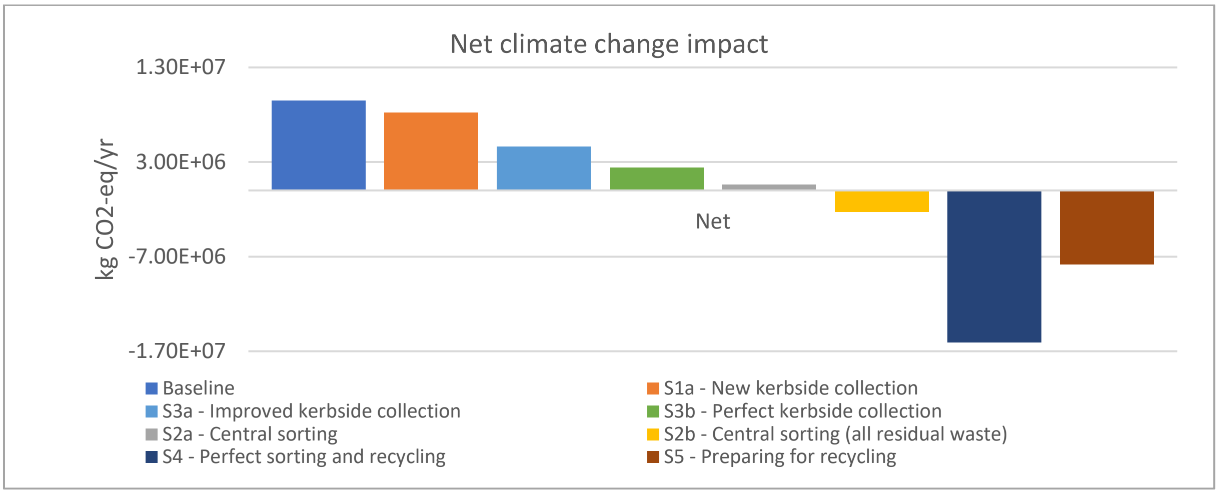


Figure 49 - Net climate change impact, 2035

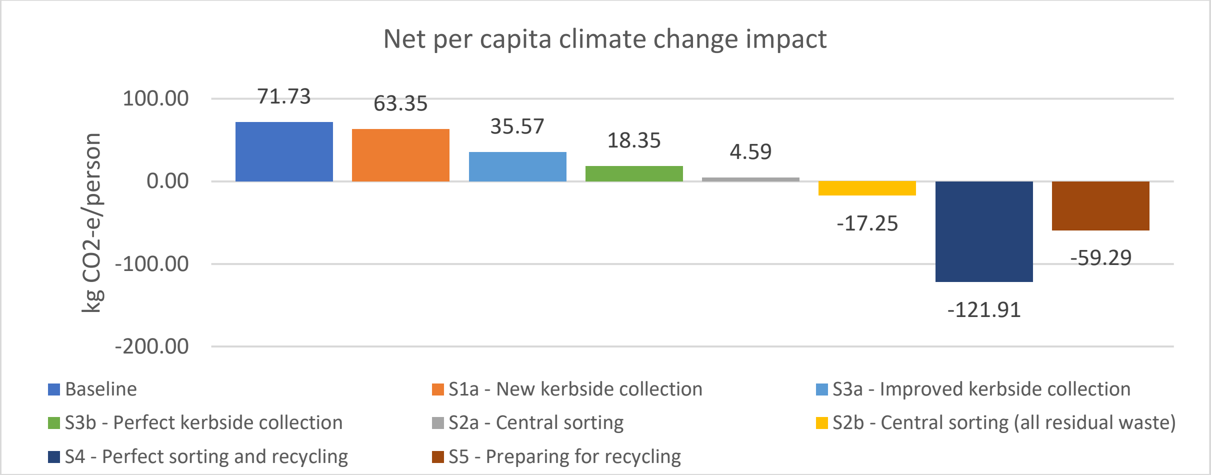


Figure 50 - Net per capita climate change impact

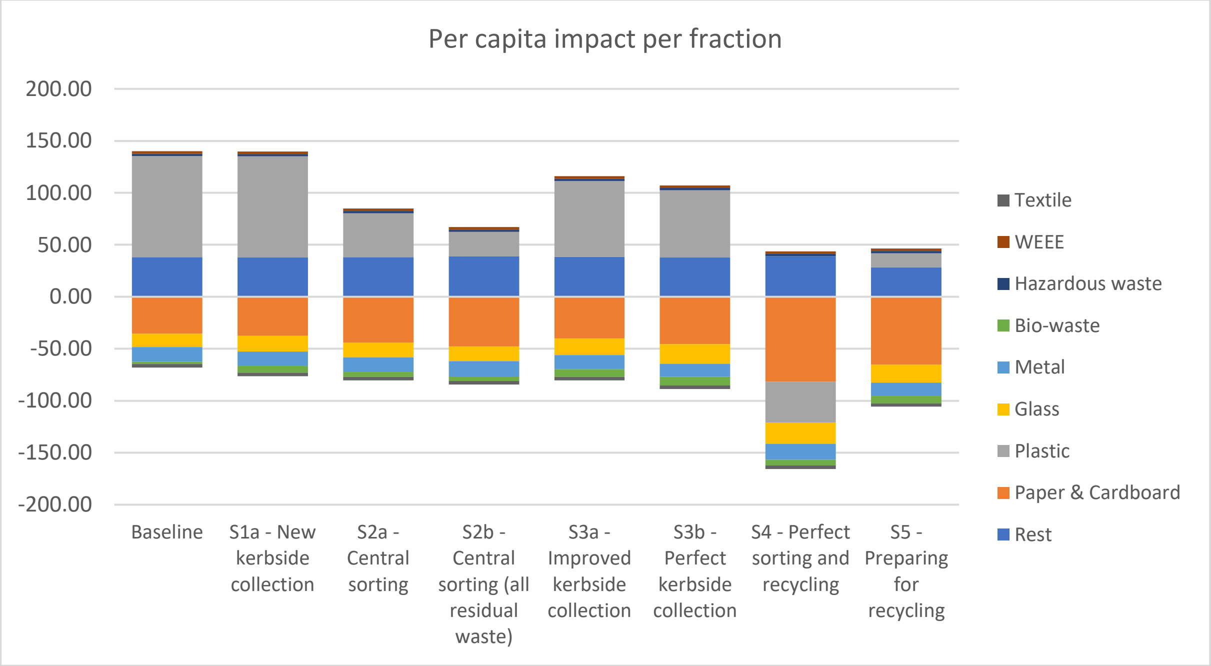


Figure 51 - Per capita climate change impact, 2035

The summary of the impact distribution of the generated GHG emission show (Figure 52) that waste incineration has the biggest contribution to generated emission, followed by emission generated during recycling processes. Process and transport energy use acounts for 10-20% of the generated GHG emission across the different scenarios.

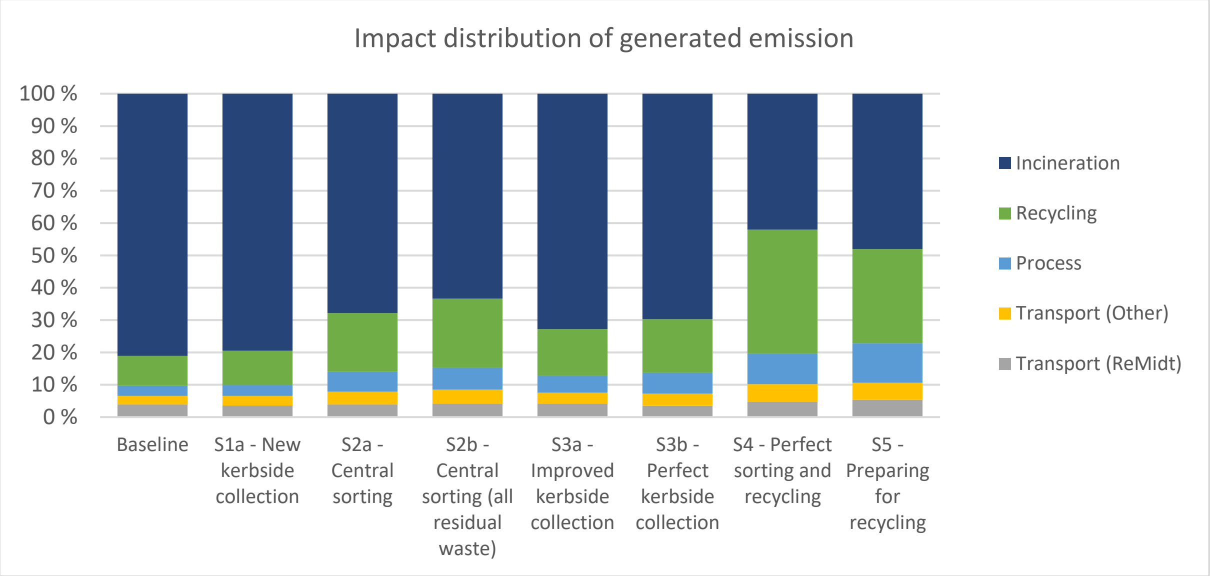


Figure 52 - Impact distribution of generated GHG emission, 2035

The distributions of the avoided GHG emission in the different scenarios (Figure 53 and Figure 54) show that material recycling contributes the most to emission savings. Regarding different fractions, the treatment of paper and cardboard and plastic takes up the biggest share of the avoided GHG emission.

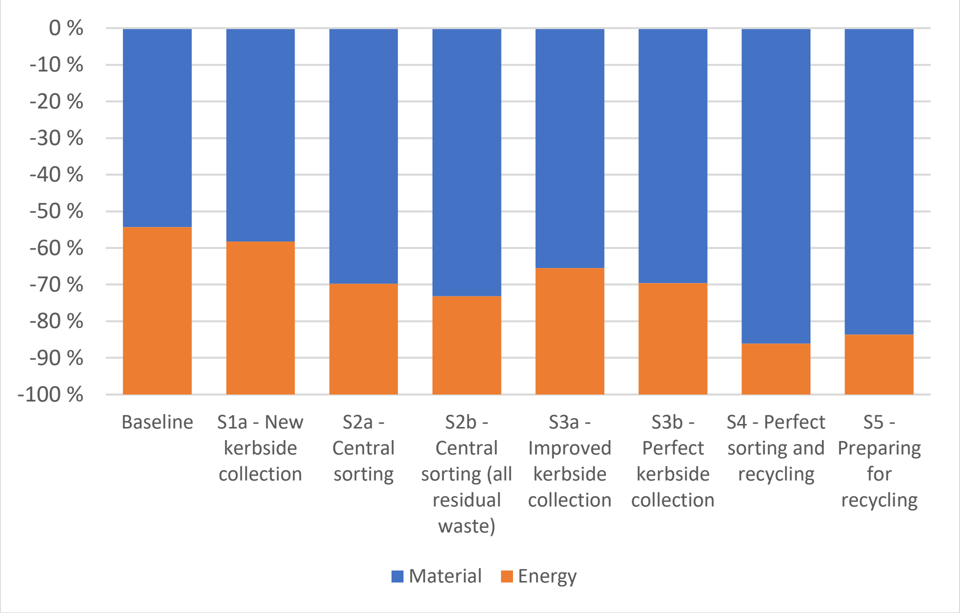


Figure 53 - Distribution of avoided GHG emission per treatment, 2035

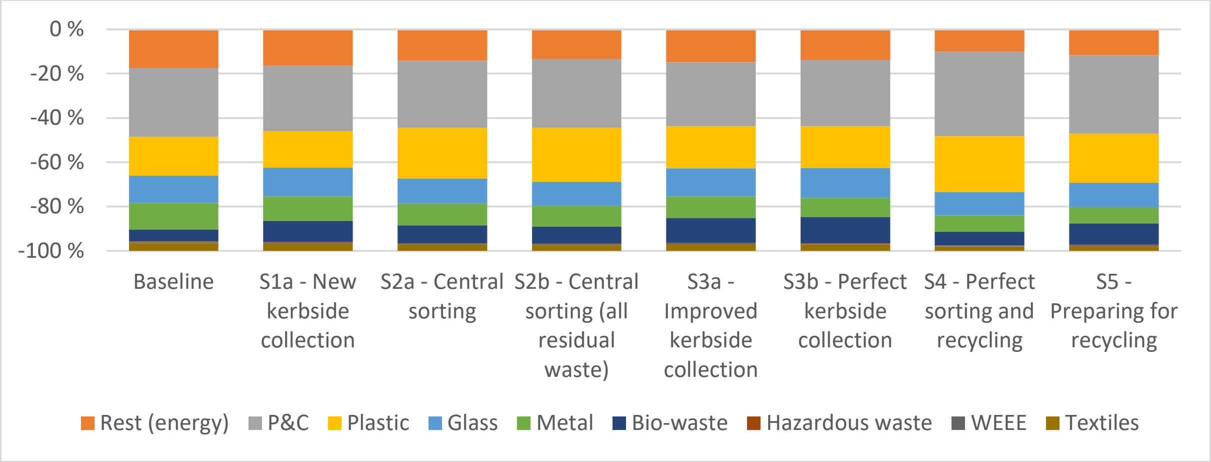


Figure 54 - Distribution of avoided GHG emission per fraction

5.3. Sensitivity

Results from the sensitivity analyses on the three main material efficiency parameters are presented in the tables below.

Collection efficiency

The source sorting of food waste within the kerbside collection system has the biggest impact on the aggregated collection efficiency. By reducing the amount of food waste in residual waste (kerbside) by 10%, the aggregated collection efficiency increases by 1.8 percentage points and the fraction specific collection efficiency growths with 4.5 percentage points. After food waste, plastic packaging sorting influences the most the collection efficiency. 10% reduction of plastic fraction in residual waste (kerbside) result in 1 percentage point increase in aggregated collection efficiencies and 6.2 percentage points in the fraction specific efficiency rate. Overall, collection efficiency is more sensitive to changes in residual waste composition in the kerbside system than in the bring system.

Table 7 - Sensitivity of the collection efficiency indicator

				Rate of change	
Flow	Collection system	Change	Changed value (%)	Fraction	Total
X01	Kerbside	Less paper and cardboard fractions in residual waste and more in the right bin	-10%/+10%	**2.0 %**	**0.5 %**
X01	Kerbside	Less plastic in residual waste and more in the right bin	-10%/+10%	**6.2 %**	**1.0 %**
X01	Kerbside	Less glass in residual waste and more in the right bin	-10%/+10%	**1.7 %**	**0.1 %**
X01	Kerbside	Less metal in residual waste and more in the right bin	-10%/+10%	**5.1 %**	**0.2 %**
X01	Kerbside	Less food waste in residual waste and more in the right bin	-10%/+10%	**4.5 %**	**1.8 %**
X03	Bring	Less paper and cardboard fractions in residual waste and more in the right bin	-10%/+10%	**0.9 %**	**0.2 %**
X03	Bring	Less plastic in residual waste and more in the right bin	-10%/+10%	**2.1 %**	**0.3 %**
X03	Bring	Less glass in residual waste and more in the right bin	-10%/+10%	**0.5 %**	**0.1%**
X03	Bring	Less metal in residual waste and more in the right bin	-10%/+10%	**2.5 %**	**0.1 %**
X03	Bring	Less food waste in residual waste and more in the right bin	-10%/+10%	**0.1 %**	**0.1 %**

Material recycling efficiency

The material recycling efficiency sensitivity shows similar patterns as collection efficiency results. By reducing the amount of food waste and plastic packaging sent to incineration by 10%, the aggregated efficiency rate increases by 1.1 and 0.9 percentage points respectively, and the fraction specific material recycling efficiency increases by 3.9 and 8.1 percentage points.

Table 8 - Sensitivity of the material recycling efficiency indicator

			Rate of change	
Flow	Change	Changed value (%)	Fraction	Total
X4-8/X4-5	Less paper and cardboard are incinerated, and more is recycled	-10%/+10%	**1.3 %**	**0.2 %**
X4-8/X4-5	Less plastic is incinerated, and more is recycled	-10%/+10%	**8.1 %**	**0.9 %**
X4-8/X4-5	Less glass is incinerated, and more is recycled	-10%/+10%	**0.1 %**	**0.0 %**
X4-8/X4-5	Less metal is incinerated, and more is recycled	-10%/+10%	**0.4 %**	**0.0 %**
X4-8/X4-7	Less food waste is incinerated, and more is recycled	-10%/+10%	**3.9 %**	**1.1 %**

Preparation rate for recycling

The sensitivity of the preparation rate for recycling to the reduction of recyclable fractions sent to incineration show similar patterns as sensitivity of the other indicators. Overall, the sensitivity results show that the three main system efficiency indicators are most sensitive for food and plastic packaging waste.

Table 9 - Sensitivity of the rate of preparing municipal waste for recycling.

			Rate of change	
Flow	Fraction type	Changed value (%)	Fraction	Total
X4-8/X4-5	Less paper and cardboard to energy recovery and more prepared for recycling	-10%/+10%	**2.9 %**	**0.5 %**
X4-8/X4-5	Less plastic to energy recovery and more prepared for recycling	-10%/+10%	**8.3 %**	**0.9 %**
X4-8/X4-5	Less glass to energy recovery and more prepared for recycling	-10%/+10%	**2.1 %**	**0.1 %**
X4-8/X4-5	Less metal to energy recovery and more prepared for recycling	-10%/+10%	**0.6 %**	**0.0 %**
X4-8/X4-7	Less food waste to energy recovery and more prepared for recycling	-10%/+10%	**4.6 %**	**1.2 %**

5.4. Uncertainties

The uncertainties of model results were tested for the individual waste fractions and the total amount of waste and net emission generated.

As the figure below shows, the generated food waste amount has the biggest range of uncertainty spam (+/-881.35 tonnes/yr), followed by paper and cardboard (+/-487.41 tonnes/yr), plastic (+/-300.25 tonnes/yr), glass (+/-166.84 tonnes/yr), metal fractions (+/-66.67 tonnes/yr), and garden and park waste (+/-47.26 tonnes/yr).

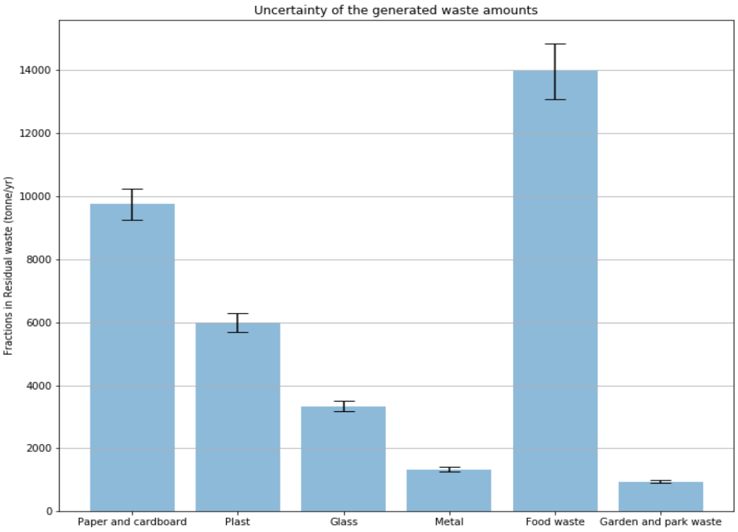


Figure 55 - Uncertainty of the generated waste amounts

The normal probability distribution (μ= 35348.32 and σ=2000) of the total generated waste amounts is visualised below.

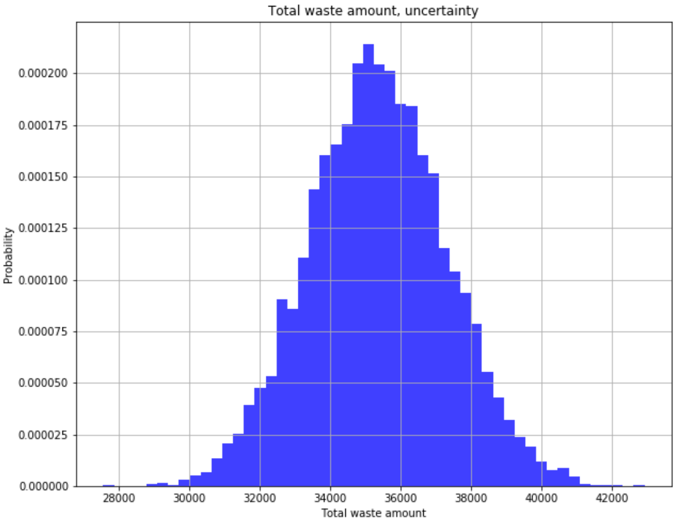


Figure 56 – Probability distribution of total waste amounts

The net emission (generated+avoided) associated with the treatment of paper and cardboard fractions has the biggest range of uncertainty spam (+/-908.86 tonnes of CO2-eq/yr), followed by glass treated abroad (+/- 710.89 tonnes of CO2-eq/yr), plastic (+/- 616.85 tonnes of CO2-eq/yr), metal treated abroad (+/- 568.54 tonnes of CO2-eq/yr), glass treated in Norway (+/- 243.88 tonnes of CO2-eq/yr), metal treated in Norway (+/- 218.19 tonnes of CO2-eq/yr), and food waste utilised in Norway (88.25 tonnes of CO2-eq/yr). Emission results calculated for glass and metal fractions that were recycled abroad show a bigger range of uncertainty than fractions that were treated in Norway. This is because the uncertainty of the emission factors gathered for the recycling processes abroad are assumed to be higher.

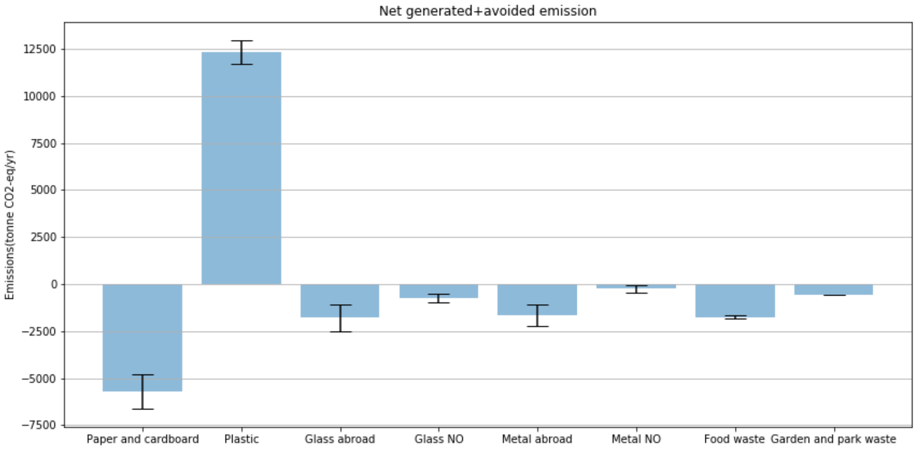


Figure 57 - Uncertainty of net GHG emission results (recyclables)

The probability distribution of the net GHG emission of the recyclable fractions is visualised below.

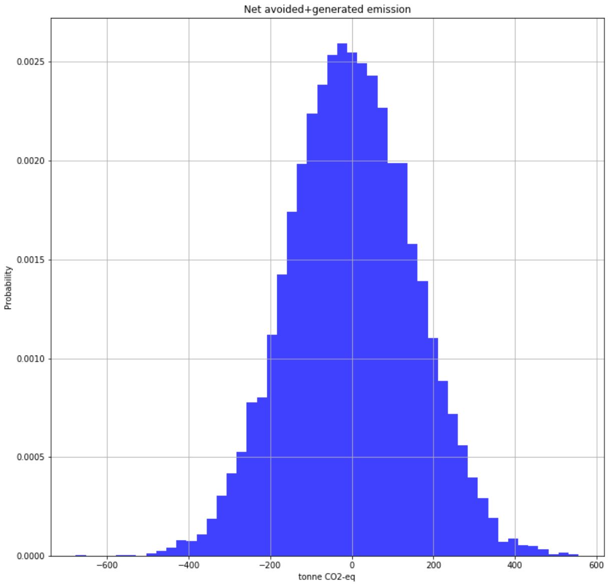


Figure 58 - Uncertainty of net GHM emission (recyclables)

6. Discussion

Waste management opportunities at ReMidt IKS

The overall goal of this study is to gain a deeper understanding of the complexity of a Norwegian MSWM system, and to assess how local waste management actors can help implement the circular economy. The research questions addressed in this study are the following:

- What is the current performance of the studied MSWM system?
- How do new waste management measures affect system performance?
- What are the most important measures that influence system performance?
- Is it feasible to achieve the 65% target by 2035?

A baseline and five alternative scenarios were defined and modelled to describe the current performance of ReMidt, and to test the impact of various measures on system efficiencies identified as: collection, material recycling and energy efficiencies, rate of preparing municipal waste for recycling, and climate change impact. This chapter is divided into sub-sections that describe the current performance of ReMidt and compare it to the different scenarios to trace changes in system efficiencies. Furthermore, the most important measures influencing system performance will be highlighted and discussed in further detail. In the *EU targets vs. reality* section the feasible to achieve the 65% target by 2035 will be tested. Finally, alterative scenarios and the strengths and weaknesses of this study will be discussed.

Better source separation

Since waste collection is the only process that ReMidt has a direct influence on, collection efficiency serves an important indicator for measuring the performance of ReMidt operations. In 2020, *collection efficiency* was **31.7%,** meaning that less than 32% of all the recyclable municipal waste fractions (paper and cardboard, plastic, glass and metal packaging and bio-waste) were source separated.

Scenario analysis shows that the introduction of the new kerbside collection system (S1) can lead to 49% collection efficiency by 2025. This 17-percentage points increase is due to the improved source separation of food and glass and metal packaging waste. To raise collection efficiency up to 70% by 2035 (S3a), ReMidt must implement measures targeting plastic packaging too. In 2020, only 13% of plastic waste fractions were source separated which should be increased up to 63% to meet the target.

Bio-waste sorting must improve from 54% in 2025 to 81% in 2035. In this study measures influencing only food waste sorting were considered. However along with the finding of the Norwegian Environmental Agency; the introduction of kerbside garden and park waste collection could lead to both improved collection efficiencies, and higher preparation rates for recycling. This is one of the costliest measures a MSWM company can introduce. Therefore, a more detailed and company specific feasibility analysis should be carried out in the future if ReMidt wants to consider this measure. The introduction of a new waste fee systems (S3b), such as the “Pay for what you throw” scheme, could offer an economic incentive to ReMidt customers for better source separation. ReMidt is advised to consider this measure to improve its system performance in the future.

Measures targeting waste collection have an influence on transport energy use and associated emission. The annual fuel consumption of waste trucks operated by ReMidt decrease by 6 percentage points in S1. This is a result of a more unified kerbside collection system in which all fractions are collected by trucks equipped with two-chamber technology. Increase in the amount of source separated recyclables influences downstream energy use. In S1, downstream transport energy demand increases by 3 percentage points. There are regional variations in net and waste type specific energy requirements. The net kerbside transport energy demand is higher in bigger regions, for instance in Orkland and Melhus+MG, where the distance between customers is lager during a collection round. In more densely populated regions such as the city of Kristiansund, waste trucks require less diesel fuel. Considering the per tonne fuel requirement of the kerbside collection system, results show that fuel consumption increases in all regions. The reason for this is that in the new kerbside system additional transport rounds are introduced to collect food and glass and metal packaging waste.

Improved kerbside collection results in -1.8 percentage points net emission reductions (S1a, 2025). The impact of replacing the vehicle fleet in Orkland and Melhus+MG regions with biogas trucks leads to an additional 0.3 percentage points reduction, totalling -2.1 percentage points. This means that the replacement of diesel fuel with biogas in collection transport has a limited environmental benefit from a system perspective. While transport energy usage shows some variations across the different scenarios, on average transport processes only contribute to ~10% of the total GHG emission generated by the MSWM system. It is important to highlight that transport emission calculations are not representative in this study because a generic model was used to calculate energy use and associated climate impact. Furthermore, the environmental load of fossil diesel use in logistic transport is often associated with local impacts, such as bad air quality. However, in this study such impact categories were not considered.

As it was pointed out previously, in this study system efficiencies were calculated for all municipal waste without considering differences between collection technologies and ReMidt customers. The distribution of ReMidt customers is shown in Table 10. About two-thirds of the residual waste originates from households, while the rest is from other customers. There is lack of information on the waste fraction distribution from municipal and commercial institutions, and holiday homes. Therefore, in this study waste analysis results from household waste were used on aggregated municipal waste amounts. This increases the uncertainty of collection efficiency results, because as a waste analysis carried out for TRV in Trondheim (Sandberg, Kolås and Miklós, 2020a, 2020b) shows; municipal institutions have less percentage of food waste and glass and metal fractions in residual waste than household. ReMidt has plans to conduct new waste analysis which could be utilised in future collection efficiency calculations.

Table 10 - Distribution of municipal waste origins, ReMidt 2020

Waste type	Household	Municipal and commercial institutions	Holiday homes
RW	63 %	18 %	19 %
P&C	81 %	14 %	5 %
G&M	83 %	0 %	17 %
Food	93 %	7 %	

Improved infrastructure, technology, and design for recycling

Better source separation has an important role in ensuring that cleaner waste streams enter sorting and recycling operations. However, due to infrastructural, technological and product design challenges fewer secondary resources are recovered from municipal waste. This is one of the reasons why Norway has a low, 3% material circularity rate (Circle Economy and Circular Norway, 2020).

The *material recycling efficiency* of the system was **17.4%** in 2020. This means that from all the collected municipal waste at the end less than 18% was recycled back to the economy as secondary raw material. Since a significant portion of plastic, and glass and metal fractions are exported to recycling abroad; not all the recovered materials are circulated back to the local economy. If Norway would like to improve its material circularity rate, then it is crucial to invest more in the domestic waste recovery sector. In addition, Norway could become a more proactive actor in realising the EU's circular economy plan by utilising secondary raw materials from the European market.

In S2 the impact of improved waste sorting infrastructure was tested. It was assumed that in addition to the new kerbside collection system (S1), ReMidt would also send its residual waste to the Sesam central sorting facility from 2025 onwards. In S1, material recycling efficiency increased by 10 percentage points (from 17% to 27%) compared to the Baseline. The central sorting of RW collected within the kerbside system (S2a) can increase material recycling efficiency up to 33%. The central sorting of all residual waste (S2b) yields to 35%. This means that the central sorting facility can contribute to an additional 6-8 percentage points increase in material recycling rates. In comparison, if the collection efficiency is increased up to 70%, then the material recycling efficiency goes up to a 42%. This indicates that improved source sorting results in cleaner waste streams and higher material recycling rates, than central sorting operations. This is because recyclable fractions get contaminated in residual waste, therefore many of them become rejects during sorting operations.

Results from S4 show that the theoretical maximum of improving material recycling rates through perfect sorting and recycling is 51%. Perfect kerbside collection yields to 42% material recycling efficiency. The achievement of the aggregated 65% preparation rate by 2035 requires a material efficiency rate at 60%. This means that the target can only be achieved if measures focusing on <u>both source separation, central sorting and recycling processes</u> are implemented. ReMidt can take extra measures to further improve its collection efficiencies within both kerbside and bring collection systems. However, changes along the downstream sorting and recycling operations are also necessary.

The energy efficiency and emission intensity of the system is strongly influenced by the amount of waste delivered to incineration. The more recyclable fractions are sorted out from residual waste, the less residual waste is utilised as heat from the incineration process. Therefore, the energy efficiency of the system decreases in the alternative scenarios. As it was pointed out by Morten Fossum from Statkraft Varme (2021), incineration is a waste treatment process and is not part of the Norwegian energy production system. Heat is only a by-product of waste incineration which is recovered and supplied to the district heating system as a supplementary energy source. Therefore, waste management measures that lead to reduced incinerated waste amounts should not be influenced by the energy demand of a district heating system.

Reduced waste incineration rate does not only decrease the energy efficiency of the MSWM system but it also leads to lower GHG emission. Waste incineration has a bigger climate change impact than recycling. Therefore, measures leading to higher recycling rates also reduce net GHG emission generated by the MSWM system.

Fraction specific recycling rates

Plastic packaging

In 2020, only 4% of plastics were recycled. This low recycling rate of plastics is not unique for the case study. Currently only about 30% of the plastic packaging is recycled in the EU because many of the disposed products are either poor quality or the price of recycled products is too low (European Commission, 2018a). Global plastics production and the incineration of plastic waste accounts for approximately 400 million tonnes of CO_2 per year. In addition, between 1.5% to 4% of the global plastics products end up in the oceans each year. The EU is responsible for about 4% of the global plastic marine litter. To improve material circularity and to reduce the environmental load of plastic packaging generated by EU member states, the European Commission has developed a European strategy for plastics. It sets a target that by 2030 "all plastics packaging placed on the EU market is either reusable or can be recycled in a cost-effective manner" (European Commission, 2018a). Furthermore, the Commission has implemented new rules on the Extended Product Responsibility schemes and product design. In addition, new investment and cohesion funds were created to improve the quality and value of recycled materials on the market.

Norwegian waste management actors have a key role in this strategy through improving source separation and collection rates, and by investing in innovative recycling technologies. Scenario results show that both source separation and central sorting have a positive impact on plastic recycling efficiency. With central sorting the recycling rate for plastics can grow from 4% to 41% (S2a) and 54% (S2b). According to Kathrine Kirkevaag (2021) a domestic market for recycled plastics must be established. The public sector and companies within the building and infrastructure sectors could play an important role in growing the demand for recycled plastic materials. "Plast Løftet" is an ongoing Norwegian multi-stakeholder project which focuses on reducing plastic consumption, creating a market for recycled materials, and designing products for recycling.

Paper and cardboard and packaging

Improving the recycling rate of P&C fractions in Norway is two-folded. On one hand, better source separation could improve the quality of P&C delivered to recycling. On the other hand, according to Askeland, Wærner and Tellnes (2017), the Norwegian market has been oversupplied with virgin wood products due to the closure of many paper and wood producing industries during the past few years. This development has been reducing the need for secondary P&C on the domestic market.

Glass and metal packaging

Glass and metal fractions have relatively high recycling rates. However, the high energy demand of the recovery processes is associated with high emission rates. More energy efficient technologies and the increased share of renewables in the energy mix could reduce the environmental impact glass and metal recycling processes have.

Bio-waste

Bio-waste, especially food has received a heightened attention from policymakers during the past years. Based on 2012 estimates, 53% of food waste was generated by household in the EU, which equals to 173 kg per person (European Parliament, 2017). In Norway, ~80 kg food waste is generated per capita, half of it is edible food (Syversen, Hanssen and Bratland, 2018). In addition to the mandatory sorting of food waste by 2023, the WFD also states that Member States should improve consumer awareness of the meaning of 'use-by' and 'best-before' dates to reduce food waste. The Norwegian government has launched the "ForMat" and "KuttMatsvinn2020" research projects to implement science-based measures to reduce food waste generation in Norway.

EU targets vs. reality

In 2020, the aggregated *rate of preparing municipal waste for recycling was* 17%.

To validate model results, ReMidt preparation rates were compared to a national analysis conducted by Bjørnerud et al (2019). In this study a simplistic scenario analysis was carried out to model the impact of waste management measures on future waste amounts. In addition to paper and cardboard, plastic, glass and metal packaging and food waste, the analysis included other recyclable fractions too.

Table 11 compares the preparation rates across three scenarios: baseline, realistic and EU 65%. In the realistic Norwegian scenario, it is assumed that the kerbside collection of food and plastic waste will be implemented in all municipalities by 2035. Furthermore, new central sorting facilities will be built by this time. This is comparable with S2a - Central sorting scenario.

Table 11 – EU target, ReMidt vs. Norwegian average

	Baseline (2020)			**Realistic (2035)**			**EU 65% (2035)**		
Recyclables	ReMidt, Baseline	Norwegian average	Diff.	ReMidt, S2a	Norwegian average	Diff.	ReMidt, S5	Norwegian average	Diff.
Aggregated	17 %	37 %	-21%	37 %	46 %	-9%	65%	65 %	-
P&C	39 %	79 %	-40%	50 %	80 %	-30%	80 %	90 %	-10%
Plastic	9 %	24 %	-15%	49 %	50 %	-1%	80 %	75 %	15%
Glass	67 %	79 %	-12%	76 %	85 %	-9%	92 %	95 %	-3%
Metal	90 %	83 %	7%	94 %	90 %	4%	88 %	95 %	-7%
Bio-waste	12%	42 %	-30%	54 %	60 %	-6%	90 %	80 %	10%
Food waste[28]	6%	42 %	-36%	51 %	60 %	-9%	89 %	80 %	9%

In the Baseline, ReMidt's preparation rate for recycling is below the Norwegian average, except for metals. The reason is that less rejects were assumed in the bottom ash recovery process, than in the Bjørnerud et al (2019) study. The Norwegian average is significantly higher for food waste because there are municipalities with already established kerbside collection systems at national scale. Overall, the Norwegian average (37%) is more than twice as high as ReMidt's aggregated preparation rate (17%).

In the realistic scenarios the difference is reduced to only 9 percentage points. As the sensitivity analysis carried out in this study indicates, food and plastic waste sorting have the biggest impact on the system efficiency indicators. This is in line with the findings of the Norwegian Environmental Agency (Mepex and Østfoldforskning, 2018). Therefore, the improved collection and sorting of plastic and food waste at ReMidt could increase the preparation rate to similar levels as the national average. However, it is important to stress that Bjørnerud et al (2019) included hazardous, WEEE, wood and textile waste in their analysis. These fractions were excluded from ReMidt's preparation rate calculations.

Due to these differences, parameters influencing waste collection, sorting, and recycling operations were adjusted differently in the EU 65% scenario (S5). For instance, higher plastic and bio-waste preparation rates were assumed than in the Norwegian average scenario. Interestingly, ReMidt's preparation rate for metal decreases compared to the baseline and realistic (S2a) scenarios. The reason for this is that in S5 fewer metal fractions will end up in the residual waste. Therefore, less will be sent to incineration and more to recycling. The reject rate during the sorting operation (process 5 in S5) for source separated metal packaging is assumed to be higher than for bottom ash treatment (process 10 in S5). Meaning that better metal source separation leads to lower efficiencies than when metal is recovered from incineration bottom ash. This is in line with findings of a study carried out by Avfall Norge. In 2017, 39% of metal packaging was recovered from source separated G&M waste, 60% from incineration bottom ash and 1% from central sorted residual waste (Syversen, Kirkevaag and Bjørnerud, 2019).

---

[28] Bjørnerud et al (2019) included food waste in their analysis instead of all bio-waste. Therefore, results for only food waste were also added to the Table.

While the Bjørnerud et al (2019) study is not completely comparable with the analysis carried out in this master thesis; the comparison of the scenario results presented above indicate similar future trends. One of the main conclusions that can be drawn is that the achievement of the 65% preparation rate requires ambitious measures. As it was mentioned in section 4.5, the Norwegian Environmental Agency carried out a study on the impact of waste management measures on the rate of preparing municipal waste for re-use and recycling. Results show that within a realistic framework the 65% cannot be achieved at a national level. Even with the most ambitious estimates, Norway would reach only 59% by 2035.

Two out of the three most important measures suggested by this analysis focus on improved kerbside collection of municipal waste. In comparison, the effect of improved central sorting and recycling rates tend to be smaller. This is in line with the findings of this master thesis. Results show that when perfect kerbside collection is assumed (S3b) then the preparation rate can increase to 50%. In case of perfect sorting and recycling (S4) the preparation rate increases from only 3%, up to 53%. Since S3b only considers perfect collection within the kerbside system, it is likely that cleaner waste streams from the bring system could lead to higher overall preparation rates.

The comparison of the system efficiencies in the Baseline scenario and S5 shows that both collection and material recycling efficiencies must improve to achieve the 65% preparation rate (Table 12).

Table 12 - System efficiencies 2035, Baseline vs. S5

Fractions	Baseline 2035	S5 2035
Collection efficiency	32%	80%
Material recycling efficiency	16.9%	60%
Rate of preparing for recycling	17.4%	65%
Rest	0 %	29 %
P&C	39 %	80 %
Plastic	9 %	80 %
Glass	67 %	92 %
Metal	90 %	88 %
Bio-waste	12 %	90 %

The climate change impact of the MSW system

As it was mentioned in section 2.4, LCA is common method used for quantifying the environmental impact of MSWM systems. However, due to the limited timeframe only a simplified environmental assessment was carried out in this study. Generated and avoided GHG emission rates were calculated to quantify the net climate change impact of the MSWM system. An uncertainty analysis was carried out to show the uncertainty range of the net GHG emission rate calculated for S1. Results indicate that the climate change impact quantified in this study should be interpreted with caution. Therefore, it is recommended to conduct a detailed LCA study in the future.

The summary of the scenario analysis shows that waste incineration has the biggest contribution to generated emission, followed by emission occuring during recycling processes. Process and transport energy use acounts for 10-20% of the generated GHG emission across the different scenarios. Plastic waste incineration generates the most GHG emission, while paper and cardboard recycling yields to the biggest emission savings. The overall conclusion is that the more waste is delivered to recycling, the less GHG emission is generated. Measures leading to high collection and material recycling efficiencies yield to net negative emission. The core principle of CE is that products and materials should kept in use, without generating waste and emission and exploiting natural systems. Therefore, this is an important finding regarding the circular economy.

Alternative scenarios and future work

The following alternative scenarios have not been modelled in this study but are discussed as additional measures that could be considered by ReMidt in the future.

Mixed recycling bin

ReMidt has shown interest in exploring the feasibility of introducing a kerbside collection system where all the dry recyclables are collected mixed in one bin. Residual waste and food waste would be collected in their own containers. Currently, none of the Norwegian municipalities have implemented such system. In the European context, the city of London has such kerbside collection system in inner London boroughs. The following waste fractions are collected in the mixed recycling bin:

Figure 59 - Mixed recycling bin content[29]

The organic and residual waste fractions are collected in residual waste and sent to incineration.

In outer, less dense London boroughs the recyclable bin is divided into three additional bins for food waste, paper and cardboard, and glass, metal, and plastic waste (Maarten *et al.*, 2020).

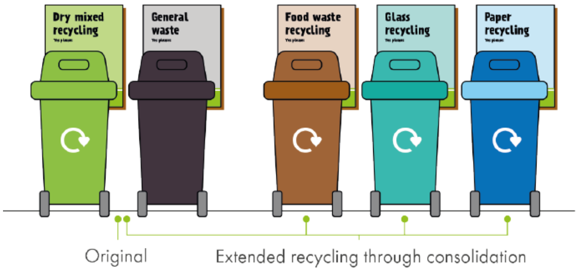


Figure 60 - Extended kerbside collection system in London[30].

---

[29] Figure waste taken from: https://londonrecycles.co.uk/business/download/. Accessed: 30.05.2021

[30] Figure waste taken from: https://londonrecycles.co.uk/business/download/. Accessed: 30.05.2021

The collection frequency of the different bins varies a lot depending on the borough. In densely populated inner districts, waste bins are emptied at least weekly, while outer regions have less frequent collection schedules. Recycling rates[31] also differ across boroughs. Bexley which has the four-bin system had the highest collection rate in 2020 (54%), while Newham and Westminster boroughs with two-bin system and no food waste collection had the worst collection rate during this period (17%) (London recycles, 2021; Yurday, 2021). As Table 13 indicates, six out of seven boroughs with the lowest recycling rates did not have separate food waste collection. Four out of seven had only a two-bin system. This shows that those districts that have one bin for all dry recyclables perform the worst. However, there are various socio-economic factors that also contribute to low collection and recycling rates, such as housing type, population density, ethnicity, level of knowledge about recycling, willingness to recycle etc. Regions with high population density and where most people live in either flats or houses of multiple occupation (HMO)[32] tend to have lower recycling rates (London Waste and Recycling Board, 2020a, 2020b, 2020c).

Table 13 - Collection efficiency in best and worst boroughs in London, 2020

Best five boroughs in 2020

1. Bexley (54%): 4 bins
2. Bromley (51%): 4 bins
3. Kingston upon Thames (49%): 4 bins + separate recycling sacks for electronics, batteries, and textiles (collected only from houses and not from flats)
4. Sutton (49%): 4 bins + separate recycling sacks for electronics and textiles (collected only from houses and not from flats)
5. Ealing (48%) 3 bins

Worst boroughs in 2020

1. Newham (17%): 2 bins, no food waste collection
1. Westminster (17%): 2 bins, no food waste collection
2. Tower Hamlets (22%): 4 bins; no food waste coll. for estates or flats with communal bins
3. Wandsworth (24%): 2 bins, no food waste collection
4. Redbridge (25%): 3 bins, no food waste
4. Barking & Dagenham (25%): 2 bins, no food waste collection
5. Camden (26%): 3 bins + separate recycling sacks for electronics, batteries, and textiles (collected only from houses and not from flats)

It is challenging to argue whether a mixed recycling bin solution could work in ReMidt because detailed information on such system could only be found in the context of the city of London. The sizes of the MSWM system in London and the one operated by ReMidt differ a lot. Just to illustrate, London has about 9.4 million inhabitants while Kristiansund which is the most populous city in the ReMidt region had only 24 179 inhabitants in 2020. Another aspect is that material recovery facilities (MRF) operating in London are specific for sorting mixed recyclable fractions. The proposed Sesam central sorting facility is designed for sorting residual waste that might include significant percentage of organic fractions. Furthermore, this CS facility would not be able to sort glass fractions out, while the MRF in London are equipped for glass sorting. Information on how the introduction of the mixed recycling bin would influence transport energy requirements and associated emission could not be found. Due to these uncertainties and the fact that kerbside collection systems based on Norwegian best practices, and legal and local specific requirements have already been established. Therefore, it is less likely that this new mixed recycling bin solution becomes widespread in the future.

---

[31] In this context recycling rate refers to the percentage of recyclable fractions collected separately and sent to material recovery facilities.

[32] HMO, where more than three tenants share common areas.

Kerbside garden waste collection

According to the Norwegian Environmental Agency the introduction of a kerbside collection scheme for garden and park waste has the highest effect - about 1.6 percentage points - on EU preparation rates for recycling and reuse. The estimated cost is about NOK 5,100 / tonne. The impact of this measure was not tested in this study, but a feasibility analysis could be conducted in the future to evaluate whether this is a realistic measure for ReMidt or not.

Kerbside textile collection

The environmental impact of textiles has received growing attention from policy makers at both at national and EU level. It is stated in the WFD that "Member States shall set up separate collection at least for paper, metal, plastic and glass, and, by 1 January 2025, for textiles". Separate collection includes both kerbside collection, as well as bring collection at collection point and recycling stations (Maarten *et al.*, 2020). The problem with this definition is that used textiles that are delivered to textile containers for re-use are considered as a gift and not as waste by Norwegian law. The WFD defines sorted textile "that does not undergo further processing before its utilization for the production of textile fibers, rags or granulates". Lystad et al. (2020) pointed out that because of differences in definitions, accounting for textile flows can be interpreted in different ways. This influences what would be included in statistics and target calculations. A reporting scheme for textile waste will be introduced from 2021 onwards.

In 2020, Watson *et al.*,(2020) mapped used textile and textile waste flows in Norway and found that despite the collection of used textiles have increased by 50% since 2010, at least half of the textiles consumed by households end up in the residual waste and sent to incineration. The study also found that only 3% of used textiles collected in Norway are utilized domestically. 97% is exported to other countries for re-use or recycling. Due to the large quantity and low quality of textiles delivered for further treatment, the global market is saturated. The picture is further complicated by the various technical, economic, and regulatory challenges associated with textile recycling.

To address these and various other challenges associated with textile consumption, re-use, and recycling, Avfall Norge lunched the multi-stakeholder "Tekstil 2025" research project. The goal is to find solutions for textile manufacturing and EoL treatment challenges in Norway. Due to the complex nature of the "textile dilemma" and the current wave of new research focusing on this issue, textiles were excluded from this study. In the future, ReMidt could take part in similar research projects.

Re-use

Re-use was excluded from this study because a quantification method for re-useable products is currently under development. According to the WFD, re-use should be counted as a waste preparation activity. Therefore, in the future a new analysis could be conducted which includes the impact of re-use on system efficiencies.

Strengths and limitations

The novelty of this thesis work is three-folded. First, this is the first study that measures the system performance of ReMidt IKS based on collection, material recycling and energy efficiencies, rate of preparing municipal waste for recycling, and climate change impact. Second, this study took a holistic approach by extending the system boundary to the whole MSWM system instead of only focusing on waste management processes which are under direct control of ReMidt. Finally, material flows were quantified by not only as main waste types (weight of municipal waste disposed in the RW, P&C, P, G&M, FW, and G&P containers) but also at fraction level (weight of residual waste, packaging of paper and cardboard, plastic, glass, metal, and bio-waste fractions found in the MSWM system). Due to failed source sorting, the main waste types are contaminated. For example, a significant amount of plastic packaging is not source separated (in the P container) but disposed into the RW container. As it was highlighted previously, the EU targets should be calculated based on the amount of sorted waste fractions that are sent to final material recycling. This means that only source separated waste fraction amounts should be counted in target calculations and not the weight of the different waste types. Most of the reviewed literature as well as national statistics calculate the EU targets based on waste types which leads to higher preparation rates. Therefore, it can be argued that the method used for calculating preparation rate is more accurate in this study. However, it is important to highlight, the preparation rate in this study excludes re-use as opposed to the EU target definition. Re-use was not considered because a calculation method for quantifying the amount of municipal waste prepared for re-use is still under development by the Norwegian Environmental Agency.

Another strength of this study is that primary data was collected from ReMidt and downstream waste management actors to quantify the waste and energy flows in the MSWM system. This reduced the uncertainty of the total generated waste amounts and energy consumed during transport and treatment processes. However, it must be noted that due to the absence of a ReMidt specific waste analysis study, the quantification of the waste fraction amounts in the different containers are based on analysis carried out by other Norwegian MSWM companies. This increases the uncertainty of the model results (see section 4.7). Another weakness of this study is that due to time constraints, no detailed LCA analysis was carried out to quantify the climate change impact of the MSWM system. Therefore, the net GHG emission results presented in this study are not representative. It is strongly recommended to conduct a more detailed environmental impact assessment in the future, which considers not only GHGs but other types of emission as well. Thereby, the impact of the various waste management alternatives can be evaluated from a broader environmental perspective.

7. Conclusions

Norway has a low degree of material circularity, which can be explained by the various factors influencing the Norwegian waste-, sewage, - and recycling industries. Core challenges are the lack of comprehensive regulatory framework, overview on the material and waste streams and fragmented waste management systems. When it comes to material circularity at regional scale, this study showed that from the 54045.14 tonnes of municipal waste collected by ReMidt, only about 17% was recycled back to the economy in 2020. The rest had been incinerated or sent to landfill.

The overall goal of this study was to gain a deeper understanding of the complexity of MSWM in Norway, and to assess how local waste management actors can help implement the circular economy. The aim was to understand how the collection and treatment of different waste streams can influence material, energy, and emission flows within a MSWM system. Five indicators were chosen to measure the system performance of ReMidt: collection, material recycling and energy efficiencies, rate of preparing municipal waste for recycling, and climate change impact.

The current collection efficiency of the analysed MSWM system is 32%. This means that only 32% of the recyclable municipal waste fractions were collected separately either within the kerbside or bring collection systems. These fractions are packaging of paper and cardboard, plastic, and glass and metal, and bio-waste. Other recyclable fractions such as electronics, hazardous, textile and wood waste were excluded from the analysis. As the EU Waste Framework Directive (WFD) underlines, waste is a resource which should be managed in a sustainable way. Effective waste collection is a prerequisite of such management system to work. ReMidt has an important role in implementing measures to improve better waste separation and thereby delivering cleaner waste streams to further treatment. Therefore, the introduction of new waste collection measures was tested in three scenarios: S1, S3a and S3b. When the introduction of a *new kerbside collection system* (S1) was modelled, results show that the sorting of food waste and glass and metal packaging can increase collection efficiency up to 41%. *To achieve 70% collection efficiency* (S3a), ReMidt should take measures that increase the sorting of plastic fractions too. The theoretical maximum collection efficiency ReMidt could achieve by *improving kerbside waste collection* is 86% (S3b).

The current material recycling efficiency of the system is under 17%. This means that of all the recyclable materials entering the MSWM system, 83% is either thrown into the residual waste bin or becomes reject during sorting and recycling operations. Plastic packaging has the lowest material recycling rate. On one hand, ~87% of plastic waste was discarded in the residual waste and the remaining 13% was collected separately. On the other hand, large losses occur during sorting and recycling processes; 34% of source separated plastic packaging is recycled back to the economy. This is only 4% of all plastic waste found in the MSWM system. While only 20% of the metal fractions are source separated, metals have the highest material recycling efficiency at 90%. Metal recovery from incineration bottom has a large contribution to this high efficiency rate. Scenario 2 and 4 tested the impact of improved waste sorting and recycling on system efficiencies. The introduction of *central waste sorting* (S2a and S2b) can increase material recycling efficiency by 16-18 percentage points. *Perfect waste sorting and recycling* (S4) can lead to a 34 percentage points increase. In comparison, *more efficient waste collection* (S1, S3a, S3b) can grow material recycling efficiency by 10-25 percentage points.

The rate of preparing municipal waste for recycling is just over 17%. This rate is calculated as the percentage of all recyclables that are delivered to final recycling, as it is defined in the WFD. Since some losses occur during plastic and food waste recycling, the material recycling efficiency is lower than the preparation rate.

The *waste preparation scenario* (S5) tested what it takes for ReMidt to reach a 65% preparation rate for recycling by 2035. The scenario analysis showed that this ambitious target requires measures targeting both waste collection and treatment. Such measures include:

- Source separating food waste and glass and metal packaging waste.
- Introducing a "Pay for what you throw" scheme in the kerbside and bring collection systems to improve the sorting rate of recyclables, especially plastics.
- Central sorting of residual waste.
- Investing in state-of-the-art sorting and recycling technologies to recover more residual, organic, and plastic fractions.
- Reducing rejects during sorting and recycling processes, especially for food waste and plastics.
- Changing legislations regarding biogas production, bio-waste feedstock and biogas vehicles.
- Designing products for recycling.

In addition, a broader system change is needed which entails reduced material consumption and fossil fuel use during production processes, and better utilisation of the existing material stocks. Furthermore, improved waste statistics and a better overview of the material and energy flows within the economy are needed.

One of the main conclusions of this study is that the preparation rate for recycling should be used only as a benchmark to measure the performances of MSWM systems at company level. Municipal companies that are responsible for waste collection alone, do not have a direct impact on preparation and final recycling rates. However, improved recycling rates depend on the quality of fractions that can be improved by better source separation.

Energy efficiency and climate change impact are the two remaining system efficiency indicators quantified in this study. **The current energy efficiency of the system is 61%**. This means that 61% of the energy required for operating the MSWM system can be covered by the energy generated from municipal waste. The scenario analysis showed that the more waste is delivered to recycling, the lower the energy efficiency of the system is. This is because less energy is recovered from waste incineration, and more is stored in recycled materials. Energy efficiency was chosen as an indicator to illustrate that a MSWM system is a part of a bigger system, where by-product of waste incineration can be utilised as heat in the district heating system. Even though this form of energy recovery is not part the Norwegian energy production system, still results show that waste management measures have an indirect impact on other systems too.

Transport energy use counts for ~10% of the total energy requirement of the MSWM system. 61% of the energy used for transport was consumed by ReMidt operations in 2020 and the rest is associated with external actors. The scenario analysis showed that the more recyclables are sorted at source, the lower energy demand waste collector trucks operated by ReMidt have. At the same time downstream transport energy requirements increase because more waste is transported to the different sorting and recycling facilities.

The climate change impact of the system was net positive in 2020. This means that generated emission from waste transport and treatment processes could not be compensated with the avoided emission from recycling and energy recovery. The incineration of residual and plastic fractions contributes the most to generated GHG emission, and paper and cardboard packaging takes the biggest share of avoided GHG emission. The scenario analysis shows that improved collection efficiency is not enough to reduce the climate change impact of the MSWM significantly. More effective waste collection, sorting and treatment are needed to achieve a net negative GHG emissions rates (S2b, S4, S5). The overall conclusion is that the more recyclable fractions are delivered to recycling, the lower climate impact the MSWM system have. Energy efficiency and climate change impact results should be interpreted carefully, and a more throughout analysis should be conducted in the future.

In the circular economy the value of resources is maintained in a way that environmental and human well-being, and economic prosperity are secured. The overall conclusion of this master thesis is that the Norwegian waste management sector has a crucial role in balancing these three pillars of sustainability by implementing waste management measures that ensure the effective and save collection and treatment of end-of-life materials.

References

Arnøy, S., Modahl, I. S. and Lyng, K. (2013) *Avfallshåndtering i Midt-Norge Sammenligning av klimaprestasjon for innsamling og behandling av*.

Askeland, E., Wærner, E. and Tellnes, L. G. (2017) *Materialstrømsanalyse treavfall*. Available at: https://avfallnorge.no/fagomraader-og-faggrupper/rapporter.

Avfall Norge (2019) *Bedre avfallsstatistikk Forslag til forbedringer for avfall fra husholdninger*.

Bjørnerud, S. and Syversen, F. (2017) *Plukkanalyse RIR Prosjektrapport*.

Bjørnerud, S., Syversen, F. and Dalen, A. (2019) 'Avfallsmengder fram mot 2035: Energigjenvinningens rolle i sirkulærøkonomien', *Avfall Norge*. Available at: https://avfallnorge.no/fagomraader-og-faggrupper/rapporter/avfallsmengder-fram-mot-2035.

Boesch, M. E. *et al.* (2014) 'An LCA model for waste incineration enhanced with new technologies for metal recovery and application to the case of Switzerland', *Waste Management*, 34(2), pp. 378–389. doi: 10.1016/j.wasman.2013.10.019.

Brunner, P. H. and Rechberger, H. (2004) *Practical handbook of material flow analysis, New York*. CRC Press LLC.

Calisto Friant, M., Vermeulen, W. J. V. and Salomone, R. (2020) 'A typology of circular economy discourses: Navigating the diverse visions of a contested paradigm', *Resources, Conservation and Recycling*. Elsevier, 161(April), p. 104917. doi: 10.1016/j.resconrec.2020.104917.

Callewaert, P. (2017a) 'Analysing the sustainability performance and critical improvement factors of urban municipal waste systems (Master's Thesis)', (June), p. 104.

Callewaert, P. (2017b) 'Documentation for a generic municipal solid waste management model', pp. 1–22.

Callewaert, P. G. and Jahren, S. (2017) *Analysing the sustainability performance and critical improvement factors of urban municipal waste systems case study RoAF*. Norwegian University of Science and Technology.

Carbon Footprint (2019) *Country specific electricity grid greenhouse gas emission factors*. Available at: https://www.carbonfootprint.com/docs/2019_06_emissions_factors_sources_for_2019_electricity.pdf.

Christensen, T. H. (2011) *Solid Waste Technology & Management*. Wiley.

Circle Economy and Circular Norway (2020) *The Circularity Gap Report. Closing the Circularity Gap in Norway*. Available at: https://www.circularity-gap.world/norway (Accessed: 19 October 2020).

Cullen, J. M. (2017) 'Circular Economy: Theoretical Benchmark or Perpetual Motion Machine?', *Journal of Industrial Ecology*. Blackwell Publishing, pp. 483–486. doi: 10.1111/jiec.12599.

Deloitte (2020) *Study for a National Strategy for Circular Economy: Short summary*.

Eggen, E. S. (2020) *Utsortering for ombruk og materialgjenvinning*.

Ellen MacArthur Foundation (2020) *What is the circular economy?* Available at: https://www.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy

(Accessed: 19 October 2020).

Engan, P. I. (2021) ‘Personal communication between Per Inge Engan from Retura TRV and Zsófia Miklós’.

European Commission (2015) ‘Closing the loop - An EU action plan for the Circular Economy’, *European Commission*, COM(2015). Available at: https://eur-lex.europa.eu/resource.html?uri=cellar:8a8ef5e8-99a0-11e5-b3b7-01aa75ed71a1.0012.03/DOC_1&format=HTML&lang=EN&parentUrn=COM:2015:614:FIN (Accessed: 23 October 2020).

European Commission (2018a) ‘A European Strategy for Plastics’, *European Comission*, p. 24. Available at: http://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy-brochure.pdf%0Ahttp://ec.europa.eu/environment/circular-economy/index_en.htm.

European Commission (2018b) ‘Circular Economy Package: Four legislative proposals on waste’, *EU Legislation in Progress*, (March). Available at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2018/614766/EPRS_BRI%282018%29614766_EN.pdf.

European Commission (2020) *A European Green Deal Striving to be the first climate-neutral continent*. Available at: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (Accessed: 19 October 2020).

European Parliament (2017) *Food waste: the problem in the EU in numbers [infographic], Society*. Available at: https://www.europarl.europa.eu/news/en/headlines/society/20170505STO73528/food-waste-the-problem-in-the-eu-in-numbers-infographic.

European Parliament and Council of the European Union (2018) ‘Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste’, *Official Journal of the European Union*, 150(1907), pp. L-150/109–140.

Eurostat (2020) *Municipal waste statistics*. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php/Municipal_waste_statistics (Accessed: 19 October 2020).

Fellner, J. *et al.* (2017) ‘Present Potentials and Limitations of a Circular Economy with Respect to Primary Raw Material Demand’, *Journal of Industrial Ecology*, 21(3), pp. 494–496. doi: 10.1111/jiec.12582.

Fløan, T. (2020) ‘Personal communication between Tore Fløan from Ecopro and Zsófia Miklós’.

Fossum, M. E. N. (2021) ‘Personal communication between Morten Einar Nyrø Fossum from Statkraft Varme and Zsófia Miklós’. Statkraft Varme.

Fostervold, K. (2021a) ‘Avfallsmengdene øker’. online: Avfall Norge. Available at: https://avfallnorge.no/bransjen/nyheter/avfallsmengdene-oker.

Fostervold, K. (2021b) ‘Presentation at Avfall Norge’s Gjenvinningsseminar’, in *Bedre rammevilkår for biogass*. Avfall Norge.

Grønn Punkt Norge (2021) *Plastemballasje fra husholdning*. Available at: https://www.grontpunkt.no/gjenvinning/plastemballasje-fra-husholdninger/.

Grønt Punkt Norge (2019) *Fakta og tall*.

Haas, W. *et al.* (2015) ‘How circular is the global economy?: An assessment of material flows, waste production, and recycling in the European union and the world in 2005', *Journal of Industrial Ecology*, 19(5), pp. 765–777. doi: 10.1111/jiec.12244.

Haddeland, T. (2011) 'Hvor mye energi sender Haugesund fra seg i form av avfall ?' Haugesund: Høyskolen Stord/Haugesund-Studie for ingeniørfag.

Hamos Forvaltning IKS (2018) *Prosjekt MGM – Kartlegging*.

Haupt, M. *et al.* (2018) 'Is there an environmentally optimal separate collection rate?', *Waste Management*. Elsevier Ltd, 77, pp. 220–224. doi: 10.1016/j.wasman.2018.03.050.

Haupt, Melanie, Kägi, T. and Hellweg, S. (2018) 'Life cycle inventories of waste management processes', *Data in Brief*. Elsevier Inc., 19, pp. 1441–1457. doi: 10.1016/j.dib.2018.05.067.

Haupt, M., Kägi, T. and Hellweg, S. (2018) 'Modular life cycle assessment of municipal solid waste management', *Waste Management*, 79, pp. 815–827. doi: 10.1016/j.wasman.2018.03.035.

Hunderi, S. (2021) 'Personal communication with Sissel Hunderi from Statkraft Varme and Zsófia Miklós'.

Innherred Renovasjon (2019) *Plukkanalyse*.

Johansen, U. (2018) *Plukkanalyse av brennbart restavfall fra container 2018 – MNA – Hamos - IR*.

Karlsen, K., Medeiros, M. and Solheim, M. (2020) *Kildesortering: Gjøres det på riktig måte i dag?* Trondheim.

Kirchherr, J., Reike, D. and Hekkert, M. (2017) 'Conceptualizing the circular economy: An analysis of 114 definitions', *Resources, Conservation and Recycling*. Elsevier B.V., pp. 221–232. doi: 10.1016/j.resconrec.2017.09.005.

Kirkevaag, K. (2021) 'Et marked for sirkulær plast'. Mepex.

Klima- og miljødepartementet (2021) *Avfallsdirektivet: gjennomføringsbestemmelser om måling og rapportering av ombruk*. Available at: https://www.europalov.no/rettsakt/avfallsdirektivet-gjennomforingsbestemmelser-om-maling-rapportering-av-ombruk/id-28594.

Limi, I. P. and Evjen, T. (2020) 'Personal communication between Ida Plassen Lime and Torbjørn Evjen from ReMidt IKS and Zsófia Miklós'. Orkanger.

Limi, P. I. (2021) 'Personal communication between Ida Plassen Lime from ReMidt IKS and Zsófia Miklós'.

Liu, Y. (2020) 'Welcome to the Life Cycle Impact Assessment (LCIA)'. NTNU: Sustainability Assessment TØL4010.

London recycles (2021) *Find out more about recycling*. Available at: https://londonrecycles.co.uk/recycling-services/.

London Waste and Recycling Board (2020a) *Making recycling work for people in flats*.

London Waste and Recycling Board (2020b) *Motivating young Londoners to recycle*.

London Waste and Recycling Board (2020c) *Sharing a house, sharing responsibility: Recycling in London's HMOs*. Available at: https://relondon.gov.uk/resources/report-recycling-in-londons-hmos.

Lystad, H., Iks, O. I. and Meissner, K. R. (2020) 'Materialgjenvinningsmuligheter for tekstiler i IVAR-området'.

Maarten, D. *et al.* (2020) *Guidance for separate collection of municipal waste*.

Mayer, A. *et al.* (2019) 'Measuring Progress towards a Circular Economy: A Monitoring Framework for Economy-wide Material Loop Closing in the EU28', *Journal of Industrial Ecology*, 23(1), pp. 62–76. doi: 10.1111/jiec.12809.

Mepex (2016) 'ROAF IKS: Plukkanalyser 2016'.

Mepex and Østfoldforskning (2018) 'Utsortering og materialgjenvinning av biologisk avfall og plastavfall - Utredning av konsekvenser av forslag til forskrift for avfall fra husholdninger og liknende avfall fra næringslivet', p. 211. Available at: http://tema.miljodirektoratet.no/no/Publikasjoner/2018/Oktober-2018/Utsortering-og-materialgjenvinning-av-biologisk-avfall-og-plastavfall/.

Merli, R., Preziosi, M. and Acampora, A. (2018) 'How do scholars approach the circular economy? A systematic literature review', *Journal of Cleaner Production*. Elsevier Ltd, pp. 703–722. doi: 10.1016/j.jclepro.2017.12.112.

Miljødirektoratet (2021) *Tabeller for omregning fra energivare til utslipp*. Available at: https://www.miljodirektoratet.no/myndigheter/klimaarbeid/kutte-utslipp-av-klimagasser/klima-og-energiplanlegging/tabeller-for-omregning-fra-energivarer-til-kwh/.

Morken, J. *et al.* (2017) 'Veileder for biogassanlegg -mulighetsstudie, planlegging og drift. - Revidert utgave', *REALTEK Rapport 56*. Available at: https://nmbu.brage.unit.no/nmbu-xmlui/bitstream/handle/11250/2600069/REALTEK Rapport 2018.pdf?sequence=1&isAllowed=y.

Norsk Resy (2018) *Innsamlingen*. Available at: https://resy.no/nb/?option=com_k2&view=item&id=6:innsamlingen&Itemid=206.

NVE (2021) *Strømforbruk i Norge har lavt klimagassutslipp*. Available at: https://www.nve.no/nytt-fra-nve/nyheter-energi/stromforbruk-i-norge-har-lavt-klimagassutslipp/.

Olbergsveen, H. R. (2019) 'Avfallsplan 2020-2025: Status og planer for avfallshåndtering, inkludert avfallsforebyggingsprogram', *Miljødirektoratet*. Available at: https://www.miljodirektoratet.no/publikasjoner/2019/desember-2019/avfallsplan-2020-2025/.

Olbergsveen, H. R. and Knagenhjelm, M. (2021) *Analyse av tiltak og virkemidler for økt forberedelse til ombruk og materialgjenvinning av husholdningsavfall og lignende næringsavfall*. Available at: https://www.miljodirektoratet.no/publikasjoner/2021/april-2021/m2021.pdf/.

Raadal, H. L., Modahl, I. S. and Lyng, K. A. (2009) *Klimaregnskap for avfallshåndtering, fase I og II. Fase 1: Glassemballasje, metallemballasje, papir, papp, plastemballasje og våtorganisk avfall. Fase 2: Treavfall og restavfall fra husholdninger*.

ReMidt IKS (2019) *Hva er ReMidt*. Available at: https://www.remidt.no/om-oss/#!/main (Accessed: 29 October 2020).

ReMidt IKS (2020) *Hjemmekompostering*. Available at: https://www.remidt.no/hjemmekompostering/#!/main (Accessed: 29 October 2020).

ReMidt IKS (2021) *Samarbeid om avfallsutstyr*. Available at: https://www.remidt.no/samarbeid-om-avfallsutstyr/#!/main.

RoAF (2020) *Ettersorteringsanlegget*. Available at:

https://roaf.no/kildesortering/ettersorteringsanlegget/.

de Römph, T. J. and Cramer, J. M. (2020) ‘How to improve the EU legal framework in view of the circular economy’, *Journal of Energy and Natural Resources Law*, pp. 1–16. doi: 10.1080/02646811.2020.1770961.

de Sadeleer, I., Brattebø, H. and Callewaert, P. (2020a) ‘Waste prevention, energy recovery or recycling - Directions for household food waste management in light of circular economy policy’, *Resources, Conservation and Recycling*. Elsevier B.V., 160. doi: 10.1016/j.resconrec.2020.104908.

de Sadeleer, I., Brattebø, H. and Callewaert, P. (2020b) ‘Waste prevention, energy recovery or recycling - Directions for household food waste management in light of circular economy policy’, *Resources, Conservation and Recycling*. Elsevier, 160(May), p. 104908. doi: 10.1016/j.resconrec.2020.104908.

Samferdselsdepartementet (2016) *Nasjonal transportplan 2018-2029*. Available at: https://www.regjeringen.no/no/tema/transport-og-kommunikasjon/nasjonal-transportplan/id2475111/.

Sandberg, K., Kolås, A. and Miklós, Z. (2020a) *Analyse av husholdningsavfall i Trondheim kommune*.

Sandberg, K., Kolås, A. and Miklós, Z. (2020b) *Analyse av kommunalt næringsavfall i Trondheim kommune , høsten 2020*.

Sandsdalen, E. (2021) ‘Personal communication between Espen Sandsdalen from Sirkel Glass AS and Zsófia Miklós’.

Saxegaard, J. and Hansen, K. (2013) *Avfallssug – effekter på materialgjenvinning*.

Sørgard, K. D. (2018) ‘Environmental analysis of alternative food waste solutions in the urban waste system of BIR’.

SSB (2018) *Kommune-Stat-Rapportering: KOSTRA*. Available at: https://www.ssb.no/offentlig-sektor/kostra/ (Accessed: 19 October 2020).

SSB (2020a) *05212: Population in densely and sparsely populated areas, by sex (M) 1990 – 2020*. Available at: https://www.ssb.no/en/statbank/table/05212/ (Accessed: 29 October 2020).

SSB (2020b) *12313: Avfall frå hushalda, etter region, materiale, behandling, statistikkvariabel og år*. Available at: https://www.ssb.no/en/statbank/table/13136 (Accessed: 28 April 2021).

SSB (2020c) *Avfall frå hushalda*. Available at: https://www.ssb.no/avfkomm (Accessed: 19 October 2020).

SSB (2021) *Regionale befolkningsframskrivinger 2020-2050*. Available at: https://ssb1.maps.arcgis.com/apps/MapSeries/index.html?appid=8feeedde1c2a40aa99cc5f0a3bc7fb13.

Statsministerens kontor (2019) *Granavolden-plattformen*. Available at: https://www.regjeringen.no/no/dokumenter/politisk-plattform/id2626036/?fbclid=IwAR1RMjUt7p4d5ZFiJN43WS-nNIS1qHzaI0Set4s7KibCxEMrbxxI_HmS0rA (Accessed: 19 October 2020).

Syed, S. and Hovland, K. (2018) *Test av poser i avfallssug*.

Syversen, F. and Bjørnerud, S. (2015) *Plukkanalyser avfall SESAM- området 2015*

Prosjektrapport.

Syversen, F., Hanssen, O. J. and Bratland, H. (2018) ‘Nasjonal beregning av mengde matsvinn på forbrukerleddet’. Available at: https://www.miljodirektoratet.no/Documents/publikasjoner/M1016/M1016.pdf.

Syversen, F., Kirkevaag, K. and Bjørnerud, S. (2019) ‘Renere råvarer. Case: Optimalisering av verdikjeden for glass- og metallemballasje’, *Avfall Norge*.

Turner, D. A., Williams, I. D. and Kemp, S. (2015) ‘Greenhouse gas emission factors for recycling of source-segregated waste materials’, *Resources, Conservation and Recycling*. Elsevier B.V., 105, pp. 186–197. doi: 10.1016/j.resconrec.2015.10.026.

Turner, D. A., Williams, I. D. and Kemp, S. (2016) ‘Combined material flow analysis and life cycle assessment as a support tool for solid waste management decision making’, *Journal of Cleaner Production*. Elsevier Ltd, 129, pp. 234–248. doi: 10.1016/j.jclepro.2016.04.077.

UK Department for Business, E. & I. S. (2020) *Greenhouse gas reporting: conversion factors 2020*. Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020.

Watnebryn, O. W. and Fredriksen, K. Ø. (2018) ‘Felles ettersorteringsanlegg Sesam Ressurs AS’, (August).

Watson, D. *et al.* (2020) *Kartlegging av brukte tekstiler og tekstilavfall i Norge*.

Yurday, E. (2021) *London Recycling Rates: Best and Worst Boroughs Revealed*. Available at: https://www.nimblefins.co.uk/london-recycling-rates-best-worst-boroughs-revealed.

Appendix

A.1.

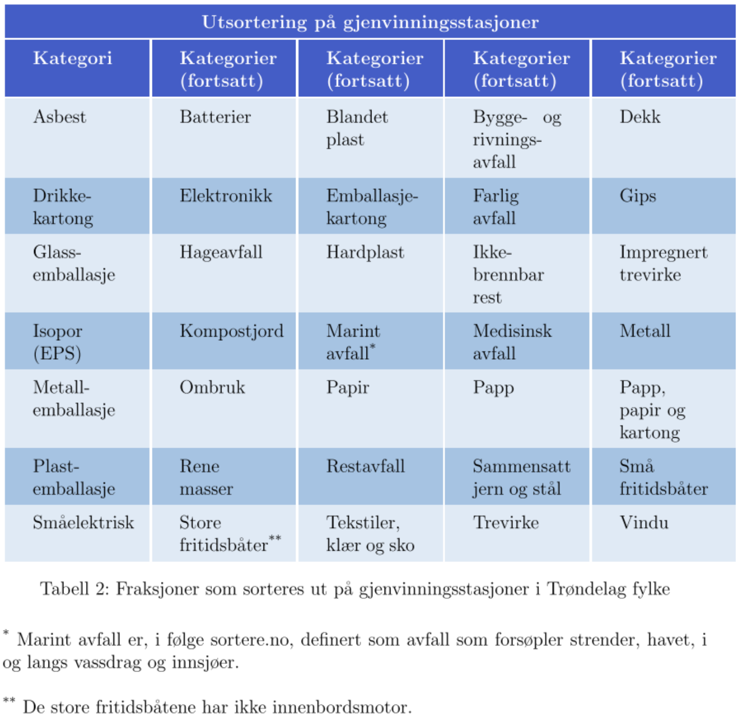
Waste categories. Adopted from Sortere.no.

Fraction	Sub-fractions	Fraction	Sub-fractions	Fraction	Sub-fractions	Fraction	Sub-fractions
Residual waste	Vacuum cleaner bag	Paper	Book with soft cover	Corrugated cardboard packaging	Transport packaging	Cardboard packaging	Breakfast mix box
	Straw		Newspaper		Moving boxes		Taco box
	Q-tips		weekly magazine		Cardboard wine box		Pizza
	Chewing gum		Advertising		Cardboard box		Pasta
	Snuff		Gift wrapping in kraft paper				Box from small electronics
	Cigarette butt		Toilet paper roll				Toy box
	Cotton		Bread bags in paper				Cardboard biscuit package
	contact lenses		Envelope				Cardboards with plastic window
	Diapers		Writing paper				
	Bandages and tampons		Post-it notes				
	Condoms		Paper bags for baking				
	Drinking glasses		Drawing paper				
	Crushed cup		Gift bags in paper				
	Dirty packaging		Shredded paper				
	Compostable disposable packaging						
	Degradable plastic						
	CD / DVD disc and cover						
	VHS tapes						
	Shoes, broken and worn						
	Nylon tea bag						
	Plastic and metal packaging						
	Plastic and paper packaging						
	Large meat bones						

Fraction	Sub-fractions	Fraction	Sub-fractions	Fraction	Sub-fractions	Fraction	Sub-fractions
Plastic packaging	Grape cup	Glass packaging	Glass bottle	Metal packaging	Cans	Food waste	Peel
	Sausage package		Jam jars		Cold cuts tube in metal		Scrap
	Spaghetti bag		Perfume bottle		Tealight holder in metal		Fruit stones
	Meat wrapping, in plastic		Baby food glasses		Jam lid		Coffee grounds
	Cheese packaging in plastic		Wine bottle		Aluminium cup		Eggshell
	Onion stocking		Beer bottle		Aluminium foil		Tissue paper
	Plastic packaging		Soft drink bottle in glass		Mackerel in tomato box		Napkins
	Plastic bottle without deposit		Feta cheese ice cream		Liver mailbox		Nutshell
	Plastic foil		Skin cream jar in glass		Torch box		Shrimp shells
	Carrying bag in plastic		Vials, without medicine residue		Pet food in shape		Tea bags
	Yogurt cup		Cooking oil bottle in glass		cooking oil jug		Small meat bones
	Sour cream cup		Spice jars		Drink box without deposit		fish bone
	Flowerpot		Tomato puree glass				Food leftovers
	Plant tray						Vegetables
	Shampoo bottle						Fruit
	Detergent bottle						Bakery
	Snus box						Bread
							cakes
							Rice and pasta
							Fish and shellfish
							Fat and cooking oil

A.2.

Waste types delivered to recycling stations in Trøndelag county. Copied from Karlsen, Medeiros and Solheim (2020)



Utsortering på gjenvinningsstasjoner				
Kategori	Kategorier (fortsatt)	Kategorier (fortsatt)	Kategorier (fortsatt)	Kategorier (fortsatt)
Asbest	Batterier	Blandet plast	Bygge- og rivningsavfall	Dekk
Drikkekartong	Elektronikk	Emballasjekartong	Farlig avfall	Gips
Glassemballasje	Hageavfall	Hardplast	Ikke-brennbar rest	Impregnert trevirke
Isopor (EPS)	Kompostjord	Marint avfall[*]	Medisinsk avfall	Metall
Metallemballasje	Ombruk	Papir	Papp	Papp, papir og kartong
Plastemballasje	Rene masser	Restavfall	Sammensatt jern og stål	Små fritidsbåter
Småelektrisk	Store fritidsbåter[**]	Tekstiler, klær og sko	Trevirke	Vindu

Tabell 2: Fraksjoner som sorteres ut på gjenvinningsstasjoner i Trøndelag fylke

[*] Marint avfall er, i følge sortere.no, definert som avfall som forsøpler strender, havet, i og langs vassdrag og innsjøer.

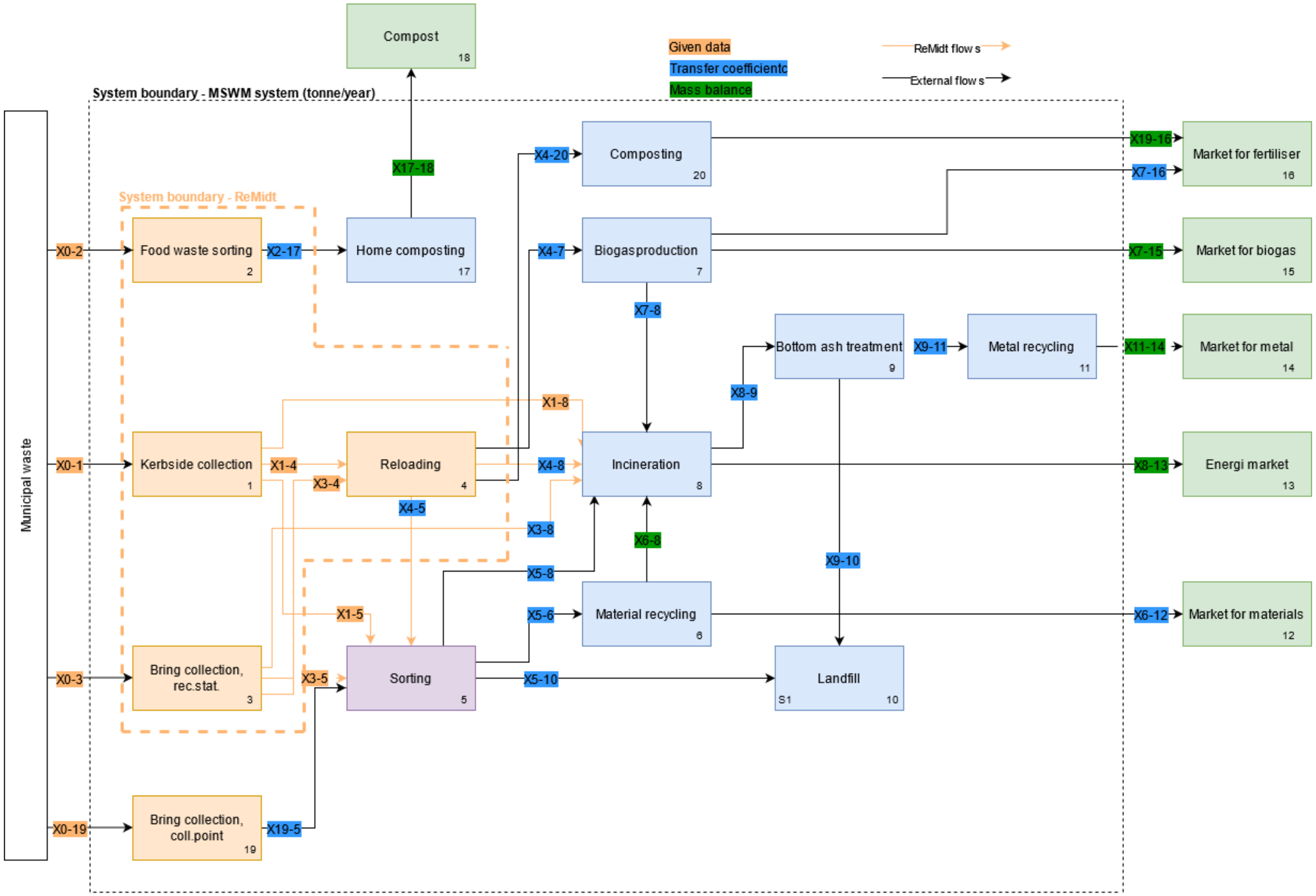
[**] De store fritidsbåtene har ikke innenbordsmotor.

A.3.

Table 14 – Changes in parameters in the different scenarios

Parameter	Baseline	S1 – New kerbside collection	S2 – Central sorting (S1+Central sorting)	S3 – Improved kerbside collection	S4 - Perfect sorting and recycling	S5 - min 65% EU target
Year	2020, 2025, 2035	2025, 2035	2035	2035	2035	2035
Waste amounts, Fraction distribution and TCs	Data gathered from waste analysis carried out by ReMidt	↓ FW in RW bin ↓ G&W in RW bin ↑ G&W in G&W bin ↑ FW in FW bin No bring collection of G&M at collection points TC: same as baseline	Fraction distribution: Same as S1 No bring collection of G&M at collection points TCs from central sorting: SESAM project report	S3a: Fraction distribution and waste amount are adjusted to improve collection efficiency to 70% S3b: 100% collection efficiency of recyclable fractions (P&C, P, G&M, FW) No bring collection of G&M at collection points TC: same as baseline	Fraction distribution: Same as S1 No bring collection of G&M at collection points TC: 100% sorting and recycling of P&C, P and G&M	Fraction distribution: adjusted to achieve 80% collection efficiency. No bring collection of G&M at collection points TC: 70% P&C fractions are sorted 80% of P fraction is sorted 30% FW fraction is sorted 30% rest fraction is sorted 80% P is recycled 10% FW reject
Fuel type	Diesel	S1a: Diesel S1b: Biogas in Orkland and Melhus regions, rest uses diesel.	Diesel	Diesel	Diesel	Diesel
Transport Distance	Calculated information provided by ReMidt	Adjusted in accordance with changed waste flows	Adjusted in accordance with changed waste flows	Adjusted in accordance with changed waste flows	Adjusted in accordance with changed waste flows	Adjusted in accordance with changed waste flows
Process energy (downstream)	Data from specific downstream actors	Same as baseline	Same as baseline Central sorting: Data from SESAM project report	Same as baseline	Same as baseline Central sorting: Data from SESAM project report	Same as baseline Central sorting: Data from SESAM project report

A.4. Baseline Scenario 2020, 2025, 2035



A.4.1. Material layer: Flows, Baseline 2020

In the following section the flows and transfer coefficients used in the Baseline scenario are listed with explanations and sources. It is important to note that only known or calculated flows and transfer coefficients are listed here, missing flows are calculated by the MFA model used in this study.

Estimates about the inflows from the kerbside collection (X0-1) and bring collection system at recycling stations (X0-3) are based on waste accounting conducted by ReMidt IKS for the year 2020. The amount of home compost (X0-2) generated by households is calculated by:

$$Home\ compost\ \left(\frac{t}{yr}\right) = number\ of\ home\ composting\ subsribtions * 0.167$$

In 2020, ReMidt had total 4321 home composting subscriptions. External actors collecting G&M packaging from collection points were contacted to acquire information on how much G&M packaging is collected at collection points. Unfortunately, specific information could not be gathered. Glass and metal packaging waste inflows from bring collection system at collection points (X0-19) are estimates, calculated from average per capita waste amounts from municipalities that have had already separate G&M kerbside collection scheme (~5.3 kg/capita).

Table 15 - Home composting subscriptions. Source: ReMidt

Municipality	Number of home composting subscriptions
Aure	37
Averøy	0
Frøya	213
Heim	343
Hitra	301
Kristiansund	184
Melhus	201
Midtre Gauldal	77
Oppdal	54
Orkland	718
Rennebu	127
Rindal	153
Skaun	371
Smøla	0
Sunndal	470
Surnadal	599
Tingvoll	473
Sum	4321

The model inputs in the Baseline scenario are shown on Table 16. The *flow* row includes the total amount of waste collected with the different collection processes per waste type. The percentages indicate the waste fraction distribution of the different waste types.

Table 16 - Inflows and fraction distributions, Baseline 2020

	Flow	Unit	RW	P&C	P	G&M	FW	Compost	G&P
flow	**X02**	**t/yr**	0.00	0.00	0.00	0.00	0.00	721.61	0.00
Rest		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P&C		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plastic		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glass		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Metal		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bio-waste		%	0.00	0.00	0.00	0.00	0.00	100.00	0.00
Hazardous waste		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WEEE		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Textiles		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
flow	**X01**	**t/yr**	29505.05	6679.30	556.36	650.33	61.52	0.00	0.00
Rest		%	28.33	3.54	3.54	0.48	7.50	0.00	0.00
P&C		%	6.60	95.24	0.04	0.00	0.00	0.00	0.00
Plastic		%	13.27	0.33	96.15	0.00	3.00	0.00	0.00
Glass		%	2.95	0.04	0.00	87.90	0.00	0.00	0.00
Metal		%	2.57	0.03	0.15	11.37	0.00	0.00	0.00
Bio-waste		%	41.89	0.75	0.00	0.00	89.50	0.00	0.00
Hazardous waste		%	0.35	0.02	0.00	0.25	0.00	0.00	0.00
WEEE		%	0.35	0.01	0.00	0.00	0.00	0.00	0.00
Textiles		%	3.69	0.04	0.13	0.00	0.00	0.00	0.00
flow	**X03**	**t/yr**	12433.65	368.86	243.58	1207.34	4.68	0.00	923.48
Rest		%	66.70	0.00	0.00	0.00	0.00	0.00	0.00
P&C		%	7.25	100.00	0.00	0.00	0.00	0.00	0.00
Plastic		%	9.96	0.00	100.00	0.00	0.00	0.00	0.00
Glass		%	1.06	0.00	0.00	90.00	0.00	0.00	0.00
Metal		%	2.55	0.00	0.00	10.00	0.00	0.00	0.00
Bio-waste		%	0.88	0.00	0.00	0.00	100.00	0.00	100
Hazardous waste		%	1.11	0.00	0.00	0.00	0.00	0.00	0.00
WEEE		%	1.46	0.00	0.00	0.00	0.00	0.00	0.00
Textiles		%	9.03	0.00	0.00	0.00	0.00	0.00	0.00
flow	**X019**	**t/yr**	0.0	0	0	689.39	0	0	0.00
Rest		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P&C		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plastic		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glass		%	0.00	0.00	0.00	90.00	0.00	0.00	0.00
Metal		%	0.00	0.00	0.00	10.00	0.00	0.00	0.00
Bio-waste		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hazardous waste		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WEEE		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Textiles		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source and comments:

Kerbside collection (X0-1):

- RW: Average results from waste analysis carried out on residual waste collected from households at waste management companies operating within the SeSamen areas in Trøndelag county (Envina and Hamos) (Syversen and Bjørnerud, 2015).
- P&C: Average results from waste analysis carried out on residual waste collected from households at waste management companies operating within the SeSamen areas in Trøndelag county (Envina and Hamos) (Syversen and Bjørnerud, 2015).
- P: Average results from waste analysis of source separated plastic packaging collected from households at Trondheim Renholdsverk (Sandberg, Kolås and Miklós, 2020a).
- FW: Average results from waste analysis of food waste collected from households in Romsdalen Region (RIR) (Bjørnerud and Syversen, 2017).
- G&M: Average results from waste analysis of G&M waste collected from households in Innherred Renovasjon (IR) (Innherred Renovasjon, 2019).

Bring collection: Recycling station (X0-3) and collection points (S0-19)

- RW: Average results from waste analysis carried out on residual waste collected from recycling station at Hamos (Johansen, 2018).
- G&M: Average results from waste analysis carried out by Sirkel (Sandsdalen, 2021).
- P&C and P: assumed to have 100% clean fractions.

As it was pointed out in Section 3.2, in 2020 ReMidt municipalities had different kerbside collection systems, which influenced transport energy requirements. As explained in Section 4.3.4, transport energy demand is calculated on the bases of transported waste amounts. Therefore, X1-4 kerbside collection flow was divided into regions and municipalities. Table 17 shows how the total waste flows collected within the kerbside collection system and transported to reloading are distributed across the different regions.

Table 17 - Distribution of X14, per region and municipality, Baseline 2020

	Distribution of municipalities (% of total waste flow)				
X14	**RW**	**P&C**	**P**	**G&M**	**FW**
Hitra	9.07	5.07	8.14	0.00	0.00
Hitra	4.49	2.51	4.03	0.00	0.00
Frøya	4.58	2.56	4.11	0.00	0.00
Orkland	36.95	51.63	34.93	0.00	0.00
Surnadal	8.49	6.08	8.44	0.00	100.00
Surnadal	5.36	4.02	5.59	0.00	0.00
Tingvoll	3.13	2.06	2.86	0.00	100.00
Kr.Sund_city	20.56	17.71	22.75	68.96	0.00
Kr.Sund_rural	10.63	8.39	10.77	4.39	0.00
Aure	2.98	2.57	3.30	0.00	0.00
Averøy	4.92	4.24	5.45	0.00	0.00
Smøla	2.73	1.58	2.02	4.39	0.00
Oppdal	8.68	6.37	8.35	10.20	0.00
Sunndal	5.63	4.76	6.62	16.45	0.00

Melhus+MG region is excluded from X1-4 because from this region residual waste is transported directly to incineration (X1-8) and the source separated waste types (P&C and P) are sent directly to sorting.

Waste collected within the bring collection systems were sent directly to sorting or in case of food waste it was sent to reloading. These collection processes were not divided by regions but show the total amount waste collected across ReMidt. Table 18 shows the amount of waste that was collected within the bring collection system and transported to further treatment.

Table 18 – Melhus+GM region and Bring collection flows, Baseline 2020

	Flow size (t/yr)					
	RW	P&C	P	G&M	FW	G&P
X15: Melhus+MG	0.00	882.74	109.10	0.00	0.00	0.00
X18: Melhus+MG	4828.44	0.00	0.00	0.00	0.00	0.00
X35	0.00	368.86	243.58	1207.34	0.00	0.00
X34	0.00	00.0	0.00	0.00	4.68	923.48
X38	12433.65	0.00	0.00	0.00	0.00	0.00

Material layer: Flows, Baseline 2025 and 2035

Generated waste amounts grow but the fraction distribution remains the same as in 2020. Because of changes in population the regional distribution of the flow X14 will change in 2025 and 2035.

Table 19 - Inflows, Baseline 2025

Flow	Unit	RW	P&C	P	G&M	FW	Compost	G&P
X02	**t/yr**	0.00	0.00	0.00	0.00	0.00	724.23	0.00
X01	**t/yr**	29730.28	6728.93	560.66	648.75	61.79	29730.28	0.00
X03	**t/yr**	12506.58	375.12	244.99	1216.80	2.73	12506.58	930.71
X019	**t/yr**	0	0	0	702.74	0	0	0.00

Table 20 - Distribution of flow X14, per region and municipality, Baseline 2025

	Distribution of municipalities (% of total waste flow)				
X14	**RW**	**P&C**	**P**	**G&M**	**FW**
Hitra	9.33	5.21	8.38	0.00	0.00
Hitra	4.61	2.58	4.14	0.00	0.00
Frøya	4.72	2.63	4.24	0.00	0.00
Orkland	37.11	51.84	35.10	0.00	0.00
Surnadal	8.36	5.98	8.32	0.00	100.00
Surnadal	5.24	3.93	5.46	0.00	0.00
Tingvoll	3.13	2.05	2.86	0.00	100.00
Kr.Sund_city	20.51	17.67	22.72	69.31	0.00
Kr.Sund_rural	10.58	8.35	10.73	4.36	0.00
Aure	2.96	2.55	3.27	0.00	0.00
Averøy	4.94	4.25	5.47	0.00	0.00
Smøla	2.68	1.55	1.99	4.36	0.00
Oppdal	8.63	6.33	8.31	10.21	0.00
Sunndal	5.48	4.63	6.44	16.12	0.00

Table 21 - Inflows, Baseline 2035

Flow	Unit	RW	P&C	P	G&M	FW	Compost	G&P
X02	**t/yr**	0.00	0.00	0.00	0.00	0.00	729.46	0.00
X01	**t/yr**	30180.75	6828.19	569.25	645.58	62.32	30180.75	0.00
X03	**t/yr**	12652.46	387.65	247.81	1235.71	2.85	12652.46	945.18
X019	**t/yr**	0	0	0	725.43	0	0	0.00

Table 22 - Distribution of waste flows, per region and municipality, Baseline 2025

	Distribution of municipalities (% of total waste flow)				
X14	**RW**	**P&C**	**P**	**G&M**	**FW**
Hitra	9.33	5.21	8.38	0.00	0.00
Hitra	4.61	2.58	4.14	0.00	0.00
Frøya	4.72	2.63	4.24	0.00	0.00
Orkland	37.11	51.84	35.10	0.00	0.00
Surnadal	8.36	5.98	8.32	0.00	100.00
Surnadal	5.24	3.93	5.46	0.00	0.00
Tingvoll	3.13	2.05	2.86	0.00	100.00
Kr.Sund_city	20.51	17.67	22.72	69.31	0.00
Kr.Sund_rural	10.58	8.35	10.73	4.36	0.00
Aure	2.96	2.55	3.27	0.00	0.00
Averøy	4.94	4.25	5.47	0.00	0.00
Smøla	2.68	1.55	1.99	4.36	0.00
Oppdal	8.63	6.33	8.31	10.21	0.00
Sunndal	5.48	4.63	6.44	16.12	0.00

A.4.2. Material layer: Transfer coefficients (TCs), Baseline 2020, 2025, 2035

Table 23 shows those TCs for waste types that are collected by household or sent to reloading.

Table 23 - Transfer coefficients (%)

TC (Collection) Fractions	T217 Compost	T45 P&C+P+GW	T47 FW	T48 RW	T420 G&P
Rest	0.00	100.00	100.00	100.00	0.00
P&C	0.00	100.00	100.00	100.00	0.00
Plastic	0.00	100.00	100.00	100.00	0.00
Glass	0.00	100.00	100.00	100.00	0.00
Metal	0.00	100.00	100.00	100.00	0.00
Bio-waste	100.00	100.00	100.00	100.00	100.00
Hazardous waste	0.00	100.00	100.00	100.00	0.00
WEEE	0.00	100.00	100.00	100.00	0.00
Textiles	0.00	100.00	100.00	100.00	0.00

Sources and comments:

All information about TCs and flows up until delivery to sorting/treatment is coming from ReMidt (Limi and Evjen, 2020).

T217 – All mixed bio-waste fractions collected as compost is utilised as home compost.

T45 – All P&C, P and G&M waste types are transported from reloading to sorting.

T47 – All FW from reloading goes to the biogas facility (Ecopro).

T48 – All RW from reloading goes to incineration.

T420 – All bio-waste fractions collected as garden and park waste is utilised in composting.

Table 24 shows those TCs for the sorting process (P5).

Table 24 - Transfer coefficients (%)

TC (Sorting)	T56			T58			T510		
Fractions	P&C	P	G&M	P&C	P	G&M	P&C	P	G&M
Rest	0.00	0.00	0.00	100	100	100	0	0	0
P&C	55.80	0.00	0.00	44.20	100	100	0	0	0
Plastic	0.00	65.70	0.00	100	34.3	100	0	0	0
Glass	0.00	0.00	96.27	100	100	0	0	0	3.73
Metal	0.00	0.00	81.25	100	100	0	0	0	18.75
Bio-waste	0.00	0.00	0.00	100	100	100	0	0	0
Hazardous waste	0.00	0.00	0.00	100	100	100	0	0	0
WEEE	0.00	0.00	0.00	100	100	100	0	0	0
Textiles	0.00	0.00	0.00	100	100	100	0	0	0

Sources and comments:

Based on Grønn Punkt Norway estimates (2019), on average 55.8% of cardboard packaging is sent from sorting to final recycling (T56) and the rest is incinerated (T58).

According to estimates from Grønn Punkt Norway (2021), of all source separated plastic packaging from households that go into sorting plants abroad, 65.7% is sent on to material recycling (T56) the rest is sent to incineration (T58)

Based on waste analysis carried out by Innherred Renovasjon (IR) (Innherred Renovasjon, 2019), 96.27% of the glass fraction in G&M waste is glass packaging which can be sorted out and sent to is sent to recycling (T56). The remaining 3.73% is other type of glass which is sent to landfill (T510). The same analysis shows that 81.25% of metal fractions in G&M waste are recyclable and the 18.75% (other metal) is assumed to be sent to landfill.

Table 25 shows those TCs for the treatment processes.

Table 25 - Transfer coefficients (%)

TC (Treatment)	T612			T78	T716	T2016	T89	T911
Fractions	P&C	P	G&M	FW	FW	G&M	All	All
Rest	0	0	0	100	0	0	10.2	0
P&C	100	0	0	100	0	0	56	0
Plastic	0	51	0	100	0	0	1.8	0
Glass	0	0	100	100	0	0	97	0
Metal	0	0	100	100	0	0	94	98.5
Food waste	0	0	0	16	28	100	13.3	0
Hazardous waste	0	0	0	100	0	0	10	0
WEEE	0	0	0	100	0	0	0	0
Textiles	0	0	0	100	0	0	4	0

Sources and comments:

Since relevant information could not be gathered it is assumed that all paper and cardboard and glass and metal fractions that were prepared for recycling are recycled.

According to estimates from Grønn Punkt Norway (2021), only *33.5% of the total source sorted plastic packaging* is actually recycled as secondary raw material from P6 and the remaining is incinerated. As it was mentioned above, the sorting process for plastic packaging works with 65.7% efficiency and 34.3% is lost. T612 for plastic packaging is calculated by

$$T612_{Plastic} = \frac{0.335}{0.657} = 0.51$$

This means that 51% of plastic prepared for recycling is recycled and the rest is incinerated.

T78 shows that all contaminations and 16% of the food waste fraction in FW are sorted out and incinerated. During the biogas production process, 28% of the food waste fraction ends up as by-product and utilised as fertiliser (T716) and the rest is recovered as biogas (Morken *et al.*, 2017).

T2016 shows that it is assumed that 100% of garden and park waste sent to composting is utilised as fertiliser.

T89 represents the transfer coefficient of the different waste fractions that end up in the bottom ash as the by-product of residual waste incineration. Data on the ash content of residual waste was taken from figure on page 370 in Christensen (2011). Bottom ash is treated (P9) and 98.5% of the metals in bottom ash are recovered and sold on the market (TC 911) (Callewaert, 2017a). The rest is sent to landfill.

A.4.3. Energy layer: Transport energy, Baseline 2020, 2025, 2035

The energy intensity of the fuel used for transportation is calculated by the following equation:

$$\boldsymbol{Energy\ intensity}_{\boldsymbol{f,t,i}}\left(\frac{\boldsymbol{kWh}}{\boldsymbol{yr}}\right)=\frac{Energy\ consumption_{f,t,i}\left(\frac{kWh}{yr}\right)}{Weight_{f,t,i}\left(\frac{t}{yr}\right)*route\ distance_{f,t,i}(km)},$$

where f is specific fuel type, t is collection technology and i is the type of waste.

Diesel was used as the only fuel type in the Baseline scenario. Information on driven km per year was given by ReMidt per waste company (NIR, Hamos/Envina) per municipality per waste truck.

Transport information was provided by former Hamos, NIR and Envina IKSs on diesel consumption and driven km per waste truck per municipality for year 2019 (Table 26). Fuel consumption was calculated by dividing total fuel consumption with the total distance driven. Diesel consumption was missing for Kristiansund rural, Oppdal and Sunndal regions.

Table 26 - Transport energy use and driven distance, 2020

Truck per region and municipality	Diesel (l/yr)	Distance (km/yr)	Fuel consumption (l/km)	Comment
Hitra	35802.80	58082.00	0.61	
Frøya	*19718.10*	*30100.00*	*0.66*	
Hitra	*16084.70*	*27982.00*	*0.57*	
Orkland	106197.00	161788.57	0.68	
Orkanger 1	*15090.30*	*21411.00*	*0.70*	
Orkanger 2	*14997.30*	*17459.00*	*0.86*	
Orkanger 3	*21179.30*	*31745.00*	*0.67*	
Orkanger 4	*18309.50*	*29568.00*	*0.62*	
Orkanger 5	*19942.00*	*37941.00*	*0.53*	
Orkanger 6	*16678.60*	*23664.57*	*0.70*	
~~*Orkanger 7*~~	~~*2142.50*~~	~~*22827.00*~~	~~*0.09*~~	Given diesel consumption rates deviate from the other trucks operating in this region. Therefore, these trucks were excluded from calculations.
~~*Orkanger 8*~~	~~*14037.70*~~	~~*42958.00*~~	~~*0.33*~~	
~~*Orkanger 9*~~	~~*24291.30*~~	~~*19790.00*~~	~~*1.23*~~	
Surnadal	43478.99	66400.00	0.65	
Surnadal	*11987.60*	*16610.00*	*0.72*	
Surnadal	*9840.10*	*19790.00*	*0.50*	
Tingvoll	*21651.29*	*30000.00*	*0.72*	
Kr.Sund_city	30900.00	36811.81	0.84	
Kr.Sund 1	9852.00	10480.85	0.94	
Kr.Sund 2	10596.00	13584.62	0.78	
Kr.Sund 3	6144.00	7492.68	0.82	
Kr.Sund 4	4308.00	5253.66	0.82	
~~Kr.Sund 5~~	~~5976.00~~	~~13581.82~~	~~0.44~~	An extra car was used is an addition to the scheduled trucks. Since this tuck had very low diesel consumption per km compared to regular tucks in this region, this truck was excluded from calculations.
Kr.Sund_rural		65000.00		
Aure		18756.50		Aure and Smøla shared a truck that drove 35000 km in 2019. Division is based on the amount of waste generated in these two municipalities. Smøla: 778.95 tonne waste collected from households (46.41%) Aure: 899.41 tonne waste collected from households (53.59%)
Smøla		16243.50		

Averøya		30000.00		
Oppdal		25000.00		
Oppdal		25000.00		
Sunndal		25000.00		
Sunndal		25000.00		
Melhus+MG	68582.46	135221.00	0.51	
Melhus+MG 1	10939.45	19353.00	0.57	
Melhus+MG 2	15006.17	32349.00	0.46	
Melhus+MG 3	14581.64	25955.00	0.56	
Melhus+MG 4	7832.79	19112.00	0.41	
Melhus+MG 5	9406.77	17951.00	0.52	
Melhus+MG 6	10815.64	20501.00	0.53	

When calculating transport energy intensities, it is assumed that in urban area (Kristiansund city region) the fuel consumption is 0.8 l/km, while in rural areas (all the other regions) waste trucks use 0.6 l/km. According the Norwegian Environmental Agency (2021) the energy content of diesel used in heavy load transport vehicles is 10.08 kWh/l. This factor was used to convert litre diesel to kWh.

As it was mentioned in Section 3.3, chamber technology influences transport fuel demand. Therefore, the calculation of the energy intensity for one vs. two chamber technologies differ:

$$Energy\ intensity_{one\ chamber}\ \left(\frac{kwh}{tk}\right)=\frac{Energy\ requirement\ \left(\frac{l}{yr}\right)_{waste} * Energy\ content\ \left(\frac{khw}{l}\right)}{Weight\ (t)_{Waste\ A} * Route\ distance(km)}$$

$$Energy\ intensity_{two\ chambers}\ \left(\frac{kwh}{tk}\right)=\frac{Energy\ requirement\ \left(\frac{l}{yr}\right)_{waste\ A+B} * Energy\ content\ \left(\frac{khw}{l}\right)}{Weight\ (t)_{Waste\ A+B} * Route\ distance(km)}$$

In some of the regions, one waste type is collected with two other types in different collection frequencies. For instance, in Oppdal residual waste was collected with glass and metal or with plastic in every other week in 2020.

The following equations is used to calculate the transport energy intensity in such regions:

$$\begin{aligned}&Energy\ intensity_{two\ chambers,\ A\ with\ B\ and\ C}\ \left(\frac{kwh}{tk}\right)\\&=\frac{Energy\ requirement\ \left(\frac{l}{yr}\right)_{waste\ A+B} * Energy\ content\ \left(\frac{khw}{l}\right)}{Weight\ (t)_{\frac{Waste\ A}{2}+B} * Route\ distance(km)}\\&+\frac{Energy\ requirement\ \left(\frac{l}{yr}\right)_{waste\ A+C} * Energy\ content\ \left(\frac{khw}{l}\right)}{Weight\ (t)_{\frac{Waste\ A}{2}+C} * Route\ distance(km)}\end{aligned}$$

Energy requirement is calculated by:

$$Energy\ requirement\ \left(\frac{l}{yr}\right)=Collection\ frequency\ \left(\frac{\frac{route}{region}}{year}\right)*\ (Route\ distance\ \left(\frac{km}{route}\right)*$$
$$Fuel\ consumption\ rate\ \left(\frac{l}{km}\right)$$

As it was mentioned in Section 3.3, transport fuel consumption information used for 2020 are based on 2019 estimates. The comparison of primary data from 2019 and model results for 2020 show some deviations (Figure 61). The reason for this is that average fuel consumption rates were used for urban and rural regions in the modelling of the system in 2020.

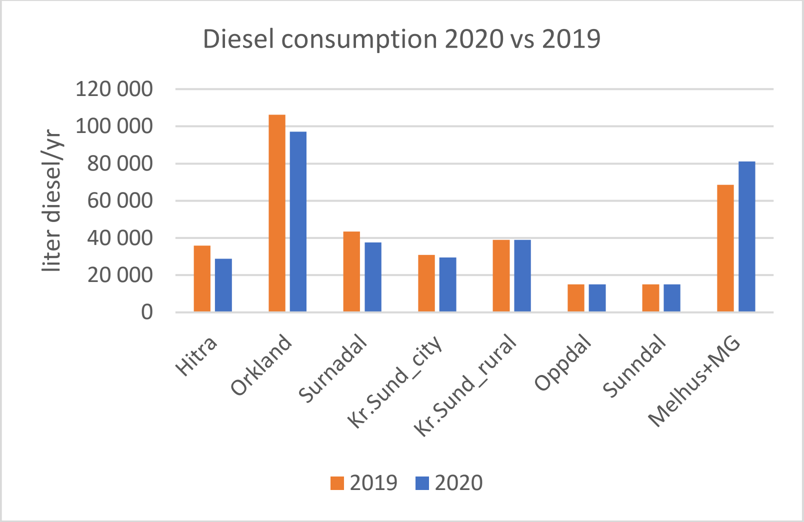


Figure 61 - Diesel consumption, 2019 vs. 2020

The following tables summarise input data for calculating transport energy intensity for the different ReMidt regions and downstream transport flows.

Hitra region

Hitra region Cars	Total driven distance km/yr	Number of routes routes/yr	Route distance km/route	Energy requirement (l/yr)
Hitra	27982.00	39.00	717.49	16789.20
Frøya	19718.10	39.00	505.59	11830.86
Sum/average	23850.05		611.54	28620.06

Hitra region	Energy requirement (l/yr)				
Car	RW	P&C	P	G&M	FW
Hitra	11192.80	5596.40		0	0
Frøya	7887.24	3943.62		0	0
Sum	19080.04	9540.02		0	0

Hitra region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Hitra	1107.43	145.35	18.02	0.00	0.00	0.14	0.48	0.48	0.00	0.00
Frøya	1129.57	148.25	18.38	0.00	0.00	0.14	0.47	0.47	0.00	0.00
Sum	2237.00	293.60	36.40	0.00	0.00	0.14	0.48	0.48	0.00	0.00

Orkland region

Orkland region Cars	Total driven distance km/yr	Number of routes routes/yr	Route distance km/route	Energy requirement (l/yr)
Car 1	21411.00	39.00	549.00	12846.60
Car 2	17459.00	39.00	447.67	10475.40
Car 3	31745.00	39.00	813.97	19047.00
Car 4	29568.00	39.00	758.15	17740.80
Car 5	37941.00	39.00	972.85	22764.60
Car 6	23664.57	39.00	606.78	14198.74
Sum/average	26964.76		691.40	97073.14

Orkland region	Energy requirement (l/yr)				
Car	RW	P&C	P	G&M	FW
Car 1	8564.40	4282.20		0.00	0.00
Car 2	6983.60	3491.80		0.00	0.00
Car 3	12698.00	6349.00		0.00	0.00
Car 4	11827.20	5913.60		0.00	0.00
Car 5	15176.40	7588.20		0.00	0.00
Car 6	9465.83	4732.91		0.00	0.00
Sum	64715.43	32357.71		0.00	0.00

Orkland region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	1519.83	498.84	26.03	0.00	0.00	0.10	0.15	0.15	0.00	0.00
Car 2	1519.83	498.84	26.03	0.00	0.00	0.10	0.15	0.15	0.00	0.00
Car 3	1519.83	498.84	26.03	0.00	0.00	0.10	0.15	0.15	0.00	0.00
Car 4	1519.83	498.84	26.03	0.00	0.00	0.10	0.15	0.15	0.00	0.00
Car 5	1519.83	498.84	26.03	0.00	0.00	0.10	0.15	0.15	0.00	0.00
Car 6	1519.83	498.84	26.03	0.00	0.00	0.10	0.15	0.15	0.00	0.00
Sum/average	9119.00	2993.04	156.21	0.00	0.00	0.10	0.15	0.15	0.00	0.00

Surnadal region

Surnadal region Cars	Total driven distance km/yr	Number of routes routes/yr	Route distance km/route	Energy requirement (l/yr)
Surnadal	18200.00	39.00	466.67	10920.00
Car 1	*16610.00*	*39.00*	*425.90*	*9966.00*
Car 2	*19790.00*	*39.00*	*507.44*	*11874.00*
Tingvoll	30000.00	52.00	576.92	15750.00
Sum/average	24100.00		542.18	26670.00

Surnadal region	Energy requirement (l/yr)				
Car	RW	P&C	P	G&M	FW
Surnadal	7280.00	3640.00		0.00	0.00
Car 1	*6644.00*	*3322.00*		*0.00*	*0.00*
Car 2	*7916.00*	*3958.00*		*0.00*	*0.00*
Tingvoll	9000.00	4500.00		0.00	2250.00
Sum	16280.00	8140.00		0.00	2250.00

Surnadal region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Surnadal	1322.32	233.17	25.00	0.00	0.00	0.24	0.61	0.61	0.00	0.00
Car 1	661.16	116.59	12.50	0.00	0.00	0.24	0.61	0.61	0.00	0.00
Car 2	661.16	116.59	12.50	0.00	0.00	0.24	0.61	0.61	0.00	0.00
Tingvoll	771.60	119.15	12.77	0.00	61.52	0.20	0.60	0.60	0.00	1.28
Sum/average	1432.76	235.73	25.27	0.00	61.52	0.22	0.60	0.60	0.00	1.28

Comment: During the calculation of energy requirement of collecting food waste in Tingvoll municipality, route distance was reduced by 50% because about half of the customers have home composting subscription. Therefore, they do not have food waste bin (info provided by ReMidt).

Kristiansund_city region

This is the only region where 0.8 l/km fuel consumption was assumed for the waste trucks.

Kristiansund_city region Cars	Total driven distance km/yr	Number of routes routes/yr	Route distance km/route	Energy requirement (l/yr)
Car 1	10480.85	26.00	403.11	8384.68
Car 2	13584.62	26.00	522.49	10867.69
Car 3	7492.68	26.00	288.18	5994.15
Car 4	5253.66	26.00	202.06	4202.93
Sum/average	7867.25		353.96	29449.45

Kristiansund_city region	Energy requirement (l/yr)				
Car	RW	P&C	P	G&M	FW
Car 1	4192.34	4192.34		0.00	0.00
Car 2	5433.85	5433.85		0.00	0.00
Car 3	2997.07	2997.07		0.00	0.00
Car 4	2101.46	2101.46		0.00	0.00
Sum	14724.72	14724.72		0.00	0.00

Comment: G&M is collected with RW 13 times a year. Therefore, the energy requirement of transporting G&M includes in the energy requirement of transport RW.

Kristiansund_city region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	1268.09	256.71	25.44	112.11	0.00	0.08	0.37	0.37	0.08	0.00
Car 2	1268.09	256.71	25.44	112.11	0.00	0.08	0.37	0.37	0.08	0.00
Car 3	1268.09	256.71	25.44	112.11	0.00	0.08	0.37	0.37	0.08	0.00
Car 4	1268.09	256.71	25.44	112.11	0.00	0.08	0.37	0.37	0.08	0.00
Sum/average	5072.37	1026.85	101.75	448.44	0.00	0.08	0.37	0.37	0.08	0.00

Kristiansund_rural region

Kristiansund_rural region Cars	Total driven distance km/yr	Number of routes routes/yr	Route distance km/route	Energy requirement (l/yr)
Aure	18756.50	45.00	416.81	11253.90
Averøya	30000.00	39.00	769.23	18000.00
Smøla	16243.50	51.00	318.50	9746.10
Sum/average	17500.00		318.50	39000.00

Kristiansund_rural region	Energy requirement (l/yr)				
Car	RW	P&C	P	G&M	FW
Aure	6502.25	3251.13	1500.52	0.00	0.00
Averøya	12000.00	6000.00		0.00	0.00
Smøla	4968.60	2484.30	1146.60	1146.60	0.00
Sum	23470.85	14382.55		1146.60	0.00

Kristiansund_rural region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Aure	735.71	148.94	14.76	0.00	0.00	0.21	0.53	2.46	0.00	0.00
Averøya	1214.23	245.81	24.36	0.00	0.00	0.13	0.29	0.29	0.00	0.00
Smøla	672.90	91.31	9.05	28.57	0.00	0.23	0.86	4.01	1.27	0.00
Sum/average	2622.85	486.05	48.16	28.57	0.00	0.19	0.56	2.25	0.42	0.00

Oppdal region

Oppdal region Cars	Total driven distance km/yr	Number of routes routes/yr	Route distance km/route	Energy requirement (l/yr)
Oppdal	25000.00	52.00	480.77	15000.00
Sum/average	25000.00		480.77	15000.00

Oppdal region	Energy requirement (l/yr)				
Car	RW	P&C	P	G&M	FW
Oppdal	0.00	7500.00	3750.00	3750.00	0.00
Sum	0.00	7500.00	3750.00	3750.00	0.00

Comment: Residual waste is collected 13 times a year with G&M waste and 13 times with Plastic waste. Therefore, the energy requirement calculated for G&M and P includes the energy requirement of collecting RW too.

Oppdal region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Oppdal	2142.47	369.00	37.36	66.32	0.00	0.07	0.43	0.07	0.07	0.00
Sum/average	2142.47	369.00	37.36	66.32	0.00	0.07	0.43	0.07	0.07	0.00

Sunndal region

Sunndal region Cars	Total driven distance km/yr	Number of routes routes/yr	Route distance km/route	Energy requirement (l/yr)
Sunndal	25000.00	45.00	555.56	15000.00
Sum/average	25000.00		555.56	15000.00

Sunndal region	Energy requirement (l/yr)				
Car	RW	P&C	P	G&M	FW
Sunndal	8666.67	4333.33		2000.00	0.00
Sum	8666.67	4333.33		2000.00	0.00

Sunndal region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Sunndal	1389.00	275.70	29.61	107.00	0.00	0.11	0.26	0.26	0.34	0.00
Sum/average	1389.00	275.70	29.61	107.00	0.00	0.11	0.26	0.26	0.34	0.00

Melhus and Midtre Gauldal region

Melhus+MG region Cars	Total driven distance km/yr	Number of routes routes/yr	Route distance km/route	Energy requirement (l/yr)
Car 1	19353.00	39.00	496.23	11611.80
Car 2	32349.00	39.00	829.46	19409.40
Car 3	25955.00	39.00	665.51	15573.00
Car 4	19112.00	39.00	490.05	11467.20
Car 5	17951.00	39.00	460.28	10770.60
Car 6	20501.00	39.00	525.67	12300.60
Sum/average	22536.83		577.87	81132.60

Melhus+MG region	Energy requirement (l/yr)				
Car	RW	P&C	P	G&M	FW
Car 1	7741.20	3870.60		0.00	0.00
Car 2	12939.60	6469.80		0.00	0.00
Car 3	10382.00	5191.00		0.00	0.00
Car 4	7644.80	3822.40		0.00	0.00
Car 5	7180.40	3590.20		0.00	0.00
Car 6	8200.40	4100.20		0.00	0.00
Sum	54088.40	27044.20		0.00	0.00

Melhus+MG region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	804.74	147.12	18.18	0.00	0.00	0.20	0.48	0.48	0.00	0.00
Car 2	804.74	147.12	18.18	0.00	0.00	0.20	0.48	0.48	0.00	0.00
Car 3	804.74	147.12	18.18	0.00	0.00	0.20	0.48	0.48	0.00	0.00
Car 4	804.74	147.12	18.18	0.00	0.00	0.20	0.48	0.48	0.00	0.00
Car 5	804.74	147.12	18.18	0.00	0.00	0.20	0.48	0.48	0.00	0.00
Car 6	804.74	147.12	18.18	0.00	0.00	0.20	0.48	0.48	0.00	0.00
Sum/average	4828.44	882.74	109.10	0.00	0.00	0.20	0.48	0.48	0.00	0.00

Downstream transport distance and energy intensities

Transport distances are based on estimates and measurement made in Google Maps. The energy intensities were calculated based on transported waste amount and associated truck category.

Truck type (max load)	Tonne waste per year	Energy intensity (kWh/tkm)
7.5t	<400	0.925
12t	400<x<600	0.724
24t	600<x<800	0.427
40t	800t<	0.273

Source: Callewaert (2017)

Table 27 - Downstream transport model input parameters

	Distance (km)						**Energy intensity (kWh/tkm)**						
Flow	**RW**	**P&C**	**P**	**G&P**	**FW**	**G&P**	**RW**	**P&C**	**P**	**G&M**	**FW**	**G&M**	**Comment**
X35	0	140	140	0	0	0	0	0.925	0.925	0.273	0	0	140 km to sorting at Retura TRV in Heimdal 600 km to sorting at Fredrikstad (Sirkel)
X38	135.6	0	0	0	0	0	0.273	0	0	0	0	0	Average distance to Tanfjor and Statkraft Varme incinerators
X45	0	140	140	0	0	0	0	0.273	0.724	0.427	0	0	140 km to sorting at Retura TRV in Heimdal 600 km to sorting at Fredrikstad (Sirkel)
X56	0	600	500	0	0	0	0	0.273	0.724	0.273	0	0	600 km: from Heimdal (Retura TRV) to mill in Halden (Norske Skog Saugbrugs AS) The average distance is used for G&M: Magnetic metal goes to Metalco in Trondheim from Fredrikstad (600km) Non-magnetic metal is sent to Hydro in

													Germany (1300 km) 950 km: Distance from Oslo to the recycling facility in Germany.
X68	0	0	50	0	0	0	0	0	0.925	0	0	0	Assumption
X47	0	0	0	200	200	0	0	0	0	0	0.925	0	200 km: From reloading to Ecopro in Verdal, biogas production
X48	135.6	0	0	0	0	0	0.273	0	0	0	0	0	Average distance to Tanfjor and Statkraft Varme incinerators
X58	0	3	3	0	0	0	0	0.273	0.925	0.925	0	0	Incineration either in Heimdal where P&C and P sorting facility is located or in Fredrikstad where G&M sorting happens.
X78	0	0	0	102	102	0	0	0	0	0	0.925	0	Contamination and rejects from Verdal sent to Heimdal for incineration
X89	500	500	500	500	500	0	0.273	0.273	0.925	0.925	0.925	0	500 km: Average from incineratior in Heimdal and Ålesund to bottomash treatment at Fortum in Oslo
X910	50	50	50	50	50	0	0.273	0.273	0.925	0.925	0.925	0	Assumption
X510	0	0	0	0	0	0	0	0	0	0.925	0	0	Assumption
X911	50	50	50	0	0	0	0.273	0.925	0.925	0.925	0	0	Assumption
X195	0	0	0	0	0	0	0	0	0	0.273	0	0	600 km: to sorting at Fredrikstad (Sirkel)
X420	0	0	0	0	0	200	0	0	0	0	0	0.273	Average transport distance to composting

A.5. S1: New kerbside collection scenario 2025 and 2035

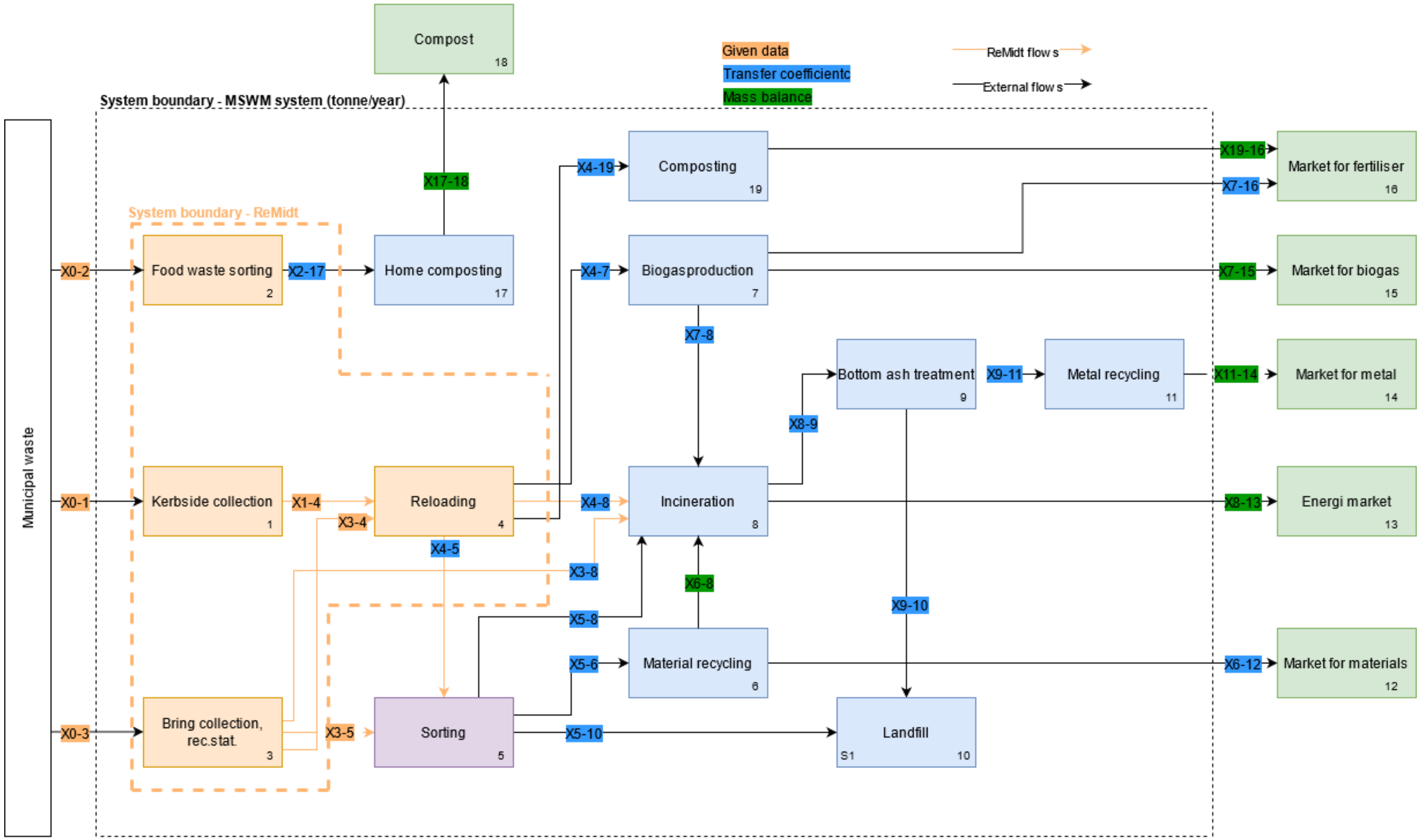


Figure 62 - Flowchart, S1

A.5.1. Material layer: Flows

In the following section the flows and transfer coefficients used in S1 are listed with explanations and sources. It is important to note that only known or calculated flows and transfer coefficients are listed here, missing flows are calculated by the MFA model used in this study.

Estimates about the inflows from home composting (X0-2), kerbside collection (X0-1) and bring collection system at recycling stations (X0-3) are based on per capita waste amount calculated from Baseline estimates from 2020 and multiplied them with population estimates in 2025. Adjustments were made in both total generated waste amount and fraction distributions in accordance with the new kerbside collection system. The description of the parameter adjustments is explained under Section 4.5 - New kerbside collection scenario (S1).

S1 2025 model inputs are shown in the table below.

In S1 the kerbside system is unified, which does not only change the distribution of waste amount and waste fractions but also influences the distribution of the waste generated by the different municipalities and regions. Changes in municipal level population estimates for year 2025 were considered in the calculations.

Table 29 shows the distribution factors used to divide the waste amounts across the different regions.

Table 28 - Inflows and fraction distributions, S1 2025

	Flow	Unit	RW	P&C	P	G&M	FW	Compost	G&P
flow	**X02**	**t/yr**	0.00	0.00	0.00	0.00	0.00	724.23	0.00
Rest		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P&C		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plastic		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glass		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Metal		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Food waste		%	0.00	0.00	0.00	0.00	0.00	100.00	0.00
Hazardous waste		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WEEE		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Textiles		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
flow	**X01**	**t/yr**	22417.59	6728.93	560.66	1687.41	7032.63	0.00	0.00
Rest		%	34.60	3.54	3.54	0.48	7.50	0.00	0.00
P&C		%	8.52	95.24	0.04	0.00	0.00	0.00	0.00
Plastic		%	16.34	0.33	96.15	0.00	3.00	0.00	0.00
Glass		%	2.50	0.04	0.00	87.90	0.00	0.00	0.00
Metal		%	3.00	0.03	0.15	11.37	0.00	0.00	0.00
Food waste		%	29.37	0.75	0.00	0.00	89.50	0.00	0.00
Hazardous waste		%	0.44	0.02	0.00	0.25	0.00	0.00	0.00
WEEE		%	0.45	0.01	0.00	0.00	0.00	0.00	0.00
Textiles		%	4.78	0.04	0.13	0.00	0.00	0.00	0.00
flow	**X03**	**t/yr**	12506.58	375.12	244.99	1220.70	4.75	0.00	930.71
Rest		%	66.70	0.00	0.00	0.00	0.00	0.00	0.00
P&C		%	7.25	100.00	0.00	0.00	0.00	0.00	0.00
Plastic		%	9.96	0.00	100.00	0.00	0.00	0.00	0.00
Glass		%	1.06	0.00	0.00	90.00	0.00	0.00	0.00
Metal		%	2.55	0.00	0.00	10.00	0.00	0.00	0.00
Food waste		%	0.88	0.00	0.00	0.00	100.00	0.00	100
Hazardous waste		%	1.11	0.00	0.00	0.00	0.00	0.00	0.00
WEEE		%	1.46	0.00	0.00	0.00	0.00	0.00	0.00
Textiles		%	9.03	0.00	0.00	0.00	0.00	0.00	0.00

Table 29 - Distribution of waste flows, per region and municipality, S1, 2025

X14	Distribution of municipalities (% of total waste flow)				
	RW	P&C	P	G&M	FW
Hitra	7.42	4.51	6.71	7.25	8.25
Hitra	3.67	2.23	3.32	3.58	4.08
Frøya	3.75	2.28	3.39	3.67	4.17
Orkland	30.66	44.88	28.11	25.66	29.19
Surnadal	7.54	5.18	6.66	6.08	5.42
Surnadal	4.19	3.40	4.38	3.99	4.54
Tingvoll	3.35	1.78	2.29	2.09	0.88
Kr.Sund_city	16.74	15.30	18.20	26.65	18.96
Kr.Sund_rural	8.63	7.23	8.60	8.09	8.96
Aure	2.31	2.21	2.62	2.40	2.73
Averøy	3.86	3.68	4.38	4.01	4.56
Smøla	2.45	1.34	1.60	1.67	1.66
Oppdal	7.83	5.48	6.66	3.93	5.47
Sunndal	4.37	4.01	5.16	6.20	5.38
Melhus+MG	16.81	13.41	19.90	16.15	18.37

In S1 2035, the total generated waste flows will increase but the fraction distribution remains the same as in 2025.

Table 30 - Inflows, S1 2035

Flow	Unit	RW	P&C	P	G&M	FW	Compost	G&P
X02	t/yr	0.00	0.00	0.00	0.00	0.00	729.46	0.00
X01	t/yr	22747.09	6828.19	569.25	1710.54	7142.69	0.00	0.00
X03	t/yr	12652.46	387.65	247.81	1247.43	4.89	0.00	945.18

Table 31 shows the distribution factors used to divide the waste amounts across the different regions in S1 2035.

Table 31 - Distribution of waste flows, per region and municipality, S1, 2035

X14	Distribution of municipalities (% of total waste flow)				
	RW	P&C	P	G&M	FW
Hitra	7.79	4.74	7.04	7.62	8.65
Hitra	3.84	2.34	3.47	3.76	4.27
Frøya	3.95	2.40	3.57	3.86	4.39
Orkland	30.75	45.02	28.19	25.77	29.26
Surnadal	7.31	4.99	6.42	5.87	5.18
Surnadal	3.98	3.23	4.15	3.79	4.31
Tingvoll	3.33	1.77	2.27	2.08	0.87
Kr.Sund_city	16.59	15.16	18.02	26.43	18.77
Kr.Sund_rural	8.49	7.14	8.48	7.99	8.84
Aure	2.26	2.16	2.56	2.35	2.67
Averøy	3.87	3.69	4.38	4.02	4.56
Smøla	2.36	1.29	1.54	1.62	1.60
Oppdal	7.70	5.38	6.54	3.86	5.37
Sunndal	4.11	3.77	4.85	5.83	5.05
Melhus+MG	17.26	13.80	20.46	16.63	18.88

A.5.2. Material layer: Transfer coefficients (TCs), S1, 2025 and 2035

Transfer coefficients are the same as in the Baseline scenario.

A.5.3. Energy layer: Transport energy, S1 2025 and 2035

It is assumed that the same waste trucks are operating in S1 as in the Baseline scenario. The route distances also remain the same. Only the collection frequencies change due to change in the kerbside collection system.

In S1b, the waste trucks in Orkland and Melhus+MG regions are replaced with biogas trucks. The following fuel consumption and energy content information were used for calculating transport energy intensities in these two regions in S1b:

	Fuel consumption	Energy content
Biogas	1 m3/km	3.70 kwh/m3
Source	Assumptions	(Miljødirektoratet, 2021)

The following tables summarise input data for calculating transport energy intensity for the different ReMidt regions and downstream transport flows.

Hitra region (S1a;S1b)

Hitra region Cars	Number of routes routes/yr	Route distance km/route	Energy requirement (l/yr)
Hitra	34.00	717.49	24394.56
Frøya	34.00	505.59	17190.14
Sum/average		611.54	41584.70

Hitra region	Energy requirement (l/yr)		
Car	RW+FW	P&C+FW	G&M+P
Hitra	9327.33	9327.33	5739.90
Frøya	6572.70	6572.70	4044.74
Sum	15900.03	15900.03	9784.64

2025

Hitra region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Hitra	822.32	150.07	18.60	60.48	286.77	0.05	0.16	0.37	0.37	0.11
Frøya	841.01	153.48	19.03	61.86	293.29	0.05	0.16	0.37	0.37	0.10
Sum	1663.33	303.54	37.63	122.34	580.06	0.05	0.16	0.37	0.37	0.11

2035

Hitra region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Hitra	874.05	159.51	19.78	64.29	304.81	0.08	0.25	0.58	0.58	0.16
Frøya	898.26	163.92	20.32	66.07	313.25	0.07	0.25	0.56	0.56	0.16
Sum	1772.31	323.43	40.10	130.36	618.06	0.08	0.25	0.57	0.57	0.16

Orkland region (S1a)

Orkland region Cars	Number of routes routes/yr	Route distance km/route	Energy requirement (l/yr)
Car 1	34.00	549.00	11199.60
Car 2	34.00	447.67	9132.40
Car 3	34.00	813.97	16605.08
Car 4	34.00	758.15	15466.34
Car 5	34.00	972.85	19846.06
Car 6	34.00	606.78	12378.39
Sum/average		691.40	84627.87

Orkland region	Energy requirement (l/yr)		
Car	RW+FW	P&C+FW	G&M+P
Car 1	4282.20	4282.20	2635.20
Car 2	3491.80	3491.80	2148.80
Car 3	6349.00	6349.00	3907.08
Car 4	5913.60	5913.60	3639.14
Car 5	7588.20	7588.20	4669.66
Car 6	4732.91	4732.91	2912.56
Sum	32357.71	32357.71	19912.44

2025

Orkland region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	1145.41	503.36	26.27	72.17	342.18	0.06	0.12	0.49	0.49	0.09
Car 2	1145.41	503.36	26.27	72.17	342.18	0.06	0.12	0.49	0.49	0.09
Car 3	1145.41	503.36	26.27	72.17	342.18	0.06	0.12	0.49	0.49	0.09
Car 4	1145.41	503.36	26.27	72.17	342.18	0.06	0.12	0.49	0.49	0.09
Car 5	1145.41	503.36	26.27	72.17	342.18	0.06	0.12	0.49	0.49	0.09
Car 6	1145.41	503.36	26.27	72.17	342.18	0.06	0.12	0.49	0.49	0.09
Sum/average	6872.43	3020.14	157.62	433.02	2053.10	0.06	0.12	0.49	0.49	0.09

2035

Orkland region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	1165.96	512.39	26.74	73.46	348.32	0.06	0.11	0.48	0.48	0.09
Car 2	1165.96	512.39	26.74	73.46	348.32	0.06	0.11	0.48	0.48	0.09
Car 3	1165.96	512.39	26.74	73.46	348.32	0.06	0.11	0.48	0.48	0.09
Car 4	1165.96	512.39	26.74	73.46	348.32	0.06	0.11	0.48	0.48	0.09
Car 5	1165.96	512.39	26.74	73.46	348.32	0.06	0.11	0.48	0.48	0.09
Car 6	1165.96	512.39	26.74	73.46	348.32	0.06	0.11	0.48	0.48	0.09
Sum/average	6995.78	3074.35	160.45	440.79	2089.95	0.06	0.11	0.48	0.48	0.09

Orkland region (S1b, 2025)

Orkland region Cars	Number of routes routes/yr	Route distance km/route	Energy requirement (l/yr)
Car 1	34.00	549.00	11199.60
Car 2	34.00	447.67	9132.40
Car 3	34.00	813.97	16605.08
Car 4	34.00	758.15	15466.34
Car 5	34.00	972.85	19846.06
Car 6	34.00	606.78	12378.39
Sum/average		691.40	84627.87

Orkland region	Energy requirement (l/yr)		
Car	RW+FW	P&C+FW	G&M+P
Car 1	7137.00	7137.00	4392.00
Car 2	5819.67	5819.67	3581.33
Car 3	10581.67	10581.67	6511.79
Car 4	9856.00	9856.00	6065.23
Car 5	12647.00	12647.00	7782.77
Car 6	7888.19	7888.19	4854.27
Sum	53929.52	53929.52	33187.40

Orkland region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	1145.41	503.36	26.27	72.17	342.18	0.04	0.07	0.30	0.30	0.05
Car 2	1145.41	503.36	26.27	72.17	342.18	0.04	0.07	0.30	0.30	0.05
Car 3	1145.41	503.36	26.27	72.17	342.18	0.04	0.07	0.30	0.30	0.05
Car 4	1145.41	503.36	26.27	72.17	342.18	0.04	0.07	0.30	0.30	0.05
Car 5	1145.41	503.36	26.27	72.17	342.18	0.04	0.07	0.30	0.30	0.05
Car 6	1145.41	503.36	26.27	72.17	342.18	0.04	0.07	0.30	0.30	0.05
Sum/average	6872.43	3020.14	157.62	433.02	2053.10	0.04	0.07	0.30	0.30	0.05

Surnadal region (S1a; S1b)

Surnadal region Cars	Number of routes routes/yr	Route distance km/route	Energy requirement (l/yr)
Surnadal	34.00	466.67	9520.00
Car 1	*34.00*	*425.90*	*8688.31*
Car 2	*34.00*	*507.44*	*10351.69*
Tingvoll	34.00	576.92	11769.23
Sum/average		542.18	21289.23

Surnadal region	Energy requirement (l/yr)		
Car	RW+FW	P&C+FW	G&M+P
Surnadal	7280.00	7280.00	4480.00
Car 1	*3322.00*	*3322.00*	*2044.31*
Car 2	*3958.00*	*3958.00*	*2435.69*
Tingvoll	4500.00	4500.00	2769.23
Sum	11780.00	11780.00	7249.23

2025

Surnadal region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Surnadal	939.46	228.89	24.54	67.41	319.61	0.14	0.40	1.05	1.05	0.27
Car 1	469.73	114.44	12.27	33.70	159.81	0.14	0.40	1.05	1.05	0.27
Car 2	469.73	114.44	12.27	33.70	159.81	0.14	0.40	1.05	1.05	0.27
Tingvoll	751.71	119.67	12.83	35.24	61.79	0.10	0.52	1.01	1.01	0.31
Sum/average	1221.44	234.11	25.10	68.95	221.59	0.12	0.46	1.03	1.03	0.29

2035

Surnadal region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Surnadal	904.27	220.31	23.62	64.88	307.64	0.15	0.42	1.09	1.09	0.28
Car 1	452.13	110.16	11.81	32.44	153.82	0.15	0.42	1.09	1.09	0.28
Car 2	452.13	110.16	11.81	32.44	153.82	0.15	0.42	1.09	1.09	0.28
Tingvoll	758.22	120.70	12.94	35.55	62.32	0.10	0.52	1.00	1.00	0.31
Sum/average	1662.49	341.02	36.56	100.43	369.97	0.12	0.47	1.05	1.05	0.30

Comment: During the calculation of energy requirement of collecting food waste in Tingvoll municipality, route distance was reduced by 50% because about half of the customers have home composting subscription. Therefore, they do not have food waste bin (info provided by ReMidt).

Kristiansund_city region (S1a; S1b)

Kristiansund_city region Cars	Number of routes routes/yr	Route distance km/route	Energy requirement (l/yr)
Car 1	34.00	403.11	10964.58
Car 2	34.00	522.49	14211.60
Car 3	34.00	288.18	7838.50
Car 4	34.00	202.06	5496.14
Sum/average		353.96	38510.81

Kristiansund_city region	Energy requirement (l/yr)		
Car	RW+FW	P&C+FW	G&M+P
Car 1	4192.34	4192.34	2579.90
Car 2	5433.85	5433.85	3343.91
Car 3	2997.07	2997.07	1844.35
Car 4	2101.46	2101.46	1293.21
Sum	14724.72	14724.72	9061.37

2025

Kristiansund_city region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	938.17	257.41	25.51	112.41	333.36	0.09	0.25	0.47	0.47	0.17
Car 2	938.17	257.41	25.51	112.41	333.36	0.09	0.25	0.47	0.47	0.17
Car 3	938.17	257.41	25.51	112.41	333.36	0.09	0.25	0.47	0.47	0.17
Car 4	938.17	257.41	25.51	112.41	333.36	0.09	0.25	0.47	0.47	0.17
Sum/average	3752.67	1029.63	102.02	449.65	1333.45	0.09	0.25	0.47	0.47	0.17

2035

Kristiansund_city region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	943.24	258.80	25.64	113.02	335.16	0.09	0.25	0.47	0.47	0.17
Car 2	943.24	258.80	25.64	113.02	335.16	0.09	0.25	0.47	0.47	0.17
Car 3	943.24	258.80	25.64	113.02	335.16	0.09	0.25	0.47	0.47	0.17
Car 4	943.24	258.80	25.64	113.02	335.16	0.09	0.25	0.47	0.47	0.17
Sum/average	3772.94	1035.19	102.58	452.08	1340.65	0.09	0.25	0.47	0.47	0.17

Kristiansund_rural region (S1a; S1b)

Kristiansund_rural region	Number of routes	Route distance	Energy requirement
Cars	routes/yr	km/route	(l/yr)
Aure	34.00	416.81	8502.95
Averøya	34.00	769.23	15692.31
Smøla	34.00	318.50	6497.40
Sum/average		318.50	30692.65

Kristiansund_rural region	Energy requirement (l/yr)		
Car	RW+FW	P&C+FW	G&M+P
Aure	3251.13	3251.13	2000.69
Averøya	6000.00	6000.00	3692.31
Smøla	2484.30	2484.30	1528.80
Sum	11735.43	11735.43	7221.801

2025

Kristiansund_rural region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Aure	518.83	148.39	14.70	40.53	192.17	0.13	0.32	0.88	0.88	0.22
Averøya	866.37	247.78	24.55	67.68	320.90	0.08	0.19	0.52	0.52	0.13
Smøla	548.63	90.32	8.95	28.26	116.97	0.13	0.53	1.30	1.30	0.33
Sum/average	1933.83	486.48	48.21	136.47	630.03	0.11	0.35	0.90	0.90	0.23

2035

Kristiansund_rural region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Aure	514.97	147.28	14.59	40.23	190.74	0.13	0.32	0.88	0.88	0.23
Averøya	880.18	251.73	24.94	68.76	326.01	0.08	0.19	0.52	0.52	0.13
Smøla	536.59	88.33	8.75	27.64	114.40	0.13	0.54	1.33	1.33	0.34
Sum/average	1931.74	487.35	48.29	136.63	631.15	0.11	0.35	0.91	0.91	0.23

Oppdal region (S1a; S1b)

Oppdal region	Number of routes	Route distance	Energy requirement
Cars	routes/yr	km/route	(l/yr)
Oppdal	34.00	480.77	9807.69
Sum/average		480.77	9807.69

Oppdal region	Energy requirement (l/yr)		
Car	RW+FW	P&C+FW	G&M+P
Oppdal	3750.00	3750.00	2307.69
Sum	3750.00	3750.00	2307.69

2025

Oppdal region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Oppdal	1757.42	369.00	37.36	66.32	385.06	0.04	0.14	0.47	0.47	0.09
Sum/average	1755.16	368.53	37.31	66.23	384.56	0.04	0.14	0.47	0.47	0.09

2035

Oppdal region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Oppdal	1750.64	367.58	37.22	66.06	383.57	0.04	0.14	0.47	0.47	0.09
Sum/average	1750.64	367.58	37.22	66.06	383.57	0.04	0.14	0.47	0.47	0.09

Sunndal region (S1a; S1b)

Sunndal region Cars	Number of routes routes/yr	Route distance km/route	Energy requirement (l/yr)
Sunndal	34.00	555.56	11333.33
Sum/average		555.56	11333.33

Sunndal region	Energy requirement (l/yr)		
Car	RW	G&M	FW
Sunndal	4333.33	4333.33	2666.67
Sum	4333.33	4333.33	2666.67

2025

Sunndal region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Sunndal	1002.02	275.70	29.61	107.00	386.98	0.07	0.17	0.35	0.35	0.12
Sum/average	979.52	269.51	28.94	104.60	378.29	0.07	0.17	0.35	0.35	0.12

2035

Sunndal region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Sunndal	934.52	257.13	27.61	99.79	360.91	0.07	0.18	0.38	0.38	0.13
Sum/average	934.52	257.13	27.61	99.79	360.91	0.07	0.18	0.38	0.38	0.13

Melhus and Midtre Gauldal region (S1a)

Melhus+MG region Cars	Number of routes routes/yr	Route distance km/route	Energy requirement (l/yr)
Car 1	34.00	496.23	10123.11
Car 2	34.00	829.46	16921.02
Car 3	34.00	665.51	13576.46
Car 4	34.00	490.05	9997.05
Car 5	34.00	460.28	9389.75
Car 6	34.00	525.67	10723.60
Sum/average		577.87	70730.98

Melhus+MG region	Energy requirement (l/yr)		
Car	RW+FW	P&C+FW	G&M+P
Car 1	3870.60	3870.60	2381.91
Car 2	6469.80	6469.80	3981.42
Car 3	5191.00	5191.00	3194.46
Car 4	3822.40	3822.40	2352.25
Car 5	3590.20	3590.20	2209.35
Car 6	4100.20	4100.20	2523.20
Sum	27044.20	27044.20	16642.58

2025

Melhus+MG region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	628.25	150.42	18.59	45.41	215.29	0.11	0.30	0.76	0.76	0.21
Car 2	628.25	150.42	18.59	45.41	215.29	0.11	0.30	0.76	0.76	0.21
Car 3	628.25	150.42	18.59	45.41	215.29	0.11	0.30	0.76	0.76	0.21
Car 4	628.25	150.42	18.59	45.41	215.29	0.11	0.30	0.76	0.76	0.21
Car 5	628.25	150.42	18.59	45.41	215.29	0.11	0.30	0.76	0.76	0.21
Car 6	628.25	150.42	18.59	45.41	215.29	0.11	0.30	0.76	0.76	0.21
Sum/average	3769.50	902.54	111.55	272.44	1291.75	0.11	0.30	0.76	0.76	0.21

2035

Melhus+MG region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	654.45	157.02	19.41	47.40	224.74	0.10	0.29	0.72	0.72	0.20
Car 2	654.45	157.02	19.41	47.40	224.74	0.10	0.29	0.72	0.72	0.20
Car 3	654.45	157.02	19.41	47.40	224.74	0.10	0.29	0.72	0.72	0.20
Car 4	654.45	157.02	19.41	47.40	224.74	0.10	0.29	0.72	0.72	0.20
Car 5	654.45	157.02	19.41	47.40	224.74	0.10	0.29	0.72	0.72	0.20
Car 6	654.45	157.02	19.41	47.40	224.74	0.10	0.29	0.72	0.72	0.20
Sum/average	3926.67	942.15	116.45	284.40	1348.44	0.10	0.29	0.72	0.72	0.20

Melhus and Midtre Gauldal region (S1b, 2025)

Melhus+MG region Cars	Number of routes routes/yr	Route distance km/route	Energy requirement (l/yr)
Car 1	34.00	496.23	10123.11
Car 2	34.00	829.46	16921.02
Car 3	34.00	665.51	13576.46
Car 4	34.00	490.05	9997.05
Car 5	34.00	460.28	9389.75
Car 6	34.00	525.67	10723.60
Sum/average		577.87	70730.98

Melhus+MG region	Energy requirement (l/yr)		
Car	RW+FW	P&C+FW	G&M+P
Car 1	6451.00	6451.00	3969.85
Car 2	10783.00	10783.00	6635.69
Car 3	8651.67	8651.67	5324.10
Car 4	6370.67	6370.67	3920.41
Car 5	5983.67	5983.67	3682.26
Car 6	6833.67	6833.67	4205.33
Sum	45073.67	45073.67	27737.64

Melhus+MG region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	628.25	150.42	18.59	45.41	215.29	0.07	0.19	0.46	0.46	0.13
Car 2	628.25	150.42	18.59	45.41	215.29	0.07	0.19	0.46	0.46	0.13
Car 3	628.25	150.42	18.59	45.41	215.29	0.07	0.19	0.46	0.46	0.13
Car 4	628.25	150.42	18.59	45.41	215.29	0.07	0.19	0.46	0.46	0.13
Car 5	628.25	150.42	18.59	45.41	215.29	0.07	0.19	0.46	0.46	0.13
Car 6	628.25	150.42	18.59	45.41	215.29	0.07	0.19	0.46	0.46	0.13
Sum/average	3769.50	902.54	111.55	272.44	1291.75	0.07	0.19	0.46	0.46	0.13

Downstream transport distance and energy intensities

The downstream transport distances remain the same as in the Baseline. Only the energy intensities change due to changes in G&M and FW waste amounts transported between downstream processes (highlighted with orange). Downstream waste amounts are calculated by the model. In both 2025 and 2035 the same energy intensities are used.

Table 32 - Downstream transport model input parameters. S1 2025 and 2035

	Distance (km)						Energy intensity (kWh/tkm)					
Flow	RW	P&C	P	G&M	FW	G&P	RW	P&C	P	G&M	FW	G&P
X35	0	140	140	600	0	0	0	0.925	0.925	0.273	0	0
X38	135.6	0	0	0	0	0	0.273	0	0	0	0	0
X45	0	140	140	600	0	0	0	0.273	0.724	0.273	0	0
X56	0	600	500	950	0	0	0	0.273	0.724	0.273	0	0
X68	0	0	50	0	0	0	0	0	0.925	0	0	0
X47	0	0	0	0	200	0	0	0	0	0	0.273	0
X48	135.6	0	0	0	0	0	0.273	0	0	0	0	0
X58	0	3	3	3	0	0	0	0.273	0.925	0.925	0	0
X78	0	0	0	0	102	0	0	0	0	0	0.427	0
X89	500	500	500	500	500	0	0.273	0.273	0.925	0.925	0.925	0
X910	50	50	50	50	50	0	0.273	0.273	0.925	0.925	0.925	0
X510	0	0	0	50	0	0	0	0	0	0.925	0	0
X911	50	50	50	50	0	0	0.273	0.925	0.925	0.925	0	0
X419	0	0	0	0	0	200	0	0	0	0	0	0.273

A.6. S2: Central sorting scenario 2035

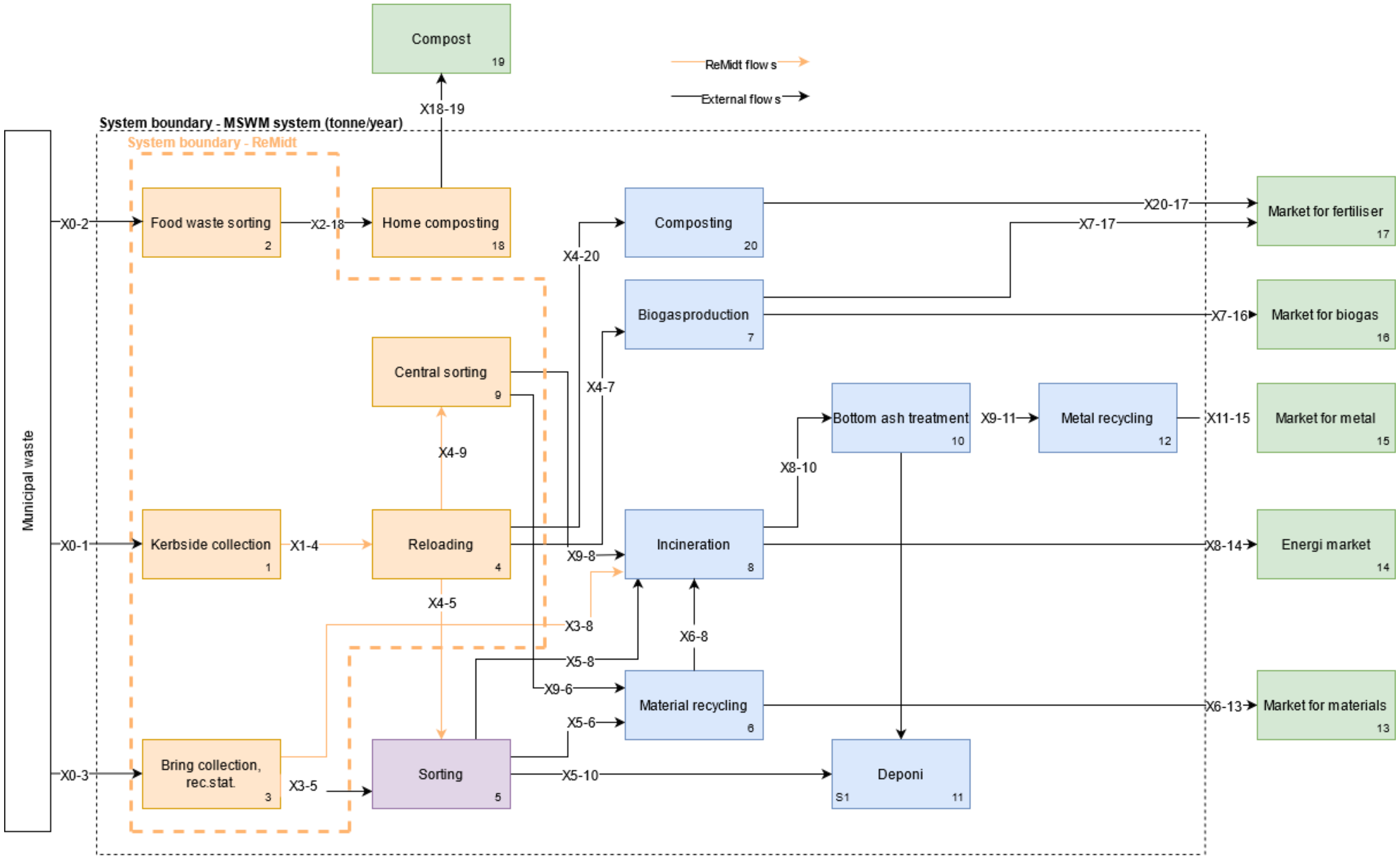


Figure 63 - Flowchart, S2a

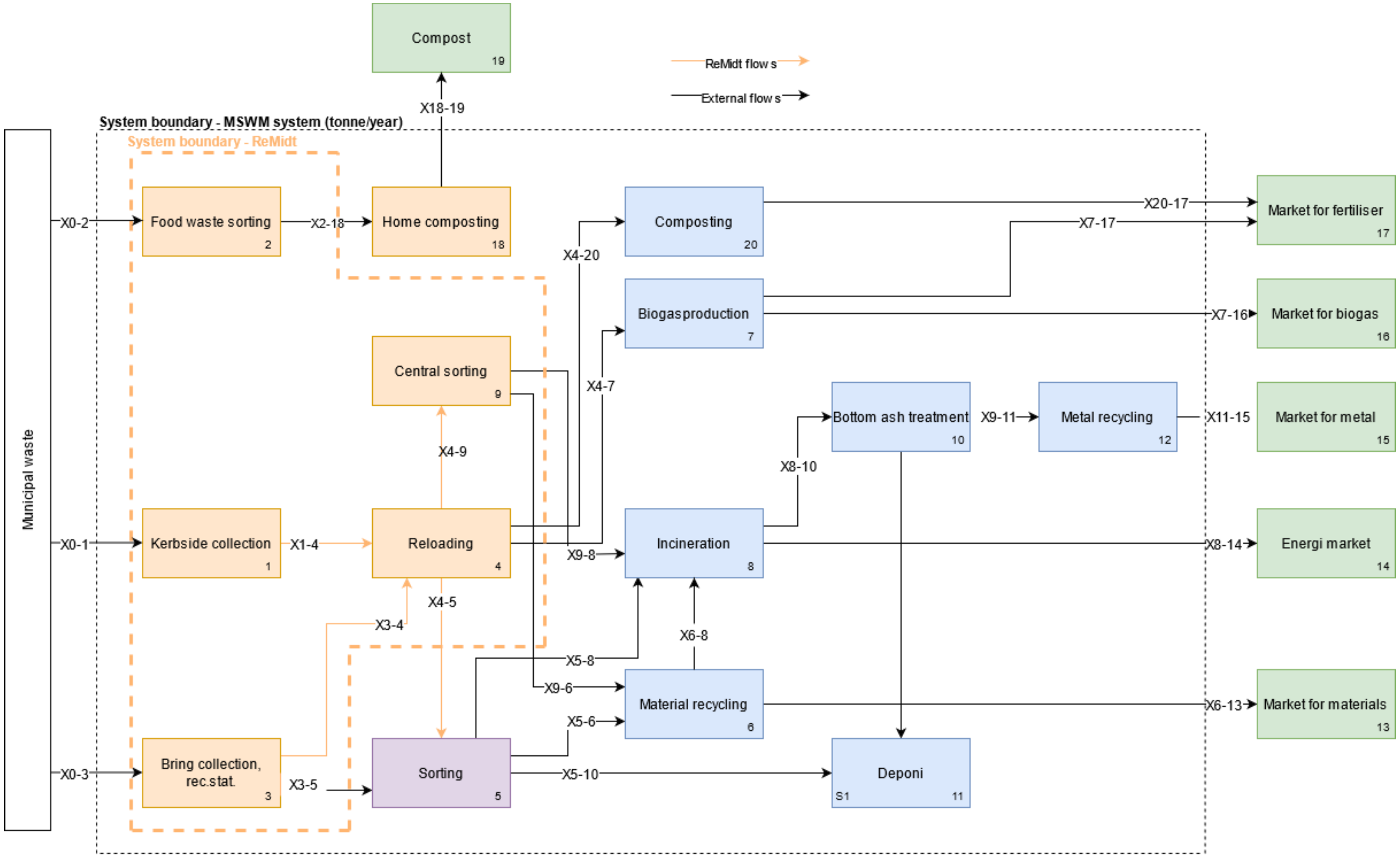


Figure 64 - Flowchart, S2b

A.6.1. Material layer: Flows

S2 has identical collection system as S1. Thereby, inflows are the same as in the 2035 S1.

A.6.2. Material layer: Transfer coefficients (TCs), S2, 2035

Transfer coefficients for the central sorting facility are calculated from information provided in the Sesam project report (Watnebryn and Fredriksen, 2018).

Table 33 - Sorting efficiency at Sesam central sorting facility, including green bags.

	Inflow				**Outflow**	
Sortable fractions	Tonne/yr	% of inflow	% without green bags	Sorting efficiency (SESAM, NIR technology)	Sorted (t/yr)	Non-recyclable
PE Folie plastic	8023			66 %	5281	2742
Hard plastic total:	5203			78 %	4068	1135
HDPE	1194			84 %	1006	188
PP	2231			84 %	1870	361
PET food packaging	1265			65 %	817	448
PET bottles	513			73 %	374	139
Sum plastic	**13226**	**15 %**	**16 %**	**71 %**	**9348**	**3878**
Mixed paper	**7341**	**8 %**	**9 %**	**52 %**	**3854**	**3487**
Metal, ferrous	**1618**	**2 %**	**2 %**	**96 %**	**1557**	**61**
Metal, non-ferrous	**1272**	**1 %**	**2 %**	**96 %**	**1223**	**49**
Food waste in green bags	**7827**	**9 %**		**87 %**	**6789**	**1038**
Waster loss (vapour)					4460	
To incineration						**4053**
Sum of recyclable, sorted fractions	**31284**				**27231**	
Non-recyclables						
Other plastics	2532	3 %	**3 %**			2532
Textiles	4084	5 %	**5 %**			4084
Glass	3541	4 %	**4 %**			3541
WEEE and hazardous	698	1 %	**1 %**			698
Solid Residue Fuel (SRD) fractions	19127	21 %	**24 %**			19127
Fine particles (FP) under 60mm	27927	31 %	**34 %**			27927
30% non-organic	8378.1					
70% organic	19548.9					
Sum of non-recyclables	**57909**					
Total inflow	**89193**	100 %	100 %			

Table 34 - Sorting efficiency at Sesam central sorting facility, without green bags.

Fractions	Recyclable	Non-recyclable	Total	**% of total**	Calculation
Residual	0.00	27505.1	27505.10	33.8 %	SRF+FP$_{\text{non-organic}}$
Paper and Cardboard	3854.00	3487	7341.00	9.0 %	Given
Plastic	9348.00	6410	15758.00	19.4 %	Given
Glass	0.00	3541	3541.00	4.4 %	Given
Metal	2780.00	110	2890.00	3.6 %	Given
Bio-waste (food)	0	19548.9	19548.90	24.0 %	FP$_{\text{organic}}$
Hazardous waste	0.00	349	349.00	0.4 %	Given
WEEE	0.00	349	349.00	0.4 %	Given
Textiles	0.00	4084	4084.00	5.0 %	Given
Sum	15982.00	65384.00	81366.00	100%	

Table 35 - Calculating TC96 (%) (from central sorting to recycling)

Fractions	TC96 RW	Calculation
Residual	0.00	
Paper and Cardboard	52.5	Recyclable$_{\text{Paper and Cardboard}}$ / Total$_{\text{Paper and Cardboard}}$
Plastic	59.3	Recyclable$_{\text{Plastis}}$ / Total$_{\text{Plastic}}$
Glass	0.00	
Metal	96.2	Recyclable$_{\text{Metal}}$ / Total$_{\text{Metal}}$
Bio-waste (food)	0	
Hazardous waste	0.00	
WEEE	0.00	
Textiles	0.00	

Table 36 - Calculating TC98 (%) (from central sorting to incineration)

Fractions	T98 RW	T90 RW	Calculation
Residual	100	0	
Paper and Cardboard	47.5	0	
Plastic	40.7	0	
Glass	100	0	
Metal	3.8	0	
Bio-waste (food)	82.1	17.9	Rest is vapour (X90)
Hazardous waste	1	0	
WEEE	1	0	
Textiles	1	0	

A.6.3. Energy layer: Transport energy, S2

The same kerbside collection is assumed in S2 as in S1. Therefore, the kerbside transport energy efficiencies are the same as in S1.

Downstream transport distance and energy intensities

The downstream transport distances remain the same as in the Baseline. Central sorting changes the amount of waste transported between downstream processes. This has an influence on downstream transport energy intensities compared to the Baseline scenario (with orange).

Table 37 - Downstream transport model input parameters, S2

	Distance (km)						Energy intensity (kWh/tkm)						Comment
Flow	**RW**	**P&C**	**P**	**G&M**	**FW**	**G&P**	**RW**	**P&C**	**P**	**G&M**	**FW**	**G&P**	
X35	0	140	140	600	0	0	0	0.925	0.925	0.273	0	0	
X38	135.6	0	0	0	0	0	0.273	0	0	0	0	0	
X45	0	140	140	600	0	0	0	0.273	0.724	0.273	0	0	
X56	0	600	500	950	0	0	0	0.273	0.724	0.273	0	0	
X58	0	3	3	3	0	0	0	0.273	0.925	0.925	0	0	Incineration either in Heimdal where PC and P sorting facility is located or in Fredrikstad where the G&M sorting is.
X96	963	0	0	0	0	0	0.273	0	0	0	0	0	963km: Average of transporting recyclable fractions sorted out at CS to final recycling
X98	3	0	0	0	0	0	0.273	0	0	0	0	0	3km: The proposed CS facility will be located in close proximity to the incineration facility in Heimdal.
X68	0	0	50	0	0	0	0	0	0.925	0	0	0	
X47	0	0	0	0	200	0	0	0	0	0	0.273	0	
X49	135.6	0	0	0	0	0	0.273	0	0	0	0	0	Instead of incineration, RW is sent to CS which will locates close to Statkraft Varme, so the distance is the same.
X78	0	0	0	0	102	0	0	0	0	0	0.273	0	
X810	500	500	500	500	500	0	0.273	0.273	0.925	0.925	0.925	0	
X1011	50	50	50	50	50	0	0.273	0.273	0.925	0.925	0.925	0	
X511	0	0	0	50	0	0	0	0	0	0.925	0	0	
X911	50	50	50	50	0	0	0.925	0.925	0.925	0.925	0	0	
X420	0	0	0	0	200	0	0	0	0	0	0	0.273	

A.7. S3: Improved kerbside collection 2035

A.7.1. Material layer: Flows, S3a and S3b

In S3a the goal is to increase the collection efficiency up to minimum 70%. To achieve this, the total generated waste amounts per waste type are adjusted (flow X01), as well as the waste composition of the residual waste bin (figure below). System boundary is the same as in S1.

Table 38 - Inflows and fraction distributions, S3a, 2035

	Flow	Unit	RW	P&C	P	G&M	FW	Compost	G&P
flow	**X02**	**t/yr**	0.00	0.00	0.00	0.00	0.00	729.46	0.00
Rest		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P&C		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plastic		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glass		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Metal		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Food waste		%	0.00	0.00	0.00	0.00	0.00	100.00	0.00
Hazardous waste		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WEEE		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Textiles		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
flow	**X01**	**t/yr**	14421.20	7603.41	3542.75	2279.22	11151.19	0.00	0.00
Rest		%	54.58	3.18	0.57	0.36	4.80	0.00	0.00
P&C		%	8.06	95.73	0.01	0.00	0.00	0.00	0.00
Plastic		%	5.15	0.30	99.38	0.00	1.92	0.00	0.00
Glass		%	2.37	0.04	0.00	75.95	0.00	0.00	0.00
Metal		%	2.37	0.03	0.02	23.50	0.00	0.00	0.00
Food waste		%	18.53	0.67	0.00	0.00	93.27	0.00	0.00
Hazardous waste		%	0.69	0.02	0.00	0.19	0.00	0.00	0.00
WEEE		%	0.71	0.01	0.00	0.00	0.00	0.00	0.00
Textiles		%	7.54	0.04	0.02	0.00	0.00	0.00	0.00
flow	**X03**	**t/yr**	12652.46	387.65	247.81	1247.43	4.89	0.00	945.18
Rest		%	66.70	0.00	0.00	0.00	0.00	0.00	0.00
P&C		%	7.25	100.00	0.00	0.00	0.00	0.00	0.00
Plastic		%	9.96	0.00	100.00	0.00	0.00	0.00	0.00
Glass		%	1.06	0.00	0.00	90.00	0.00	0.00	0.00
Metal		%	2.55	0.00	0.00	10.00	0.00	0.00	0.00
Food waste		%	0.88	0.00	0.00	0.00	100.00	0.00	100
Hazardous waste		%	1.11	0.00	0.00	0.00	0.00	0.00	0.00
WEEE		%	1.46	0.00	0.00	0.00	0.00	0.00	0.00
Textiles		%	9.03	0.00	0.00	0.00	0.00	0.00	0.00

In S3b perfect kerbside collection efficiency was assumed. To achieve this, the total generated waste amounts per waste type (flow X01) and associated waste composition of the residual and plastic bins are adjusted (figure below).

Table 39 - Inflows and fraction distributions, S3b, 2035

	Flow	Unit	RW	P&C	P	G&M	FW	Compost	G&P
flow	**X02**	**t/yr**	0.00	0.00	0.00	0.00	0.00	729.46	0.00
Rest		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P&C		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plastic		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glass		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Metal		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Food waste		%	0.00	0.00	0.00	0.00	0.00	100.00	0.00
Hazardous waste		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WEEE		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Textiles		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
flow	**X01**	**t/yr**	9160.25	8687.92	4521.89	2967.26	13660.44	0.00	0.00
Rest		%	85.92	2.78	0.45	0.28	3.92	0.00	0.00
P&C		%	0.00	97.16	0.00	0.00	0.00	0.00	0.00
Plastic		%	0.00	0.00	99.54	0.00	0.00	0.00	0.00
Glass		%	0.00	0.00	0.00	69.93	0.00	0.00	0.00
Metal		%	0.00	0.00	0.00	29.65	0.00	0.00	0.00
Food waste		%	0.00	0.00	0.00	0.00	96.08	0.00	0.00
Hazardous waste		%	1.09	0.02	0.00	0.14	0.00	0.00	0.00
WEEE		%	1.12	0.01	0.00	0.00	0.00	0.00	0.00
Textiles		%	11.87	0.03	0.02	0.00	0.00	0.00	0.00
flow	**X03**	**t/yr**	12652.46	387.65	247.81	1247.43	4.89	0.00	945.18
Rest		%	66.70	0.00	0.00	0.00	0.00	0.00	0.00
P&C		%	7.25	100.00	0.00	0.00	0.00	0.00	0.00
Plastic		%	9.96	0.00	100.00	0.00	0.00	0.00	0.00
Glass		%	1.06	0.00	0.00	90.00	0.00	0.00	0.00
Metal		%	2.55	0.00	0.00	10.00	0.00	0.00	0.00
Food waste		%	0.88	0.00	0.00	0.00	100.00	0.00	100
Hazardous waste		%	1.11	0.00	0.00	0.00	0.00	0.00	0.00
WEEE		%	1.46	0.00	0.00	0.00	0.00	0.00	0.00
Textiles		%	9.03	0.00	0.00	0.00	0.00	0.00	0.00

The regional distribution of X14 remains the same as in S1.

A.7.2. Material layer: Transfer coefficients (TCs), S3

Transfer coefficients remain the same as in S1.

A.7.3. Energy layer: Transport energy, S3

Due to increased collection efficiencies, source separated waste amounts will increase, while RW waste reduces. This changes transport energy intensities. Only transported waste amount changes all the other parameters remain the same as S1.

Hitra region (S3a;S3b)

S3a

Hitra region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Hitra	554.13	177.62	123.07	85.66	475.87	0.13	0.34	0.34	0.34	0.13
Frøya	569.48	182.54	126.48	88.03	489.05	0.12	0.33	0.33	0.33	0.12
Sum	1123.61	360.15	249.55	173.69	964.92	0.13	0.33	0.33	0.33	0.13

S3b

Hitra region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Hitra	351.98	202.95	157.09	111.52	582.95	0.12	0.16	0.18	0.18	0.14
Frøya	361.73	208.57	161.44	114.61	599.10	0.12	0.15	0.18	0.18	0.14
Sum	713.71	411.52	318.52	226.13	1182.05	0.12	0.16	0.18	0.18	0.14

Orkland region (S3a:S3b)

S3a

Orkland region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	739.20	570.56	166.43	97.89	543.80	0.10	0.16	0.16	0.16	0.10
Car 2	739.20	570.56	166.43	97.89	543.80	0.10	0.16	0.16	0.16	0.10
Car 3	739.20	570.56	166.43	97.89	543.80	0.10	0.16	0.16	0.16	0.10
Car 4	739.20	570.56	166.43	97.89	543.80	0.10	0.16	0.16	0.16	0.10
Car 5	739.20	570.56	166.43	97.89	543.80	0.10	0.16	0.16	0.16	0.10
Car 6	739.20	570.56	166.43	97.89	543.80	0.10	0.16	0.16	0.16	0.10
Sum/average	4435.19	3423.39	998.58	587.33	3262.83	0.10	0.16	0.16	0.16	0.10

S3b

Orkland region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	469.53	651.95	212.43	127.44	666.17	0.10	0.08	0.14	0.14	0.09
Car 2	469.53	651.95	212.43	127.44	666.17	0.10	0.08	0.14	0.14	0.09
Car 3	469.53	651.95	212.43	127.44	666.17	0.10	0.08	0.14	0.14	0.09
Car 4	469.53	651.95	212.43	127.44	666.17	0.10	0.08	0.14	0.14	0.09
Car 5	469.53	651.95	212.43	127.44	666.17	0.10	0.08	0.14	0.14	0.09
Car 6	469.53	651.95	212.43	127.44	666.17	0.10	0.08	0.14	0.14	0.09
Sum/average	2817.20	3911.68	1274.57	764.63	3997.03	0.10	0.08	0.14	0.14	0.09

Surnadal region (S3a;S3b)

S3a

Surnadal region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Surnadal	573.29	245.33	146.99	86.46	480.29	0.25	0.55	0.55	0.55	0.25
Car 1	286.64	122.66	73.50	43.23	240.15	0.25	0.55	0.55	0.55	0.25
Car 2	286.64	122.66	73.50	43.23	240.15	0.25	0.55	0.55	0.55	0.25
Tingvoll	480.70	134.41	80.53	47.37	97.30	0.23	0.50	0.50	0.50	0.23
Sum/average	1053.99	379.73	227.52	133.82	577.59	0.24	0.52	0.52	0.52	0.23

S3b

Surnadal region Car	Weight (t/yr)					Energy intensity (kWh/tkm)				
	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Surnadal	364.15	280.32	187.62	112.55	588.37	0.24	0.27	0.32	0.32	0.26
Car 1	182.07	140.16	93.81	56.28	294.18	0.24	0.27	0.32	0.32	0.26
Car 2	182.07	140.16	93.81	56.28	294.18	0.24	0.27	0.32	0.32	0.26
Tingvoll	305.34	153.58	102.79	61.67	119.19	0.22	0.37	0.29	0.29	0.29
Sum/average	669.49	433.89	290.41	174.22	707.56	0.23	0.32	0.31	0.31	0.27

Kristiansund_city region (S3a; S3b)

S3a

Kristiansund_city region Car	Weight (t/yr)					Energy intensity (kWh/tkm)				
	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	597.99	288.18	159.60	150.60	523.26	0.19	0.35	0.35	0.35	0.19
Car 2	597.99	288.18	159.60	150.60	523.26	0.19	0.35	0.35	0.35	0.19
Car 3	597.99	288.18	159.60	150.60	523.26	0.19	0.35	0.35	0.35	0.19
Car 4	597.99	288.18	159.60	150.60	523.26	0.19	0.35	0.35	0.35	0.19
Sum/average	2391.97	1152.72	638.38	602.38	2093.03	0.19	0.35	0.35	0.35	0.19

S3b

Kristiansund_city region Car	Weight (t/yr)					Energy intensity (kWh/tkm)				
	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	379.84	329.28	203.70	196.06	641.00	0.15	0.16	0.16	0.16	0.16
Car 2	379.84	329.28	203.70	196.06	641.00	0.15	0.16	0.16	0.16	0.16
Car 3	379.84	329.28	203.70	196.06	641.00	0.15	0.16	0.16	0.16	0.16
Car 4	379.84	329.28	203.70	196.06	641.00	0.15	0.16	0.16	0.16	0.16
Sum/average	1519.36	1317.14	814.82	784.23	2564.01	0.15	0.16	0.16	0.16	0.16

Kristiansund_rural region (S3a; S3b)

S3a

Kristiansund_rural region Car	Weight (t/yr)					Energy intensity (kWh/tkm)				
	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Aure	326.48	164.00	90.83	53.60	297.78	0.21	0.42	0.42	0.42	0.21
Averøya	558.02	280.31	155.24	91.62	508.97	0.12	0.25	0.25	0.25	0.12
Smøla	340.19	98.36	54.47	36.83	178.60	0.25	0.69	0.69	0.69	0.25
Sum/average	1224.68	542.68	300.54	182.05	985.36	0.20	0.45	0.45	0.45	0.20

S3b

Kristiansund_rural region Car	Weight (t/yr)					Energy intensity (kWh/tkm)				
	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Aure	207.38	187.39	115.93	69.78	364.79	0.20	0.21	0.26	0.26	0.21
Averøya	354.45	320.29	198.14	119.28	623.50	0.12	0.12	0.15	0.15	0.12
Smøla	216.09	112.39	69.53	47.95	218.79	0.24	0.35	0.41	0.41	0.30
Sum/average	777.91	620.08	383.60	237.01	1207.08	0.19	0.23	0.27	0.27	0.21

Oppdal region (S3a; S3b)

S3a

Oppdal region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Oppdal	1109.87	409.31	231.61	88.03	598.83	0.08	0.18	0.18	0.18	0.08
Sum/average	1109.87	409.31	231.61	88.03	598.83	0.08	0.18	0.18	0.18	0.08

S3b

Oppdal region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Oppdal	704.98	467.69	295.63	114.60	733.58	0.07	0.09	0.12	0.12	0.08
Sum/average	704.98	467.69	295.63	114.60	733.58	0.07	0.09	0.12	0.12	0.08

Sunndal region (S3a; S3b)

S3a

Sunndal region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Sunndal	592.46	286.32	171.86	132.97	563.45	0.11	0.22	0.22	0.22	0.11
Sum/average	592.46	286.32	171.86	132.97	563.45	0.11	0.22	0.22	0.22	0.11

S3b

Sunndal region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Sunndal	376.33	327.16	219.35	173.11	690.24	0.11	0.12	0.12	0.12	0.11
Sum/average	376.33	327.16	219.35	173.11	690.24	0.11	0.12	0.12	0.12	0.11

Melhus and Midtre Gauldal region (S3a;S3b)

S3a

Melhus+MG region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	414.91	174.85	120.78	63.16	350.86	0.17	0.37	0.37	0.37	0.17
Car 2	414.91	174.85	120.78	63.16	350.86	0.17	0.37	0.37	0.37	0.17
Car 3	414.91	174.85	120.78	63.16	350.86	0.17	0.37	0.37	0.37	0.17
Car 4	414.91	174.85	120.78	63.16	350.86	0.17	0.37	0.37	0.37	0.17
Car 5	414.91	174.85	120.78	63.16	350.86	0.17	0.37	0.37	0.37	0.17
Car 6	414.91	174.85	120.78	63.16	350.86	0.17	0.37	0.37	0.37	0.17
Sum/average	2489.43	1049.11	724.70	378.95	2105.18	0.17	0.37	0.37	0.37	0.17

S3b

Melhus+MG region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	263.55	199.79	154.16	82.22	429.82	0.16	0.19	0.20	0.20	0.18
Car 2	263.55	199.79	154.16	82.22	429.82	0.16	0.19	0.20	0.20	0.18
Car 3	263.55	199.79	154.16	82.22	429.82	0.16	0.19	0.20	0.20	0.18
Car 4	263.55	199.79	154.16	82.22	429.82	0.16	0.19	0.20	0.20	0.18
Car 5	263.55	199.79	154.16	82.22	429.82	0.16	0.19	0.20	0.20	0.18
Car 6	263.55	199.79	154.16	82.22	429.82	0.16	0.19	0.20	0.20	0.18
Sum/average	1581.27	1198.75	924.99	493.34	2578.89	0.16	0.19	0.20	0.20	0.18

Downstream transport distance and energy intensities

The downstream transport distances remain the same as in the Baseline. Central sorting changes the amount of waste transported between downstream processes. This has an influence on downstream transport energy intensities compared to the Baseline scenario (highlighted with orange).

Table 40 - Downstream transport model input parameters. S3a

	Distance (km)						Energy intensity (kWh/tkm)					
Flow	RW	P&C	P	G&M	FW	G&P	RW	P&C	P	G&M	FW	G&P
X35	0	140	140	600	0	0	0	0.427	0.273	0.273	0	0
X38	135.6	0	0	0	0	0	0.273	0	0	0	0	0
X45	0	140	140	600	0	0	0	0.273	0.273	0.273	0	0
X56	0	600	500	950	0	0	0	0.273	0.273	0.273	0	0
X68	0	0	50	0	0	0	0	0	0.273	0	0	0
X47	0	0	0	0	200	0	0	0	0	0	0.273	0
X48	135.6	0	0	0	0	0	0.273	0	0	0	0	0
X58	0	3	3	3	0	0	0	0.273	0.273	0.925	0	0
X78	0	0	0	0	102	0	0	0	0	0	0.273	0
X89	500	500	500	500	500	0	0.273	0.273	0.925	0.925	0.925	0
X910	50	50	50	50	50	0	0.273	0.273	0.925	0.925	0.925	0
X510	0	0	0	50	0	0	0	0	0	0.925	0	0
X911	50	50	50	0	0	0	0.427	0.925	0.925	0	0	0
X419	0	0	0	0	0	200	0	0	0	0	0	0.273

Table 41 - Downstream transport model input parameters. S3b

	Distance (km)						Energy intensity (kWh/tkm)					
Flow	RW	P&C	P	G&M	FW	G&P	RW	P&C	P	G&M	FW	G&P
X35	0	140	140	600	0	0	0	0.925	0.925	0.273	0	0
X38	135.6	0	0	0	0	0	0.273	0	0	0	0	0
X45	0	140	140	600	0	0	0	0.273	0.273	0.273	0	0
X56	0	600	500	950	0	0	0	0.273	0.273	0.273	0	0
X68	0	0	50	0	0	0	0	0	0.273	0	0	0
X47	0	0	0	0	200	0	0	0	0	0	0.273	0
X48	135.6	0	0	0	0	0	0.273	0	0	0	0	0
X58	0	3	3	3	0	0	0	0.273	0.273	0.925	0	0
X78	0	0	0	0	102	0	0	0	0	0	0.273	0
X89	500	500	500	500	500	0	0.273	0.273	0.925	0.925	0.925	0
X910	50	50	50	50	50	0	0.273	0.273	0.925	0.925	0.925	0
X510	0	0	0	50	0	0	0	0	0	0.925	0	0
X911	50	0	0	0	0	0	0.925	0	0	0	0	0
X419	0	0	0	0	0	200	0	0	0	0	0	0.273

A.8. S4: Perfect sorting and recycling 2035

A.8.1. Material layer: Flows, S4

In this scenario the collection system is identical to S1, including waste amounts, waste distribution and kerbside collection energy intensities. System boundary is the same as in S2b.

A.8.2. Material layer: Transfer coefficients (TCs), S4

The following TCs were changes to achieve perfect sorting and recycling.

Table 42 - Transfer coefficients (%)

TC (Sorting)	T56			T58			T96	T98	T90
Fractions	P&C	P	G&M	P&C	P	G&M	RW	RW	RW
Rest	0.00	0.00	0.00	100	100	100	0	100	0.00
P&C	100	0.00	0.00	0	100	100	100	0	0.00
Plastic	0.00	100	0.00	100	0	100	100	0	0.00
Glass	0.00	0.00	100	100	100	0	100	0	0.00
Metal	0.00	0.00	100	100	100	0	100	0	0.00
Food waste	0.00	0.00	0.00	100	100	100	0	82.11	17.89
Hazardous waste	0.00	0.00	0.00	100	100	100	0	100	0.00
WEEE	0.00	0.00	0.00	100	100	100	0	100	0.00
Textiles	0.00	0.00	0.00	100	100	100	0	100	0.00

Table 43 - Transfer coefficients (%)

TC (Treatment)	T612	T612	T612	T78
Fractions	P&C	P	G&M	FW
Rest	0	0	0	100
P&C	100	0	0	100
Plastic	0	100	0	100
Glass	0	0	100	100
Metal	0	0	100	100
Food waste	0	0	0	0
Hazardous waste	0	0	0	100
WEEE	0	0	0	100
Textiles	0	0	0	100

A.8.3. Energy layer: Transport energy, S4

Collection transport distances and energy intensities are the same as in S1. Only downstream transport energy intensities were changes.

Table 44 - Downstream transport model input parameters, S4

	Distance (km)						Energy intensity (kWh/tkm)						
Flow	RW	P&C	P	G&M	FW	G&P	RW	P&C	P	G&M	FW	G&P	Comment
X35	0	140	140	600	0	0	0	0.925	0.925	0.273	0	0	
X38	135.6	0	0	0	0	0	0.273	0	0	0	0	0	
X45	0	140	140	600	0	0	0	0.273	0.724	0.273	0	0	
X56	0	600	500	950	0	0	0	0.273	0.427	0.273	0	0	
X96	963	0	0	0	0	0	0.273	0	0	0	0	0	963km: Average of transporting recyclable fractions sorted out at CS to final recycling
X98	3	0	0	0	0	0	0.273	0	0	0	0	0	3km: The proposed CS facility will be located in close proximity to the incineration facility in Heimdal.
X47	0	0	0	0	200	0	0	0	0	0	0.273	0	
X49	135.6	0	0	0	0	0	0.273	0	0	0	0	0	Instead of incineration, RW is sent to CS which will locates close to Statkraft Varme, so the distance is the same.
X78	0	0	0	0	102	0	0	0	0	0	0.427	0	
X810	500	500	500	500	500	0	0.273	0.925	0.925	0.925	0.925	0	
X1011	50	50	50	50	50	0	0.273	0.925	0.925	0.925	0.925	0	
X1012	0	50	50	50	0	0	0	0.925	0.925	0.925	0	0	
X420	0	0	0	0	0	200	0	0	0	0	0	0.273	

A.9. S5: Preparing for recycling 2035

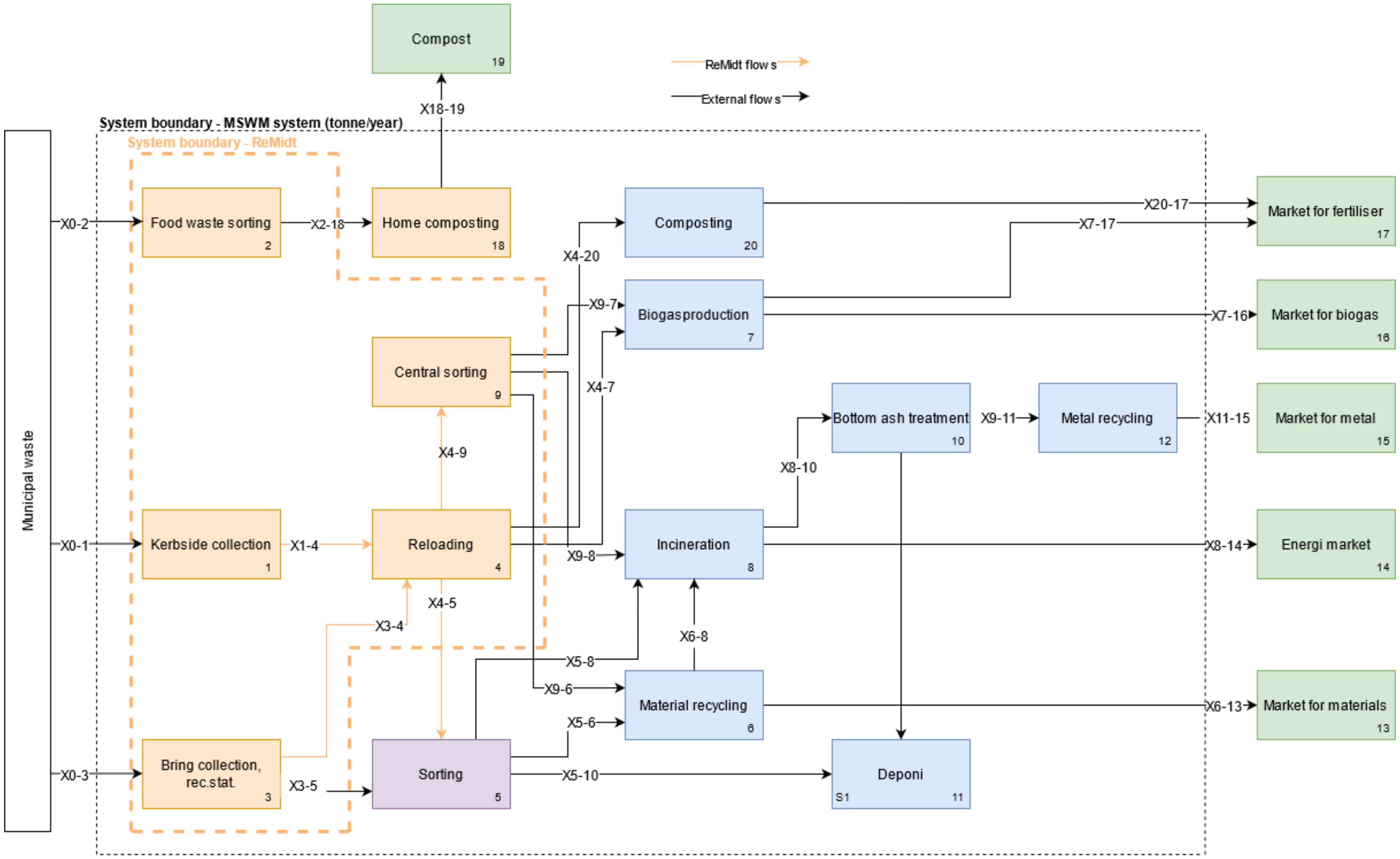


Figure 65 - Flowchart, S5

A.9.1. Material layer: Flows, S5

To achieve the 65% rate of preparing municipal waste for recycling the generated waste amounts and waste fractions distributions were change.

Table 45 - Inflows and fraction distributions, S5 2035

	Flow	Unit	RW	P&C	P	G&M	FW	Compost	G&P
flow	**X02**	**t/yr**	0.00	0.00	0.00	0.00	0.00	729.46	0.00
Rest		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P&C		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plastic		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glass		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Metal		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bio-waste		%	0.00	0.00	0.00	0.00	0.00	100.00	0.00
Hazardous waste		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WEEE		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Textiles		%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
flow	**X01**	**t/yr**	12774.31	7797.22	4100.28	2506.69	11819.27	0.00	0.00
Rest		%	61.61	3.10	0.49	0.33	4.53	0.00	0.00
P&C		%	7.59	95.83	0.00	0.00	0.00	0.00	0.00
Plastic		%	1.45	0.29	99.46	0.00	1.81	0.00	0.00
Glass		%	0.89	0.04	0.00	78.13	0.00	0.00	0.00
Metal		%	2.67	0.03	0.02	21.37	0.00	0.00	0.00
Bio-waste		%	15.69	0.66	0.00	0.00	93.65	0.00	0.00
Hazardous waste		%	0.78	0.02	0.00	0.17	0.00	0.00	0.00
WEEE		%	0.80	0.01	0.00	0.00	0.00	0.00	0.00
Textiles		%	8.51	0.04	0.02	0.00	0.00	0.00	0.00
flow	**X03**	**t/yr**	10827.09	754.57	1381.97	1516.04	60.56	0.00	945.18
Rest		%	77.95	0.00	0.00	0.00	0.00	0.00	0.00
P&C		%	5.08	100.00	0.00	0.00	0.00	0.00	0.00
Plastic		%	1.16	0.00	100.00	0.00	0.00	0.00	0.00
Glass		%	0.25	0.00	0.00	81.13	0.00	0.00	0.00
Metal		%	1.49	0.00	0.00	18.87	0.00	0.00	0.00
Bio-waste		%	0.51	0.00	0.00	0.00	100.00	0.00	100
Hazardous waste		%	1.30	0.00	0.00	0.00	0.00	0.00	0.00
WEEE		%	1.71	0.00	0.00	0.00	0.00	0.00	0.00
Textiles		%	10.55	0.00	0.00	0.00	0.00	0.00	0.00

A.9.2. Material layer: Transfer coefficients (TCs), S5

The following TCs were changes to achieve the minimum 60% target.

Table 46 - Transfer coefficients (%)

TC (Sorting)	T56		T58		T78		T717	T96	T98	T97	T613
Fractions	P&C	P	P&C	P	RW	FW	RW	RW	RW	RW	
Rest	0.00	0.00	100	100	0	0	0	30	70	0	0
P&C	70	0.00	30	100	0	0	0	70	30	0	0
Plastic	0.00	80	100	20	0	0	0	80	20	0	80
Glass	0.00	0.00	100	100	0	0	0	0	100	0	0
Metal	0.00	0.00	100	100	0	0	0	96.2	3.8	0	0
Bio-waste	0.00	0.00	100	100	10	10	28	0	52.11	30	0
Hazardous waste	0.00	0.00	100	100	0	0	0	0	100	0	0
WEEE	0.00	0.00	100	100	0	0	0	0	100	0	0
Textiles	0.00	0.00	100	100	0	0	0	0	100	0	0

A.9.3. Energy layer: Transport energy, S5

Due to increased collection efficiencies, source separated waste amounts will increase, while RW waste reduces. This changes transport energy intensities. Only transported waste amount changes all the other parameters remain the same as S1.

Hitra region (S5)

	2035									
Hitra region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Hitra	498.29	177.62	142.44	94.21	504.38	0.10	0.18	0.20	0.20	0.14
Frøya	512.10	182.54	146.39	96.82	518.35	0.10	0.18	0.20	0.20	0.14
Sum	1010.39	360.15	288.83	191.03	1022.73	0.10	0.18	0.20	0.20	0.14

Orkland region (S5)

	2035									
Orkland region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	664.72	570.56	192.62	107.66	576.38	0.08	0.09	0.16	0.16	0.09
Car 2	664.72	570.56	192.62	107.66	576.38	0.08	0.09	0.16	0.16	0.09
Car 3	664.72	570.56	192.62	107.66	576.38	0.08	0.09	0.16	0.16	0.09
Car 4	664.72	570.56	192.62	107.66	576.38	0.08	0.09	0.16	0.16	0.09
Car 5	664.72	570.56	192.62	107.66	576.38	0.08	0.09	0.16	0.16	0.09
Car 6	664.72	570.56	192.62	107.66	576.38	0.08	0.09	0.16	0.16	0.09
Sum/average	3988.30	3423.39	1155.73	645.95	3458.31	0.08	0.09	0.16	0.16	0.09

Surnadal region (S5)

	2035									
Surnadal region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Surnadal	515.52	245.33	170.13	95.08	509.07	0.20	0.31	0.36	0.36	0.26
Car 1	257.76	122.66	85.06	47.54	254.53	0.20	0.31	0.36	0.36	0.26
Car 2	257.76	122.66	85.06	47.54	254.53	0.20	0.31	0.36	0.36	0.26
Tingvoll	432.26	134.41	93.21	52.09	103.13	0.16	0.42	0.33	0.33	0.29
Sum/average	947.79	379.73	263.33	147.18	612.20	0.18	0.37	0.35	0.35	0.28

Kristiansund_city region (S5)

	2035									
Kristiansund_city region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	537.74	288.18	184.71	165.63	554.61	0.13	0.19	0.18	0.18	0.16
Car 2	537.74	288.18	184.71	165.63	554.61	0.13	0.19	0.18	0.18	0.16
Car 3	537.74	288.18	184.71	165.63	554.61	0.13	0.19	0.18	0.18	0.16
Car 4	537.74	288.18	184.71	165.63	554.61	0.13	0.19	0.18	0.18	0.16
Sum/average	2150.96	1152.72	738.85	662.50	2218.43	0.13	0.19	0.18	0.18	0.16

Kristiansund_rural region (S5)

2035

Kristiansund_rural region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Aure	293.58	164.00	105.12	58.95	315.62	0.17	0.24	0.29	0.29	0.21
Averøya	501.79	280.31	179.67	100.76	539.46	0.10	0.14	0.17	0.17	0.12
Smøla	305.91	98.36	63.05	40.50	189.30	0.20	0.41	0.47	0.47	0.30
Sum/average	1101.28	542.68	347.83	200.22	1044.39	0.16	0.26	0.31	0.31	0.21

Oppdal region (S5)

2035

Oppdal region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Oppdal	998.04	409.31	268.06	96.81	634.71	0.06	0.11	0.13	0.13	0.08
Sum/average	998.04	409.31	268.06	96.81	634.71	0.06	0.11	0.13	0.13	0.08

Sunndal region (S5)

2035

Sunndal region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Sunndal	532.77	286.32	198.90	146.24	597.21	0.09	0.13	0.14	0.14	0.11
Sum/average	532.77	286.32	198.90	146.24	597.21	0.09	0.13	0.14	0.14	0.11

Melhus and Midtre Gauldal region (S5)

2035

Melhus+MG region	Weight (t/yr)					Energy intensity (kWh/tkm)				
Car	RW	P&C	P	G&M	FW	RW	P&C	P	G&M	FW
Car 1	373.10	174.85	139.79	69.46	371.88	0.14	0.22	0.23	0.23	0.18
Car 2	373.10	174.85	139.79	69.46	371.88	0.14	0.22	0.23	0.23	0.18
Car 3	373.10	174.85	139.79	69.46	371.88	0.14	0.22	0.23	0.23	0.18
Car 4	373.10	174.85	139.79	69.46	371.88	0.14	0.22	0.23	0.23	0.18
Car 5	373.10	174.85	139.79	69.46	371.88	0.14	0.22	0.23	0.23	0.18
Car 6	373.10	174.85	139.79	69.46	371.88	0.14	0.22	0.23	0.23	0.18
Sum/average	2238.60	1049.11	838.75	416.77	2231.30	0.14	0.22	0.23	0.23	0.18

Downstream transport distance and energy intensities

The downstream transport distances remain the same as in the Baseline. Central sorting changes the amount of waste transported between downstream processes. This has an influence on downstream transport energy intensities compared to the Baseline scenario (highlighted with orange).

Table 47 - Downstream transport model input parameters, S5

	Distance (km)						Energy intensity (kWh/tkm)						
Flow	**RW**	**P&C**	**P**	**G&M**	**FW**	**G&P**	**RW**	**P&C**	**P**	**G&M**	**FW**	**G&P**	**Comment**
X35	0	140	140	600	0	0	0	0.427	0.273	0.273	0	0	
X38	135.6	0	0	0	0	0	0.273	0	0	0	0	0	
X45	0	140	140	600	0	0	0	0.273	0.273	0.273	0	0	
X56	0	600	500	950	0	0	0	0.273	0.273	0.273	0	0	
X96	0	3	3	3	0	0	0	0.273	0.273	0.925	0	0	
X98	963	0	0	0	0	0	0.273	0	0	0	0	0	
X47	200	0	0	0	0	0	0.273	0	0	0	0	0	200km: FW sorted from RW at CS in Heimdal to Verdal for biogas prod.
X49	3	0	0	0	0	0	0.273	0	0	0	0	0	
X78	0	0	50	0	0	0	0	0	0.273	0	0	0	
X810	0	0	0	0	200	0	0	0	0	0	0.273	0	
X1011	135.6	0	0	0	0	0	0.273	0	0	0	0	0	Instead of incineration, RW is sent to CS which will locates close to Statkraft Varme, so the distance is the same.
X1012	0	0	0	0	102	0	0	0	0	0	0.427	0	
X420	0	0	0	0	0	200	0	0	0	0	0	0.273	

A.10. Model inputs in all Scenarios

A.10.1. Energy layer: Process energy

Table 48 gives an overview of all the process energy intensities used in all scenarios.

Table 48 - Overview of energy intensities of the energy carriers used in model processes.

Process	Process name	Fraction	Source	kWh/tonne Electricity	Diesel	Natural gas	HFO	Propane	Light fuel oil	Biogas
5	Sorting	Plastic	Engan (2021)	16.98						
5	Sorting	Paper and Carboard	Engan (2021)	16.98						
5	Sorting	Glass and metal	Sandsdalen (2021)	17.00						34.44
6	Final recycling	Plastic	Ecoinvent 3.7.1: polyethylene production, high density, granulate, recycled (Europe)	489.00		76.67		0.03		
6	Final recycling	Paper and Carboard	EPD of all paper products, Norske Skog[33]	2944.00						
6	Final recycling	Glass and Metal	Calculations: Table 49	143.32	11.92	667.81	189.70	0.06		6
6	*Final recycling*	*Glass packaging*	*Ecoinvent 3.7.1: packaging glass production, green (Germany)*	*159.00*	*20.52*	*630.74*	*268.80*			
6	*Final recycling*	*Glass packaging*	*Ecoinvent 3.7.1: packaging glass production, white (Germany)*	*159.00*	*15.19*	*734.06*	*283.20*			
6	*Final recycling*	*Glass packaging*	*Ecoinvent 3.7.1: packaging glass production, brown (Germany)*	*159.00*	*16.69*	*721.27*	*279.60*			
6	Final recycling	Glass packaging (43%)	Average of the three different packaging glass production processes in Germany	159.00	17.47	695.36	277.20			
6	Final recycling	Glasopor (47%)	EPD: Glasopor production (Norway)[34]	120.52		779.32				
6	Final recycling	Aluminium (1%)	Ecoinvent 3.7.1: treatment of aluminium scrap, post-consumer, prepared for recycling, at remelter	133.00		858.33	29.72		3.36	
6	Final recycling	Steel (9%)	Turner et al. (2016): steel can production in Europe	347.00		38.38				
6	Final recycling	Residual waste	Assumption: same as plastic recycling	489.00		76.67		0.03		
6	Biological treatment	Food waste	Fløan (2020)	80						

---

[33] https://www.norskeskog.com/Responsibility/Environment/Paper-profile. Accessed: 21.05.2021

[34] https://www.glasopor.no/dokumentasjon/miljodokumentasjon/. Accessed: 21.05.2021

8	Incineration	Mixed municipal waste	Fossum (2021)	100		
10	Bottom ash treatment	Mixed municipal waste	Boesch et al. (2014): MSWI slag: scrap metal separation in Switzerland	3		
9 (in S2, S4, S5)	Central sorting	Mixed municipal waste	Callewaert (2017) : RoAF central sorting facility	43.00	2.00	7.00

Table 49 - Calculating average process energy requirement of recycling G&M waste

			kwh/tonne					Kwh					
X5-6 G&M 2020	%	**tonne**	**Electricity**	**Diesel**	**Natural gas**	**HFO**	**LFO**	**Electricity**	**Diesel**	**Natural gas**	**HFO**	**LFO**	
Glass	100 %	**1596.38**						**2.38E+05**	**2.09E+04**	**1.14E+06**	**3.32E+05**	**0.00E+00**	
Closed loop (DE)	75 %	1197.29	159.00	17.47	695.36	277.20		1.90E+05	2.09E+04	8.33E+05	3.32E+05	0.00E+00	
Open loop (NO)	25 %	399.10	120.52		779.32			4.81E+04	0.00E+00	3.11E+05	0.00E+00	0.00E+00	
Metal	100 %	**158.15**						**1.30E+04**	**0.00E+00**	**2.81E+04**	**9.40E+02**	**1.06E+02**	
Al (DE)	20 %	31.63	133.00		858.33	29.72	3.36	4.21E+03	0.00E+00	2.71E+04	9.40E+02	1.06E+02	
Steel (NO)	80 %	25.30	347.00		38.38			8.78E+03	0.00E+00	9.71E+02	0.00E+00	0.00E+00	
Sum		**1754.54**						**2.51E+05**	**2.09E+04**	**1.17E+06**	**3.33E+05**	**1.06E+02**	
								143.32	***11.92***	***667.81***	***189.70***	***0.06***	***Kwh/tonne***

A.10.2. Energy layer: Feedstock energy

Table 50 - Feedstock energy used in the model. LHV stands for lower heating value.

Fraction	*LHV MJ/tonne*	*LHV kWh/tonne*	*Source*
Rest	7650	2125	(Callewaert, 2017a)
P&C	6440	1788.8889	(Christensen, 2011)
Plastic	20144	5595.5556	
Glass	-73	-20.27778	
Metal	-147	-40.83333	
Hazardous waste	10500	2916.6667	(Haddeland, 2011)
WEEE	10500	2916.6667	(Haddeland, 2011)
Textiles	11789	3274.7222	(Christensen, 2011)
Food waste	1912	531.11111	(Christensen, 2011)

A.10.3. Emission layer: Generated emission

Table 51 – Generated emission during the incineration process[35].

Waste fraction	*Generated emission: Incineration (kg CO_2-eq/kg)*
Rest	0.50
P&C	0.05
Plastic	2.84
Glass	0.03
Metal	0.02
Food waste	0.03
Hazardous waste	1.43
WEEE	1.43
Textiles	0.15

Table 52 – Generated emission during recycling processes

Fraction	*Recycled product*	*Generated emission: Recycling (kg Co2-eq/kg)*	*Source*
Rest	Solid Refuse Fuel (SRF)	0.06	Assumption
P&C	Newsprint from virgin wood (close-loop)	0.37	Haupt, Kägi and Hellweg (2018)
Plastic	Plastic (closed-loop, PET)	0.67	Raadal et al (2009)
Glass	Glass closed-loop recycling: green glass packaging	0.35	Haupt, Kägi and Hellweg (2018)
Glass	Glass open-loop recycling: XPS foam glass insulation	0.13	Haupt, Kägi and Hellweg (2018)
Metal	Metal closed-loop: primary aluminium in aluminium can	1.11	Turner et al (2015)
Metal	Metal closed-loop: primary steel in steel can	0.53	Turner et al (2015)
Bio-waste	Bio-waste	0.06	Mepex and Østfoldforskning (2018)
Hazardous waste	Hazardous waste	-	
WEEE	WEEE	-	
Textiles	Textiles	-	

---

[35] Source: Raadal, H. L., Modahl, I. S. and Lyng, K. A. (2009)

Table 53 - Emission factors, energy carriers.

Energy carrier	*kg Co2-eq/kWh*	*Source*
Diesel (transport fuel)	0.26	Miljødirektoratet (2021)
Electricity (Norway)	0.02	NVE (2021)
Electricity (Germany)	0.47	Carbon Footprint (2019)
Diesel (machinery)	0.27	Miljødirektoratet (2021)
Natural gas	0.20	Miljødirektoratet (2021)
Propane	0.24	Miljødirektoratet (2021)
HFO (Heavy Fuel Oil/Fyringsolje/)	0.27	Miljødirektoratet (2021)
LFO (Light fuel oil)	0.20	UK Department for Business, Energy & Industrial Strategy (2020)
Biogas	0.196	Miljødirektoratet (2021)

A.10.4. Emission layer: Avoided emission

Table 54 shows the parameters used for calculating the avoided emission from incinerating municipal solid waste. Information on the energy mixed and the total energy consumption of the district heating system in Trondheim is based on data acquired from Statkraft Varme. Based on personal communication with Sissel Hunderi (2021), Senior environmental specialist at Statkraft Varme, 2020 was a relatively mind year in Norway. Therefore, way fewer fossil fuels were used to cover peak load heating demand during winter months. In this study it was assumed that the incineration of municipal solid waste substitutes for the use of 46.2% electricity, 45.5% LPG and 8.3% fuel types with biological origin.

Table 54 - Avoided emission from incinerating municipal solid waste, 2020

Energy mix, district heating (MWh)	**Production (kWh)**	**Division**	**kg CO2-eq/kwh**	**Alternative division**	**Alternative Prod (kwh)**	**Kg CO2-eq**
Waste	521650000	74.6 %		0.0 %	0	
Biogas	4550000	0.7 %	0.20	0.7 %	4550000	891800
Bio-boiler (Biokjel)	31800000	4.5 %		4.5 %	31800000	6232800
Bio-oil	7000000	1.0 %		1.0 %	7000000	1372000
Waste heat (Rockwool)	2600000	0.4 %		0.4 %	2600000	509600
Electric boilers	62000000	8.9 %	0.02	46.2 %	322825000	5488025
LNG	10500000	1.5 %	0.20	1.5 %	10500000	2121000
LPG	57200000	8.2 %	0.24	45.5 %	318025000	74735875
Oil boilers	2000000	0.3 %	0.27	0.3 %	2000000	532000
Sum	699300000	100.0 %		100.0 %	699300000	91883100

By dividing the total emission generated in the alternative scenario with the total amount of energy needed to operate the district heating in Trondheim in 2020, results show that 0.13 kg CO1-eq/kWh energy is generated by the system. Therefore, the incineration of municipal waste with heat energy recovery yields to -0.13 kg CO2-eq/kWh avoided emission. This is used for all the waste types in the system. This is used as an average estimate for all waste that was incinerated both at Statkraft and Tafjord in Ålesund. In addition, separate calculations were not made for waste that was incinerated abroad. This means that the same emission factors were used for the treatment of waste fractions in Norway and abroad.

Table 55 - Avoided emission factor for incinerating municipal solid waste.

Faction	*Avoided emission: Incineration*	*unit*
All fractions	-0.13	kg Co2-eq/kWh

Table 56 - Avoided emission factors for recycling municipal solid waste

Fraction	*Recycled product*	*Avoided emission: Recycling (kg CO_2-eq/kg)*	*Source*
Rest	Avoided diesel	-0.27 (kg CO_2-eq/kwh)	Assumption
P&C	Avoided virgin wood	-1.62	Haupt, Kägi and Hellweg (2018)
Plastic	Avoided primary PET	-1.78	Raadal et al (2009)
Glass	Avoided primary green glass packaging	-1.31	Haupt, Kägi and Hellweg (2018)
Glass	Avoided primary green glass packaging	-1.31	Haupt, Kägi and Hellweg (2018)
Metal	Avoided primary aluminium	-8.14	Turner et al (2015)
Metal	Avoided primary steel	-0.86	Turner et al (2015)
Food waste	Biogas: Avoided diesel	-0.27 (kg Co2-eq/kwh)	Raadal, H. L., Modahl, I. S. and Lyng, K. A. (2009)
Home compost	Compost	-3.06	Sørgard (2018)
Bio-waste	Avoided mineral fertiliser	-0.29	Mepex and Østfoldforskning (2018)

NTNU
Norwegian University of
Science and Technology

ReMidt