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Life cycle assessment of a mobile recycling centre in Gothenburg

Master's thesis in Industrial Ecology

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ABSTRACT

A great amount of waste is discarded every year in Gothenburg where the biggest fraction is bulky waste. One of the five recycling centres in Gothenburg is Högsbo recycling centre (RC). The recycling centre is located in the west part and manages the largest amount of waste of all the recycling centres in Gothenburg. Because of the high pressure on the recycling centre and the transport distances from the households to the stationary RC there is interest to implement a mobile RC. The aim of this master´s thesis is to examine if there is any change in environmental impact through the introduction of a mobile RC in the west districts of Gothenburg. The aim is met through a life cycle assessment, using the modelling program Gabi Professional 2017 Student version. The functional unit in the study is as follows: the average management of bulky waste produced by one of Gothenburg's citizens, living in the districts of Askim-Frölunda-Högsbo and west Gothenburg, during one year. The impact categories considered in the study are acidification, eutrophication and global warming.

Three scenarios are modelled, depending on various waste management methods. The first scenario, stationary RC, entails that there only is a stationary RC available in Askim-Frölunda-Högsbo and west Gothenburg. In the second scenario, implementing mobile RC, an assumed mobile RC is implemented, visiting seven various locations around the aforementioned districts five times during one year. In the latter aforementioned scenario, 10 percent of the citizens visit the mobile RC two times a year and 95 percent still visit the stationary RC. In the third scenario, mobile RC, 100 percent of the citizens visit the mobile RC two times a year. Furthermore, a system expansion is made to manage an assumed increase of reusable textile. In the system expansion, the second scenario in combination with the impact from textile is compared with the first scenario.

The study relies on several assumptions, but can be seen as an indication of the environmental impacts of implementing a mobile RC. The study implies that the environmental impact decreased in the implementing mobile RC- and mobile RC scenarios, even though the total average transport distance of waste increased in the mentioned scenarios because of the implementation of the mobile RC. In a more realistic scenario, implementing mobile RC, environmental impacts are only slightly lower than in the stationary RC scenario, were as the environmental impacts are clearly lower in the theoretical best-case scenario, mobile RC. The decrease in environmental impact is partly due to the shift in transportation mode from private cars to walking and biking. Also, the total transport distance by car is shorter in the implementing mobile RC- and mobile RC scenario compared to the stationary RC scenario, which reduces the environmental impact. However, the total transport distance with truck, powered by HVO, has increased, which implies that trucks are more environmental beneficial than cars in this study.

It can be concluded that the implementation of a mobile RC has a low environmental benefit if few citizens use it, as in the implementing mobile RC scenario. The environmental benefit of introducing a mobile RC is increased when more citizens use the recycling centre, as in the mobile RC scenario. Nevertheless, this is only valid in the case the citizens also decrease their visits to the stationary RC. However, the decrease in environmental impact is overestimated in the mobile RC scenario. The transport from the mobile RC to the stationary RC would have to increase because of limited storage capacity.

The study also shows that a collecting system that enables an increase in collected reusable textiles has a significantly high potential to reduce the environmental impacts studied. Other geographical areas and other assumptions on how the mobile RC is operated may change the results. Thus, the results are only valid under the specific conditions given in this report.

Key words: Life Cycle Assessment, waste management, mobile recycling centre, stationary RC, reuse of textiles.

Livscykelanalys av en mobil återvinningscentral i Göteborg.

Examensarbete inom mastersprogrammet Industrial Ekologi

THERESE HOLMGREN
Institutionen för energi och miljö
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SAMMANFATTNING

En stor mängd avfall kasseras varje år i Göteborg där den största delen består av grovavfall. Högsbo återvinningscentral är en av fem återvinningscentralerna i Göteborg. Återvinningscentralen ligger i de västra delarna och hanterar den största mängden avfall av alla återvinningscentraler i Göteborg. På grund av det höga trycket på återvinningscentralen och invånarnas transportavstånd till den stationära återvinningscentralen, är det av intresse att implementera en mobil återvinningscentral. Syftet med detta examensarbete är att undersöka om införandet av en mobil återvinningscentral i Göteborgs västra delar kommer medföra någon förändring gällande miljöpåverkan. Syftet nås genom en livscykelanalys, med modelleringsprogrammet GaBi Professional 2017 Student version. Den funktionella enheten i studien är: den genomsnittliga hanteringen av grovavfall som producerats av en av Göteborgs invånare, som bor i distrikten Askim-Frölunda-Högsbo och västra Göteborg, under ett år. De miljöpåverkanskategorier som betraktas i studien är försurning, övergödning och global uppvärmning.

Tre scenarier modelleras med avseende på olika avfallshanteringar. Det första scenariot, stationary RC, innebär att det enbart finns en stationär återvinningscentral tillgänglig för invånarna i västra Göteborg. I det andra scenariot, implementing mobile RC, är en antagen mobil återvinningscentral implementerad. Denna gästar sju olika platser runt de tidigare nämnda distrikten fem gånger under året. I det andra scenariot besöker 10 procent av medborgarna den mobila återvinningscentralen två gånger per år och 95 procent besöker den stationära återvinningscentralen. I det tredje scenariot, mobile RC, besöker 100 procent av invånarna den mobila återvinningscentralen två gånger på ett år. Utöver dessa tre scenarier görs en systemutvidgning för att hantera en antagen ökning av återanvändbar textil. Här jämförs det andra scenariot kombinerat med påverkan från textil mot det första scenariot.

Studien bygger på flera antaganden men kan ses som en vägledning mot ett beslut om huruvida man bör implementera en mobil RC eller inte. Studien visade att miljöpåverkan minskade i implementing mobile RC och mobile RC scenariot. Detta trots att det totala genomsnittliga transportavståndet för avfall ökade i de nämnda scenarierna på grund av implementeringen av den mobila återvinningscentralen. I det mer realistiska scenariot, implementing mobile RC, är miljöpåverkan något mindre än i scenariot stationary RC. Samtidigt är miljöpåverkan klart lägre i det teoretiska bästa fallet mobile RC. Minskningen av miljöpåverkan beror delvis på byte i transportmedel från privatbilar till promenader och cykling. Det totala transportavståndet med bil är kortare i implementing mobil RC- och mobil RC scenariot jämfört det stationära RC scenariot, vilket minskar miljöpåverkan. Vidare ökar det totala transportavståndet med lastbil, som drivs av HVO, vilket tyder på att lastbilarna är mer miljövänliga än bilarna i detta fall.

Slutsatsen är att implementeringen av en mobil återvinningscentral medför en låg miljöfördel om få invånare använder den, som i scenariot implementing mobile RC. Miljöfördelen av att införa en mobil återvinningscentral ökar ju fler invånare som använder återvinningscentralen, som i scenariot mobile RC. Hur som helst, slutsatsen gäller enbart om invånarna även minskar sina besök till den stationära återvinningscentralen. Minskningen i miljöpåverkan överskattad gällande scenariot mobile RC. Detta då transporten av den mobila återvinningscentralen till den stationära återvinningscentralen skulle behöva öka på grund av begränsad lagringskapacitet.

Studien visar att ett insamlingssystem som möjliggör en ökning av insamlade återanvändbara textilier har en signifikant hög potential att minska de studerade miljöeffekterna.
Andra antaganden om hur den mobila återvinningscentralen handhas samt geografiska skillnader kan leda till ett annat resultat. Således är rapportens resultat endast giltiga under de särskilda förhållandena som studeras i denna uppsats.

Nyckelord: Livscykelanalys, avfallshantering, mobil återvinningscentral, stationär återvinningscentral, återanvändning av textilier.

CONTENTS

Preface

This study was conducted during spring 2017 and was a part of the master program Industrial Ecology at Chalmers University of Technology, department of Energy and Environment and division of Environmental System Analysis.

I would like to thank those who have contributed with advice and opinions on this work. A special thanks to my supervisor David Palm, Senior Consultant in waste prevention, policy and life cycle assessment at Ramböll, for all the positive, pedagogic and supportive advices during the entire process of this study. Furthermore, I also want to thank the examiner of the thesis Maria Ljunggren Söderman, Environmental Systems Analysis, at Chalmers University of Technology, for her valuable inputs. The study relies on collected data and I would like to say an extra thank you to the process leader at the collection and treatment unit Waste Department at Kretslopp och vatten, Göteborgs Stad, for providing me with statistics and information about the waste management in Gothenburg. Also, a thank you to employees at Kretslopp och vatten, Renova, Stena recycling and Emmaus Björkå for your willingness to share statistics and expertise. Finally, I would like to thank my family for all the love and support.

Gothenburg June 2018
Therese Holmgren

Abbreviations

Bin waste – Included in the expression bin waste is the households trash bags, excluding food waste.

Bulky waste – Describes household waste that is too big to be accepted in the regular waste collection, for examples, furniture, frying pans and construction waste.

CH_4 – Methane

CO_2 – Carbon dioxide

CO – Carbon monoxide

Combustible waste – Is a mixture of various waste types which burns by their own power. The material can be crushed or torn.

LCA – Life Cycle Assessment

Mobile RC – Mobile recycling centre

N – Nitrogen organic bound

NH_3 – Ammonia

N_2O – Nitrous oxide

NO_3^- – Nitrate

NO – Nitrogen monoxide

PO_4^{3-} – Phosphate

SO_2 – Sulphur dioxide

SO – Sulphur oxide

Stationary RC – Stationary recycling centre

1 Introduction

Included in the introduction chapter are background, aim and research questions, delimitations and method used.

1.1 Background

Nowadays, environmental problems such as resource depletion, eutrophication, and global warming are a reality and it is known that the usage and consumption of raw materials affect the planet (Jackson and Jackson, 1996). In the waste sector, recyclable materials are too often discarded in the households' bin waste, which later goes to incineration instead of reuse or recycling (Avfall Sverige, 2016). However, a reduction of the negative environmental impact is possible and the waste sector has an opportunity to be an important part.

The modern waste management system emerged in the late 1900s focused on recycling and the environment. Waste separation of newspaper, glass and batteries started in the 80s. Sorting and collection of inter alia packaging started in the 90s when legislation regarding producer responsibility was introduced. (Baumann & Tillman, 2004; Renova, n.d.a)

Today the citizens of Sweden have multiple options when it comes to discard their waste. The alternatives available depend on the municipality. Examples of options in Gothenburg municipality are conventional recycling centres and stations, various deposit systems and municipal waste collection. (Göteborgs Stad, n.d.a) However, even though there are multiple disposal options, waste types such as textile-, electronic- and hazardous waste are sometimes discard in the household bin waste. (Kretslopp och vatten, n.d.a) A consequence may be that the materials end up on a lower waste hierarchy step than preferred, seen from an environmental point of view.

A large amount of waste is discarded every year in Gothenburg where the biggest fraction is bulky waste at nearly 50 percent (Kretslopp och vatten, n.d.a). It is important with a well-functioned waste collection system that also has a minimal impact on the environment. Conventional recycling centres can handle greater amount of bulky waste but are few and often located in industrial areas. This often means long transport distance for the citizens and going by car is required. The aforementioned together with the waste that is discarded in the household bin waste instead of being submitted to a recycling centre puts pressure on the environment.

A solution could be to implement a, so called, mobile recycling centre (RC). Bulky waste, textiles, electronics and hazardous waste could thereby be collected at various locations in the city, potentially decrease the transport needed. Furthermore, the increased availability may influence the amount of waste discarded in the bin waste. An increased number of municipalities in Sweden are investigating the possibility of more flexible recycling centre options (Dalek, 2016).

For the highly visited Högsbo recycling centre, located in the west part of Gothenburg, implementing a mobile RC could be a beneficial alternative. This is to decrease the pressure set on the stationary RC, which is running over its capacity. This is also to decrease the emissions from traffic related to the stationary RC.

1.2 Purpose and Research Questions

The aim of this master´s thesis is to examine if there is any change in environmental impact through the introduction of a mobile RC in the west districts of Gothenburg.

The following questions are stated to fulfil the aim;

- Is there any change regarding the environmental impact when a mobile RC is introduced?
- Which factors contributes the most to the change in environmental impact?

Stakeholders should be able to use the report for guidance and support when deciding if a mobile RC should be implemented. A possible stakeholder is the Administration of water and waste (Kretslopp och vatten), which handles questions regarding waste management in the municipality of Gothenburg. Another is Avfall Sverige, which is a Swedish Waste Management association. Since the study is site-specific it is not possible for other municipalities to directly use the result for themselves. However, the thesis can still work as a guide of which parameters that are of importance when consider implementing a mobile RC.

1.3 Delimitations

- The report focuses on the waste management situation in Sweden with focus on the west part of Gothenburg.
- Waste produced by households is considered, with focus on bulky waste.
- Life cycle assessment is used as method to fulfil the aim and answer the research questions.
- Economic and socioeconomics aspects are not considered in the study.

1.4 Method

In the following section the approach and strategy for the report is described. First, a literature study is made to better understand the subject. Further on, a life cycle assessment is conducted utilizing the modelling program GaBi. The life cycle assessment of a mobile RC is the core of the thesis, which intention is to answer the research questions and fulfil the aim. Data for the life cycle assessment is collected from literature, Thinkstep (2017), Ecoinvent (2017) and CPM (2017). Information conducted from interviews, meetings and email contact with people involved in the studied area is used in the life cycle assessment and the literature study.

1.4.1 Literature study

The literature study is conducted with the aim to obtain an understanding of the studied area, relate to previous work and to create a foundation for the life cycle assessment. The study includes information retrieved from scientific papers within waste management and information found on specific selected stakeholder's webpages. Keywords when searching are; Life Cycle Assessment, waste management, mobile RC, stationary RC and textiles.

1.4.2 Life cycle assessment

The traditional life cycle assessment is an attributional life cycle assessment with a consequential life cycle assessment added in order to show benefits of various waste management options. The method is similar to the approach in the EN 15804:2012 standard, where a module D is added, showing end of life benefits. The module D handles benefits and loads beyond the system boundary and is a way to manage reuse in a life cycle assessment.

Environmental impacts associated with a product or service are described in an attributional life cycle assessment, whereas a consequential assessment describes how relevant environmental flows are changed in response to alternative courses and actions. (Baumann & Tillman, 2004) In this study, attributional data is used, but to handle the avoided environmental impacts connected to reuse of textiles the attributional life cycle assessment transitions towards a consequential life cycle assessment.

According to ISO 14040:2006, the life cycle assessment procedure consists of four phases, which are displayed in figure 1. The first phase is goal and scope, where the investigated system is defined together with the study´s purpose. In the second phase, inventory analysis, a life cycle assessment model is constructed and the in- and outflows of natural resources, emissions and waste during the life cycle are calculated. In phase three, impact assessment, steps such as classification and characterization links the emissions and resources to various environmental problems. In the final phase, an interpretation of the results is done. (ISO 14040:2006)

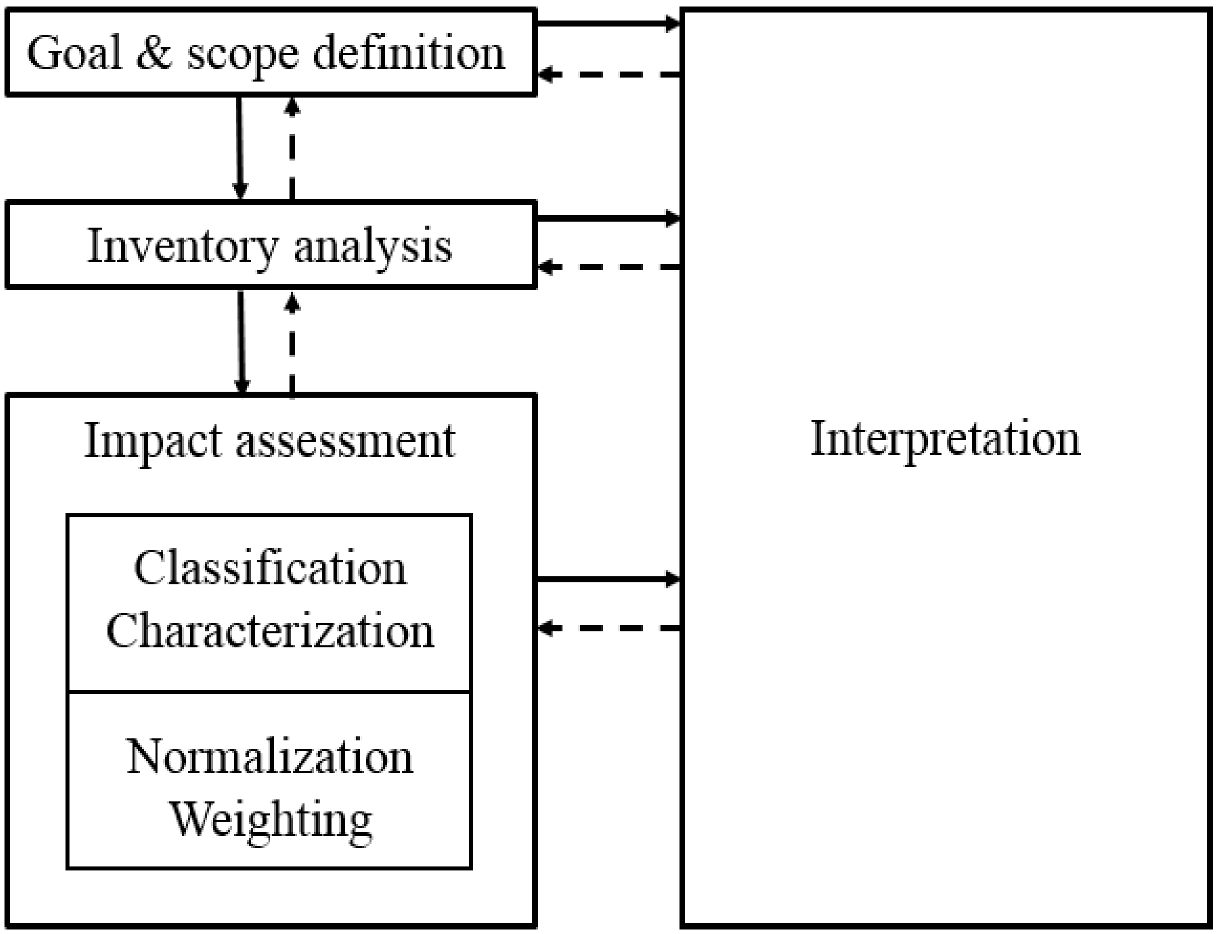

Figure 1. Life cycle assessment procedure. Based on ISO 14040:2006.

Goal and scope definition

In the goal and scope definition the life cycle assessment´s goal is determined, and from that the scope is stated. It is of high importance that this step is accurate since it is the foundation of the report. (ISO 14044:2006) The goal definition answers questions on what is studied, why is the study done, who is the intended audience that is to use the result and if the result is disclosed to the public. (ISO 14040:2006; ISO 14044:2006) In this thesis the goal definition is incorporated with the purpose and research questions (see section 1.2), whereas the scope is stated in section 3.1.

It is important that the scope meets the intended goal, and with a distinct scope, that guarantees breadth, depth and the level of detail of the study, this is possible. The scope includes the studied product system, the product system´s function, functional unit, the system boundaries, allocation procedures, method used in the life cycle impact assessment and the impacts considered. Also included are the interpretation method, assumptions and limitations. (ISO 14040:2006; ISO 14044:2006)

As information and data are collected, various parts of the scope may have to be altered to meet the intended goal. This makes the life cycle assessment study to an iterative method to use. (ISO 14040:2006)

Inventory analysis

Included in the inventory analysis, in accordance to ISO 14044:2006, are data collection and calculation procedures due to that relevant inputs and outputs of the investigated system need to be quantified. The study mainly retrieves input- and putout data from Thinkstep (2017) and Ecoinvent (2017). Moreover, input from industry and scientific publications are collected for foundation for the calculations.

The inventory analysis is, according to ISO 14040:2006, an iterative process in the sense that there, in general, are alterations after the impact assessment is conducted, which aligns with this study. Furthermore, alterations in the goal and scope were made during the inventory analysis process.

Life cycle impact assessment

A frequently used impact assessment method is applied in the study, called CML 2001. With the help of the results from the inventory analysis the environmental loads, from the studied system, are translated into environmental impacts. (Thinkstep, n.d.; ISO 14044:2006).

There are, according to ISO 14044:2006, three steps that need to be included in the impact assessment. The first step is to select which impact categories that are to be studied. Impacts considered in this study are acidification, eutrophication and global warming potential. Global warming is mainly caused by anthropogenic emissions of greenhouse gases, such as, CH_4, CO_2 and N_2O. All of which are emitted when burning fossil fuel. (Jackson and Jackson, 1996) This implies that transport and energy production are sources of greenhouse gases, which makes global warming potential to a key factor to include in the study. Also connected to the burning of fossil fuel are NO, NH_3 and SO, which are the main contributors to acidification in air, soil and water. (Jackson and Jackson, 1996) The aforementioned is the reason for including the environmental impact category acidification potential in the impact assessment. The NO_x from the burning of fossil fuel are also a reason for eutrophication (Selman and Greenhalgh, 2009), which is included as an environmental impact category.

Distributing the results from the inventory analysis over the selected impact categories is called classification and is the second step in the impact assessment. The category indicator results are calculated in the final mandatory step of the impact assessment, called characterisation. (ISO 14044:2006)

Besides the mandatory steps in an impact assessment there are four parts that are optional. These are, normalization, grouping, weighting and analyse the data quality. The normalization step provides an idea of an environmental impact's magnitude, while grouping sorts and ranks the impact categories. Weighting uses numerical factors based on value-choices to convert and likely aggregate indicator results across impact categories. (ISO14044: 2006) Normalization, grouping and weighting are not included in the study. The fourth step, analysing data quality, uses three different techniques when analysing. The techniques are gravity analysis, uncertainty analysis and sensitivity analysis. The study includes gravity analysis and sensitivity analysis. The gravity analysis detects the most polluting activities in the life cycle. How the results can be affected by data and mythological changes is evaluated in the sensitivity analysis (section 5.3.3.1).

Life cycle interpretation

The life cycle interpretation phase intention is to make the study understandable for parties in interest. The findings from the inventory analysis and impact assessment have been compared in order to draw the conclusions of this study. (ISO14044:2006) It is of high importance that the results, as far as possible, are clear and concise and cannot be misinterpreted by the average reader.

2 EU directive concerning waste management

As a member state in the European Union (EU), Sweden is obligated to implement the directives the union agrees upon. The EU waste framework directive is of high importance, because it states how the Member States should manage their waste (European Commission, 2008). According to reason 28 in European Commission (2008), the directive intends to help the EU strive towards a recycling society where waste-generation is avoided and waste is used as a resource. Action ought to be taken to ensure sorting, collection and recycling of priority waste flows. Considerations regarding if it is technically, environmentally and economically feasible may be taken. (European Commission, 2008)

To forestall, minimizing and, if possible, eliminate the sources of pollution or nuisances it is up to inter alia the Members States to establish a framework regarding waste. (European Commission, 2008) When doing so the Member States should, according to article 4 European Commission (2008), include the waste hierarchy, see figure 2, which displays how to prioritize the various waste management options in priority order.

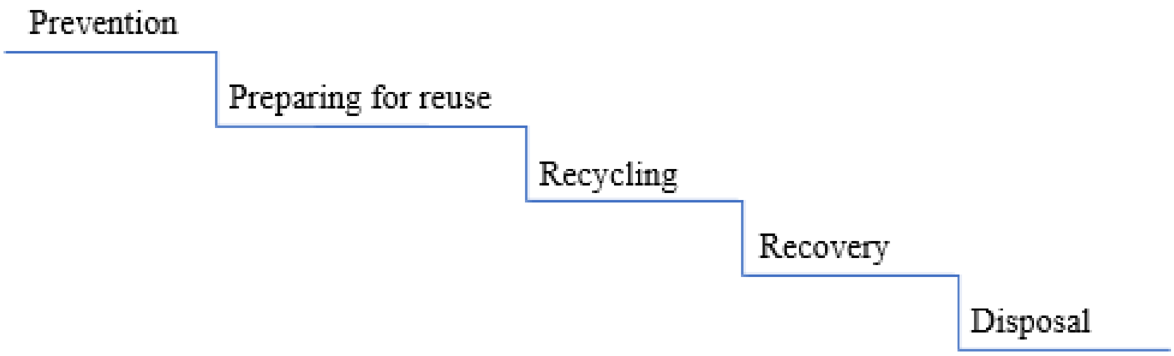

Figure 2. The waste hierarchy displaying five different waste management options in the order of most preferred alternative, starting from the top left. (based on European commission (2008))

It is stated in 83§ waste ordinances, EU, that the Swedish Environmental Protection Agency's task it to ensure a national waste plan and a waste reducing program that fulfil the requirements set in the reasons 28-30 (European Commission, 2008). The current waste plan and waste reducing program are valid till December 2017. The Swedish Environmental Protection Agency is working on a revised plan and program that is valid between 2018 and 2023. (Naturvårdsverket, 2017)

3 Waste management in Gothenburg

Municipalities in Sweden are responsible for disposal and reuse of household waste. (15 kap. 20 § miljöbalken) Gothenburg municipality has established a waste management plan (in accordance with European Commission (2008)), which describes how the waste management system in Gothenburg operates. Collecting, sorting and treatment are covered in the waste management plan.

3.1 Recycling installations in Gothenburg

There are alternatives regarding recycling installations in Gothenburg for residential waste. The selectable alternatives in Gothenburg are presented in this section of the report with an addition of the proposed mobile RC, which has been introduced in other municipalities in Sweden.

Stationary RC

The five manned recycling centres, shown in the map in figure 3 below, Bulycke, Tagene, Sävenäs, Högsbo and Alelyckan are stationed in various areas in Gothenburg. The recycling centres hold several containers for various waste types, which are;

- asbestos (only possible to deposit at Tagene recycling centre);
- combustible garden waste;
- corrugated paper;
- electronic waste;
- filling material;
- fine combustible waste;
- furniture with steel springs;
- gypsum;
- hazardous waste;
- metal;
- non-combustible household waste;
- painted wood;
- pressure treated wood;
- tires, with rim;
- tires, without rim and
- twigs and branches.

The recycling park Alelyckan is somewhat different than the other four recycling centres, as it gives visitors the opportunity to leave their usable waste in a sorting station located before the actual recycling centre. The usable items are then given to various social work organizations. (Renova, n.d.) This also applies to the other recycling centres, but in a much smaller extent.

Present at all the recycling centres are bins owned by social work organizations, collecting used textiles. At Högsbo recycling centre, Human Bridge took over the textile collection from Emmaus Björkå in the fall 2016.[1] In addition to the waste types presented in table 1, it is possible to leave packaging, batteries and other waste types (see Recycling station below) included by extended producer responsibility systems at the recycling centres.

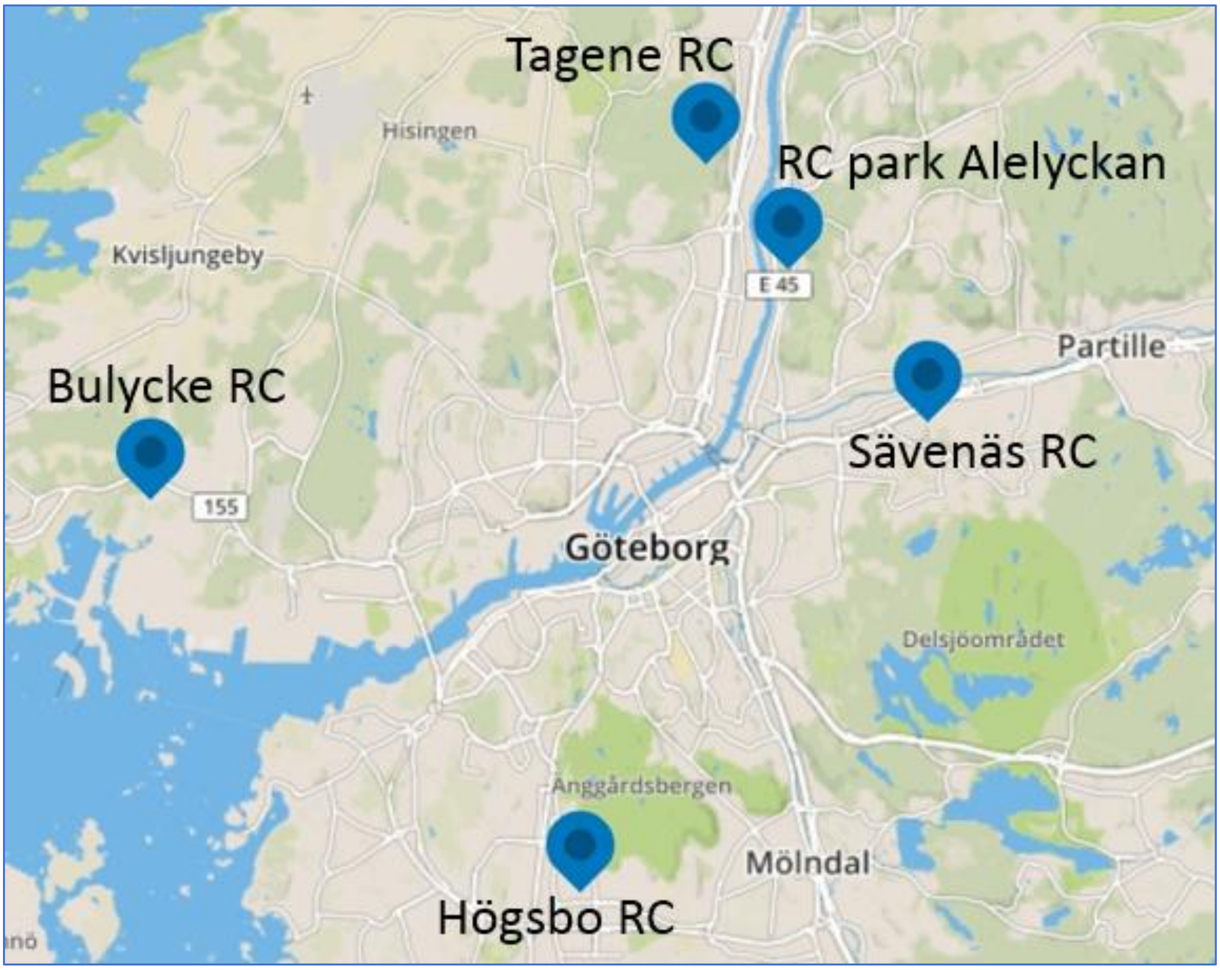

Figure 3. The map shows where the recycling centres (RC) belonging to the municipality of Gothenburg are located. (OpenStreetMaps, 2017)

Högsbo RC

Högsbo recycling centre manage the largest amount of Gothenburg's household's bulky waste, over 40 percent 2016. In high season the recycling centre handles up to 7000 visitors, which causes traffic queues. Furthermore, the queues cause idling that contribute with emissions to air. (Höglund, 2014; Tjulander, 2017) A mobile RC may be a solution to move traffic from the stationary centre and thereby decrease the queues and associated emissions.

[1] Informant 1 (Collecting and Sustainability Manager, Emmaus Björkå) e-mail 28 March 2017.

Recycling station

The Swedish municipalities are responsible for the recycling and the disposal of household waste. However, this does not include the waste that falls under the extended producer responsibilities, which are packaging, waste paper, tires, cars, batteries, electrical- and electronic waste and pharmaceuticals from households. Some exceptions may occur, such as, packaging, waste paper, batteries and electronic waste that are not returned at the producers own collecting system. These then fall under the municipalities' obligation. (Sopor.nu, n.d)

There are, according to Kretslopp och vatten (n.d.d), approximately 330 recycling stations in Gothenburg. Following waste types are received at the recycling stations:

- newspapers;
- paper packaging products (including corrugated);
- plastic packaging (hard and soft);
- metal packaging;
- colourless glass packaging;
- coloured glass packaging;
- batteries.

Förpacknings- och Tidningsinsamlingen is a company that, on behalf of newspaper producers, manages the recycling stations and are responsible for emptying the containers, transport the waste to the right treatment facilities and keeps the stations clean. (Fti, n.d.) The battery box however, falls under the company El-Kretsen´s obligation. (El-Kretsen, n.d.) At the recycling stations a bin intended for textiles may be present, exhibited by, for examples, Emmaus Björkå or Human Bridge.

Eco-station

Located at service stations and marinas are the eco-station that receive hazardous waste such as fuels and oils, paints and adhesive residues, lighter fluid and solvents etcetera. The hazardous waste is kept in a locked container on the gas station and in a shed on the marinas. There are in total 18 eco-stations in Gothenburg. (Kretslopp och vatten, n.d.c)

Mobile hazardous waste collection

Electronic- and hazardous waste, such as batteries and corrosive substances, and smaller electronical- and electronic products are examples of waste types collected at the mobile hazardous waste collector. (Kretslopp och vatten, n.d.b)

The mobile hazardous waste collector follows a time and location schedule. The tour goes through Gothenburg´s centre, Hisingen, west of-, east of- and northeast of Gothenburg between the months April to June and September to November. Following the collector's schedule, is a truck owned by the charity organization Emmaus which collects items for reuse. (Kretslopp och vatten, n.d.b)

Samlaren

Samlaren receives waste types such as lighting bulbs including LED, fluorescent and incandescent. Also, smaller batteries, spray cans, fluorescent and small electronic devices are handled by Samlaren. Samlaren is stationed in several larger stores in Gothenburg and is a special made security cabinet that handle hazardous waste. (Kretslopp och vatten, n.d.e)

Mobile RC

There are municipalities in Sweden that have implemented mobile RCs. The recycling centre is, as the name implies, mobile and usually moved to various locations within a municipality. The company SÖRAB operates in several municipalities in the Stockholm region with one set of a mobile RC. The mobile RC has designated containers for various waste types. Private individuals can leave mostly the same waste types as at a stationary RC, with some exceptions varying between the municipalities. (Miva, 2017; Nyköping kommun, 2017; SÖRAB, n.d.)

Gothenburg does not have a mobile RC. However, there is an ongoing pilot project in the Gothenburg region that aims to obtain practical experience to support future decision making regarding a mobile RC. (Dalek, 2016) The pilot project is carried out in four municipalities; Ale, Härryda, Kungälv and Mölndal. The mobile RC is active two to three days per municipality and stationed at different locations every day, with an exception of Kungälv where it is active in only one area. Three containers are used and are in the sizes 12, 16 and 25 m^3. The mobile RC is also accompanied by a mobile hazardous waste collector.[2]

It has been concluded that citizens use an operating mobile RC. However, it has been challenging for several municipalities, including the pilot project, to draw any conclusion regarding changes in amount collected waste.[3] What can be concluded is that most of the collected waste sooner or later would have ended up at the stationary RCs if there were no operating mobile RC. There is a chance that collected quantities of some waste types, now discarded in the bin waste, would increase if a mobile RC is implemented. However, there is no conclusive evidence for this statement.[4]

[2] Informant 2 (Business development, Renova AB) e-mail 24 March 2017.

[3] Informant 3 (Collecting Manager, SÖRAB) e-mail 20 March 2017.

[4] Informant 2 (Business development, Renova AB) e-mail 24 March 2017.

4 Similar research

Studies regarding mobile RCs are difficult to come across, which implies that it is a relatively new concept and that it may not be a commonly used waste collecting system. However, several municipalities across Sweden already have implemented some sort of mobile RC or intend to do so in a near future. (Miva, 2017; SÖRAB, n.d.) The aforementioned implies that it is a preferable addition to a municipalities waste management system. A common argument for implementing a mobile RC is the expected increase in service assigned the citizens in the municipality. The municipality of Nyköping state that through actions such as increased availability for the citizens to discard waste via a mobile RC it is possible to restrict the environmental impact from transport connected to the waste management system. The environmental impact is restricted due to shorter transport distance made by the citizens when discard waste. (Nyköping, 2017)

A relatively old study made by Baky et al. (2000) investigated, with the help of the simulation software ORWARE (ORganic WAste REsearch), various waste management systems´ environmental impacts and resource use in the municipalities Falun and Borlänge. Baky et al. (2000) developed four scenarios, one of which was the current waste management state. In the second scenario, the amount of recycling stations was increased and in the fourth scenario the recycling stations were replaced with retrieval at the households. Environmental impacts to be studied were global warming potentials, acidification and eutrophication. No major differences regarding environmental impact connected to the transport in any of the mentioned scenarios where detected. Also, there was a larger environmental impact from the collection of waste than from the long-range transport. However, the study showed that the transport over all had a minor impact on the result in comparison to combustion of waste. (Baky et al., 2000)

A study made by Ljunggren Söderman et.al. (2011) on the Alelyckan Recycling Park showed that an increased availability for reuse in the waste management system can lead to prevention of various waste types. It was concluded that textile, furniture and building products where the major waste types that where prevented. The study, also showed that textile was the waste type that contributed the most to a lower environmental impact when reused instead of material- or energy recovered or landfilled. It was also, in a study by Tekie et al. (2013), concluded that collection of textiles suitable for reuse is largely beneficial.

A study made by Tekie et.al. (2013), with backing of Palm (2011), states that it is the production of textile that has a significant environmental impact, not the waste management of textiles. By reusing textile waste there is an opportunity to a more resource-efficient waste management system (Tekie et al., 2013).

The most crucial factors for citizens to submit textiles for reuse are the easy access and vicinity to collecting systems (Mueller, 2013; Joung, 2013). An increase in number of collection bins does, according to Tekie et al. (2013), result in an increased collection of textiles. Also, it is stated in the report A Nordic textile strategy, Part II by Palm et al. (2014) that due to increased availability of textile collection points, collection has become more attractive for Nordic citizens.

5 Life cycle assessment

The life cycle assessment follows the steps in the ISO standard 14040:2006). First the scope is presented, followed by an inventory analysis, impact assessment and finally interpretation of the result. The goal is incorporated with the aim and research questions in section 1.2. Briefly, the goal of the report is to answer if there is any change regarding the environmental impact when introduction a mobile RC and which factors that most significantly contribute to the change in environmental impact.

5.1 Scope

The scope of this study is defined by the functional unit, the system boundaries and delimitations.

5.1.1 Functional unit

The life cycle assessment's functional unit is the average management of bulky waste produced by one of Gothenburg's citizens, living in the districts Askim-Frölunda-Högsbo and west Gothenburg, during one year.

5.1.2 System boundaries

The studied system begins at the household, where waste is produced, and ends at the transport to the end-of-life treatment facilities. However, waste management is included regarding textiles due to an anticipated change of treatment method. The change implies that textiles discarded in the bin waste are reused instead. The study is based on current available waste management systems. Consideration regarding future increase or decrease of waste flows, transport or population growth is not taken.

Data for waste types and waste flows are obtained locally from Gothenburg, data concerning ambient systems, incineration and district heating, are collected locally, regionally and nationally. Data regarding vehicles are collected from Thinkstep (2017) and are based on EU-27 member countries. Lastly, energy production and transport connected to textile production are based on Chinese datasets obtained from Thinkstep (2017).

Personnel-related environmental impact is not included in the report. Neither are capital goods such as buildings, machinery, vehicles, and infrastructure.

The reuse of textiles is handled by system expansion. The same goes for district heating and electricity connected to the mentioned waste type. The end-of-life treatment considered for textiles are reuse and incineration.

The impact categories considered are acidification, eutrophication and global warming. The study's focus is on the environmental aspects of introducing a mobile RC, compared to a stationary RC. Waste types included in the study are corrugated cardboard, combustible waste, electronic waste, hazardous waste, garden waste, non-combustible waste, scrap-metal, textiles and twigs and branches. Visitors at Högsbo recycling centre are assumed to reside in the districts Askim-Frölunda-Högsbo and west Gothenburg.

5.2 Inventory Analysis

Data collection, modelling and the result of the inventory analysis are presented in following chapter. The student version of the life cycle assessment software GaBi Professional 2017 Database was used for the modelling and calculations. The data collected is as accurate as possible and are based on literature, software data and assumptions when lacking site-specific data. Alteration of data is made to match the studied case.

Flowcharts of the analysed systems are developed and presented in figure 5, 6 and 7. The flowcharts display the activities and the flows connected to them. For a more detailed flowchart see appendix C. Extraction of raw materials, production, distribution and use phase are not included in the system boundary, considering it is assumed that it would derive the exact same result regardless if the mobile RC is implemented or not. The aforementioned applies because the generated waste quantities are constant. An exception is made regarding textile waste, where the generated waste quantity differs, which is handled in a system expansion (figure 8).

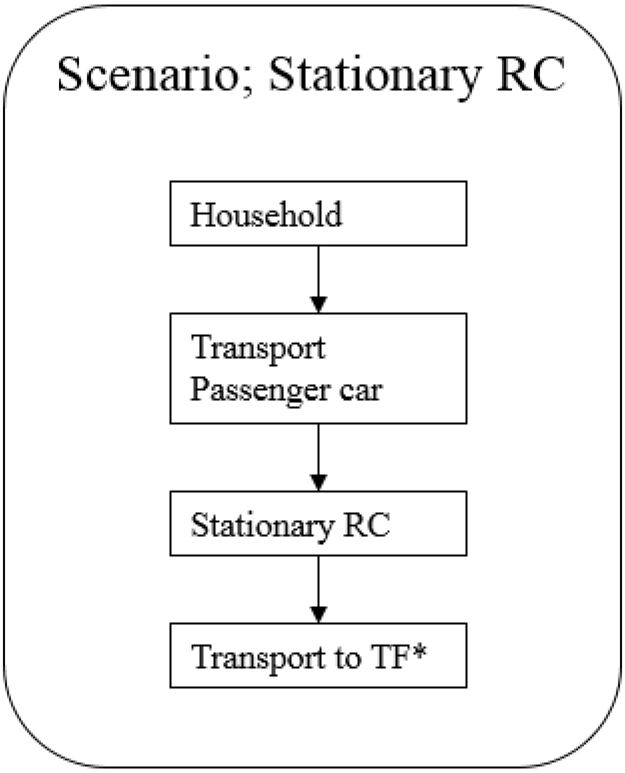

Figure 5. Simplified flowchart over the scenario when no mobile RC is implemented.

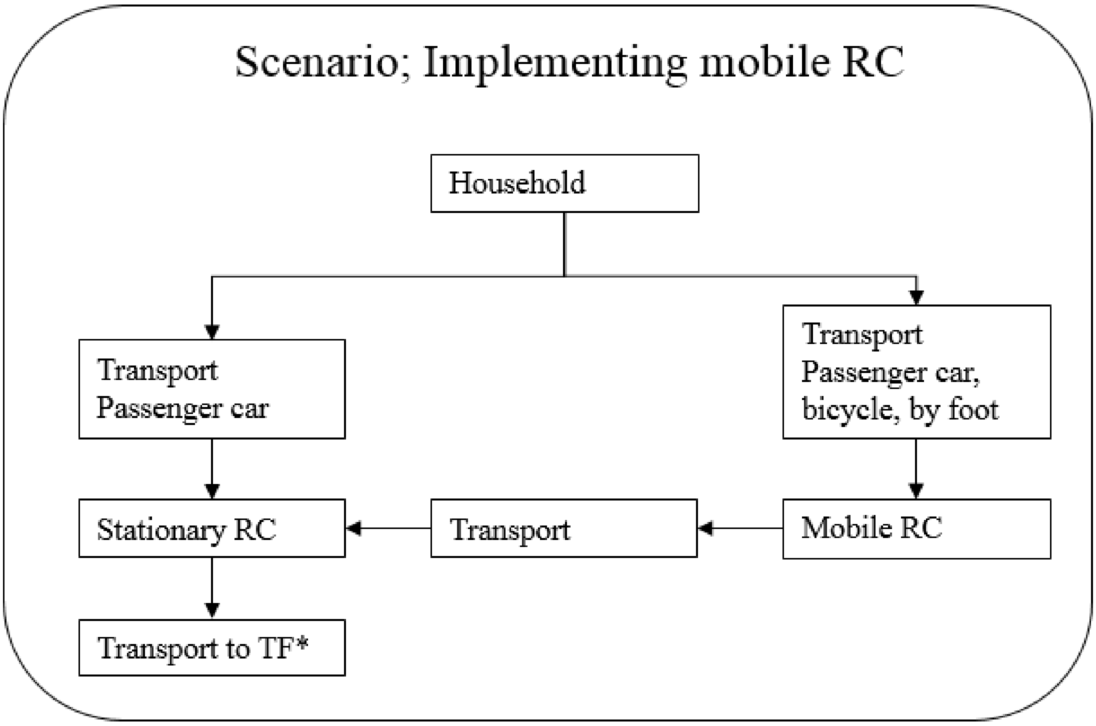

Figure 6. Simplified flowchart over the scenario when a mobile RC is implemented.

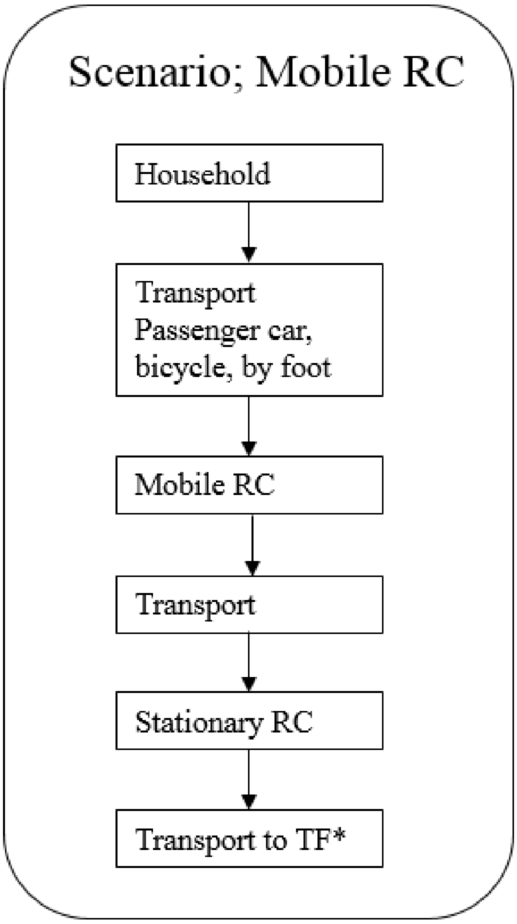

Figure 7. Simplified flowchart over the scenario when a mobile RC is implemented and 100 percent of the citizens in Askim-Frölunda-Högsbo and west Gothenburg uses the mobile RC.

**Treatment Facility*

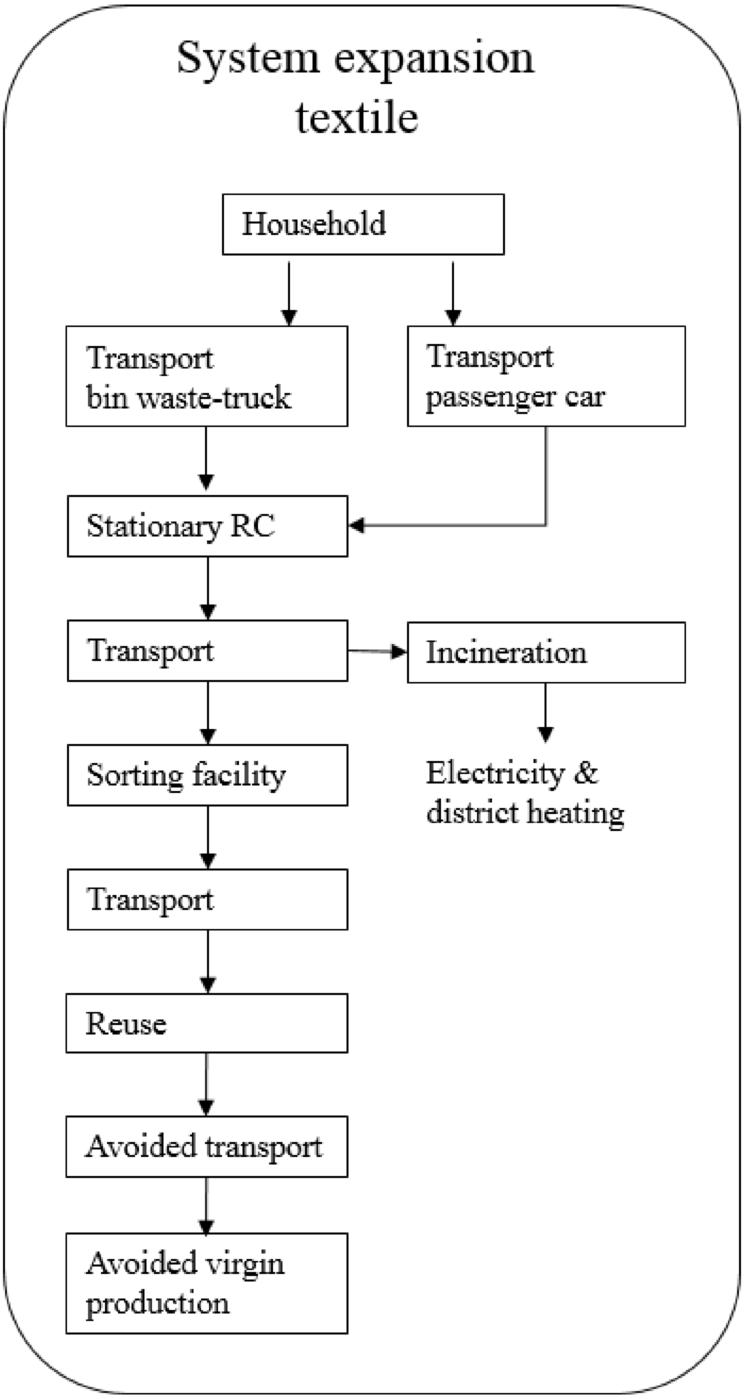

Figure 8. Simplified flowchart over the system expansion of textile.

5.2.1 Studied districts in Gothenburg

The districts of interest are west Gothenburg together with Askim-Frölunda-Högsbo, maps are found in appendix A. Further in this report, Askim-Frölunda-Högsbo is included in the term west Gothenburg. The primary area Styrsö is not included in the study because the area has its own way of collecting bulky waste. (Göteborgs Stad, n.d.c)

5.2.2 Mobile RC

The studied mobile RC consists of one van collecting electronic- and hazardous waste, a demountable truck with trailer that carry a total of three containers, size 34 m^3, to discard bulky waste. Furthermore, a smaller bin or bag for collecting textiles is included in the mobile RC. The aforementioned components are a combination that is used in several other municipalities that have implemented a mobile RC (SÖRAB, n.d.).

The mobile RC departures from Högsbo recycling centre, Västra Frölunda, where it also is stored when not in use. The recycling centre stops at seven locations, see figure 9, five times a year. The numbering in figure 9 represents a possible order for the mobile RC to visit the various stops. The locations are selected based on following requirements:

- the locations are in west Gothenburg;
- the locations are spread out from each other;
- the locations are near densely populated areas;
- it is possible to easily access the locations by truck, car, bike and by foot;
- there is room for the mobile RC and
- it is possible for visitors by car to enter and exit the locations without disturbing other visitors or nearby residents.

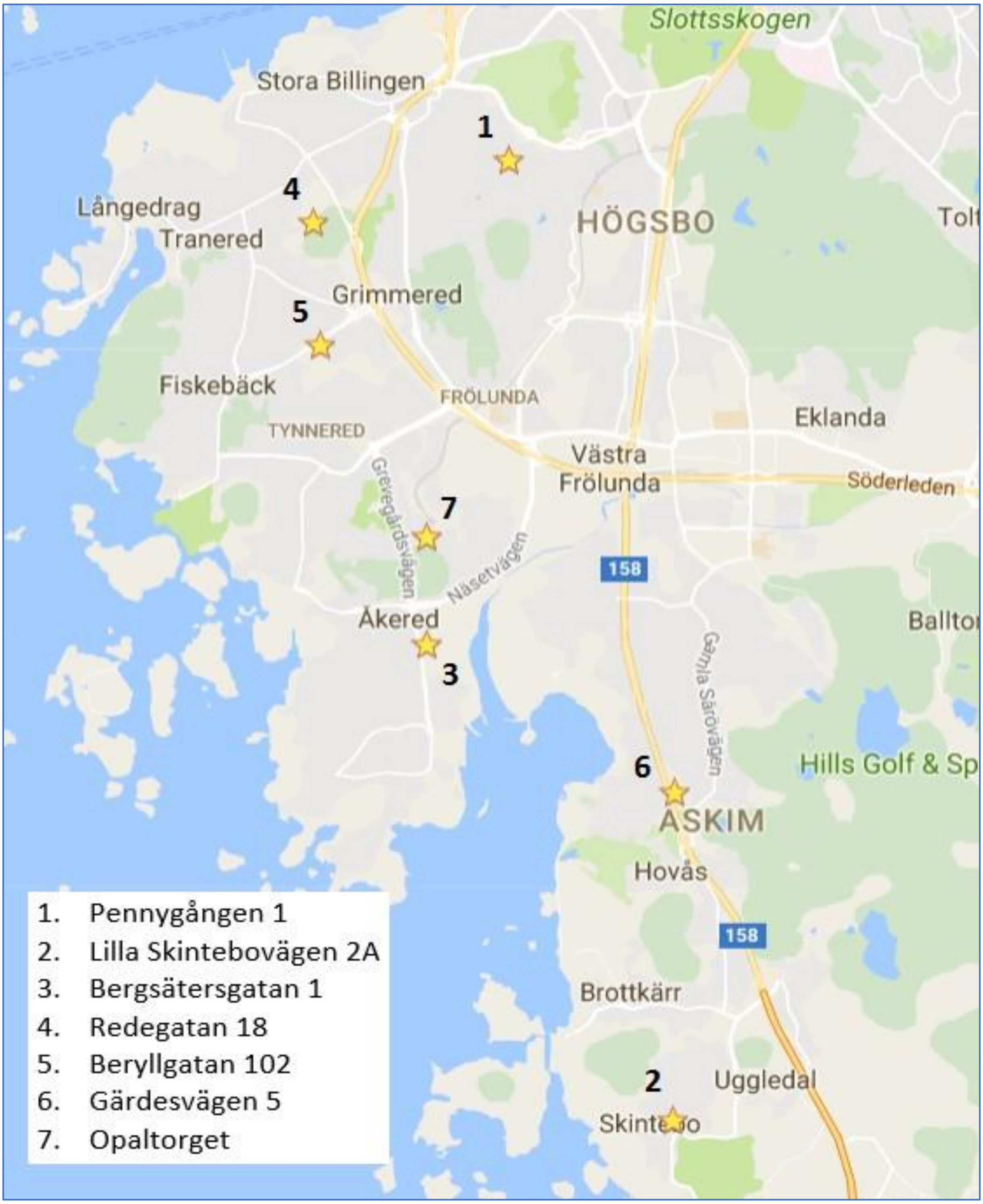

Figure 9. A map of west Gothenburg with the locations for the mobile RC's stops marked out with a star. The addresses connected to the locations are showed in the white box in the left side corner. The numbering represents a possible order for the mobile RC to visit the various stops. (Based on google maps)

It is not possible to discard all waste types normally discarded at a stationary RC at a mobile RC due to limitation in capacity. The waste types possible to leave at the mobile RC are based on commonly used fractions in existing mobile RCs in Sweden. Also, the waste types are adapted after which fractions the citizens in west Gothenburg discards at Högsbo RC. Following waste types are possible to discard at the mobile RC:

- Combustible waste, small and large;
- non-combustible waste;
- corrugated cardboard;
- textiles;
- electronic- and hazardous waste;
- metal;
- garden waste, and
- twigs and branches.

5.2.3 Waste quantity

The waste quantities used are based on statistic from 2016, provided by Kretslopp och vatten[5] and Emmaus Börkå[6] (see appendix C). The main purpose of knowing the waste quantity is to decide number of transport and size of the trucks shipping the waste to the stationary RC and the treatment facilities.

All waste types are distributed equally over the citizens of west Gothenburg to match the functional unit of the study. In 2016, the population was close to 112 500 and the average amount of waste 115kg[7]. (Göteborgs Stad, 2016b)

There is a slight difference in the waste flow patterns after the introduction of a mobile RC. The change occurs because the waste is collected at the mobile RC instead of the stationary RC. When the waste has been collected at the mobile RC it is transported to the sorting facility located at the existing stationary RC. From here on the waste follows the same procedure as the waste collected directly at the stationary RC.

5.2.4 Transport

The travelled distance and type of vehicle affects the environmental impact.

Distance

The two studied districts are divided into primary areas. Google maps is used to select one to three addresses based on possible higher population density in the primary areas. (Göteborgs Stad, 2016a; Göteborgs Stad, 2016c) Both the distance to the stationary RC and the nearest mobile RC are estimated by taking the average distance from the first and last house on the street to the recycling centres, see appendix B.

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[5] Informant 4 (Process Leader, Kretslopp och vatten) ongoing e-mail conversation spring 2017.
[6] Informant 1 (Collecting and Sustainability Manager, Emmaus Björkå) e-mail 28 March 2017.
[7] Informant 4 (Process Leader, Kretslopp och vatten) ongoing e-mail conversation spring 2017.

The average transport distance for the citizens to the mobile RC is decided by measuring the distance from the considered addresses to each of the seven mobile RC stops, with help of google maps. The shortest distance from an address to a mobile RC stop decides which stop that address is visiting. The number of citizens, living in respective primary area, are divided over the considered addresses to get an understanding of how many visitors each mobile RC stop have. The citizens can access the mobile RC with car or other means of transport, for examples bicycle or by foot. It is assumed that other means of transport accessible for the citizens does not cause any environmental impact.

To calculate the environmental impact from transport, assumptions regarding means of transport and habits are done. The means of transport are restricted to car and other media that causes no environmental impact. Assumptions are made when deciding on the percentage of trips made with the various means of transport, they are:

- If the distance is less than 0.5 km, round-trip, 0% of the citizens take the car.
- If the distance is between 0.5 km and 2 km, round-trip, 33% of the citizens take the car.
- If the distance is between 2 km and 5 km, round-trip, 50% of the citizens take the car.
- If the distance is over 5 km, round-trip, 100% of the citizens take the car.

The distance from the mobile RC to the stationery RC is given in the same way as above, with starting point at one of the seven mobile RC stops. Transport distance from the mobile RC stops to the stationary RC is presented in table 1 below. Also displayed in table 1 is the share regarding means of transport. The table shows the percentage of citizens that use the car when transporting themselves to the various mobile RC stops. In total 45 percent of the citizens choose to travel by car when visiting a mobile RC.

Table 1 Transport distance between the mobile RC stops and the stationary RC are presented in the third column. In the fourth column, the share of visitors that travel by car to the various mobile RC stops are displayed.

	Address	**Distance to the stationary RC [km]**	**Share of transport to mobile RC that is done by car [%]**
1	Pennygången 1	4.1	45%
2	Lilla Skintebovägen 2A	10.1	42%
3	Bergsätersgatan 1	6.1	33%
4	Redegatan 18	7.5	41%
5	Beryllgatan 102	6.4	46%
6	Gärdesvägen 5	7	45%
7	Opaltorget	6.7	50%

The distances from the stationery RC to the treatment facility are given by measuring the distance from the stationery RC's address to the treatment facilities' addresses, with help of google maps. The distance from the stationary RC to the treatments facilities are the same in all three scenarios. Transport path and distance connected to the collected waste on the stationery RC is showed in table 2 below.

Table 2. The table shows the way of different waste types from the stationary RC to connected treatment facility. Also, the distances coupled to the route are presented.

Waste type	**Route**	**Distance [km]**
Combustible waste (large)	RC - Sorting (Högsbo)	0*
	Sorting - Incineration (Sävenäs)	17
Combustible waste (small)	RC - Transhipment centre (Högsbo)	0*
	Transhipment centre - Incineration	17
Corrugated cardboard	RC – Depot (Skarvik)	15
Garden waste	RC - Composting (Marieholm)	17
Electrical- and hazardous waste	RC - Transhipment centre (Sävenäs)	17
	Transhipment centre (Högsbo) - Recycling	16
	Transhipment centre - Incineration	0*
	Transhipment centre - Landfill (Tagene)	12
Metal	RC – Depot	15
Non-combustible waste	RC - Transhipment centre	0*
	Transhipment centre - Filling (Tagene)	21
	Transhipment centre - Depot	15
	Transhipment centre - Incineration	17
Textiles	RC - Depot (Mölndal)	5
	Depot - Sorting (Huskvarna)	160
Twigs and branches	RC - Incineration (Sävenäs)	17

**The sorting- and transhipment facilities are in conjunction to the stationary RC.*

Vehicles

There are several types of vehicle occurring in the studied system; passenger car, other means of transport and truck. Environmental pressure from other means of transport is considered to be negligible.

Passenger car

Type of car, used by the citizens of west Gothenburg when driving to the mobile- and stationary RC, is assumed to be of a common sized passenger car in Sweden with an engine size of 1.4-2l. The fuel powering the car is a mix of various fuel types and is based on the statistics displayed in table 3 below.

Table 3. Statistic regarding what fuel type passenger cars is driven by 2015.[8]

Fuel type	**Passenger cars in traffic 2015 by fuel [number]**	**Share of passenger cars in traffic 2015 by fuel [%]**
Gasoline	111 383	61%
Diesel	55 301	30%
Electric	436	0%
Hybrids	3 015	2%
Plug-in hybrids	479	0%
Ethanol	9 688	5%
Gas	3021	2%
Other	10	0%
Total	**183 333**	**100%**

The emissions from burning gasoline and diesel are retrieved from existing datasets in Thinkstep (2017). Ethanol, gas and hybrids are based on the data for burning gasoline. However, the emissions are altered to make the amount of emissions related to global warming more accurate, see table 4. The emissions from the electric car, plug-in hybrids and other are considered negligible, due to their low share of passenger cars in traffic, and therefore not included in the study.

Table 4. Percent reduction of environmental damaging emission per km driven regarding the different fuel types listed, in relation to emissions from a car driven by gasoline.

Fuel type	**Reduction of CO_2 in relation to emissions from a car driven by gasoline [%]**	**Reduction of other* environmental damaging substances in relation to emissions from a car driven by gasoline [%]**	**Reference**
Hybrids	30	No data	Gröna bilister (n.d.b)
Ethanol	50	No data	MiljöfordonSyd (n.d.)
Gas			
- *natural*	20	70	MiljöfordonSyd (n.d.)
- *bio*	80	70	MiljöfordonSyd (n.d.)

** Other includes for examples CH_4, CO, N_2O and SO_2.*

[8] Informant 5 (Planning Leader, Göteborgs Stad) e-mail 24 February 2017.

In the modelling program GaBi, the datasets regarding the passenger cars are not dependent on the load. It is therefore assumed that every extra 100 kg load of waste increases the passenger cars fuel consumption with 5 percent. (Gröna bilister, n.d.a)

Truck/ Mobile hazardous waste collector

The trucks used for transport follows the European emission standard stage *Euro 5* and have a load capacity ranging from 12 to 30 tonnes. The trucks are powered by HVO (hydrotreated vegetable oil) fuel that is believed to lower the CO_2 emissions with up to 90 percent compared to diesel. (Energifabriken, n.d.) The percent of reduction depend on what the raw material for the HVO is made of. The trucks used in west Gothenburg are owned by Renova and are powered by HVO mainly from slaughter house residues. When conducting life cycle assessment studies regarding HVO, the CO_2 emissions are allocated the meat.[9] Therefore, the reduction of CO_2 is expected to be approximately 90 percent. The trucks powered by HVO are based on the data for burning diesel. However, the emissions are altered to make the amount of emissions related to global warming more accurate, see table 5.

Table 5. Percent reduction of environmental damaging emissions per km driven, in relation to emissions from trucks driven by diesel.

Emission	**Reduction of emission in relation to emissions from a car driven by diesel [%]**	**Reference**
CO	24	Energifabriken (n.d.)
CO_2	90	Energifabriken (n.d.)
NO_x	9	Energifabriken (n.d.)
Particles	33	Energifabriken (n.d.)

In the modelling program GaBi, the datasets regarding the trucks are not dependent the load. It is therefore assumed that every extra 100 kg load increases the trucks fuel consumption with 5 percent. (Gröna bilister, n.d.a)

5.2.5 Textile

A study made by Ljunggren Söderman et.al. (2011) showed that a change in waste management system can lead to prevention of various waste types. It is concluded that textile is the major waste type that is prevented when the accessibility for reuse is increased. Other studies draw the conclusion that the amount of collected textile is increasing when the collection possibilities increase. (Palm et al., 2014; Tekie et al., 2013) Therefore, an assumption regarding increased separate collection of textile when implementing a mobile RC is made.

The consumption of textiles in Sweden during 2013 is estimated to be 13 kg per person. Approximately 2.5 kg of the textiles are reused, and 7.5 kg ended up in the residual waste. (Hultén et al., 2016) Assessment of textiles in a composition analysis made by Hultén et al. (2016) concluded that nearly 60 percent of the textiles are in such condition that it could be reused, 4.5 kg/(person*year).

[9] Informant 6 (Environmental investigator, Renova) e-mail 27 February 2017.

In the composition analysis made by Hultén et al. (2016), nearly 60 percent of the textiles in the household bin waste are made of cotton. The remaining 40 percent is assumed to be made of polyester which is backed by Engelhardt (2010) that states that 45 percent of the textile fibres globally produced 2010 were made by polyester fibre.

A survey made by Farrant et al. (2010) concluded that 100 second-hand garments are reducing virgin production of garments by between 60 and 85 new garments. This study is using 60 as guide value when the environmental impacts arising from the expected increase in collected reusable textiles is calculated.

Transport

Roughly 60 percent of the textiles that are reused are exported to foreign countries. The remaining 40 percent stays within Sweden. (Elander et.al. 2014) 82 percent of the exported textiles in the Nordic countries are exported to countries in the EU and Turkey. Poland and Lithuania (1200 km) are the countries that receive the largest amount. (Naturvårdsverket, 2016) In this study, the transport of the reused textile is based on aforementioned statements.

Cotton and polyester are assumed to be produced in China, which is a dominant country when it comes to production of textiles. (Palm et.al., 2013) Domestic production of textile is negligible and is not included in the study. (Elander et.al. 2014)

98 percent of the produced textiles are assumed to be transported to Gothenburg. The transport is done by truck from Xian (China) to Hong Kong, by boat from Hong Kong to Rotterdam (18100 km) and by truck the remaining distance (1128km). The remaining 2 percent are shipped directly to Gothenburg by air freight (6850 km). (Palm et al., 2013; Google maps; Beräkna avstånd, 2017) Data regarding the means of transport is based on Thinkstep (2017).

The transportation distance regarding the bin waste-truck is estimated to 6 km, with help of google maps. The estimated 6 km is the average distance from the studied primary areas to the stationary RC where the bin waste is handled. The truck used for transport has a load capacity of 5 tonnes.[10] The truck is owned by Renova and is, as the trucks from the stationary RC to treatment facilities, powered by HVO fuel. For more specific data regarding the HVO´s characteristics see chapter 5.2.4, truck/ Mobile hazardous waste collector.

Energy

The energy required for cotton production is based on the article Electric energy consumption in the cotton textile processing stages by Palamutcu (2010). The study states that the energy requirement to produce one kg cotton is 242 MJ. The energy required regarding polyester production is 339 MJ, which is 40 percent higher than for cotton. (Kalliala & Nousiainen, 1999) The data regarding energy production is based on the electrical mix for China. (Thinkstep, 2017)

[10] Informant 7 (Dustman, Renova) interview 7 April 2017.

Incineration of textile

The energy recovered when incinerating textiles is calculated by multiplying the amount of textile with its heat value and the efficiency. The heat value used is 17 MJ/kg textile for cotton and 33 MJ/kg textile for polyester. The efficiency regarding the electricity at the incineration facility in Sävenäs is calculated to 12 percent and to 82 percent regarding the heat. (Renova, 2015) To calculate the emissions related to the incineration of textiles, the heat value is multiplied with an emissions factor. A consequence of an increase in collected textiles is that heat and electricity from the incineration process are lost. This is accounted for by replacing the energy recovered from incineration of textile with Sweden's electricity grid mix and Gothenburg's district heating mix. 70 percent of the district heating mix comes from recycled energy, 12 percent from renewable energy and 18 percent from fossil energy. (Göteborg Energi, n.d.) The emissions from the avoided combustion are retrieved from Ecoinvent (2017) and the environmental report of 2015 conducted by Renova (2016).

5.2.6 The compared systems

The thesis's focus is on the environmental effects of implementing a mobile RC. Changes in transport distance and, to some extent, waste quantity are anticipated when introducing a mobile RC. Based on collected data regarding amount of waste and transport distance, a current state scenario is made, the so called stationary RC. This is compared with the estimated changes in the transport distance and means of transport after implementing the mobile RC, the so called implementing mobile RC scenario and mobile RC scenario.

A citizen's transport distance to the mobile RC is shorter than the distance to the stationary centre, as it is often placed closer to the citizen. However, it is assumed that the number of transports is increasing and thereby the total transport distance due to the maximum volume of waste acceptable to discard at the mobile RC, 1 m^3. It is assumed that the citizens visit the mobile RC twice a year.

The stationary RC scenario's characteristics are;

- 100 percent of the citizens in west Gothenburg visit the stationary RC by car.
- The citizens average is one visit a year.
- A citizen is expected to run idle with an average of 15 minutes while waiting to enter the stationary RC. This due to high pressure on the recycling centre.
- The citizens bring 100 percent of their total waste to the stationary RC.

The implementing mobile RC scenario´s characteristics are;

- 10 percent of the citizens in west Gothenburg are assumed to visit the mobile RC.
- 95 percent visit the stationary RC (5% of citizens visit both the stationary RC and the mobile RC).
- An average visit of two times a year is assumed for the citizens that visit the mobile RC and one visit for the stationary RC.
- The citizens bring 10 percent of their total waste to the mobile RC.
- No idling due to fewer visits to the stationary RC.
- The mobile RC is visiting seven various locations five times a year.

In the third scenario, it is assumed that there is no stationary RC. The mobile RC scenario's characteristics are;

- 100 percent of the citizens in west Gothenburg are assumed to visit the mobile RC.
- An average visit of two times a year is assumed for the citizens that visit the mobile RC.
- The citizens bring 100 percent of their total waste to the mobile RC.
- No engine idle.
- The mobile RC is visiting seven various locations five times a year.

The third scenario is not practically feasible due to the mobile RC's capacity and the fact that it is not possible to discards every type of bulky waste. However, the scenario is of interest because of the ability to analyse the mobile RC's maximal potential.

The quantity of bulky waste does not vary between the three scenarios.[11] In the scenarios implementing mobile RC and mobile RC, the assumption regarding increased collection of textile is handled by system expansion.

The environmental impacts of increasing separately collected textiles from the bin waste after the introduction of the mobile RC is assessed by replacing virgin production of textiles with the collected reusable textiles. An increase of 10 percent based out of the 4.5kg textile suitable for reuse, according to Hultén et al. (2016), is assumed from the added convenience of leaving reusable textiles at the mobile RC. A consequence of an increase in collected textiles is that heat and electricity from the incineration process are lost. This is accounted for in the calculations. The same quantity of textiles is assumed to be collected in both scenarios.

[11] Informant 3 (Collecting Manager, SÖRAB) e-mail 20 March 2017.

5.3 Impact assessment

A frequently used impact assessment method is applied in the study, CML 2001 (Thinkstep, n.d.). The impact assessment aims to fulfil the purpose of the study and answer how the environmental impacts vary by the introduction of a mobile RC. The impact assessment also strives to answer which factors that contributes to the variations. Table 6 presents the impact categories employed in the life cycle assessment. All the results are in relation to the functional unit of the life cycle assessment: average management of bulky waste produced by one of Gothenburg's citizens, living in the districts Askim-Frölunda-Högsbo and west Gothenburg, during one year.

Table 6. Impact categories used in the study, with respective unit.

Impact category	**Unit**
Acidification Potential (AP)	[kg SO_2-Equiv.]
Eutrophication Potential (EP)	[kg Phosphate-Equiv.]
Global Warming Potential (GWP 100 years), excl biogenic carbon	[kg CO_2-Equiv.]

The impact assessment is divided in two parts. The first part includes the environmental impacts from transport regarding the three previously mentioned scenarios. The first scenario, stationary RC, includes a stationary RC that is available in west Gothenburg. The second, implementing mobile RC, and third, mobile RC, scenarios include an assumed mobile RC. For a more comprehensive description of the scenarios see section 5.2.6.

The second part of the assessment includes a system expansion for textile. A consequence of the operating mobile RC is the assumption of an increase in collected textiles. This assumption is managed through system expansion, where the second scenario together with the impact from textile is compared against the first scenario.

5.3.1 Transport

Table 7 shows the total emissions per functional unit over each impact category for the three studied scenarios.

Table 7. The three studied scenarios, stationary RC, implementing mobile RC, and mobile RC, environmental impact contribution over the studied impact categories acidification potential (AP), eutrophication potential (EP) and global warming potential (GWP) per functional unit.

	AP [10-3kg SO2-Equiv./FU]	**EP [10-3 kg Phosphate-Equiv./FU]**	**GWP [kg CO2-Equiv./FU]**
Stationary RC	5,6	1,06	2,8
Implementing mobile RC	5,3	1,04	2,7
Mobile RC	1,8	0,36	0,69

The difference between the scenarios are also displayed in figure 10, where the stationary RC scenario is set to 100 percent and the implementing mobile RC and mobile RC scenario are calculated in relation to the stationary RC scenario.

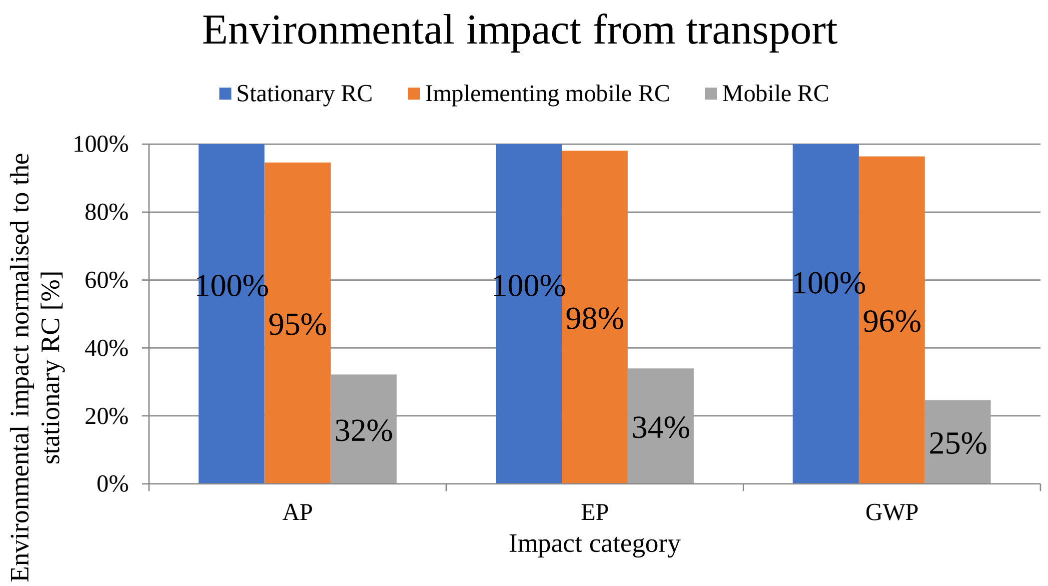

Figure 10. Environmental impacts of transports compared to stationary RC scenario for acidification potential (AP), eutrophication potential (EP) and global warming potential (GWP).

Figure 10 shows that in all three of the environmental impact categories, the implementing mobile RC scenario is slightly lower than the first scenario. The most significant difference is between the stationary RC scenario and the mobile RC scenario. Regarding the impact category acidification, the second scenario is nearly 5 percent lower than the first scenario. The eutrophication potential for the implementing mobile RC scenario decreased by 2 percent compared to the first scenario. For global warming, the second scenario is 4 percent lower than the first scenario.

For the mobile RC scenario, acidification is 68 percent lower compared to the first scenario. The impacts on eutrophication decreased 66 percent and the global warming potential decreased nearly 75 percent.

The reduction for all impact categories mainly comes from the reduced passenger transport to the stationary RC. By choosing the mobile RC, the total transport distance, with passenger cars, is shortened and thereby a decrease in environmental impact is noticeable. In what magnitude the various parts in the three scenarios contributes to the environmental impact, is analysed in the gravity analysis in section 5.3.3.1.

5.3.1.1 Gravity analysis

Transport

The environmental impact contribution from each process in the stationary RC scenario is presented in table 8. The same amount of waste follows the same route between the stationary RC and the treatment facilities in all three scenarios. The amount of emissions emitted from the mentioned transport is therefore the same in all three scenarios. Nevertheless, the mentioned transport is of interest to keep in the study to show its size compared to the other transports.

Table 8. The environmental impact contribution from each process in the stationary RC scenario over the studied impact categories acidification potential (AP), eutrophication potential (EP) and global warming potential (GWP).
** Treatment Facility.*

	AP [10-3kg SO2-Equiv.]	EP [10-3 kg Phosphate-Equiv.]	GWP [kg CO2-Equiv.]
Transport to the stationary RC	5	0,91	2,8
Transport from stationary RC to TF*	0,603	0,15	0,038

Figure 11 shows how the emissions from the two processes in the stationary RC scenario contribute to each of the three studied impact categories. For a more detailed overview of how the emissions contribute to the processes see appendix D.

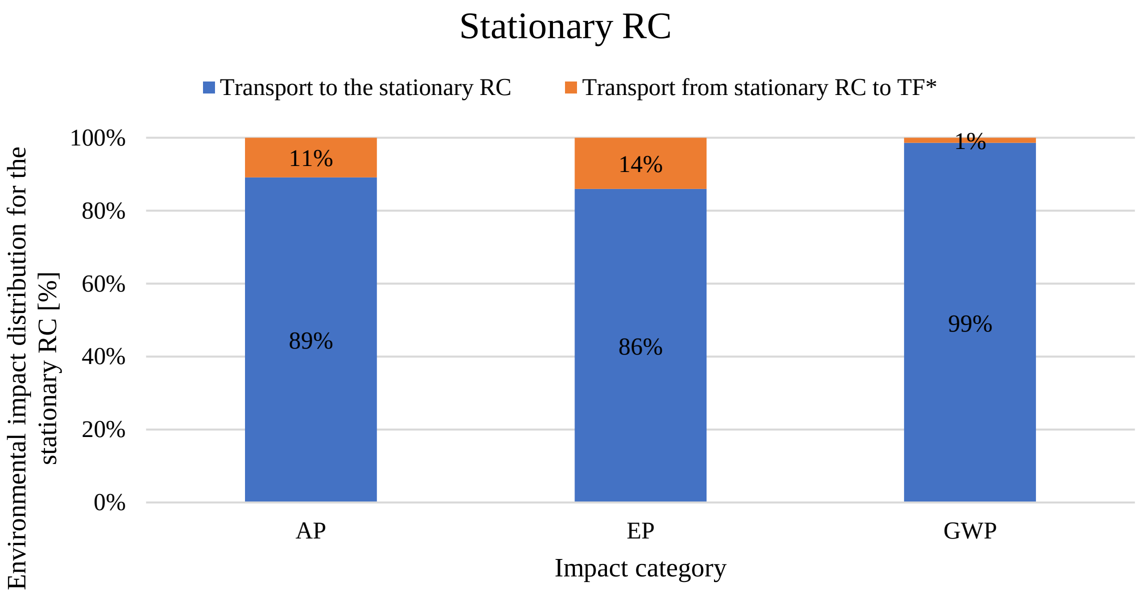

Figure 11. Overview of how the most significant processes in the stationary RC contributes to the studied environmental impact categories acidification potential (AP), eutrophication potential (EP) and global warming potential (GWP).
** Treatment Facility.*

Figure 11 shows that the passenger car transport to the stationary RC represents 89 percent of the emissions connected to acidification, whereas the transport from the stationary RC to a treatment facility is responsible for the remaining 11 percent. The acidification potential, connected to the transport to the stationary RC, mainly arises from the emission of SO_2, 39 percent, of which comes from the production of petrol and diesel which powers the passenger cars. Also, NO contributes to the environmental impacts with 33 percent originating from driving passenger cars powered by petrol and diesel. The main emission contributing to the acidification potential, regarding the transport to the treatment facilities, is NO. NO originates from driving the trucks powered by HVO.

The most significant impact on eutrophication comes from the transport to the stationary RC with 86 percent. The transport to treatment facilities is responsible for 14 percent of the impact. Of the emissions that arises from the transport to the stationary RC 83 percent are emitted to air and affects the eutrophication potential. The remaining 17 percent are emitted to fresh water. NO and other NO_x, emitted from the passenger car powered by diesel, are the foremost emissions to air, 55 percent respectively 16 percent. The emissions to fresh water mainly arise from NO_3^- and N, responsible for 39 and 38 percent respectively. The aforementioned emissions are driven from the production of petrol and diesel for passenger cars. Of the emissions that arises from the transport from the stationary RC to the treatment facilities 94 percent are emitted to air and affects the eutrophication potential. The remaining 6 percent are emitted to fresh water. NO and other NO_x, emitted from the trucks powered by HVO, are the foremost emissions to air, 89 and 9 percent respectively. The emissions to fresh water mainly arise from N, PO_4^{3-} and NO_3^-, responsible for 52, 29 and 17 percent respectively. The aforementioned emissions are driven from the production of HVO for the trucks.

For the global warming potential, the main contributor is the transport to the stationary RC which represents 99 percent. 1 percent of the environmental impacts come from the transport to treatment facilities. CO_2 emitted to air is the most significant contributor to the global warming potential representing 95 percent. Both the production of and the burning of fuel in passenger cars powered by petrol and diesel are the main source of the emitted CO_2. The environmental impact from the transport from the stationary RC to the treatment facilities is not as significant as the emissions from the transport to the stationary RC. This is because the trucks are powered by HVO, which does not emit substantial amounts of CO_2.

The environmental impact contribution from each process in the implementing mobile RC scenario is presented in table 9. The environmental impact contribution from each process in the stationary RC scenario is presented in table 8. The same amount of waste follows the same route between the stationary RC and the treatment facilities in all three scenarios. The amount of emissions emitted from the mentioned transport is therefore the same in all three scenarios. Nevertheless, the mentioned transport is of interest to keep in the study to show its size compared to the other transports.

Table 9. The environmental impact contribution from each process in the implementing mobile RC scenario over the studied impact categories acidification potential (AP), eutrophication potential (EP) and global warming potential (GWP).
** Treatment Facility.*

	AP [10-3kg SO2-Equiv.]	**EP [10-3 kg Phosphate-Equiv.]**	**GWP [kg CO2-Equiv.]**
Transport to the stationary RC	4,5	0,87	2,6
Transport from stationary RC to TF*	0,603	0,15	0,038
Transport to mobile RC	0,11	0,0204	0,062
Transport of mobile RC	0,025	0,0000062	0,0000017

Figure 12 shows how the emissions from the four processes in the stationary RC scenario contribute to each of the three studied impact categories. For a more detailed overview of how the emissions contribute to the processes see appendix D.

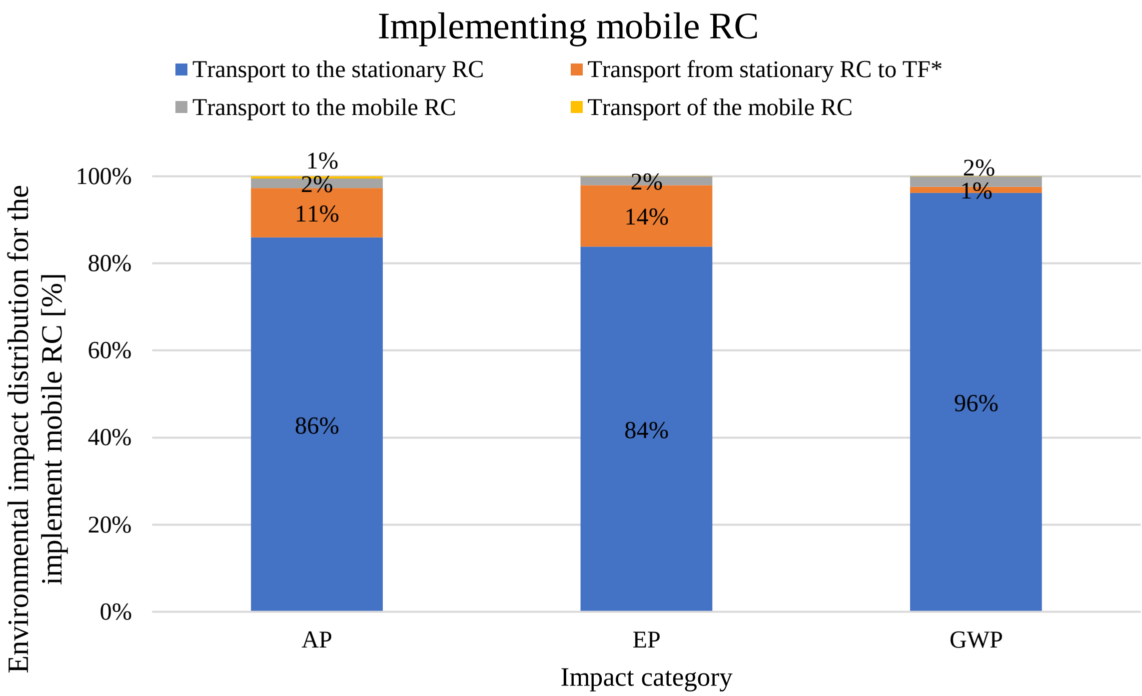

Figure 12. Overview of how the most significant processes in the implemented mobile RC scenario contributes to the studied environmental impact categories acidification potential (AP), eutrophication potential (EP) and global warming potential (GWP).
** Treatment Facility.*

Figure 12 shows that the passenger car transport to the stationary RC represents 86 percent of the emissions connected to acidification, whereas the transport from the stationary RC to a treatment facility is responsible for 11 percent. The passenger transport to the mobile RC contributes with 2 percent and the transport of the mobile RC with 1 percent. The acidification potential mainly arises from the emission of SO_2, 39 percent, of which comes from the production of petrol and diesel which powers the passenger cars. Also, NO contributes to the environmental impacts with 34 percent originating from driving passenger cars powered by petrol and diesel. The main emission contributing to the acidification potential, regarding the transport to the treatment facilities, is NO. NO originates from driving the trucks powered by HVO.

The most significant impact on eutrophication comes from the transport to the stationary RC with 84 percent. The transport to treatment facilities is responsible for 14 percent of the impact. The passenger transport to the mobile RC contributes with 2 percent and the transport of the mobile RC with less than 1 percent. Of the emissions that arises from the transport to the stationary RC 83 percent are emitted to air and affects the eutrophication potential. The remaining 17 percent are emitted to fresh water. NO and other NO_x, emitted from the passenger car powered by diesel, are the foremost emissions to air, 55 percent respectively 16 percent. The emissions to fresh water mainly arise from NO_3^- and N, responsible for 39 and 38 percent respectively. The aforementioned emissions are driven from the production of petrol and diesel for passenger cars.

Of the emissions that arises from the transport from the stationary RC to the treatment facilities 94 percent are emitted to air and affects the eutrophication potential. The remaining 6 percent are emitted to fresh water. NO and other NO_x, emitted from the trucks powered by HVO, are the foremost emissions to air, 89 and 9 percent respectively. The emissions to fresh water mainly arise from N, PO_4^{3-} and NO_3^-, responsible for 52, 29 and 17 percent respectively. The aforementioned emissions are driven from the production of HVO for the trucks.

For the global warming potential, the main contributor is the transport to the stationary RC which represents 96 percent. 1 percent of the environmental impacts come from the transport to treatment facilities with and 2 percent from the transport to the mobile RC. Less than 1 percent of the environmental impacts are driven by the transport of the mobile RC. CO_2 emitted to air is the most significant contributor to the global warming potential representing 99 percent. Both the production of and the burning of fuel in passenger cars powered by petrol and diesel are the main source of the emitted CO_2. The environmental impact from the transport from the stationary RC to the treatment facilities is not as significant as the emissions from the transport to the stationary RC. This is because the trucks are powered by HVO, which does not emit substantial amounts of CO_2.

The environmental impact contribution from each process in the mobile RC scenario is presented in table 10. The environmental impact contribution from each process in the stationary RC scenario is presented in table 8. The same amount of waste follows the same route between the stationary RC and the treatment facilities in all three scenarios. The amount of emissions emitted from the mentioned transport is therefore the same in all three scenarios. Nevertheless, the mentioned transport is of interest to keep in the study to show its size compared to the other transports.

Table 10. The environmental impact contribution from each part in the mobile RC scenario over the studied impact categories acidification potential (AP), eutrophication potential (EP) and global warming potential (GWP).
** Treatment Facility.*

	AP [10-3kg SO2-Equiv.]	**EP [10-3 kg Phosphate-Equiv.]**	**GWP [kg CO2-Equiv.]**
Transport from stationary RC to TF*	0,603	0,15	0,038
Transport to mobile RC	1,2	0,22	0,66
Transport of mobile RC	0,027	0,0000066	0,0000018

Figure 13 shows how the emissions from the three processes in the stationary RC scenario contribute to each of the three studied impact categories. For a more detailed overview of how the emissions contribute to the processes see appendix D.

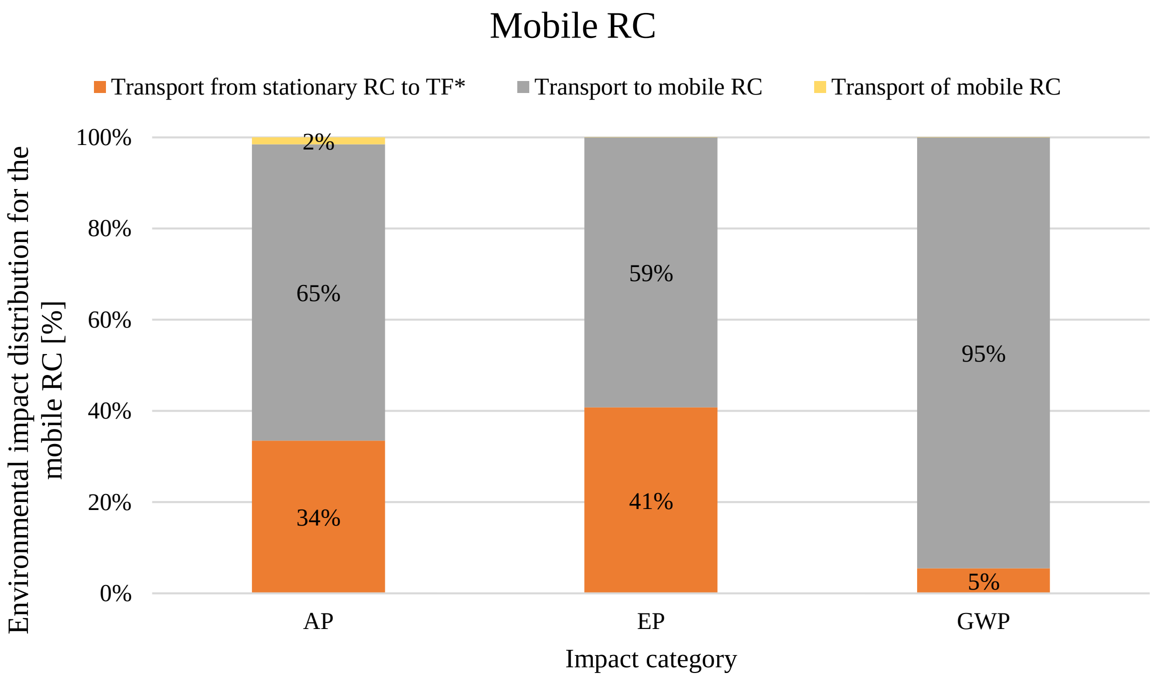

*Figure 13. Overview of how the most significant processes in the mobile RC scenario contributes to the studied environmental impact categories acidification potential (AP), eutrophication potential (EP) and global warming potential (GWP). * Treatment Facility.*

Figure 13 shows that the passenger car transport to the mobile RC represents 65 percent of the emissions connected to acidification, whereas the transport from the stationary RC to a treatment facility is responsible for 34 percent. The transport of the mobile RC contributes with 2 percent to the acidification potential. The acidification potential mainly arises from the emission of NO, 49 percent, of which originates from driving the passenger cars powered by petrol and diesel. NO also arises from the transport by trucks, powered by HVO, from the stationary RC to the treatment facilities. The emissions of SO_2 contribute to the acidification potential with 30 percent, originating from the production of diesel and petrol that is powering the passenger cars. SO_2 is also arising from the transport by truck from the stationary RC to the treatment facilities, which contributes to the acidification potential. The main emission contributing to the acidification potential, regarding the transport to the treatment facilities, is NO. NO originates from driving the trucks powered by HVO.

The most significant impact on eutrophication comes from the transport to the mobile RC with 59 percent. The transport to treatment facilities is responsible for 41 percent of the impact. The transport of the mobile RC contributes with less than 1 percent to the eutrophication potential. Of the emissions that arises from the transport to the mobile RC 87 percent are emitted to air and affects the eutrophication potential. The remaining 13 percent are emitted to fresh water. NO and other NO_x, emitted from the passenger car powered by diesel, are the foremost emissions to air, 70 percent respectively 11 percent. The emissions to fresh water mainly arise from NO_3^- and N, responsible for 31 and 40 percent respectively. The aforementioned emissions are driven from the production of petrol and diesel for passenger cars. Of the emissions that arises from the transport from the stationary RC to the treatment facilities 94 percent are emitted to air and affects the eutrophication potential.

The remaining 6 percent are emitted to fresh water. NO and other NO_x, emitted from the trucks powered by HVO, are the foremost emissions to air, 89 and 9 percent respectively. The emissions to fresh water mainly arise from N, PO_4^{3-} and NO_3^-, responsible for 52, 29 and 17 percent respectively. The aforementioned emissions are driven from the production of HVO for the trucks.

For the global warming potential, the main contributor is the transport to the mobile RC which represents 95 percent. 5 percent of the global warming potential arises from the transport to treatment facilities. Less than 1 percent of the environmental impacts are driven by the transport of the mobile RC. CO_2 emitted to air is the most significant contributor to the global warming potential representing 99 percent. Both the production of and the burning of fuel in passenger cars powered by petrol and diesel are the main source of the emitted CO_2. The environmental impact from the transport from the stationary RC to the treatment facilities is not as significant as the emissions from the transport to the stationary RC. This is because the trucks are powered by HVO, which does not emit substantial amounts of CO_2.

5.3.2 System expansion - Reuse of textiles

The environmental impact contribution from each process in the system expansion, reuse of textiles, is presented in table 11.

Table 11. The total emissions over the main processes included in the system expansion, reuse of textile, distributed over the studied impact categories acidification potential (AP), eutrophication potential (EP) and global warming potential (GWP).

	AP [10-3kg SO2-Equiv.]	EP [10-3kg Phosphate-Equiv.]	GWP [kg CO2-Equiv.]
60 % avoided virgin production	-8,9E-02	-6,5E-03	-2,1E+01
100 % avoided incineration	-1,6E-03	-6,9E-04	-6,4E-01
100 % reuse transports	3,5E-04	8,08E-05	1,5E-01
Avoided transport of bin waste-truck	-1,0E-06	-2,00E-07	-1,0E-04
Transport by passenger car to mobile RC	4,2E-06	7,7E-07	2,3E-03

The difference between the stationary RC scenario and the implementing mobile RC with an addition of textile reuse are displayed in figure 14. The implementing mobile RC + textile reuse scenario is calculated in relation to the stationary RC scenario. Included in the former mentioned scenario are avoided production, avoided incineration, avoided transport of bin waste-truck and transport by passenger car to mobile RC.

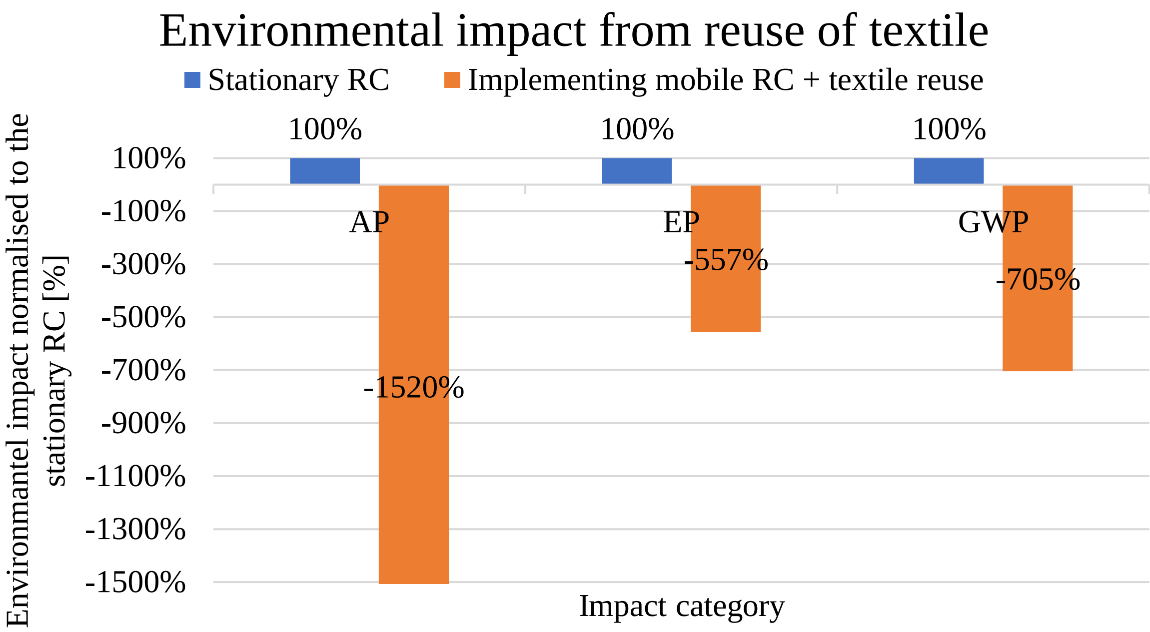

Figure 14. Environmental impacts of avoided production, avoided incineration, avoided transport of bin waste-truck and transport by passenger car to mobile RC compared to the stationary RC scenario. The environmental impact is divided over the three studied environmental impact categories acidification potential (AP), eutrophication potential (EP) and global warming potential (GWP).

There is a significant environmental benefit by reusing textiles. Figure 14 shows that, if reusing textiles, it is possible to avoid environmental impacts connected to acidification by up to 15 times compared to the stationary RC scenario. Furthermore, environmental impacts connected to eutrophication can be avoided by up to 6 times and environmental impacts associated to global warming by up to 7 times compared to the stationary RC scenario

It is above all the avoided energy use in the production of virgin textile in Asia that contributes to the environmental benefit, which is true for all the impact categories. The acidification potential is mainly affected by the emissions SO_2 and NO_x, the eutrophication potential by NO_x and the global warming potential by emission of CO_2. For a more detailed overview of the emissions connected to the avoided virgin production of textile see appendix D.

5.3.2.1 Gravity analysis

Figure 14 shows that textiles has a significant impact on the result. The emissions from the transport connected to recycling centres are nearly negligible in comparison to the saved environmental impact from textile reuse. The significant decrease in environmental impact regarding textiles mainly depends on the saved energy in the virgin production of the textiles. The transport from the country of manufacture in Asia to Sweden is nearly negligible.

5.3.3 Data quality analysis

When analysing the results obtained from the impact assessment, it appears it is the transport to the stationary RC that gives rise to the most significant environmental impact, both with and without an operating mobile RC. The result is based on several assumptions. Therefore, a sensitivity analysis is made to investigate in how significant extent some of these assumptions are contributing to the result. The sensitivity analysis manages the assumptions regarding idling and means of transport.

5.3.3.1 Sensitivity analysis

A sensitivity analysis is made regarding the assumption of idling in the stationary RC scenario, in this case called 15 min idling. The analysis can also be applied on the other two scenarios but in the interest of the result it is not necessary.

The acidification potential is increased with 0.02 percent after double the idling time from 15 minutes to 30 minutes. A 0.03 percent difference in the acidification potential is observed when increasing the idling time from 15 minutes to 60 minutes. A 0.01 percent difference in the eutrophication potential is observed when the idling time is doubled 15 minutes to 30 minutes. The eutrophication potential is increased with 0.02 percent after increasing the idling time from 15 minutes to 60 minutes. The same difference in percentage is observed for the global warming potential.

When changing the idling parameter in the GaBi model it is observed that it has not a significant impact on the result for neither of the scenarios. This implies that the idling does not have any effects on the result of the study.

Observed in the gravity analysis is that for the mobile RC scenario the transport to the mobile RC does contribute to the global warming potential in a considerable extent. A sensitivity analysis is made to analyse how altering the number of citizens that chooses the car as mean of transport in the implementing mobile RC scenario has an impact on the result, see figure 15.

The blue bars to the left, stationary RC, represent the stationary RC scenario. The orange bars in the middle, car, represent the implementing mobile RC scenario but if the transport to the mobile RC is done by car. The grey bars to the right, no EI, represent the implementing mobile RC scenario but if the transport to the mobile RC is done by other means of transport that do not have an environmental impact (e.g. walking and biking). The car and no EI case are normalized the stationary RC case.

In the previously mentioned stationary RC scenario the acidification potential reached 0.0052 kg SO2-Equiv., the eutrophication potential 0.00099 kg Phosphate-Equiv. and the global warming potential 2.6 kg CO2-Equiv.

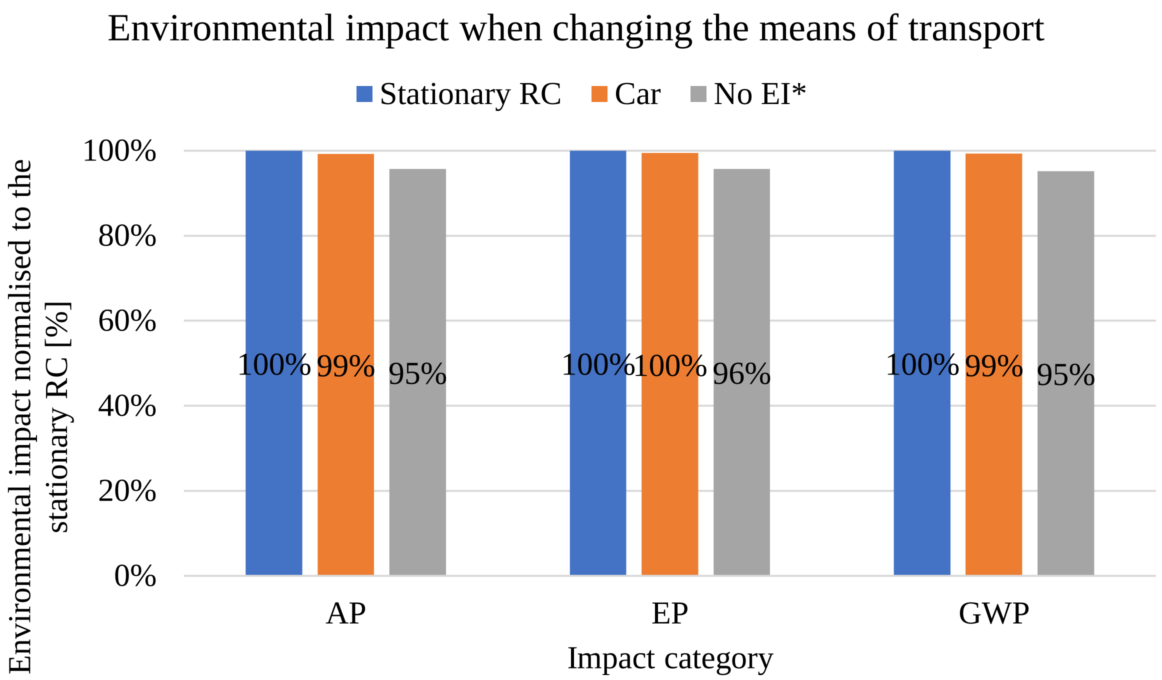

Figure 15. The change in environmental impact when choosing different means of transport to the mobile RC for the implementing mobile RC scenario. The environmental impact is divided over the three studied environmental impact categories acidification potential (AP), eutrophication potential (EP) and global warming potential (GWP).
** Environmental Impact.*

The acidification potential differs with 0.7 percent between the car and stationary RC case and with 5 percent between the no EI and stationary RC case. A difference in eutrophication of 04 percent is observed between the stationary RC and the car case. Furthermore, a change by 4 percent is noticed between the stationary RC and the no EI case regarding the eutrophication potential. A difference of 0.7 present is observed between the stationary RC and the car case regarding the global warming potential. The global warming potential difference between the stationary RC and the no EI case is 5 percent.

It is possible to conclude that the means of transport do influence the result. It is seen in the no EI case that there is an environmental benefit if leaving the passenger car at home and travel by an emission free mean of transport, for examples by foot or by bike, to the mobile RC. Also, the car case indicates that it is more preferable to transport the waste by truck powered by HVO than by passenger car that mainly is powered by diesel and petrol.

After analysing the two parameters, idling and means of transport, in the sensitivity analysis, it can be concluded that it is mainly the possibility, when implementing a mobile RC, to choose a mean of transport that is emission free that decreases the environmental impact regarding all the studied impact categories. The idling does not affect the result in a significant way.

5.4 Interpretation of result

5.4.1 Discussion

Since mobile RC:s are not that common, and this study is site specific for west Gothenburg, several assumptions about how the mobile RC would look like, function and affect the collection of waste have been made. Expectations regarding increased collection of textiles and number and length of transport by passenger car, in all scenarios, are significant assumptions. Also, the assumption on where people live may have an impact on the result connected to transport.

The locations of the mobile RC are based on the criteria stated in section 5.5.2. There is a possibility that the locations selected not are the most optimal from a population density point of view. Therefore, there might be possible to decrease the transport requirements if finding more suitable locations. Restrictions on noise and traffic might also lead to less suitable locations and thus increase transport requirements. This is not investigated in this study.

Figure 10 implies that the larger share of the visitors that use the mobile recycling centre the better. This due to shorter transport distances travelled by private cars. However, 100 percent is a high assumption and is not a realistic one. That quantity of visitors would put a very high pressure on the mobile RC and the size of the mobile RC would most certainly restrict the number of visitors. Nevertheless, if this were to occur it might be partly solved by letting the mobile RC visit the stops more frequently. Another possibility would be that parts of the mobile RC are exchanged when a container is full. That would however increase the impact due to the need of more transport with truck. However, these are statements that need to be investigated more thoroughly. A prerequisite for this scenario is that the mobile RC can accept all waste types, which is not the case for any of the mobile RCs running in Sweden today.

In the third scenario, mobile RC, it is said that a citizen visits the mobile RC two times a year discarding in total 115 kg waste. This is a large amount of waste for two opportunities when not all visits are made by car. The emissions emitted connected to the transport to the mobile RC by passenger car are therefore, in this scenario, underestimated. An increase in number of visits to the mobile RC would probably be needed for a more accurate result.

Both the acidification potential and the global warming potential normally tend to have a higher degree of correlation. A reason for the deviation in this case may be that the trucks used for the transportation from the stationary RC are powered by HVO. The HVO fuel significantly affects the reduction of CO_2 emission, which is connected to the global warming potential. The acidification potential is also affected because of the reduction in NO and NO_x. However, the reduction of NO and NO_x is not as significant as the reduction of CO_2.

It is assumed that there are no environmental impacts from other means of transport than car and trucks. This is not entirely true due to electricity production in the case of electric bikes and the production of food the citizens consume to travel. Further investigation regarding the magnitude of impact from the means of transport that are assumed to not contribute to the environmental impacts is therefore advised. It is also assumed that there is no engine idle at the stationary RC in the scenario implementing mobile RC. This is probably not the case, but since the sensitivity analysis showed no major effects when increasing the engine idle it can be assumed that the environmental impacts are not significantly affected by this assumption.

Figure 14 shows that all the transport included in this study are negligible in proportion to the impacts of reusing the collected textiles. Also, transport of the reusable textiles to the second-hand market is negligible. A minor change in the waste management for textiles has a very large effect on the environmental impacts. This implies that, in this case considering a mobile RC, it may not be the transport that are of greatest importance for the studied impact categories, while still relevant for the local environment in terms of noise and other impacts not studied.

The largest contributor to the environmental impact categories for the system expansion of textile is by far the virgin production. The largest share is caused by the energy requirement in the production. The textiles are mainly produced in other countries than Sweden, mostly China but also India and Turkey. This makes the production phase difficult to alter.

In the report, it is assumed that it is only the textiles that are affected by changes in the waste management system. There are other waste types where the collected quantity may change, for examples furniture and building products made of wood as seen in Ljunggren Söderman et al. (2011). However, these waste types are not possible to leave at all at the mobile RC considered in this study and therefore not included. Hazardous and electronic waste on the other hand are collected at the mobile RC and like textile discarded in the bin waste. Due to data quality and availability this waste type is not included in the study.

The data used in the report is as far as possible up-to-date and site specific for Gothenburg. When not available, average data regarding Sweden has been used followed by average Europe data. As last resort, global data has been used. Since only greenhouse gas related emissions was altered for the alternative fuels, other environmental impacts have a higher degree of uncertainty (table 4; table 5).

As mentioned in the delimitations (1.3), no consideration was taken to economic aspects. Economy is obviously a vital part when deciding on if implementing a mobile RC is feasible. After economic circumstances are considered the choice of the mobile RC characteristics such as; type of containers used, size, waste types acceptable to discard, number of stops, location of the mobile RC and other aspects may be different than this thesis suggest and thereby give another result regarding the environmental impacts.

Socioeconomic aspects as amount of waste generated per household, access to various means of transport and more are not included in the report and can be relevant for further studies to improve the accuracy of the study.

5.4.2 Conclusions and recommendations

The study relies on several assumptions but can be seen as an indication of the environmental impacts of implementing a mobile RC. The study implies that the environmental impact decreased in the implementing mobile RC- and mobile RC scenarios, even though the total average transport distance of waste increased in the mentioned scenarios because of the implementation of the mobile RC. The decrease in environmental impact is partly due to the shift in transportation mode from private cars to walking and biking. Also, the total transport distance by car is shorter in the implementing mobile RC- and mobile RC scenario compared to the stationary RC scenario, which reduces the environmental impact. However, the total transport distance with truck, powered by HVO, has increased, which implies that trucks are more environmental beneficial than cars.

It can be concluded that the implementation of a mobile RC has a low environmental benefit if few citizens use it, as in the implementing mobile RC scenario. The environmental benefit of introducing a mobile RC is increased when more citizens use the recycling centre, as in the mobile RC scenario. Nevertheless, this is only valid in the case the citizens also decrease their visits to the stationary RC. However, the decrease in environmental impact is overestimated in the mobile RC scenario. The transport from the mobile RC to the stationary RC would have to increase because of limited storage capacity.

The study shows that a collecting system that enables an increase in collected reusable textiles has a significantly high potential to reduce the environmental impacts studied. Other geographical areas and other assumptions on how the mobile RC is operated may change the results. Thus, the results are only valid under the specific conditions given in this report.

Recommendations to municipalities, or other stakeholders, before implementing a mobile RC is to thoughtfully choose the placement of the mobile RC. This is to ensure effective collection of reusable textiles and short travel distances for most of the citizens visiting the mobile RC by car. The implementation of the mobile RC also needs to be well advertised to decrease visits to the stationary RC.

To manage the uncertainties in the study and the fact that the modelled system is theoretical, further studies are suggested below.

5.4.3 Further studies

Economical aspect is of high importance since the recycling centre most certainly will be financed by the municipality waste fees. Cost connected to inter alia production of containers, employees managing the recycling centre, potential rent for the area where the centre would be stationed could be of interest for further studies.

An investigation concerning the visitor capacity issue at Högsbo RC could be carried out some time after an implementation of a mobile RC to acknowledge if there is any difference. Also, studies regarding possible increase in collected waste types, other than textile, would be of interest. This is to investigate how changes in the waste management for the aforementioned waste types affect the environmental impacts.

Furthermore, a study regarding the urban environment would be preferred. Factors like noise, vibrations and emissions inform of particles from the passenger transport could be of interest since these environmental impacts occur locally.

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Personal Communication

Informant 1 (Collecting and Sustainability Manager, Emmaus Björkå) e-mail 28 March 2017.

Informant 2 (Business development, Renova AB) e-mail 24 March 2017.

Informant 3 (Collecting Manager, SÖRAB) e-mail 20 March 2017.

Informant 4 (Process Leader, Kretslopp och vatten) ongoing e-mail conversation spring 2017.

Informant 5 (Planning Leader, Göteborgs Stad) e-mail 24 February 2017.

Informant 6 (Environmental investigator, Renova) e-mail 27 February 2017.

Informant 7 (Dustman, Renova) interview 7 April 2017.

Appendix A

Population

Population divided over the different primary areas in the districts Askim-Frölunda torg-Högsbo and west Gothenburg.

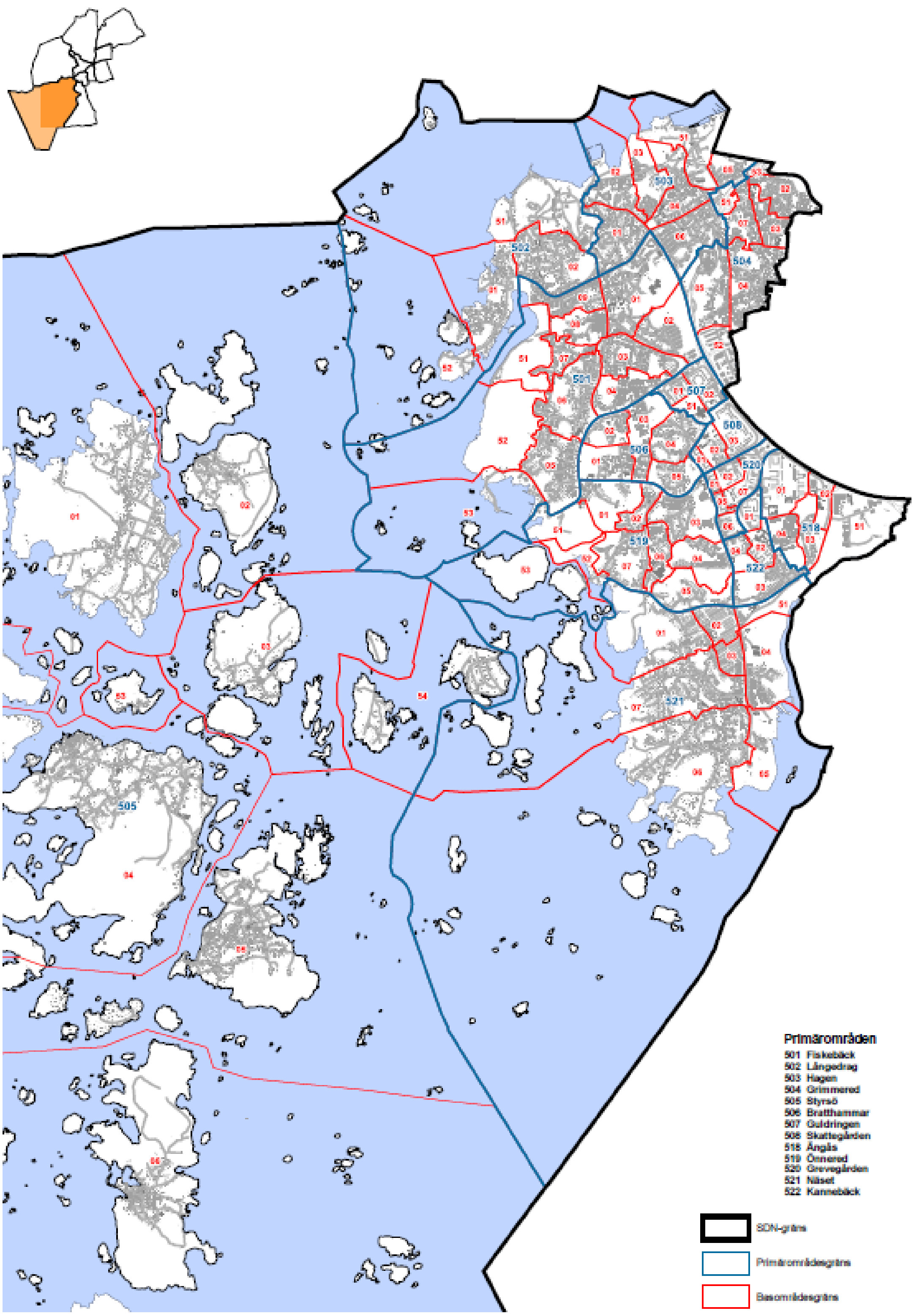
District Askim - Frölunda torg - Högsbo		**District west Gothenburg**	
Primary area	***Population***	***Primary area***	***Population***
Kaverös	4378	**Fiskebäck**	7587
Flatås	3552	**Långedrag**	2102
Högsboöjd	4233	**Hagen**	5746
Högsbotorp	7080	**Grimmered**	4299
Tofta	2695	**Bratthammar**	2480
Ruddalen	2219	**Guldringen**	2305
Järnbrott	4058	**Skattegården**	2627
Högsbo	52	**Ängås**	4000
Frölunda torg	6034	**Önnered**	3849
Askim	10206	**Grevegården**	4252
Hovås	3376	**Näset**	6144
Billdal	11440	**Kannebäck**	3186

Total	**107900**

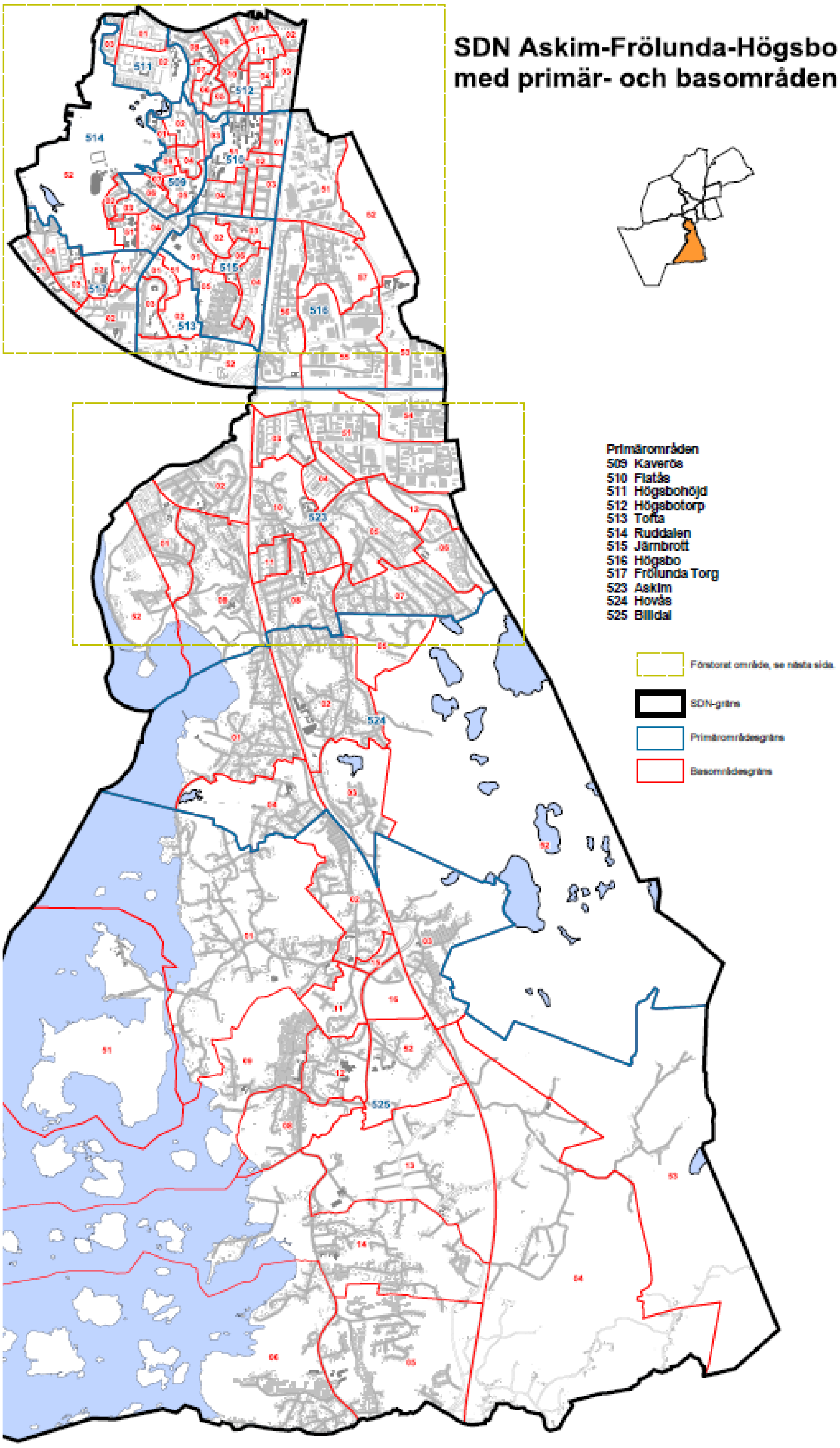
Districts

The map (Göteborgs Stad, 2016c) below shows the district west Gothenburg. The district is marked with the black line and the lines in colour blue displays the different primary areas that the district consists of.

SDN Västra Göteborg med primär- och basområden



The map (Göteborgs Stad, 2016a) below shows the district Askim–Frölunda–Högsbo. The district is marked with the black line The lines in colour blue displays the different primary areas that the district consists of.



Appendix B

Distances Stationary RC

The average distances from the households in the studied districts to the Stationary RC, linked to the different addresses and the connected primary area.

Primary area	Address divided by sub-area and based on average distance	Average distance to stationary RC [km]
Fiskebäck	Pärt-antons gata 55	7.075
	Piggvarsgatan 29	8.3
	Norra Flundregatan 8	7.55
Långedrag	Saltholmsgatan 41	9.75
	Patrullgatan 18-20	8.95
	Skonertgatan 19B	7.7
Hagen	Hagens stationsväg 23	6.7
	Skrattmåsgången 13	7.2
Grimmered	Törnrosgatan 12	6.15
	Trälåsvägen 3-5	6.8
Bratthammar	Blåbärsvägen 11	6.1
	Melongatan 48B	6.6
Guldringen	Bärnstensgatan 2	6.25
Skattegården	Briljantgatan 27	5
Kaverös	Tunnlandsgatan 12	3
Flatås	Distansgatan 27	1.65
Högsboöjd	Växelmyntsgatan 5F	4.65
Högsbotorp	Riksdalersgatan 13	3.8
	Kapplandsgatan 82	2.45
Tofta	Radiovägen 5	2.8
Ruddalen	Musikvägen 2	2.35
Järnbrott	Våglängdsgatan 18	2.65
	Bildradiogatan 12	1.55
Högsbo	Skiljemyntsgatan 11	2.7
Flölunda torg	Mandolingatan 25	2.55
	Södra Dragspelsgatan 24-26	2.9
	Lergöksgatan 14	5.25
Ängås	Briljantgatan 6.	4.85
Önnered	Tanneskärsgatan 87-91	6.6
Grevegården	Grevegårdsvägen 90B	5.7
Näset	Hammarvägen 244	6.95
	Rödgatan 18	6.65
	Östra Breviksvägen 2-4	7.9
Kannebäck	Rubingatan 25-26	5.45
	Korsåsliden 94	4.75
	Bronsåldersgatan 14	5.05

Askim	Gamla Särövägen 70	4.15
Hovås	Hovåsvägen 24	7
	Trollåsvägen 1	4.75
Billdal	Nyhagen 46	10.45
	Södra Särövägen 101	14.75

Distances Mobile RC

The average distances from the households in the studied districts to the nearest mobile RC, linked to the different addresses and the connected primary area. Also, the number of visitors and the distance to Mobile RC depending on means of transport.

Primary area	**Address divided by sub-area and based on average distance**	**Address to preferred Mobile RC**	**Maximum visitors from the sub-areas at preferred Mobile RC**	**Distance to Mobile RC depending on means of transport**		
				Car	**Bicycle**	**Walk**
Fiskebäck	Pärt-antons gata 55	Redegatan 18	2529	1.6	1	1
	Piggvarsgatan 29	Beryllgatan 102	2529	2.1	1.6	1.5
	Norra Flundregatan 8	Beryllgatan 102	2529	2.4	1.8	1.6
Långedrag	Saltholmsgatan 41	Redegatan 18	701	2.5	2.3	
	Patrullgatan 18-20	Redegatan 18	701	1.7	1.5	
	Skonertgatan 19B	Redegatan 18	701	1.3	1.3	1.3
Hagen	Hagens stationsväg 23	Redegatan 18	2873	1.1	1.1	1.1
	Skrattmåsgången 13	Redegatan 18	2873	0.6	0.6	0.6
Grimmered	Törnrosgatan 12	Pennygången 1	2149.5	1.3	1.2	1.2
	Trälåsvägen 3-5	Pennygången 1	2149.5	2.1	1.7	
Bratthammar	Blåbärsvägen 11	Beryllgatan 102	1240	3.7	0.85	0.85
	Melongatan 48B	Beryllgatan 102	1240	2.4	1.3	
Guldringen	Bärnstensgatan 2	Beryllgatan 102	2305	0.9	0.8	0.8
Skattegården	Briljantgatan 27	Opaltorget	2627	3.9	1.2	1
Kaverös	Tunnlandsgatan 12	Pennygången 1	4378	2.8	1.6	1.5
Flatås	Distansgatan 27	Pennygången 1	3552	3	2.5	
Högsboöjd	Växelmyntsgatan 5F	Pennygången 1	4233	0.55	0.55	0.55
Högsbotorp	Riksdalersgatan 13	Pennygången 1	3540	1.1	0.55	0.55
	Kapplandsgatan 82	Pennygången 1	3540	2.3	1.4	

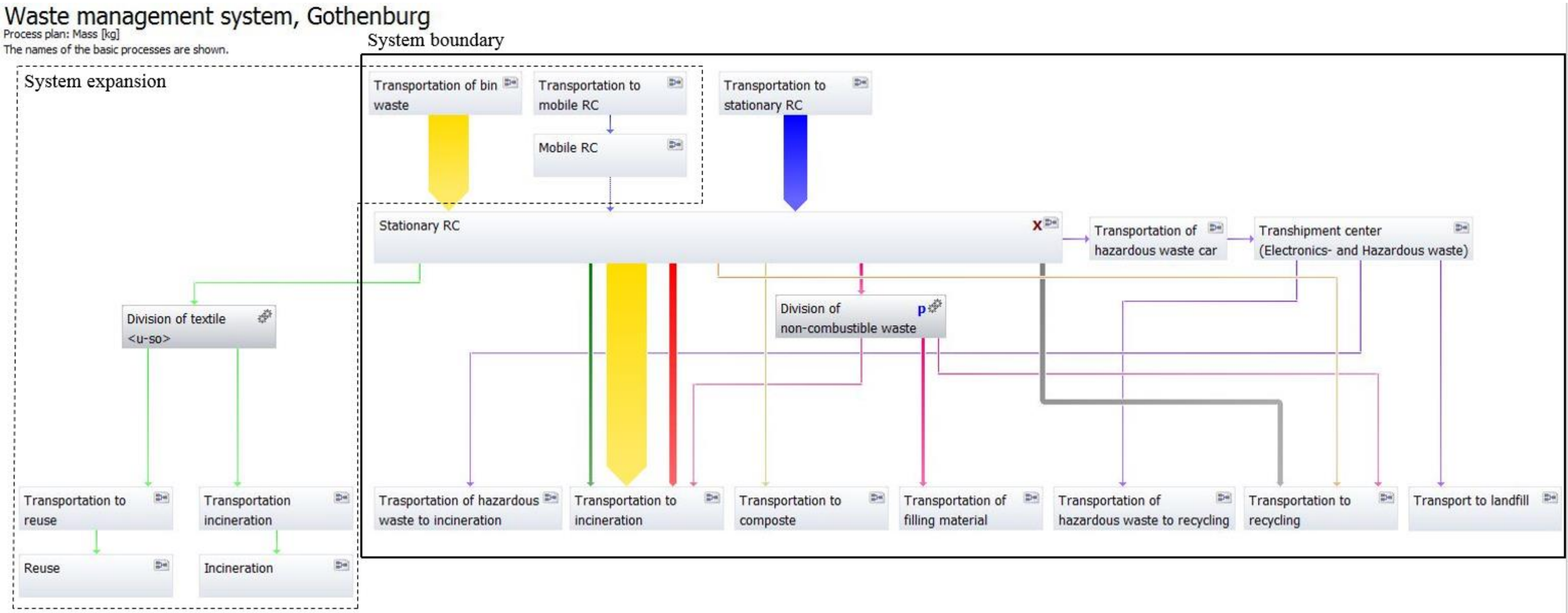
Tofta	Frölunda kyrkogata 1	Opaltorget	2695	2.7		
Ruddalen	Musikvägen 2	Pennygången 1	2219	4	2.1	
Järnbrott	Våglängdsgatan 18	RC	2029	2.1		
	Bildradiogatan 12.	RC	2029	2.1		
Frölunda torg	Mandolingatan 25	Opaltorget	2011	3.4	2.4	
	Södra Dragspelsgatan 24-26	Opaltorget	2011	2.7		
	Lergöksgatan 14	Beryllgatan 102	2011	1.6	1.4	1.3
Ängås	Briljantgatan 6	Opaltorget	4000	2.2	1.5	1.2
Önnered	Tanneskärsgatan 87-91	Opaltorget	3849	0.65	0.65	0.65
Grevegården	Grevegårdsvägen 90B	Opaltorget	4252	0.8	0.8	0.75
Näset	Hammarvägen 244	Bergsätersgatan 1	2048	1.3	1.3	0.85
	Rödgatan 18	Bergsätersgatan 1	2048	0.75	0.6	0.55
	Östra Breviksvägen 2-4	Bergsätersgatan 1	2048	0.9	1	0.9
Kannebäck	Rubingatan 25-26	Opaltorget	1062	2.9	0.9	0.9
	Korsåsliden 94	Opaltorget	1062	2.6	1.3	1
	Bronsåldersgatan 14	Opaltorget	1062	0.65	0.6	0.6
Askim	Gamla Särövägen 70	Gärdesvägen 5	10206	1.6	1.4	
Hovås	Hovåsvägen 24	Gärdesvägen 5	1688	1.6	0.85	0.85
	Trollåsvägen 1	Gärdesvägen 5	1688	2.1	1	1
Billdal	Nyhagen 46	Lilla Skintebovägen 2A	5720	0.45	0.4	0.4
	Södra Särövägen 101	Lilla Skintebovägen 2A	5720	2.5	2.5	

Appendix C
Flowchart

The plan *Waste management system, Gothenburg* constitute the main part of the model. The processes linked to transport to stationary RC are only active in the two first scenarios established in the study. The processes connected to transport to mobile RC and mobile RC are active in the two later scenarios. The arrows represent material waste flows and the colour connected to each waste type is stated in the table below.

Colour	**Waste type**	**Amount of waste per citizens and year in west Gothenburg [kg/per*year]**
Blue	Composition of several waste types	-
Cerise	Non-combustible waste	16.7
Dark green	Twigs and branches	15.3
Grey	Metal	29.9
Light green	Textile	0.751 (+ increase in collected textiles*)
Orange	Corrugated cardboard	0.008
Purple	Electrical- and hazardous waste	0.93
Red	Combustible waste (large & small)	40.7
Tan	Garden waste	10.6
Yellow	Bin waste	194

**Only true in the introducing mobile RC and mobile RC scenarios.*


Waste management system, Gothenburg
Process plan: Mass [kg]
The names of the basic processes are shown.
System boundary
System expansion
Transportation of bin waste
Transportation to mobile RC
Mobile RC
Transportation to stationary RC
Stationary RC
Transportation of hazardous waste car
Transhipment center (Electronics- and Hazardous waste)
Division of textile <u-so>
Division of non-combustible waste
Transportation to reuse
Transportation incineration
Reuse
Incineration
Trasportation of hazardous waste to incineration
Transportation to incineration
Transportation to composte
Transportation of filling material
Transportation of hazardous waste to recycling
Transportation to recycling
Transport to landfill

Appendix D

Overview of the emission effecting the three impact categories acidification potential, eutrophication potential and global warming potential.

Stationary RC

Acidification potential (AP)			
	Substance	**kg SO2-Equiv.**	**Substance distribution [%]**
AP		**5,59E-03**	
Total emission to air		**5,59E-03**	**100%**
	SO_2	2,16E-03	39%
	NO	1,87E-03	33%
	NO_2	5,67E-04	10%
	Other NO_x	5,35E-04	10%
	NH_3	4,34E-04	8%
	Other	1,61E-05	0%
Eutrophication potential (EP)			
	Substance	**kg Phosphate-Equiv.**	**Substance distribution [%]**
EP		**1,06E-03**	
Total emission to air		**8,82E-04**	**83%**
	NO	4,85E-04	55%
	NO_2	1,45E-04	16%
	Other NO_x	1,37E-04	16%
	NH_3	9,35E-05	11%
	Other	2,21E-05	2,5%
Total emission to fresh water		**1,67E-04**	**16%**
	NO_3^-	6,59E-05	39%
	N	6,37E-05	38%
	PO_4^{3-}	3,51E-05	21%
	Other	2,81E-06	1,7%
Global warming potential (GWP)			
	Substance	**kg CO2-Equiv.**	**Substance distribution [%]**
GWP		**2,80E+00**	
Total emission to air		**2,80E+00**	**100%**
	CO_2	2,67E+00	95%
	Other	1,28E-01	5%

Implementing mobile RC

Acidification potential (AP)			
	Substance	**kg SO2-Equiv.**	**Substance distribution [%]**
AP		**5,30E-03**	
Total emission to air		**5,30E-03**	**100%**
	SO_2	2,05E-03	39%
	NO	1,78E-03	34%
	NO_2	5,37E-04	10%
	Other NO_x	5,07E-04	10%
	NH_3	4,10E-04	8%
	Other	1,52E-05	0%
Eutrophication potential (EP)			
	Substance	**kg Phosphate-Equiv.**	**Substance distribution [%]**
EP		**1,04E-03**	
Total emission to air		**8,66E-04**	**83%**
	NO	4,78E-04	55%
	NO_2	1,42E-04	16%
	Other NO_x	1,34E-04	15%
	NH_3	9,13E-05	11%
	Other	2,16E-05	2%
Total emission to fresh water		**1,65E-04**	**16%**
	NO_3^-	6,49E-05	39%
	N	6,30E-05	38%
	PO_4^{3-}	3,47E-05	21%
	Other	2,77E-06	2%
Global warming potential (GWP)			
	Substance	**kg CO2-Equiv.**	**Substance distribution [%]**
GWP		**2,70E+00**	
Total emission to air		**2,70E+00**	**100%**
	CO_2	2,68E+00	99%
	Other	2,31E-02	1%

Mobile RC

Acidification potential (AP)			
	Substance	**kg SO2-Equiv.**	**Substance distribution [%]**
AP		**1,83E-03**	
Total emission to air		**1,83E-03**	**100%**
	SO_2	5,45E-04	30%
	NO	8,93E-04	49%
	NO_2	1,37E-04	7%
	Other NO_x	1,41E-04	8%
	NH_3	1,07E-04	6%
	Other	4,25E-06	0%
Eutrophication potential (EP)			
	Substance	**kg Phosphate-Equiv.**	**Substance distribution [%]**
EP		**3,60E-04**	
Total emission to air		**3,13E-04**	**87%**
	NO	2,19E-04	70%
	NO_2	3,30E-05	11%
	Other NO_x	3,41E-05	11%
	NH_3	2,19E-05	7%
	Other	5,77E-06	2%
Total emission to fresh water		**4,63E-05**	**13%**
	NO_3^-	1,44E-05	31%
	N	5,80E-06	40%
	PO_4^{3-}	1,30E-06	22%
	Other	2,48E-05	6%
Global warming potential (GWP)			
	Substance	**kg CO2-Equiv.**	**Substance distribution [%]**
GWP		**6,90E-01**	
Total emission to air		**6,90E-01**	**100%**
	CO_2	6,83E-01	99%
	Other	7,40E-03	1%

Reuse of textile

The avoided virgin production of textile.

Acidification potential (AP)			
	Substance	**kg SO2-Equiv.**	**Substance distribution [%]**
AP		**8,94E-02**	
Total emission to air		**8,94E-02**	
	SO_2	6,63E-02	74%
	NO_x	2,22E-02	25%
	Other	9,00E-04	1%
Eutrophication potential (EP)			
	Substance	**kg Phosphate-Equiv.**	**Substance distribution [%]**
EP		**6,54E-03**	
Total emission to air		**5,98E-03**	**91%**
	NO_x	5,76E-03	96%
	Other	2,20E-04	4%
Total emission to fresh water		**5,62E-04**	**9%**
	COD	3,85E-04	69%
	NO_3^-	7,64E-05	14%
	Other	1,01E-04	18%
Global warming potential (GWP)			
	Substance	**kg CO2-Equiv.**	**Substance distribution [%]**
GWP		**2,10E+01**	
Total emission to air		**2,10E+01**	**100%**
	CO_2	1,95E+01	93%
	Other	1,50E+00	7%