CHALMERS
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To reach a circular economy

Waste streams at Göteborg Energi

Master's thesis in Industrial Ecology

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ABSTRACT

The aim of this master thesis is to be part of Göteborg Energi's transition towards a circular economy. Circular economy means, among others, maximize the value of resources through loop-closing. The purpose of this study is to map the waste streams that arise throughout the value chain of Göteborg Energi. Moreover, a framework that can be used to identify which waste streams that should be prioritized to decrease the environmental impact from waste is presented, and used for the waste stream at Göteborg Energi. In addition, the study identifies Göteborg Energi's contribution towards a circular economy, and what Göteborg Energi can improve to reduce the waste quantities. This is done through personal contacts with the waste contractors, reviewing literatures and internal documents.

The result show that 9274 ton non-hazardous and 1780 ton hazardous waste were generated within Göteborg Energi in 2015. The framework that are developed suggests that the aspects that are important to consider when identifying which waste streams that should be prioritized are covered by three of Sweden's environmental objectives: *reduced climate impact*, *a non-toxic environment,* and a *good built environment*. For a *reduced climate impact* the emissions of $CO_{2\text{-}eq}$ upstream and downstream are calculated. For *a non-toxic environment,* waste streams that may contain *substances that should be phased out* are identified. For *a good built environment,* the *share of each waste stream* and the *waste hierarchy* are used to identify which waste streams that should be prioritized.

This study concludes that the non-hazardous waste streams that should be prioritized within Göteborg Energi are: *ashes, contaminated loads*, *waste to sorting,* and *other non-hazardous waste*. The hazardous waste streams that should be prioritized are: *PCB transformers, other hazardous waste* and *contaminated loads,* followed by *sludge that contain hazardous substances,* and *pylons.* Göteborg Energi is, among others, working with industrial symbiosis and recycling many waste streams. Some of the identified improvements that Göteborg Energi can implement to reduce the waste quantities are: increased recycling rate of recyclable materials, improved purchase of products, verification of chemical content in products, and demand an improved feedback from the waste contractors.

Keywords: Circular economy, Environmental objectives, Industrial Symbiosis, Waste hierarchy.

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Thank you!

Gothenburg, 2017
Felicia Tengdahl

ABBREVIATIONS

CCA	Copper, chromium, arsenic
Cd	Cadmium
CHP	Combined heat and power
CMR	Carcinogenic, mutagenic, toxic to reproduction
CO_2	Carbon dioxide
$CO_{2\text{-eq}}$	Carbon dioxide equivalents
DDT	Dichlorodiphenyltrichloroethane
GHG	Greenhouse gas
GoBiGas	Gothenburg Biomass Gasification project
GWh	Gigawatt hours
GWP	Global warming potential
Hg	Mercury
KM	"Sensitive land use"
LCA	Life cycle assessment
MFA	Material flow analysis
MKM	"Less sensitive land use"
PAH	Polycyclic aromatic hydrocarbons
Pb	Lead
PBT/VPvB	Persistent, bioaccumulative, toxic/very persistent, very bioaccumulative
PCB	Polychlorinated biphenyl
ppm	Parts per million
PVC	Polyvinyl chloride
REACH	Registration, Evaluation, Authorization and restriction of Chemicals
TWh	Terawatt hours
WCED	World Commission on Environment and Development

CONCEPTS AND TERMS

Terms	**Definition used in this master thesis**
Circular economy	Maximize the value of resources by circulation in closed loops.
Disposal	Waste sent to landfill.
Distribution	All activities that are needed to distribute electricity, district heating, cooling and gas.
Downstream	Waste management.
GothNet	GothNet is part of Göteborg Energi. The purpose of GothNet is to own and manage the city network.
Hazardous waste	Certain characteristics of the waste need to be fulfilled, such as ecotoxicity, harmfulness, flammability etc. All waste marked with an (*) in the Swedish waste regulation (2011:927) are classified as hazardous waste.
Industrial symbiosis	Exchange of materials, waste, energy, information and knowledge between for example companies.
Non-hazardous waste	All waste streams that are not classified as hazardous.
Particularly hazardous substances/Substances that should be phased out	Substances that have properties that can cause significant and long lasting effects on humans and/or the ecosystem.
PRIO	Guide for prioritization of substances developed by the Swedish Chemical Agency.
Production	Göteborg Energi's production facilities: GoBiGas, Sävenäs, Rya, Rosenlund, including other smaller facilities.
Support	Includes the office related work at Göteborg Energi's head office at Rantorget.
Take-make-dispose	Resources are taken from nature to produce products that are consumed and thereafter wasted.
Upstream	Extraction of materials and manufacturing of products.
Value chain	All activities within Göteborg Energi that are needed for producing the products and add value to them.
Waste	Object or substance that the user discards.
Waste fraction	Waste fraction means *all* waste streams, for example colored glass and non-colored glass.
Waste hierarchy	Describes in what order waste preferably should be treated: prevention, reuse, recycling, recovery and disposal.
Waste stream	Waste stream is the combination of many waste fractions, for example the waste stream *glass* includes the two waste fractions colored glass and non-colored glass.

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1. INTRODUCTION

This Chapter starts by giving a brief introduction to sustainable development, resource use, existing legislation within the field of waste management, and Göteborg Energi. Afterwards the aim and the objectives are given, followed by delimitations and the outline of this master thesis.

1.1 Background

The most common definition of sustainable development was written in 1987 in the report Our Common Future by the World Commission on Environment and Development (WCED). Today, the report is sometimes referred to as the Brundtlandt report, taken from the lady who was a driving force in the development of the report, Gro Harlem Brundtland. In the Brundtlandt report sustainable development is defined as:

"…development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (World Commission on Environment and Development, 1987)

The definition consider *needs* as well as the importance of collaboration between and within generations. Sustainable development can be divided into three dimensions: economic, social and environmental, which all need to be integrated to reach a sustainable development. (United Nations Environment Programme, 2015) One aspect that is related to sustainable development is the use of resources. According to the definition of sustainable development both intra-, and intergenerational needs should be met, which means that present generations need to leave resources for generations to come. Already in 1972, the authors of the book Limits to Growth tried to warn humanity that there is a limit to growth if the current depletion of non-renewable resources continues (Meadows et al., 2004).

The demand for resources are rising, due to factors such as an increasing population (European Commission, 2014). Krausmann et al. (2009) concludes that the total global extraction of raw materials from 1900 until 2005 has increased from 7 Gt to 59 Gt. Materials are extracted for diverse purposes, during 1900-2005 the extraction of construction minerals such as cement and asphalt stood for the largest increase in material use (Krausmann et al., 2009). The consequence of humanity's constantly increased use of materials is resource depletion of abiotic[1] and biotic[2] resources (United Nations Environment Programme, 2010).

[1] Fossil fuels and metals
[2] For example, biomass and fishes

Overshoot Day is estimated each year by the organization Global Footprint Network. The Overshoot Day is the day each year that the population has used the budget of natural resources reproduce by the earth during the year (Global Footprint Network, 2017). Year 1987, when the definition of sustainable development in the Brundtlandt report was written (World Commission on Environment and Development, 1987), the Overshoot Day was the 24th of December. Twenty-nine years later in 2016 the Overshoot Day was the 8th of August, which means that the global population consumes more than what is regenerated in nature. In 2016, the earth's population would need 1.6 planets to produce the same amount of resources that were consumed during the year. (WWF, 2016) After the resources are used the residual materials ends up as waste or emissions (United Nations Environment Programme, 2010). In Gothenburg year 2015, the average quantity of household waste per person was 401kg (Göteborgs Stad, 2017a).

The historical approach, that origin from the industrial revolution, to manage resources is the linear model or *take-make-dispose,* see Figure 1 (Andrews, 2015). Explicitly: resources are taken from nature, through manufacturing processes and additional energy, to make products. The products are distributed and sold to consumers, used, and thereafter treated as waste to be disposed or incinerated for energy recovery. This approach means that virgin materials are exploited, often faster than they can be replaced, and after usage are considered as waste. (Ellen MacArthur Foundation, 2013) The linear use of resources for a constantly increasing production is according to Meadows et al. (2004) not feasible, because the worlds resources are limited. The inefficient and unsustainable use of resources results in unnecessary high extraction rates of raw materials, generation of waste and consumed energy (Ellen MacArthur Foundation, 2013). One way to avoid the unsustainable use of resources is to rethink the linear model to make it circular.

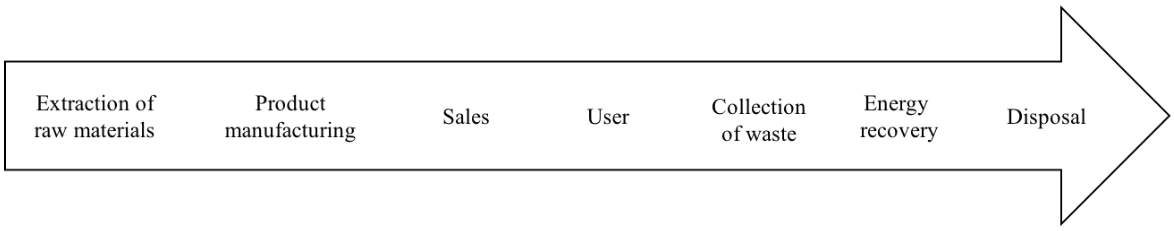

Figure 1. The linear flow of resources, from extraction to disposal, based on Ellen MacArthur Foundation (2013).

Circular economy is based on the notion of "loop-closing", where the aim is to minimize the extraction of raw materials and waste quantities. One way to approach circular economy is to increase the recycle and/or reuse rate, through for example a design that allows the products to be easy to disassemble or built on materials that can be renewed. In a circular economy, resources should be used as efficient as possible and waste should be considered as raw materials. (Naturvårdsverket, 2016d) The benefits of loop-closing such as recycling and reuse are not only to minimize the raw material extraction, but also to decrease the energy and water usage, create jobs and minimize the amount of waste generated (Stahel, 2016).

The European Union implemented a new Waste Directive in 2008 (2008/98/EG) (European Commission, 2008), which for example includes the waste hierarchy, waste management, and requirement that member countries shall promote reuse and recycling. The EU Waste Directive was introduced in the Swedish legislation through a waste regulation (2011:927) and a new chapter (15) in the Swedish Environmental Code (Naturvårdsverket, 2016j). One of the requirements from the EU Waste Directive is that the member countries shall have a waste management plan and a waste prevention program. Sweden fulfils this requirement through a national waste management plan in 2012-2017, a waste prevention program in 2014-2017 (Naturvårdsverket, 2012) both established by the Swedish Environmental Protection Agency, and a local waste management plan in every municipality. (Naturvårdsverket, 2016k) Besides that, Sweden apply a producer responsibility principle, thus the producer of selected products has the responsibility to collect and take care of the used products (Naturvårdsverket, 2016l). In addition, Sweden has 16 environmental objectives and one generational objective, which were introduced in 1999. Waste prevention contributes to the achievement of three of the environmental objectives, *reduced climate impact*, *a non-toxic environment,* and *a good built environment*. (Naturvårdsverket, 2015)

The region of Gothenburg, including Ale, Alingsås, Gothenburg, Härryda, Kungsbacka, Kungälv, Lerum, Lilla Edet, Mölndal, Partille, Stenungsund, Tjörn and Öckerö, has implemented a waste management plan that should be a guide through the whole chain of waste management. The plan consists of five overall goals set until 2020, and proposed actions for each goal. (Göteborgs Stad, 2011b) The city of Gothenburg has, besides the waste management plan, selected twelve of the national environmental objectives that are important for Gothenburg and specified own sub-goals for each one of the twelve objectives. The three objectives where waste prevention can contribute, *reduced climate impact, a non-toxic environment*, and *a good built environment* are all selected by the municipality of Gothenburg as three out of twelve environmental objectives that affect the city. (Göteborgs Stad, 2016b)

Göteborg Energi is an energy company that offers electricity, district heating, cooling, gas and other energy services. The company is owned by the municipality of Gothenburg and have facilities within and around Gothenburg, Sweden. All processes within the value chain of the company, from purchase through production and distribution to sale, service and support, cause creation of waste. (Göteborg Energi, 2015) Göteborg Energi wants to comply with the goals and regulations on a national, regional and local level, contribute to more sustainable use of resources and be in the forefront of circular thinking (Björkman, 2017). An analysis of the current condition is needed as a first step to work proactively and increase the circularity within the company. Hence, there is a need to identify and map the waste streams within the value chain of Göteborg Energi. An identification of the waste streams is the primary way to understand which streams that should be prioritized from an environmental perspective, and what opportunities for improvements that are achievable. The purpose of this study is to fulfill that gap.

1.2 Aim

The aim of this master thesis is to contribute to Göteborg Energi's transition towards a circular economy.

1.3 Objectives

The objectives that this study is intended to answer are given below.

1. Identify and map the waste streams that arise throughout the value chain of Göteborg Energi.
2. Develop a framework that can be used to identify which waste streams that should be prioritized to decrease the environmental impact from waste.
3. Based on the framework, identify which waste streams throughout the value chain of Göteborg Energi that should be prioritized.
4. Identify Göteborg Energi's contribution to the transition towards a circular economy today and what Göteborg Energi can improve to reduce the waste quantities and aim for circularity.

1.4 Delimitations

The *value chain* within Göteborg Energi is shown in Figure 2, from purchase to production, distribution, sales, service and support, and final product used by the consumers. In this master thesis, *value chain* is used as a description of all activities within Göteborg Energi that are needed for producing the products (electricity, district heating, cooling, gas and other energy services) and add value to them. The primary activities considered in this master thesis are supporting procedures (office related work), production and distribution.

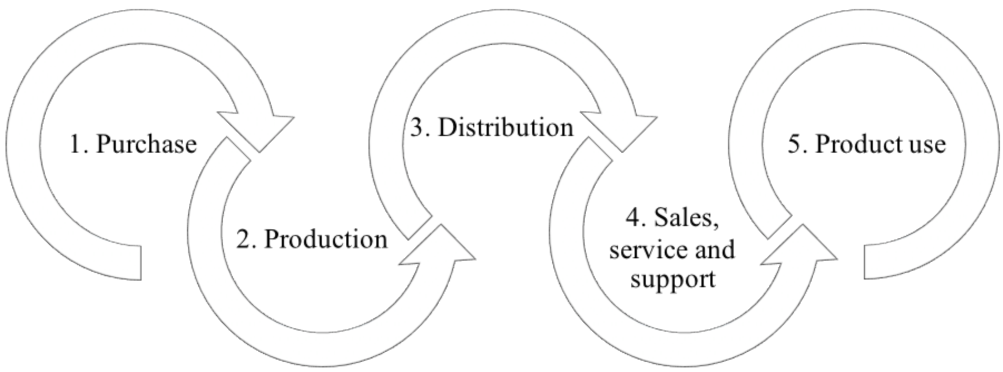

Figure 2. The value chain within Göteborg Energi.

This study is delimitated to not include the residues and waste that arise from the materials used to produce electricity, district heating, cooling and gas. Hence, only the waste streams from the supporting processes around the district heating, electricity, cooling and gas production such as maintenances, distribution, extension, and office work are considered. The study is delimited to cover the waste quantities generated during 2015. The study does not allocate the waste streams between the various products electricity, district heating, cooling and gas.

In order to present a framework over what waste streams that should be prioritized, the study is delimited to consider critical waste streams from an environmental perspective. The environmental perspective is delimited to cover three of Sweden's environmental objectives: *a reduced climate impact, a non-toxic environment*, and *a good built environment*. *A reduced climate impact* considers emissions of carbon dioxide equivalents ($CO_{2\text{-}eq}$) from upstream[3] and downstream[4]. *A non-toxic environment* cover the content of *substances that should be phased out* in the waste streams, and is due to time limits delimited to only cover *hazardous waste* streams within Göteborg Energi. *Hazardous waste* streams were chosen because to be classified as *hazardous* certain characteristics of the waste need to be fulfilled such as, ecotoxicity, harmfulness, flammability, toxicity and explosiveness. (European Commission, 2008). This means that the hazardous waste streams have higher potentials to contain *substances that should be phased out* compared to the non-hazardous waste streams. *A good built environment* embraces the share of the total mass for each waste stream and the waste hierarchy.

Strategies to reach a circular economy can focus on the whole value chain. This study is delimited to only compile information downstream, i.e. compilation of waste streams. Upstream is excluded due to time constrains and insufficient information since Göteborg Energi buys services and used materials that are hard to trace. The strategies for improvements are likewise delimited to emphasize the downstream, i.e. close loops, minimize waste and work proactively.

1.5 Outline of the report

This master thesis is divided into nine Chapters. Chapter 1 consists of background information, presents the aim, objectives and delimitations. The following Chapters 2 to 5 introduces *circular economy*, current *legislation* within waste management, perspectives on what *waste streams to prioritize*, and a short presentation of *Göteborg Energi*. The method is presented in Chapter 6 which is divided into four sections, one section per objective. Each section in Chapter 6 describes the methodology and materials used to answer the objectives. The result from the study is divided into four sections, one section per objective, and are presented in Chapter 7. Chapter 8 discusses the result and the methodology in relation to the objectives, followed by recommendations for further studies. Conclusions in relation to the objectives are given in Chapter 9.

After Chapter 9, the references are provided, followed by additional information comprised in an appendix.

[3] Extraction and manufacturing

[4] Waste management

2. CIRCULAR ECONOMY

The intention of the following Chapter is to introduce the reader to circular economy.

The *idea* of circular economy is nothing new, similar concepts have emerged since the 1970's. Concepts such as *cradle-to-cradle*, *performance economy*, *industrial ecology*, *biomimicry*, *blue economy*, *natural capitalism* and *regenerative design* have shaped the path to the circular economy. (Ellen MacArthur Foundation, 2015) Reid Lifset and Thomas E. Graedel (2002) define *industrial ecology* by dividing the concept into *industrial* and *ecology*, where *industrial* is the perspective of the industries' and companies' ability to design products, and use technologies that minimize the environmental impact. *Ecology* refers to the ecosystem that surround all human activities and maintain vital functions such as regulating and provisioning services. *Ecology* is also referred to as the effectiveness of systems where resources are recycled in the ecosystem, something that industry can apply and learn from. Within *industrial ecology* some strategies are highlighted such as *loop-closing*, *eco-design*, *dematerialization* and the need for a *system perspective* where material flow analysis (MFA) and life cycle assessment (LCA) are appropriate tools (Lifset and Graedel, 2002). Some of these strategies are the core in a circular economy and described further in this Chapter.

With some similarities to *industrial ecology*, *cradle-to-cradle* seeks to redesign products in a way that eliminate the generation of waste. McDonough and Braungart (2003) describes that materials should circulate in closed loops in a cradle-to-cradle design, where the sun is the energy source for all industrial and natural processes (McDonough and Braungart, 2003).

The *performance economy* is explained by Walter R. Stahel (2010) in the book "The Performance Economy". A *performance economy* means a change to a more sustainable economy where products are designed to contain fewer hazardous substances and generate less waste, which in turn means that the products have a minimized environmental impact. In a *performance economy* goods and products are valuable resources and should circulate in closed loops in the economy through for example reuse and remanufacturing. Another part of the *performance economy* is to change the business model from selling a product to selling a service. (Stahel, 2010) The characteristics described are recognized in the concept of circular economy.

As mentioned, the *idea* of *circular economy* has existed for 40 years but been given new strength in the past years. The Ellen MacArthur Foundation is one of the driving forces in the development of circular economy. The foundation was introduced in 2010 and has since then published reports within the field of circular economy, and collaborated with the private and public sector as well as the academia. The foundation aims to increase the knowledge and speed of the changeover from a linear to a circular economy. (Ellen MacArthur Foundation, 2017a) Circular economy is by the Ellen MacArthur Foundation described as:

"A circular economy is restorative and regenerative by design, and aims to keep products, components, and materials at their highest utility and value at all times. The concept distinguishes between technical and biological cycles."
(Ellen MacArthur Foundation, 2017b)

As explained in the citation, one aim with circular economy is to maximize the value of the resources, which can be completed by loop-closing and by using waste as a resource. Circular economy aims to, not only minimize the environmental impacts through reduced resource and energy use, but also increase profits for companies. (Ellen MacArthur Foundation, 2013) Some of the aims with a circular economy is to reduce:

- Use of chemicals
- Use of resources
- Use of energy in general, and energy from fossil sources in particular
- The generation of waste
- Costs

One approach to increase the resource efficiency and partnership among companies is through *industrial symbiosis*. *Industrial symbiosis* means according to Chertow (2000) an exchange of materials, energy and waste between companies, which means that one's waste can be another's resource. One of the first recognized examples of *industrial symbiosis* is Kalundborg in Denmark where enterprises exchange water, steam, electricity, materials etc. (Chertow, 2000). Twelve years after Chertows definition of *industrial symbiosis*, Lombardi and Laybourn (2012) added other aspects to the definition, such as the potential profits from a business perspective and the exchange of other parameters such as knowledge and experience (Lombardi and Laybourn, 2012).

Circular economy enables economic gains, for example reduced cost of materials and savings from reduced waste management and energy use. The highest profit from an economic and environmental perspective is to make the loops as small as possible, which means to maintain before reusing, reuse before remanufacturing, and remanufacture before recycling. (Ellen MacArthur Foundation, 2013) Making the loops as small as possible is supported by the EU Waste Directive (2008/98/EG) through the waste hierarchy (see Chapter 3) (European Commission, 2008). Other aims of a circular economy could result in better environmental quality through less extraction of raw materials, reduced emissions, less toxic chemicals released into the ecosystem etc. (Ellen MacArthur Foundation, 2013). Different strategies are used to reach the intentions of a circular economy, some of them are listed below and described further in the text.

- **Recycling**
  Recycling means that the discarded materials are collected to for example be melt together to produce the same or another product (Ellen MacArthur Foundation, 2013).

- **Reuse**
  For some products, it is possible to reuse them repeatedly to satisfy the same needs. As an example, the use of plates and glasses that are washed after finishing the lunch and used the day after. (Ellen MacArthur Foundation, 2013)

- **Remanufacturing**
  If only some components of a product are damaged, remanufacturing makes it possible to replace the parts that are broken, which prolong the life length of the product (Ayres and Ayres, 1996).

- **Repair**
  If a product is broken it can be repaired to prolong the life length and allow the product to be used for the same purpose (Ayres and Ayres, 1996).

- **Redesign**
  One of the core stones in a circular economy is to design products in a way that eliminate the generation of waste after usage. Designs can make products easy to disassemble or reuse, as well as minimize the use of chemicals and resources. (Ellen MacArthur Foundation, 2013)

- **Dematerialization**
  Dematerialization is as the name indicate a strategy of using less materials to produce a certain service (Ayres and Ayres, 1996).

- **Substitution**
  The strategy of substitution means that one material is replaced by another, which is appropriate if the aim is to reduce the use of toxic chemicals (Ayres and Ayres 1996).

- **Functional service**
  A common business model is that a company produce and sell a product to the consumer, whom *consume* it. Functional service changes the way of thinking regarding ownership. One example is that companies instead of selling a product could provide the service of buying the opportunity to *use* a specific product, which means that companies are responsible for the product after usage. (Ellen MacArthur Foundation, 2013)

In 2015, the European Commission published an action plan for closing the loop and move towards a circular economy. The action plan aims to minimize the waste that are generated, create new jobs and recirculate resources in the economy as long as possible. The plan includes strategies from a life cycle perspective including production, consumption and waste management. Important strategies within the action plan are to increase the reuse and recycling rate. (European Commission, 2015) Waste management is, according to the action plan written by the European Commission (2015), an essential part of circular economy and should be grounded in the waste hierarchy (European Commission, 2015).

The Swedish Government is in favor of the proposed action plan and highlight circular economy in EU as a matter of priority (Regeringskansliet, 2015). In 2016, the Swedish Government started an investigation regarding policy instruments that could be used to prevent the generation of waste and aim for circularity. The final report from the investigation was published in Mars 2017 and highlight, among others, that municipalities and governmental agencies can act as good examples in the effort towards preventing the generation of waste. (Alterå, 2017)

3. LEGISLATION

This Chapter highlight existing laws and regulations within the field of waste management.

In EU, the govern legislation regarding waste is the EU Waste Directive (2008/98/EG) implemented in 2008 (European Commission, 2008). The Directive is applied in the Swedish legislation through the Swedish waste regulation (2011:927) and chapter 15 in the Swedish Environmental Code (1998:808, chapter, 15). Sweden has in addition to this implemented 16 environmental objectives and one generational objective (Naturvårdsverket, 2016d). This Chapter aims to cover the EU Waste Directive, national and regional legislation.

3.1 EU Waste Directive (2008/98/EG)

The current Waste Directive in EU (2008/98/EG) was implemented in 2008. The Directive gives definitions regarding classification of waste, waste management etc. Waste is in the Directive defined as an object or substance that the user discard and should according to the European Commission's action plan towards a circular economy (European Commission, 2015) and the EU Waste Directive (European Commission, 2008), be managed based on the waste hierarchy, see Figure 3.

The first level of the waste hierarchy, *prevention*, underline that the generation of waste shall as a priority be prevented. If prevention is impossible and waste is generated, the waste hierarchy indicate what waste treatment method that should be applied and in which order. Waste should after prevention be *reused*, and thirdly *recycled*. The fourth opportunity is to use waste for *recovery* (for example energy recovery). The last and least desirable step is that the waste is *disposed*. (European Commission, 2008)

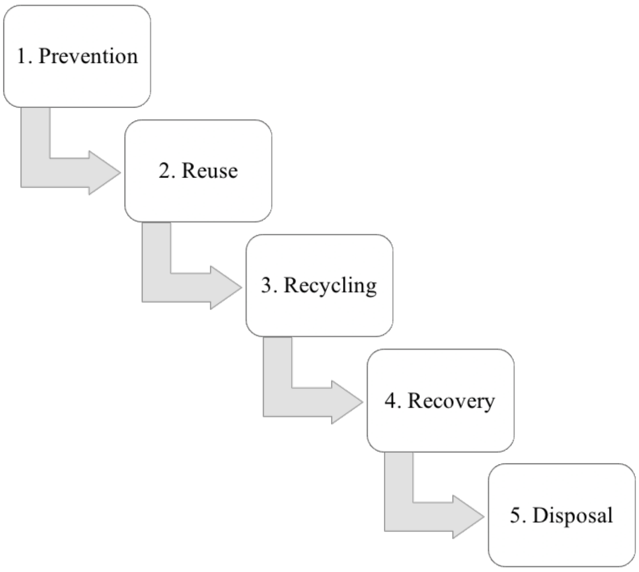

Figure 3. The waste hierarchy, based on the European Commission, (2008).

Other requirements emphasized in the EU Waste Directive are that the producer shall be responsible for the product after usage, and the polluter-pays principle. The polluter-pays principle is a guide for whom that is carrying the cost for the waste management. Included in the EU Waste Directive is a chapter describing the plans and programs that the member states should implement as part of the work towards decreasing the waste quantities. One obligation is to have a waste management plan, describing the current condition in the country, and how the country plan to make improvements in line with the EU Waste Directive. Furthermore, the member states should have a waste prevention program where goals for further waste prevention should be stressed. (European Commission, 2008) Sweden fulfils these requirements through a national waste management plan in 2012-2017 (Naturvårdsverket, 2015), and a local waste management plan in each municipality (Naturvårdsverket, 2016j).

3.2 National legislation

The EU Waste Directive was implemented in Sweden through a waste regulation (2011:927) and chapter 15 in the Swedish Environmental Code. The Swedish Environmental Protection Agency is according to the waste regulation (2011:927) responsible for the national waste management plan requested by the EU Waste Directive. The regulation includes descriptions of what a municipal waste management plan should include as well as how waste should be treated. (2011:927)

3.2.1 The Swedish Environmental Code (1998:808, chapter, 15)

The Swedish Environmental Code was implemented the first of January 1999 and includes environmental regulations that aims to promote a sustainable development. The Environmental Code is divided into seven major areas, 33 chapters, and paragraphs within each chapter. Chapter 15 named "waste" is the Swedish response to the EU Waste Directive (2008/98/EG). Chapter 15 includes, among others, definition of waste, the waste hierarchy, producer responsibility, municipal responsibility, and waste management. (1998:808)

The producer responsibility is explained in chapter 15 in the Swedish Environmental Code. (1998:808) The producers of certain products, see list below, have the responsibility to collect and take care of their used products. One of the intentions with this policy instrument is to make the producers more aware and increase the willingness to produce products from less materials including fewer hazardous substances. (Naturvårdsverket, 2016j)

- Batteries
- Cars
- Electrical and electronic waste
- Packaging
- Pharmaceutical products
- Radioactive products and orphan sources
- Recyclable papers
- Tires

3.2.2 Waste management plan 2012-2017

As a complement to the Swedish waste regulation (2011:927) and the Environmental Code, the waste management plan aims to promote conservation of resources and work for an always improving waste management system. Five highlighted areas, see list below, are defined in the waste management plan along with goals and actions within each area. (Naturvårdsverket, 2012)

- Household waste
- Illegal export of waste
- Resource management in the food chain
- Waste management in the construction sector
- Waste treatment

The existing waste management plan is valid to December 2017. At present the Swedish Environmental Protection Agency work with a new waste management plan and waste prevention program for 2018-2023, which will include a description of the present situation and potential improvements. (Naturvårdsverket, 2017c) As prevention of waste is the priority according to the waste management plan and the waste hierarchy, the Swedish Environmental Protection Agency has published a report with a program for prevention of waste valid between 2014-2017 (Naturvårdsverket, 2015).

3.2.3 Waste prevention program 2014-2017

As a complement to the waste management plan, each member state should according to the EU Waste Directive (2008/98/EG) present a program for prevention of waste. The Swedish Environmental Protection Agency is responsible for producing and publishing the report for the program in Sweden. The existing waste prevention program is valid between 2014-2017, after year 2017 a new program is planned to be published. Included in the program are goals, actions to reach the goals, as well as actions that already have been implemented. Prevention of waste means that actions are taken before waste is generated such as, use less materials for a certain function, plan the purchase to eliminate waste and borrow instead of buy new. Four prioritized areas are selected in the program. Table 1 show the four prioritized areas together with reasons for why they were selected. (Naturvårdsverket, 2015)

Table 1. Four prioritized areas in the waste prevention program, together with explanations for why they were selected (Naturvårdsverket, 2015).

Prioritized areas	**Reasons**
Construction and demolition waste	o Large quantities o Large amounts of greenhouse gas (GHG) emissions from cradle to grave
Electrical and electronic waste	o Large amounts of GHG emissions per kg o Contains hazardous substances
Food waste	o Large quantities o Large amounts of GHG emissions from cradle to grave
Textile waste	o Large amounts GHG emissions per kg o Contains hazardous substances

3.2.4 Environmental objectives

In addition to previously mentioned legislations, plans and programs, Sweden has implemented 16 environmental objectives and one generational goal (Naturvårdsverket, 2016d). Waste prevention contributes to the achievement of three of the 16 environmental objectives: *reduced climate impact, a non-toxic environment,* and *a good built environment*, as well as the *generational goal*.

To reach the environmental objective of a *reduced climate impact* the emissions of GHGs need to decrease to a level that does not impact the climate system. Throughout the process of waste management emissions of GHGs occur during incineration of plastic, transport, biological treatments, and biodegradable waste at deposition. (Naturvårdsverket, 2012)

A *non-toxic environment* emphasizes the need for eliminating the man-made toxic substances that can harm humans or the ecosystem. Some of the waste that is generated contains hazardous substances and the management of waste is therefore affecting the objective. (Naturvårdsverket, 2012)

The aim with a *good built environment* is that areas who are built (cities or other settlements) should offer a decent environment for living. Included in this objective is a description that says that the waste management should be easy and efficient, resources should be used as efficient as possible and waste prevented. (Naturvårdsverket, 2012)

The main aim with the *generational objective* is to leave a society, for the generation to come, where the major environmental problems are solved. Some of the actions that are related to waste management and need to be applied for generations to come are: efficient use of resources, reduced use of toxic substances and better management of resources. (Naturvårdsverket, 2012)

3.3 Regional legislation

Every municipality shall have a waste management plan, which is to be regulated in the EU Waste Directive (2008/98/EG) (European Commission, 2008), the Swedish Environmental Code (1998:808, chapter, 15), the Swedish waste regulation (2011:927) and a regulation (NFS 2006:6) by the Swedish Environmental Protection Agency. In the regulation (NFS 2006:6), it is defined what a municipality must include in the municipal waste management plan. The waste management plan is required to contain a description of the current condition, goals, actions and monitoring. (Naturvårdsverket, 2006)

The region of Gothenburg, including Ale, Alingsås, Gothenburg, Härryda, Kungsbacka, Kungälv, Lerum, Lilla Edet, Mölndal, Partille, Stenungsund, Tjörn and Öckerö, has together implemented a waste management plan that lasts until 2020, and intends to be a guide through the whole chain of waste management. One important strategy expressed in the plan is to use waste as a resource and apply the waste hierarchy. The plan consists of five overall goals, see list below, and sub-goals within each goal. All goals are established from a sustainability perspective including the social, economic and environmental dimensions. The waste management plan includes proposed actions to reach each goal. (Göteborgs Stad, 2011b)

- **Safety for humans and the environment**
  Including resource efficiency, prevention, reuse, reduced emissions and use of hazardous substances.

- **A good security and working environment**
  Injuries and accidents within waste management should be reduced.

- **A cost-effective waste management**
  The waste management should be at a high quality in relation to the cost.

- **Good service**
  The households should be satisfied with the current waste management.

- **A robust waste management**
  The competence within waste management should be high, and waste management should be part of the city planning.

The municipality of Gothenburg has as part of their environmental work selected 12 of Sweden's 16 environmental objectives that are connected to the city of Gothenburg and established its own sub-goals (Göteborgs Stad, 2016b). The three objectives where waste prevention can contribute according to the Swedish Environmental Protection Agency, *reduced climate impact, a non-toxic environment,* and *a good built environment* (Naturvårdsverket, 2012), are all selected by the municipality of Gothenburg as three out of twelve environmental objectives that affect the region.

Sub-goals to the objective of a *reduced climate impact* is to reduce the emissions of GHGs in general and carbon dioxide (CO_2) in particular, from consumption and production. The objective also highlight the need for a decreased energy consumption. (Göteborgs Stad, 2016b) The city of Gothenburg has developed a strategic plan for the climate, as part of the work towards a *reduced climate impact*. The strategic plan includes long-term goals and actions that aims to reduce the climate impact and emissions of GHGs until 2050. Strategies to reduce emissions of GHGs, CO_2, and the energy consumption are divided into five areas. Two of the areas are connected to waste management: *a better resource efficient urban planning* and *a climate conscious consumption*. (Göteborgs Stad, 2014b)

Two of the sub-goals within the objective *a non-toxic environment* are: substances that should be phased out must not be used or released, and contaminated areas should not harm humans or the environment. (Göteborgs Stad, 2016b) The city of Gothenburg has developed a chemical plan, as part of the work towards *a non-toxic environment*. Four strategies to reduce the use of chemicals are highlighted: introduce a chemical council, document, phase out hazardous substances classified as "substances that should be phased out", and procure non-toxic. (Göteborgs Stad, 2014a)

A good built environment, include one sub-goal highly relevant for waste management: reduced quantities of waste and more efficient use of resources (Göteborgs Stad, 2016b). The goals in *a good built environment* has been developed in parallel to the previously mentioned waste management plan in Gothenburg (Göteborgs Stad, 2011a).

Figure 4 show the connection between Sweden's environmental objectives, the city of Gothenburg's environmental objectives, the strategic plan, the chemical plan, and the waste management plan in Gothenburg.

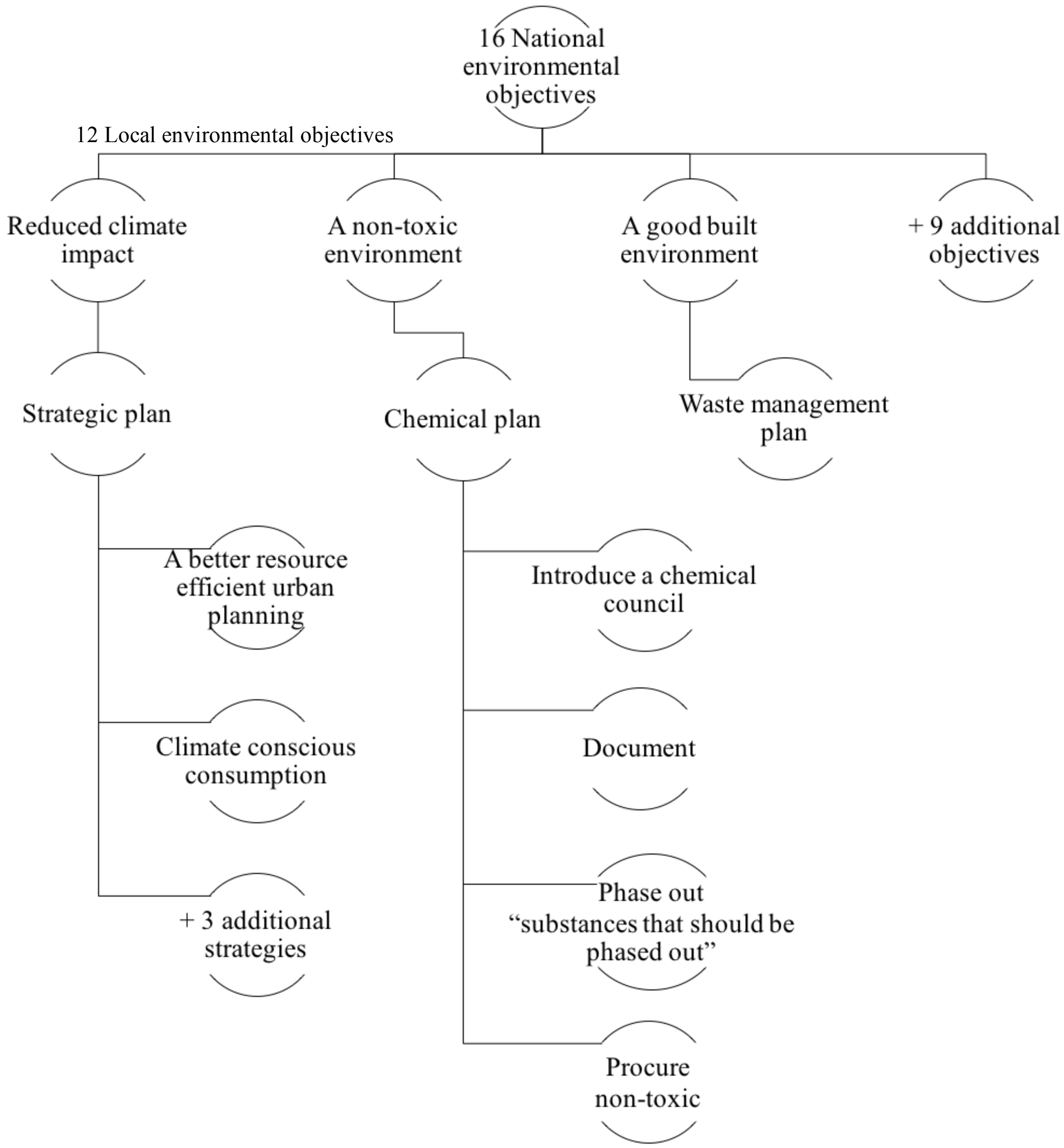

Figure 4. Sweden has 16 environmental objectives, the city of Gothenburg has selected 12 of them and established a strategic plan to reach the objective: reduced climate impact, and a chemical plan to reach the objective: a non-toxic environment. The goals in a good built environment has been developed in parallel to the waste management plan in Gothenburg. The figure is based on Göteborgs Stad (2014a), Göteborgs Stad (2014b), and Göteborgs Stad (2011a).

4. PRIORITIZED WASTE STREAMS

The purpose of this Chapter is to describe various authors viewpoint on how to evaluate what waste streams that could be considered critical, and for that reason be prioritized.

There are various perspectives to consider when evaluating what waste streams that should be prioritized. This Chapter intends to describe what waste streams that should be prioritized according to the European Commission's *action plan towards a circular economy*, Sweden's environmental objective *a non-toxic environment* in general, and *hazardous properties* in particular.

The European Commission (2015) define as part of their *action plan towards a circular economy* five areas that should be prioritized in a circular economy. The five prioritized areas *plastic*, *food waste, critical raw materials, construction and demolition,* and *biomass and bio-based products*, are described further in the text. (European Commission, 2015)

Plastic is chosen as a category because there are major problems associated with plastics, such as the large amounts that enter the ocean. For managing plastic related problems, the European Commission highlight the need to increase the amount that is recycled and emphasize better design. (European Commission, 2015)

Food waste is prioritized because it is an issue in Europe as it is connected to a high resource use and environmental problems (European Commission, 2015). The use of fertilizer during cultivation and production of food causes an increased release of nitrogen, that pollutes lakes and rivers (Rockström et al., 2009). The Food and Agriculture Organization (2013) emphasize several environmental problems caused by food that are wasted. GHGs are emitted during the life cycle of food, large land areas are used, large quantities of water consumed, and the production of food affect the biodiversity at production areas (Food and Agriculture Organization, 2013).

The third area that should be prioritized is *critical raw materials* (European Commission, 2015). The European Union has defined 20 raw materials that can be considered critical from a supply and economic significance perspective, see Appendix A. Some of the raw materials are not produced in EU and the need for imports are therefore high. (European Commission, 2017) The critical raw materials are frequently used in electronic equipment, and the mining has the potential to be harmful to the environment. At present the European Commission is working on a report that aims to define raw materials that could be considered critical in a circular economy. (European Commission, 2015)

Materials from *construction and demolition* are one of the European Commissions prioritized areas because of high quantities of waste. As with plastic, the recycling rate need to increase. (European Commission, 2015)

The production of *biomass and bio-based products* are competing with for example food production regarding land-use, hence it is important to keep the bio-based products in the biological cycle as long as possible through reuse and recycling. (European Commission, 2015)

Another perspective that can be used to identify critical waste streams is based on the content of *particularly hazardous substances*. One of the sub-goals specified in Sweden's environmental objective *a non-toxic environment* described in section 3.2.4 is the reduction and elimination of *particularly hazardous substances* (Naturvårdsverket, 2016d). *Particularly hazardous substances* have properties that could cause significant and long lasting effects on humans and/or the ecosystem (Kemikalieinspektionen, 2017a). As part of Registration, Evaluation, Authorization and restriction of Chemicals (REACH) a list over a bit less than 200 hundred *particularly hazardous substances* has been published. (Kemikalieinspektionen, 2017d).

A study by the Swedish Environmental Protection Agency (2016) shows that the waste streams that should be given extra attention because they may contain *particularly hazardous substances* are: *Polyvinyl Chloride (PVC)* (one of the most common plastic polymers), *plastics from cars* and *electrical equipment*, as well as *recycled tires used as artificial grass*. If plastics are recycled properly and separated from parts that should not be recycled because of hazardous properties, the profits of recycling can be reduced emissions of GHGs because the plastics replace the use of virgin materials. (Naturvårdsverket, 2016b) A rough indicator of the material gains from increased recycling is the quantities of waste and whether materials origin from renewable or non-renewable sources (Sternbeck et al., 2016).

A third approach to identify waste streams to prioritize is to divide *hazardous waste* and *non-hazardous waste*. *Hazardous waste* is defined in the EU Waste Directive (2008/98/EG). To be classified as *hazardous* certain characteristics of the waste need to be fulfilled such as, ecotoxicity, harmfulness, flammability, toxicity and explosiveness. (European Commission, 2008). Appendix 4 in the Swedish waste regulation (2011:927) consists of a list over various types of wastes, where those that possess hazardous properties are marked with an (*). Examples of *hazardous waste* are: sludge containing oil, mercury, organic solvent and sulfuric acid. (2011:927)

Concluding remarks

What waste streams that should be prioritized can be determined depending on various perspectives. The European Commission has a broad foundation and focus on waste streams that causes environmental problems, has economic or social implications, and are generated in large quantities. Another perspective is to prioritize the waste streams that are *hazardous* or contain *particularly hazardous substances*.

5. GÖTEBORG ENERGI

The following Chapter introduces Göteborg Energi.

Göteborg Energi is an energy company that offers electricity, district heating, cooling, gas and other energy services. The head office is located in the center of Gothenburg at Rantorget, but Göteborg Energi owns and manages plants and powerlines all over Gothenburg. (Göteborg Energi, 2016)

The district heating that is distributed in Gothenburg origin mainly from surplus heat from incineration of waste at Renova[5], and surplus heat from industrial processes and wastewater. The electricity is produced from non-renewable and renewable energy sources in combined heat and power plants (CHP), as well as from wind power. In a CHP, electricity and energy are produced simultaneously. Cooling is produced from various plants and from cold water retrieved from Göta älv that flow through Gothenburg. (Göteborg Energi, 2015) The production of biogas in the project Gothenburg Biomass Gasification Project (GoBiGas) is a research and development project that aims to increase the production of biogas from excessive materials from forestry (Göteborg Energi, 2017a).

Göteborg Energi operates on behalf of the customers that demand energy. Materials and fuels are needed for production, and supporting processes around the production, for example maintenance of powerlines, office work and distribution. Figure 5 show a simplified flowchart over inflows and outflows to and from Göteborg Energi. Within the dashed lines are the activities within Göteborg Energi. Göteborg Energi buys materials from retailers, collects all waste that are generated within the processes, and hire waste contractors to retrieve and treat the waste. Some of the waste streams are recycled to be used again by manufacturing companies, other waste streams are incinerated for energy recovery.

[5] Renova is a waste management and recycling company in Gothenburg.

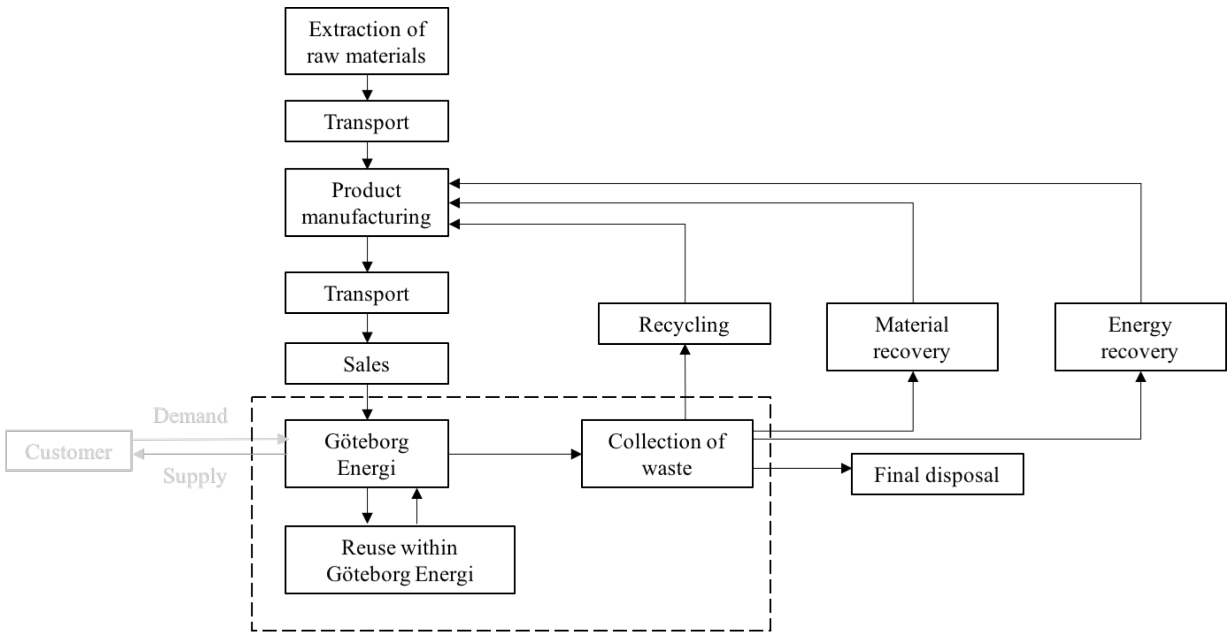

Figure 5. Flowchart over the inflows and outflows to and from Göteborg Energi.

Göteborg Energi wants to minimize the environmental impact from the operations within the company and provide conditions for customers to easily make sustainable choices. Göteborg Energi has a vision to work for *"a sustainable city of Göteborg",* a vision that should be integrated in all activities within the business. (Göteborg Energi, 2017d) During 2016 Göteborg Energi chose to focus on the two environmental objectives: *a non-toxic environment* and *a reduced climate impact* (Göteborg Energi, 2016).

Energy is needed for many purposes such as in transport, production of goods and services, for heating, cooling and light (Energimyndigheten, 2015). The production of electricity, district heating, cooling and gas within Göteborg can be divided into five areas: combined heat and power, district heating, wind power, biogas and cooling. Table 2 outline the product delivered to consumers in 2014, 2015 and 2016. (Göteborg Energi, 2016)

Table 2. Biogas, cooling, district heating and electricity delivered to consumers in 2014, 2015 and 2016 (Göteborg Energi, 2016).

Source of energy	**Product to consumer 2016 (GWh)**	**Product to consumer 2015 (GWh)**	**Product to consumer 2014 (GWh)**
Biogas*	162	170	146
Cooling	89	80	90
District heating	3586	3358	3280
Electricity from CHP, (natural gas)	615	248	242
Electricity from CHP, (renewable)	41	46	40
Electricity from wind	79	95	81

* Producing, upgrading and liquefaction of biogas

After production, the electricity, gas, cooling and district heating are distributed to the consumers through powerlines. A prerequisite to receive electricity delivered home is to be connected to the electricity supply network. Göteborg Energi is responsible for the maintenance and development of the powerlines in Gothenburg. (Göteborg Energi, 2017c) The powerlines are around 9000 kilometers (Göteborg Energi, 2015) and 94% of them are located underground (Göteborg Energi, 2017c).

After distribution and sale to consumers the electricity, district heating, cooling and gas can have different applications. Natural gas and biogas are for example used for heating, cooking, or as fuel. (Göteborg Energi, 2017e) District heating is a source for heat, and electricity has many applications such as power for the trams in Gothenburg (Göteborg Energi, 2015). The final energy consumed in Sweden year 2013 was 375 terawatt hours (TWh) (Energimyndigheten, 2015). Göteborg Energi delivered 3.358 TWh district heating and 0.389 TWh electricity to the consumers in Gothenburg during 2015 (Göteborg Energi, 2015).

Göteborg Energi works toward a non-toxic environment, where waste management is an essential component. Aspects of the present work with waste management is to phase out hazardous substances and chemicals, demand higher requirements on new products and use resources more efficient. (Göteborg Energi, 2015) Göteborg Energi is currently working towards phasing-out chemical products containing more than 0.1% of *substances that should be phased out* (Göteborg Energi, 2017b). Göteborg Energi applies the waste hierarchy based on the EU Waste Directive (2008/98/EG). The aim is to minimize the waste quantities but also manage the waste according to existing legislation. (Göteborg Energi, 2015)

6. METHODOLOGY

This Chapter intends to explain how the objectives has been answered.

This Chapter is divided into four phases. Each phase represents one objective and describes the methodology used to answer the objective. The four phases together with the objectives are listed below. Section 6.1-6.4 describes in detail how the objectives have been answered.

Phase 1.
Identify and map the waste streams that arise throughout the value chain of Göteborg Energi.

Phase 2.
Develop a framework that can be used to identify which waste streams that should be prioritized to decrease the environmental impact from waste.

Phase 3.
Based on the framework, identify which waste streams throughout the value chain of Göteborg Energi that should be prioritized.

Phase 4.
Identify Göteborg Energi's contribution to the transition towards a circular economy today and what Göteborg Energi can improve to reduce the waste quantities and aim for circularity.

6.1 Phase 1

An understanding of the value chain and the operations at Göteborg Energi was needed to be able to identify and map the waste streams. Information was collected from the homepage of Göteborg Energi, the annual report, other internal documents supplied by the company and personal contacts within the company. Information regarding retrieved waste quantities during 2015 were collected from various internal documents within Göteborg Energi. All waste quantities were compiled and divided between four sectors within Göteborg Energi: *Support, Production, Distribution* and *GothNet*, each sector is described further in the text. The division between the four sectors was made to evaluate where in the value chain that the waste streams were generated. The four sectors were chosen because Göteborg Energi has used these four sectors in their earlier compilation of waste streams.

The waste that was generated in the sector *Support* origin mainly from office related work at Göteborg Energi's head office at Rantorget. The sector *Production* includes all waste streams that were generated at Göteborg Energi's production facilities: GoBiGas, Sävenäs, Rya, Rosenlund, including other smaller facilities. The waste that was generated from the activities that are needed to distribute electricity, district heating, cooling and gas were compiled in the sector *Distribution*. The sector *GothNet* includes all waste streams that were generated within

GothNet, that is part of Göteborg Energi. The purpose of *GothNet* is to own and manage the city network.

Hazardous and *non-hazardous* waste streams have been separated. This division was made because Göteborg Energi divides *hazardous* and *non-hazardous* waste in their annual reporting, and *hazardous waste* possess certain characteristics that could be harmful for humans and/or the ecosystem. *Hazardous waste* is defined in the EU Waste Directive (2008/98/EG). To be classified as *hazardous* certain characteristics of the waste need to be fulfilled, such as: ecotoxicity, harmfulness, flammability, toxicity, and explosiveness. (European Commission, 2008). Appendix 4 in the Swedish waste regulation (2011:927) consists of a list of various types of waste, where those that possess hazardous properties are marked with an (*). This list was used to define which waste streams that are *hazardous*.

Waste fractions were combined into larger *waste streams. Waste fractions* mean all waste, for example colored glass and non-colored glass. *Waste streams* are the combination of many *waste fractions*, for example the *waste stream* glass includes the two *waste fractions* colored glass and non-colored glass. An explanation of which waste fractions that are included in each waste stream is provided in Table 3 and Table 4, for non-hazardous and hazardous waste respectively. The combination of *waste fractions* into *waste streams* was made in consultation with Göteborg Energi. The total quantity of one *waste stream* was calculated by adding all *waste fractions* within the *waste stream.*

Table 3. The non-hazardous waste fractions that are included in each waste stream.

Waste stream	**Waste fractions included in each waste stream**
Aqueous sludge	Contaminated water and sludge
Ashes	Ashes
Contaminated loads	PAH-asphalt and soil contaminated with PAH, oil and metals
Food waste	Food waste
Glass	Colored and non-colored glass
Metals and scrap	Metal packaging and scrap
Non-combustible waste	Tile, stone-materials, asphalt and other non-combustible materials
Other non-hazardous waste	Impregnated wood, combustible waste, painted wood and mixed waste
Paper, cardboard and corrugated cardboard	Office paper, magazines, paper, cardboard and corrugated cardboard
Plastic	Soft-, and hard plastic, and plastic packaging
Waste to sorting	Can include a large variation of waste fractions, such as: plastic, wood, metals etc.

Table 4. The hazardous waste fractions that are included in each waste stream.

Waste streams	**Waste fractions included in each waste stream**
Batteries	Batteries and lead batteries
Cable scrap	Cable scrap
Capacitors and switches	Capacitors and switches
Contaminated loads	PAH-asphalt and soil contaminated with PAH, oil and metals
Electronics	Electrical and electronic equipment
PCB contaminated oil	PCB contaminated oil
Other hazardous waste	Toner cartridges, mercury, solvents, aerosols, amines, mixed oil waste, organic and non-organic acids, paints, varnish, glue, sulfur containing waste, asbestos, absorbents, hazardous waste to incineration, cutting fluid, and bases
Pylons	Pylons
Sludge that contain hazardous substances	Sludge and water contaminated with oil, PAH, tar and chemicals
Source of light	Fluorescent, lamps and other sources of light
Transformers	Transformers
Used oil	Used oil

Personal contacts with nine of Göteborg Energi's waste contractors were completed to describe how the waste streams are treated. For some waste streams, more than one company retrieves the waste, in those cases the description of waste treatments was based on the information from the waste contractor that retrieved the greatest quantity of waste.

6.2 Phase 2

This section describes how the framework for identifying which waste streams that should be prioritized to decrease the environmental impact from waste was developed in this master thesis and what it includes. The framework and a description of how it should be used are presented in section 7.2. The purpose of the framework is to present a list of waste streams that should be prioritized, to motivate where largest improvements from an environmental perspective are possible. The purpose is not to present exact numbers, in contrast the framework use existing studies and within a reasonable amount of time aims to compare the magnitudes of waste streams.

This section starts by presenting why Sweden's environmental objectives *reduced climate impact*, *a non-toxic environment* and *a good built environment* were chosen in the framework to define which waste streams that should be prioritized, followed by how each objective was used and the aspects that were covered within each environmental objective. Sweden's environmental objectives *reduced climate impact*, *a non-toxic environment* and *a good built environment* were chosen because waste management has greatest significance for these objectives according to the Swedish Environmental Protection Agency (Naturvårdsverket, 2012), the reasons are explained in section 3.2.4 in this master thesis. These three environmental objectives cover emissions of GHGs, the use of hazardous substances, and resource efficiency (Naturvårdsverket, 2012).

Literatures were reviewed to identify if other reports also conclude that waste has greatest significance for the mentioned three environmental objectives. This was done by reviewing reports that highlight waste streams that are important to prioritize in Sweden and Gothenburg. Four reports were reviewed: the *waste management plan in Sweden* (Naturvårdsverket, 2012), the *waste prevention program in Sweden* (Naturvårdsverket, 2015), the *waste management plan in Gothenburg* (Göteborgs Stad, 2011b), and a study showing *prioritized waste streams in Gothenburg* (Nielsen, 2013).

The reasons for prioritizing the waste streams specified in the four reports above were reviewed to understand if the prioritization has significance for the three environmental objectives *reduced climate impact*, *a non-toxic environment* and *a good built environment.* For example, if food waste is chosen as a prioritized waste stream because this waste stream causes large amount of emissions of $CO_{2\text{-eq}}$, this prioritization has significance on a *reduced climate impact*. The result is presented Figure 6, and the relations between the four reports and the environmental objectives are presented further in the text.

Sweden's environmental objectives (Naturvårdsverket, 2016e)	**Waste management plan (Sweden)** (Naturvårdsverket, 2012)	**Waste prevention plan (Sweden)** (Naturvårdsverket, 2015)	**Waste management plan (Gothenburg)** (Göteborgs Stad, 2011)	**Prioritized waste streams (Gothenburg)** (Nielsen, 2013)
A non-toxic environment	Waste treatment, Illegal export of waste	Textile waste, Electrical and electronic waste	Safety for humans and the environment	Hazardous waste, Electrical waste
A good built environment	-	Food waste, Construction and demolition waste	Safety for humans and the environment	Electrical waste
Reduced climate impact	Waste management in the construction sector, Household waste, Resource management in the food chain	Food waste, Textile waste, Construction and demolition waste, Electrical and electronic waste	Safety for humans and the environment	Mixed household waste, Mixed industrial waste, Electrical waste

Figure 6. The first column show three of Sweden's environmental objectives. Column 2-4 show the reviewed reports and the prioritized waste streams or areas in each report. The prioritized waste streams and areas are placed in the rows depending on which objective that they impact.

In the **waste management plan** in Sweden five prioritized areas within waste management are defined: waste management in the construction sector, household waste, resource management in the food chain, waste treatment, and illegal export of waste. Waste management in the construction sector and household waste are prioritized by the Swedish Environmental Protection Agency because of potentials to increase the recycling rate in these sectors, and large amount of GHGs are emitted during extraction, production and waste management for these waste streams. The third area, resource management in the food chain, is prioritized by the Swedish Environmental Protection Agency because of potentials to decrease the GHG emissions through increased recourse efficiency. Therefore, these three prioritized areas affect the achievement of *a reduced climate impact*. The two last areas, waste treatment and illegal export of waste, are prioritized by the Swedish Environmental Protection Agency mainly because of the importance of minimize the diffusion of hazardous substances. Therefore, these two prioritized areas affect the achievement of *a non-toxic environment*. (Naturvårdsverket, 2012)

In the **waste prevention program** in Sweden, four prioritized areas within waste prevention are highlighted: food waste, textile waste, construction and demolition waste, and electrical and electronic waste. Food waste, and construction and demolition waste are prioritized by the Swedish Environmental Protection Agency because of great quantities of waste generated and emissions of GHGs from cradle to grave. Therefore, these two prioritized areas affect the achievement of *a good built environment* and *a reduced climate impact*. Textile waste, and electrical and electronic waste are prioritized by the Swedish Environmental Protection Agency because of content of hazardous substances and emissions of GHGs per kg. (Naturvårdsverket, 2015) Therefore, these two prioritized areas affect the achievement of *a non-toxic environment* and a *reduced climate impact*.

In the **waste management plan in Gothenburg** are goals within waste management emphasized. One of the goals in the waste management plan is *safety for humans and the environment,* that highlight the need to increase the resource efficiency, reduce the emissions, and reduce the amount of hazardous substances. (Göteborgs Stad, 2011b) Therefore, this goal affect the achievement of *a good built environment, a non-toxic environment,* and a *reduced climate impact*.

In the report presenting **prioritized waste streams in Gothenburg** it is concluded that the waste streams that should be prioritized are: hazardous waste, mixed household waste, mixed industrial waste, and electrical waste. Mixed household waste, and mixed industrial waste are prioritized by Nielsen (2013) because of a high climate impact, while electrical waste is chosen because of large environmental impacts in general. Therefore, these prioritized areas all affect the achievement of a *reduced climate impact*, and electrical waste also affect the achievement of *a good built environment,* and *a non-toxic environment.* Hazardous waste is prioritized by Nielsen (2013) because of the content of substances that are harmful for humans and the environment. (Nielsen, 2013) Therefore, this prioritized waste stream affect the achievement of *a non-toxic environment.*

A literature review was performed to identify which parts of the environmental objectives that are important and should be included in the framework to identify which waste streams that should be prioritized. Literatures from the Swedish Chemical Agency and the Swedish Environmental Protection Agency were reviewed. A description of which aspects that were chosen to be included in the framework within each environmental objective are presented below.

Reduced climate impact

Emissions of $CO_{2\text{-eq}}$ from upstream (extraction of raw materials and manufacturing) and downstream (waste management) for the waste streams were used to identifying which waste streams that should be prioritized.

Emissions of $CO_{2\text{-eq}}$ was chosen because the aim with the environmental objective *reduced climate impact* is that the concentration of GHGs in the atmosphere shall stabilize to a level at which humanity's effects on the climate system are harmless (Naturvårdsverket, 2016a). Different GHGs have different global warming potentials (GWP), for example CO_2 has a GWP of 1 per ton, methane 25 per ton, and nitrous oxide (N_2O) 298 per ton. The GWP are used to calculate the $CO_{2\text{-eq}}$. (Naturvårdsverket, 2017a)

Sundqvist and Palm (2010) have studied the emissions of $CO_{2\text{-eq}}$ upstream and downstream from various waste streams in Sweden, this study has been used to calculate the emissions of $CO_{2\text{-eq}}$/year in this master thesis.

A non-toxic environment
The potential content of *substances that should be phased out* in the waste streams was used in this study to identify which waste streams that impact *a non-toxic environment*. The purpose of the result was to give a guidance regarding which waste streams that may contain *substances that should be phased out* and because of that should be prioritized.

The aim with Sweden's environmental objective *a non-toxic environment* is that the man-made hazardous substances that can harm humans and/or the ecosystem shall be eliminated (Naturvårdsverket 2016e). Waste contains hazardous substances that easily can diffuse to the environment through leakage, or as gases from incineration if the waste is not handled properly. (Naturvårdsverket, 2012) One sub-goal within the environmental objective is that the use of *particularly hazardous substances* shall be prevented to the highest degree (Naturvårdsverket, 2016e). The Swedish Chemical Agency has developed a list over a bit less than 200 hundred *particularly hazardous substances* (Kemikalieinspektionen, 2017d).

The Swedish Chemical Agency has developed a guide for prioritization of substances, named PRIO [6]. Substances that should be prioritized are connected to certain health-, and environmental impacts (Kemikalieinspektionen, 2017a). In PRIO, substances are divided into two levels of priority depending on which characteristics that the substances possess (Kemikalieinspektionen, 2017c). One of the levels is *substances that should be phased out*, which was used in this study. The Swedish Chemical Agency has developed the criteria for *substances that should be phased out* consistent with the *particularly hazardous substances* presented within Sweden's environmental objective *a non-toxic environment*, and the chemical legislation used in EU (REACH), i.e. the criterions for *substances that should be phased out* and *particularly hazardous substances* resemble each other. In PRIO, *substances that should be phased out* are divided into five categories (Kemikalieinspektionen, 2017c):

- Carcinogenic, Mutagenic, Toxic to reproduction (CMR)
- Endocrine disruptors
- Particularly hazardous metals: Cadmium, Mercury and Lead (Cd, Hg, Pb)
- Persistent, Bioaccumulative, Toxic/Very Persistent, Very Bioaccumulative (PBT/vPvB)
- Ozone-destructive substances

In PRIO, it is possible to search for one of the categories, for example *CMR*, and a list of substances that can cause these effects is presented (Kemikalieinspektionen, 2017c).

[6] Note that there are a lot of substances, which should be prioritized, that are not covered by the guide PRIO. Other ways to search for substances are presented in section 7.2.2.

A good built environment
In this study, two steps were used to evaluate which waste streams that should be prioritized based on *a good built environment*. The *share of the total mass for each waste stream*, and the *waste hierarchy.*

Sweden's environmental objective *a good built environment* specifies that resources such as water, energy, land etc. shall be managed as efficient as possible. The waste management need to be as sustainable as possible which, among others, means that the total quantity of waste should decrease and the waste that are generated should be used more as a resource through for example recycling. The Swedish Environmental Protection Agency use various indicators to measure the performance of the environmental objective, for example the degree of recycling of plastic, glass, metals and paper packaging. (Naturvårdsverket, 2016d)

6.3 Phase 3

This section present assumptions that were made when the framework was used to identify which waste streams that should be prioritized within Göteborg Energi. The assumptions are presented within each heading of this section: *reduced climate impact, a non-toxic environment,* and *a good built environment.* Note that the framework and a description of how it should be used are presented in section 7.2.

Reduced climate impact

Some waste streams at Göteborg Energi could not be found from the list of waste streams presented by Sundqvist and Palm (2010). One of the reasons is that the waste that are generated depends on the processes and materials within a certain company. In their study, Sundqvist and Palm (2010) cover many of the waste streams that arise within Göteborg Energi, but the waste streams that are not covered need to be "matched" to another waste stream presented by Sundqvist and Palm (2010). The continuation of this text describes which waste streams within Göteborg Energi that are not covered in the study by Sundqvist and Palm (2010) and how they were handled.

- *Ashes* (non-hazardous) were matched with Sundqvist and Palms (2010): *waste from incineration* classified as hazardous waste.
- *Contaminated loads* (non-hazardous) were matched with Sundqvist and Palms (2010): *contaminated loads and dredged materials* classified as hazardous waste.
- *Other non-hazardous waste* (non-hazardous) were matched by Sundqvist and Palms (2010): *mixed non-differentiated materials*, where the main difference is the waste treatment. Sundqvist and Palm (2010) have assumed that *mixed non-differentiated materials* are sorted to be material recycled, incinerated, or disposed, while *other non-hazardous waste* within Göteborg Energi are incinerated.
- *Non-combustible waste* (non-hazardous) were matched with Sundqvist and Palms (2010): *mineral waste* (50% concrete and 50% sand).
- *Other hazardous waste* (hazardous), were matched with *waste from chemical processing* presented by Sundqvist and Palm (2010).

For some waste streams only the phase *downstream*, i.e. waste management, was included in the calculations by Sundqvist and Palm (2010) because the waste streams cannot be derived to a certain product or material in the phase *upstream*. These waste streams within Göteborg Energi are:

- *Sludge that contain hazardous substances* (hazardous waste)
- *PCB contaminated oil* (hazardous waste)
- *Contaminated loads* (non-hazardous and hazardous waste)
- *Ashes* (non-hazardous waste)
- *Oil waste* (hazardous waste)
- *Aqueous sludge* (non-hazardous waste)

A non-toxic environment

Due to limits of time, only the *hazardous waste* streams within Göteborg Energi were investigated to determine if they contain *substances that should be phased out*. Information regarding which substances that the various waste streams may contain was gathered from sources such as the Swedish Chemical Agency, PRIO, personal contacts within Göteborg Energi, and the Swedish waste regulation (2011:927). Each waste stream is denoted by a waste code, i.e. a code that defines the waste. In some cases, the waste codes were used to determine which substances that a waste stream contain. Appendix 4 in the Swedish waste regulation (2011:927) contains of a list over waste streams and their waste codes. If the waste codes were provided, it was possible to search in Appendix 4 in the Swedish waste regulation to find a description of the waste stream. In some cases, it was expressed what a certain waste stream contains. For example, if a transformer contains PCB the waste stream receives a different waste code compared to a transformer that do not contain PCB. Therefore, it may be possible to study the waste codes of each waste stream and Appendix 4 in the Swedish waste regulation (2011:927) to find information regarding the content of substances in the waste streams. In those cases where specific information was inadequate the general identification from Table 9 in section 7.2.2 of waste streams that contain *substances that should be phased out* was used. The waste streams where specific information was retrieved are presented in Table 14 in section 7.3.2.

The waste streams that may contain *substances that should be phased out* are shown in Table 15 in section 7.3.2. Waste streams that were excluded in Table 15 but still may contain *substances that should be phased out* are: *contaminated loads* (excluding PAH-asphalt), and *sludge that contain hazardous substances. Contaminated loads* (excluding PAH-asphalt), was not included because of incomplete information regarding how much oil, metals and which metals that the soil contain. *Sludge that contain hazardous substances* was excluded because of lack of information regarding the concentration of PAH and tar in the sludge. Another reason for excluding *sludge that contain hazardous substances* was because the largest quantity of waste was generated at the research and development plant GoBiGas and improvements will be implemented when the plant is in full operation.

A good built environment

Numerous of the waste streams within Göteborg Energi are disassembled at the waste contractors, one component can be recycled while another component may be recovered. If a waste stream is disassembled and one component is recycled while another component is recovered, the waste stream was placed between recycling and recovery in the waste hierarchy. Parts of the *contaminated loads* (both non-hazardous and hazardous) were after a primary treatment recycled to be used as for example construction materials, while the rest was disposed. Therefore, the *contaminated loads* were placed at the second least preferable treatment method i.e. recovery/disposal.

6.4 Phase 4

A literature review was performed to understand the concept of *industrial symbiosis* and to be able to identify in what way Göteborg Energi works with industrial symbiosis at present. Internal documents and personal contacts within Göteborg Energi, as well as public information of Göteborg Energi were reviewed. How Göteborg Energi works with other strategies within circular economy, such as recycling, was identified by studying the result from section 7.1 of this master thesis.

Literatures and studies were reviewed to investigate what improvements Göteborg Energi can implement to reduce the waste quantities in general and the acknowledged prioritized waste streams identified in section 7.3, in particular. Literatures within the field of for example dematerialization, substitution, recirculation, and circular economy were explored, and other good examples were searched. Some of the potential improvements that Göteborg Energi can implement were based on own observations and conclusions from studying the waste statistics and interviewed the waste contractors.

Literatures were reviewed to understand which policy instruments on a national level that may lead to a decreased generation of waste and more circular flows.

7. RESULT

This Chapter starts by presenting the compilation of waste streams and describe how the waste streams are treated, followed by a framework for identifying which waste streams that should be prioritized. Based on the framework, the waste streams within Göteborg Energi that should be prioritized are identified. The Chapter continues with a description of how Göteborg Energi works with circular economy at present and opportunities for improvements.

This Chapter is divided in four phases, separated into four sections (7.1-7.4). Each phase represents the result from one objective. The methodology behind each result is presented in Chapter 6.

7.1 Waste streams

Phase 1.

The purpose of this section is to identify and map the waste streams that arise throughout the value chain of Göteborg Energi. The waste streams that are generated within Göteborg Energi[7] are divided in the four sectors: *Support, Production, Distribution* and *GothNet,* all sectors are described in Chapter 6. The quantities of waste presented in Chapter 7 were generated during year 2015. Section 7.1.1 present the total generation of *non-hazardous waste* within Göteborg Energi. Section 7.1.2 present the total generation of *hazardous waste* within Göteborg Energi. Section 7.1.3-7.1.6 present the total generation of waste divided between the four sectors: *Support, Production*, *Distribution* and *GothNet*.

7.1.1 Non-hazardous waste streams

Commonly for Sweden is that the method for treating the waste is not set, but depends on multiple factors such as how well the waste is sorted, location, equipment at the waste contractors, as well as type of waste (Avfall Sverige, 2015). Some of the waste streams need to go through a primary treatment to for example sort the waste or undergo a biological treatment (Naturvårdsverket, 2016a). How the non-hazardous waste streams within Göteborg Energi are treated is described further in the text.

Food waste

Food waste origin mainly from Göteborg Energi's head office at Rantorget. Both from a restaurant within the company and from employees left-overs after finishing lunch. The *food waste* is collected by the waste contractor, being grinded to a slurry, and transported to Borås for biogas production. (Björkman, 2017)

[7] All quantities of waste are retrieved from internal documents within Göteborg Energi.

Paper, cardboard and corrugated cardboard

The waste fractions that are included in this waste stream are: office paper, magazines, paper packaging, cardboard and corrugated cardboard. Based on the waste statistics around half of the total generation of *paper, cardboard and corrugated cardboard* origin from office related work at the head office at Rantorget. It should those be noticed, based on own observations, that this waste stream is not always sorted within the other sectors i.e. an unknown quantity is sorted into combustible waste. The most common treatment for this waste stream is material recycling, which replace the amount of virgin materials that are needed for producing new products (Renova, 2017a).

Glass

The waste stream *glass* includes both colored and non-colored glass, for example glass packaging. The *glass* origin from the head office at Rantorget and within the sector *Production*. The most common treatment for *glass* is material recycling (Renova, 2017a) (Göteborg Energi, 2017b).

Plastic

Plastic includes soft-, and hard plastic and plastic packaging. Based on the waste statistics the *plastic* origin mainly from the head office at Rantorget, for example lunch-boxes or other plastic packaging. Though, based on own observations, this waste stream is not always sorted within the other sectors i.e. an unknown quantity is sorted into combustible waste. *Plastic* is material recycled (Renova, 2017a) (Göteborg Energi, 2017b).

Metals and scrap

The waste stream *metals and scrap* includes various kinds of metal packaging and scrap. The *metals and scrap* are mainly generated within the sectors *Production* and *Distribution*. *Metals and* scrap are retrieved and transported to Halmstad for fragmentation. Fragmentation means that all the components are decomposed to smaller fractions. The fractions are afterwards sorted into various categories such as aluminum, copper, iron and other metals. The materials are thereafter recycled to be used in other products. (Stena Recycling, 2017)

Ashes

Ashes[8] includes different ashes from production facilities. The main source of *ashes* origin from GoBiGas and is captured through various filters that are used to purify the gases before they are released from the chimney. The *ashes* are retrieved by the waste contractors, transported and deposited (Ragn-Sells, 2017).

Waste to sorting

The waste stream *waste to sorting* is one of the streams that can include a large variation of waste fractions. The waste origin from production facilities, offices, and during work related

[8] This study is limited to not cover the waste or byproducts that arise from production of biogas, district heating, electricity or cooling. Large quantities of ashes are generated during combustion of biomass, these ashes are returned to forest land, but not covered further in this study.

to distribution of electricity, district heating, cooling and gas. Common for this waste stream is that all *waste to sorting* is retrieved, transported and thereafter sorted by the waste contractors. In contrast to for example the waste stream *plastic* which is sorted within Göteborg Energi. The materials that can be reused and recycled are sorted out (plastic, metals, etc.), other combustible waste is incinerated for energy recovery (wood etc.) (Renova, 2017a).

Contaminated loads

Included in the waste stream *contaminated loads* are Polycyclic Aromatic Hydrocarbons (PAH)-asphalt (with a concentration of PAH<1000 mg/kg) and soil contaminated with PAH, oil and metals. *Contaminated loads* are excavated soil from contaminated areas and could be classified as either hazardous or non-hazardous depending on the concentration of hazardous substances. The Swedish Environmental Protection Agency defines *contaminated loads* as non-hazardous if the concentration of PAH, oil and metals are below "sensitive land use" (KM).

The Swedish Environmental Protection Agency has developed a guide for classification of contaminated loads that divide KM and "less sensitive land use" (MKM) (Naturvårdsverket, 2009). If the *contaminated loads* are classified as KM the soil has a quality that does not affect how the soil can be used. While MKM means that the quality of the soil affect how the soil can be used, in this case the soil can for example be used at industrial areas or for road constructions.

The concentration of PAH in the soil for KM vary between 1-3 mg/kg and 10-20 mg/kg for MKM (Naturvårdsverket, 2009). For soil contaminated with oil the concentration of oil for KM vary between 3-100 mg/kg and 30-1000 mg/kg for MKM (Naturvårdsverket, 2009). The classification of soil contaminated with metals depends on what metals the soil contains. The concentration of cadmium is 15 mg/kg to be classified as MKM while the concentration of lead is 400 mg/kg to be classified as MKM (Naturvårdsverket, 2009).

Contaminated loads are generated when Göteborg Energi perform projects, such as improvements of the district heating network, on contaminated areas within Gothenburg. Different locations within Gothenburg are contaminated to various degrees and pollutants. The areas where Göteborg Energi's projects are performed have been contaminated from external industrial activities during the past, meaning that Göteborg Energi cannot affect how much of this waste stream that is generated.

The treatment methodologies for *contaminated loads* varies depending on waste contractors. Some of the *contaminated loads* are primarily sorted to recycle as much as possible, afterwards samples are examined and the loads that cannot be recycled are deposited (RGS90, 2017). *Contaminated loads* containing metals are deposited. Soil contaminated with oil go through a biological degradation. When the contaminated level drops to an acceptable degree the soil is either sent to deposition or used as construction materials, to cover landfills etc. (Entropi, 2017)

Aqueous sludge

Included in the waste stream *aqueous sludge* is contaminated water and sludge. The waste contractors retrieve the waste, where it firstly is examined to investigate which substances that the *aqueous sludge* contains. The *aqueous sludge* is afterwards treated with various chemical and biological treatments, until it can be released to the surrounding environment. (Stena Recycling, 2017)

Non-combustible waste

Non-combustible waste includes tile, stone-materials, asphalt and other non-combustible materials. Asphalt stands for the largest quantity and is generated within the sector *distribution*. The *non-combustible waste* is retrieved and transported by the waste contractors. Some materials are recycled, some used as construction materials for roads etc. and the materials that cannot be recycled are deposited (Renova, 2017a).

Other non-hazardous waste

The last waste stream is *other non-hazardous waste* that includes impregnated wood, combustible waste, painted wood and mixed waste. Combustible waste stand for the largest quantity in this waste stream and is incinerated for energy recovery. (Renova, 2017a)

The total amount of non-hazardous waste generated during 2015 was 9274 ton, see Table 5 and Figure 7. Figure 7 show that *contaminated loads* is the largest waste stream. Figure 8 show the total amount of non-hazardous waste excluding *contaminated loads*. *Ashes* are the second largest waste stream followed by *metals and scrap*, and *other non-hazardous waste*.

Table 5. Total amount of non-hazardous waste in ton divided between the sectors Support, Production, Distribution and GothNet, in 2015.

Waste stream	**Support (ton)**	**Production (ton)**	**Distribution (ton)**	**GothNet (ton)**	**Total (ton)**
Ashes	0	434	0	0	434
Aqueous sludge	0	122	45	0	167
Contaminated loads	0	715	7318	0	8033
Food waste	8.0	1.9	0	0	9.8
Glass	8.1	7.8	0	0	16
Metals and scrap	1.9	116	156	0	274
Non-combustible waste	0	31	42	0	73
Other non-hazardous waste	52	70	44	2.0	168
Paper, cardboard and corrugated cardboard	27	25	3.7	2.5	58
Plastic	3.0	0.5	0.9	0	3.7
Waste to sorting	2.9	28	7.7	0	39
Total	103	1550	7616	4.5	9274

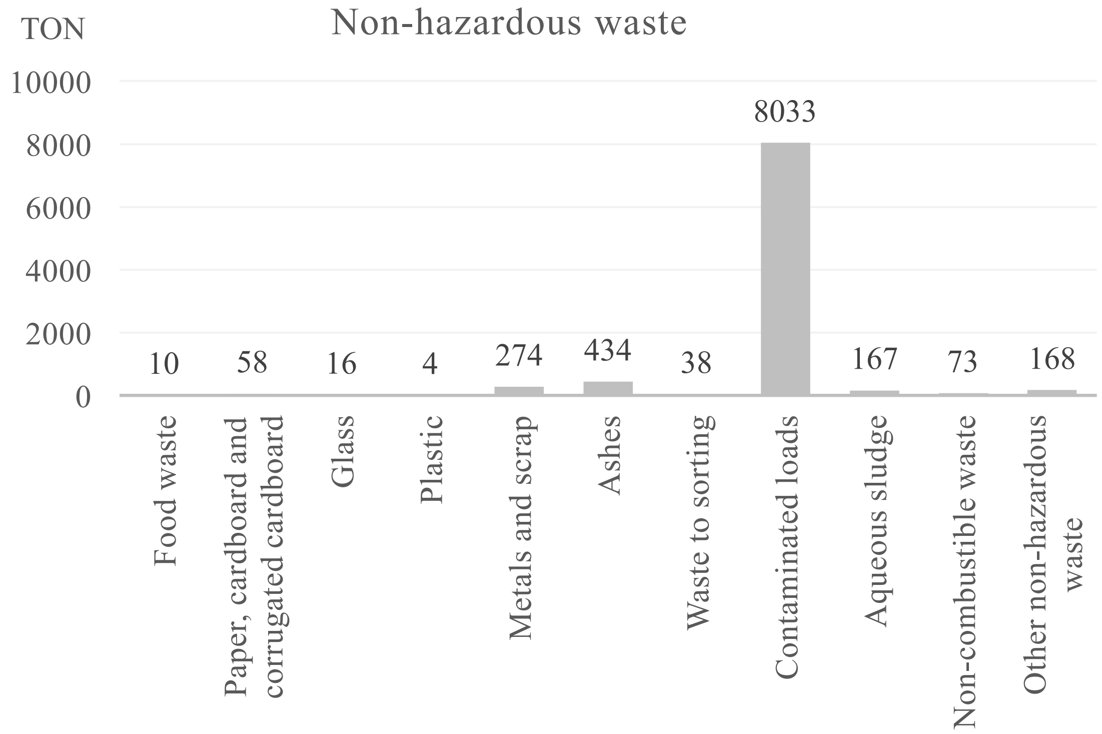

Figure 7. Non-hazardous waste in total.

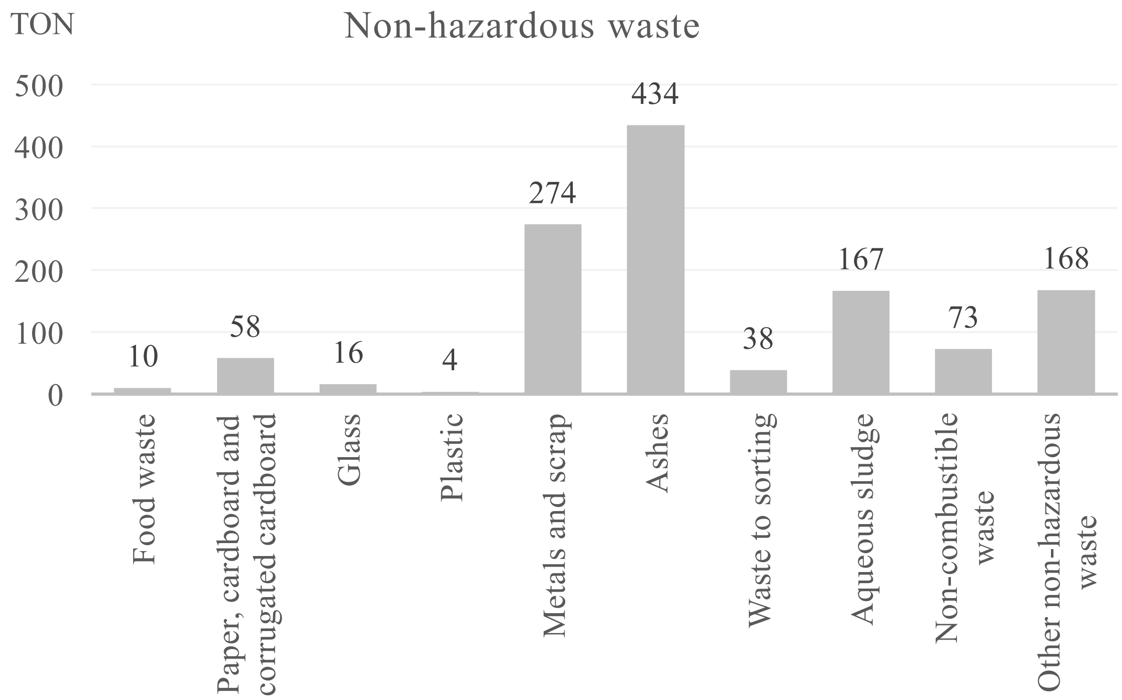

Figure 8. Non-hazardous waste in total, excluding contaminated loads.

7.1.2 Hazardous waste streams

Commonly in Sweden, is that the treatment of *hazardous waste* usually starts by separating the hazardous substances from the waste. The hazardous substances can be incinerated and the remaining materials may be recycled. (Avfall Sverige, 2016a) Some of the *hazardous waste* streams within Göteborg Energi are incinerated for energy recovery at Renova, while others need to be incinerated in extra high temperatures. If extra high temperatures are needed the waste is sent to Ekokem (previously SAKAB) in Kumla to be incinerated for energy recovery. (Renova, 2017b) How the hazardous waste streams within Göteborg Energi are treated is described further in the text.

Electronics

Electronics are all electrical and electronic equipment that are broken or replaced. The *electronics* are retrieved by the waste contractors and need in most cases to go through a primary treatment, thereafter some parts can be recycled (often metal components) or incinerated for energy recovery (often plastic components) (Renova, 2017b).

Batteries

Batteries could contain hazardous substances such as lead. The waste contractors separate the hazardous substances from the rest of the materials, the metals are recycled and the plastics incinerated for energy recovery. Some of the *batteries* are transported to treatments at other waste contractors than those retrieving the *batteries* from Göteborg Energi. (Renova, 2017b)

Used oil

The *used oil* is retrieved by the waste contractors and transported to firstly be purified and separated from for example water. Afterwards, as much oil as possible are recycled to be used again. (Renova, 2017b)

Source of light

The waste stream *source of light* includes fluorescent, lamps, and other source of light that are broken or replaced. Fluorescent usually contains mercury that needs to be separated in a closed process. Afterwards, metals, electronics and glass can be recycled and plastic incinerated for energy recovery. (Avfall Sverige, 2016b) Renova retrieves the various *source of light* at Göteborg Energi and delivers the waste to Elkretsen who perform the treatment (Renova, 2017b).

Contaminated loads

The waste stream *contaminated loads* include PAH-asphalt (with a concentration of PAH >1000mg/kg) and soil containing hazardous substances such as oil and metals. To be classified as hazardous the concentration of oil, metals and PAH in the soil should be higher than KM and MKM, see the description in section 7.1.1. The treatment method for *contaminated loads* classified as hazardous waste depends on which waste contractors that retrieves the loads. At RGS90 the *contaminated loads* are primarily sorted to recycle as much as possible, afterwards samples are examined and the loads that cannot be recycled are deposited (RGS90, 2017). All *contaminated loads* that are classified as hazardous waste that the company Entropi receives are sent to NOAH in Norway for further treatment and disposal (Entropi, 2017).

Transformers

Transformers are generated within the sector *Distribution* and may contain hazardous substances such as PCB. All *transformers* are transported to Karlstad for treatment. The *transformers* are firstly disassembled in various steps. The iron, aluminum and copper are recycled. Oil is purified and recycled, or incinerated for energy recovery. If the *transformers* contain PCB, the hazardous substances are sent to incineration and energy recovery at Ekokem. The remaining combustible materials are incinerated for energy recovery. (Stena Recycling, 2017)

Capacitors and switches

The waste stream *capacitors and switches* includes capacitors, and switches containing oil, asbestos and sulfur hexafluoride. *Capacitors and switches* are only generated in the sector *Distribution*. Stena Recycling retrieves all *capacitors and switches* from Göteborg Energi. The *capacitors and switches* are disassembled, some materials are recycled and other incinerated for energy recovery. (Stena Recycling, 2017)

Pylons

Pylons contains substances for wood preservatives and waterproofing. Creosote impregnated pylons are as much as possible recycled, otherwise incinerated for energy recovery. Copper, chromium and arsenic (CCA) timber with an arsenic content over 100 ppm are sent to Ekokem at Kumla for incineration and energy recovery. (Rundvirke Poles AB, 2017)

Sludge that contain hazardous substances

Sludge that contain hazardous substances are sludge and water contaminated with oil, PAH, tar, and chemicals. This waste stream is mainly generated during cleaning of equipment at GoBiGas. The hazardous substances are separated from the water and sent to Ekokem at Kumla for incineration and energy recovery (Clean pipe, 2017). The water is separated from sludge and oil, the oil that can be removed is used as a supporting fuel in the cement industry. The remaining water are either enough purified to be released to the sewage treatment or incinerated. (XR Miljöhantering, 2017)

Cable scrap

Much of the *cable scrap* is generated in the sector *Distribution*. The *cable scrap* is retrieved by the waste contractors, transported and disassembled. Some materials are recycled and other incinerated for energy recovery (Stena Recycling, 2017).

PCB contaminated oil

A small fraction of *PCB contaminated oil* was generated in the sector *Distribution*. The *PCB contaminated oil* is retrieved by Renova and afterwards delivered to Ekokem at Kumla for incineration and energy recovery (Renova, 2017b).

Other hazardous waste

The last waste stream *other hazardous waste* includes: toner cartridges, mercury, solvents, aerosols, amines, mixed oil waste, organic and non-organic acids, paints, varnish, glue, sulfur containing waste, asbestos, absorbents, hazardous waste to incineration, cutting fluid, and bases. The treatment of these waste fractions varies. Hazardous substances that need to be incinerated in high temperatures (higher than Renovas ability) such as mixed oil waste, amines, some sorts of solvents and paints are sent to Ekokem at Kumla for incineration and energy recovery. Metals in the aerosol products are recycled and the leftovers incinerated. (Renova, 2017b) Absorbents are incinerated and sulfur containing waste are composted (XR Miljöhantering, 2017).

The total amount of hazardous waste generated in 2015 was 1780 ton, see Table 6 and Figure 9. Figure 9 show that for hazardous waste the largest waste stream is *sludge that contain hazardous substances* followed by *contaminated loads*. Figure 10 show the total hazardous waste generated excluding *contaminated loads* and *sludge that contain hazardous substances*.

Table 6. Total amount of hazardous waste in ton divided between the sectors Support, Production, Distribution, and GothNet, in 2015.

Waste stream	**Support (ton)**	**Production (ton)**	**Distribution (ton)**	**Gothnet (ton)**	**Total (ton)**
Cable scrap	0	1.2	29	0	30
Capacitors and switches	0	0	9.6	0	9.6
Contaminated loads	0	125	306	0	431
Batteries	0.1	0.6	1.5	0	2.2
Electronics	1.7	7.3	7.4	1.7	18
PCB contaminated oil	0	0	1.0	0	1.0
Other hazardous waste	0.1	143	4.4	0	148
Pylons	0	0	43	0	43
Sludge that contain hazardous substances	0	903	6.0	0	909
Source of light	0.1	1.1	0.4	0	1.5
Transformers	0	15	166	0	181
Used oil	0	4.1	2.8	0	6.9
Total	1.9	1200	577	1.7	1780

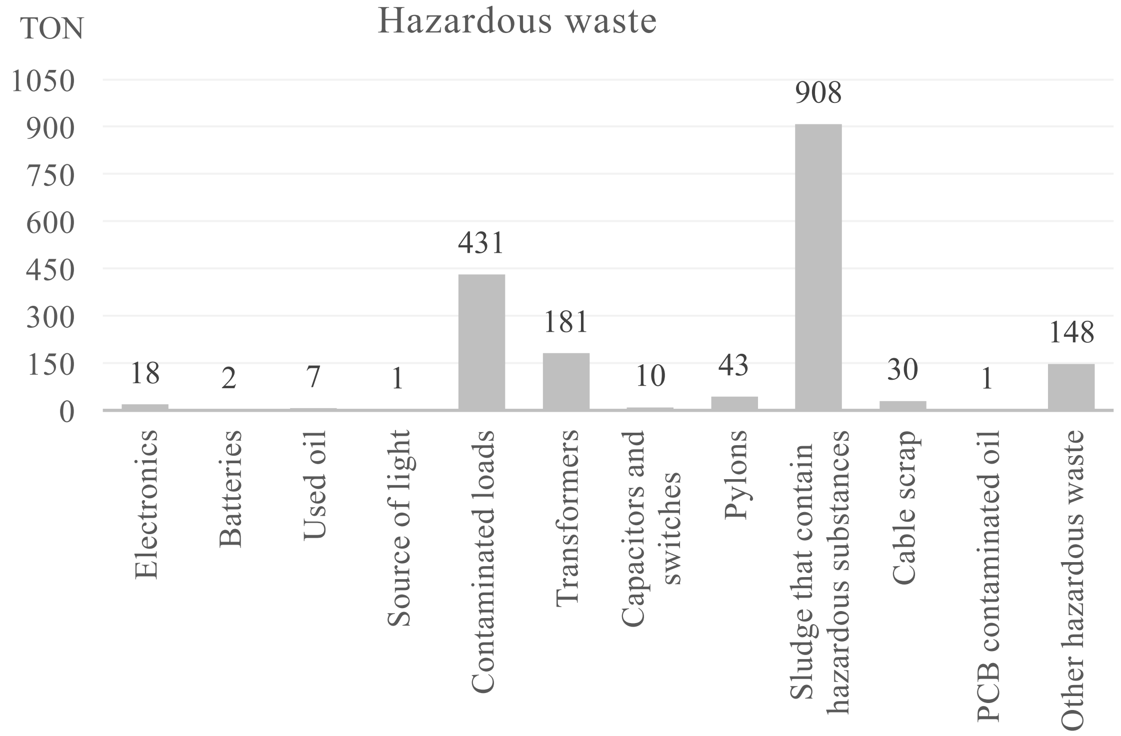

Figure 9. Hazardous waste in total.

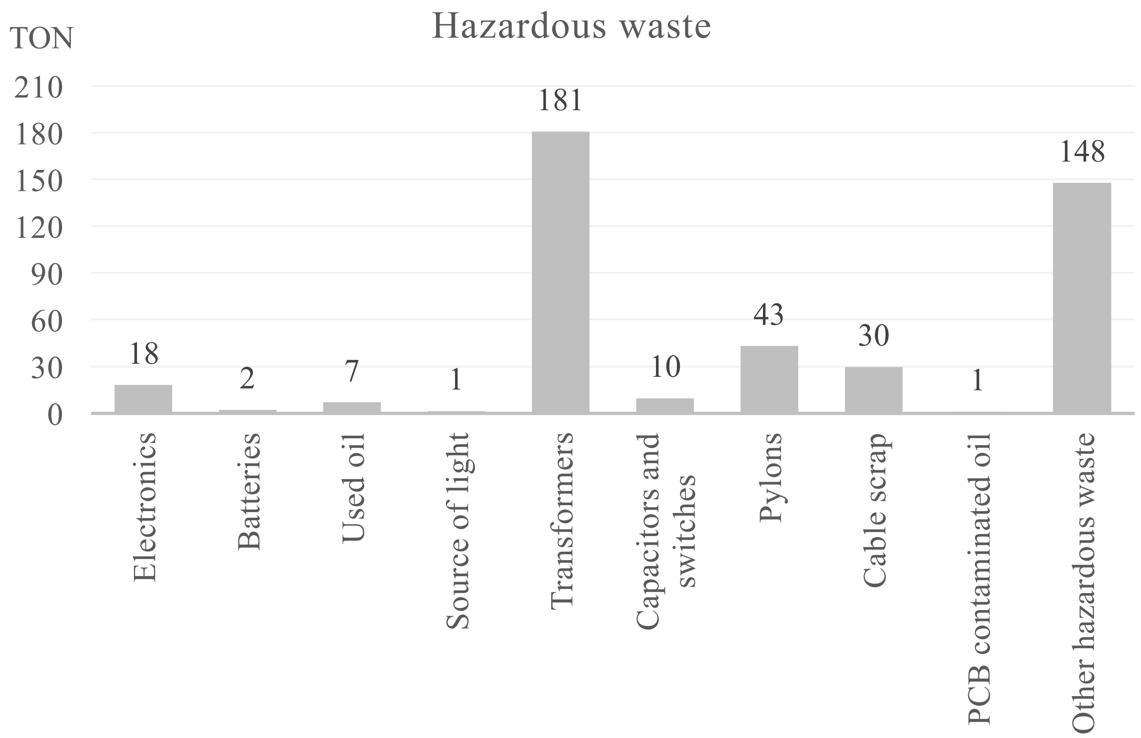

Figure 10. Hazardous waste in total, excluding contaminated loads and sludge that contain hazardous substances.

7.1.3 Support

The waste that was generated in the sector *Support* origin mainly from office related work at Göteborg Energi's head office at Rantorget. A description of what each waste stream includes are presented in section 7.1.1-7.1.2.

Figure 11 show the generation of non-hazardous waste in the sector *Support* divided per waste stream. In total around 103 ton *non-hazardous waste* was generated in 2015. The figure show that the waste streams that dominates are *other non-hazardous waste,* and *paper, cardboard and corrugated cardboard*. The waste stream *other non-hazardous waste* consists of combustible waste that is incinerated for energy recovery.

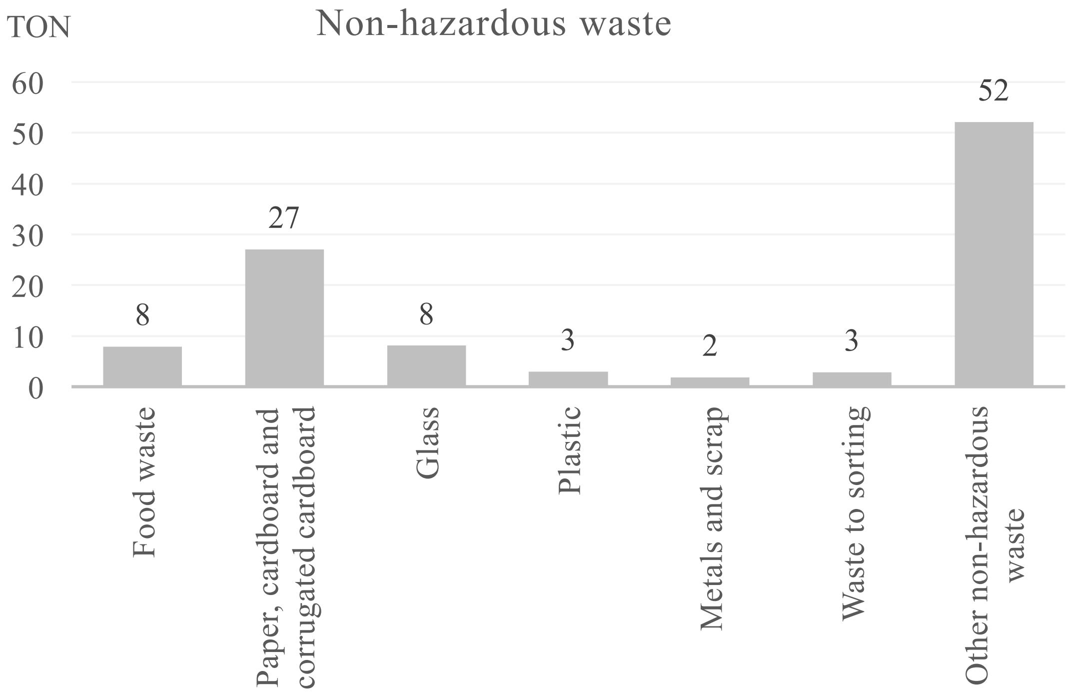

Figure 11. Non-hazardous waste, Support.

Figure 12 show the hazardous waste generated in the sector *Support*. In total around 2 ton *hazardous waste* was generated in 2015. *Electronics* are the waste stream with the largest quantity. The waste stream *other hazardous waste* generated in the sector *Support* was toner cartridges.

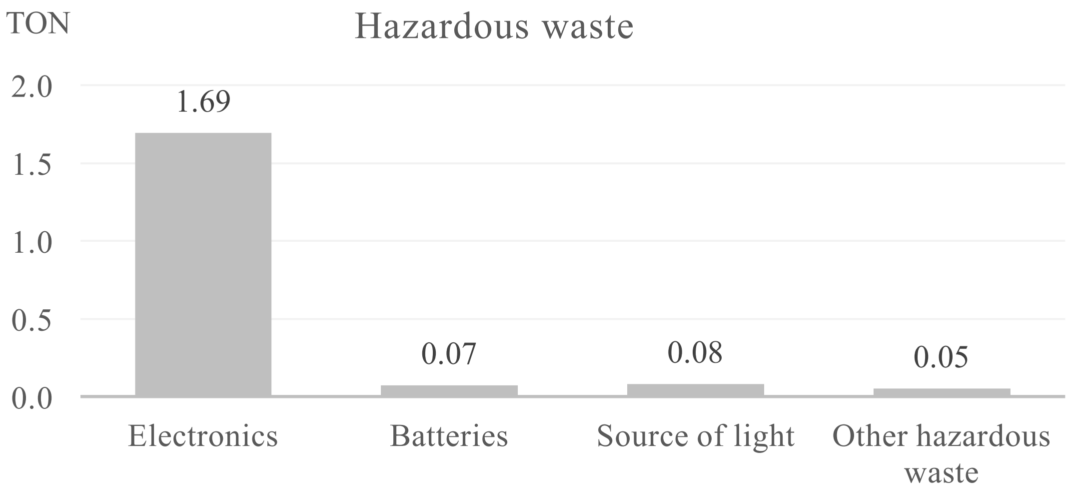

Figure 12. Hazardous waste, Support.

7.1.4 Production

The sector *Production* includes all waste that are generated at Göteborg Energi's production facilities: GoBiGas, Sävenäs, Rya, Rosenlund, including other smaller facilities. A description of what each waste stream includes are presented in section 7.1.1-7.1.2.

The total generation of non-hazardous waste in 2015 was 1550 ton. *Contaminated loads* and *ashes* were the waste streams with largest quantity, see Figure 13. *Contaminated loads* origin from soil excavation at Sävenäs, while *ashes* were generated mainly within GoBiGas.

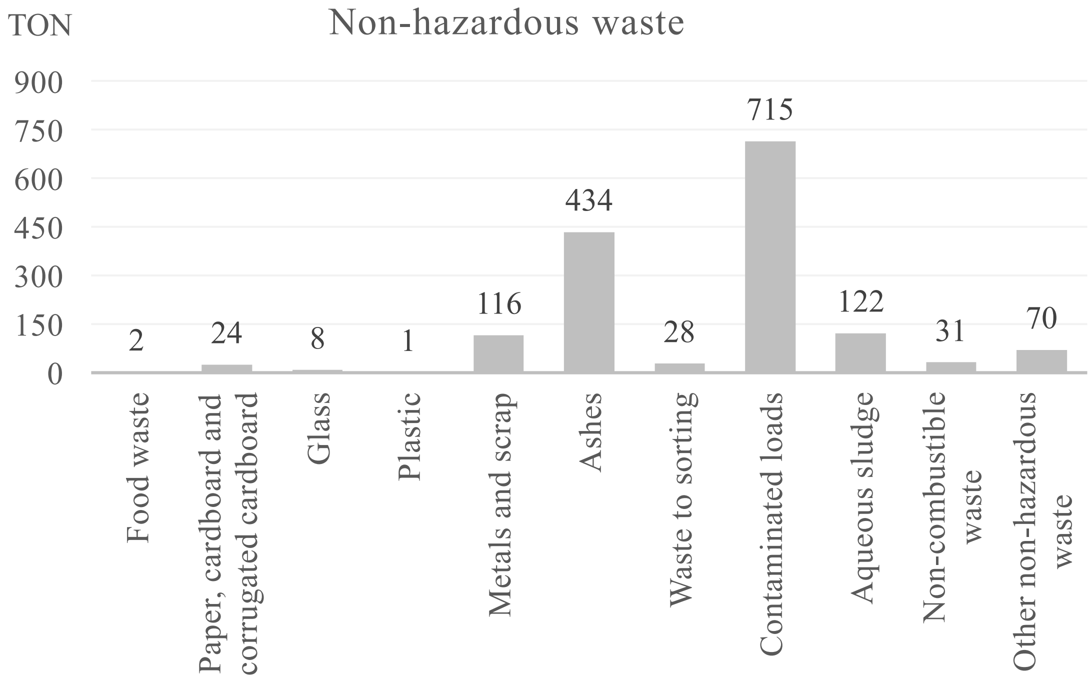

Figure 13. Non-hazardous waste, Production.

The amount of hazardous waste generated in 2015 was 1200 ton, see Figure 14. The largest waste stream is *sludge containing hazardous substances,* that origin from GoBiGas. *Other hazardous waste* is the second largest waste stream before *contaminated loads*. Included in the waste stream *other hazardous waste* are mixed oil waste, chemicals, acids, aerosols, amines, solvents etc.

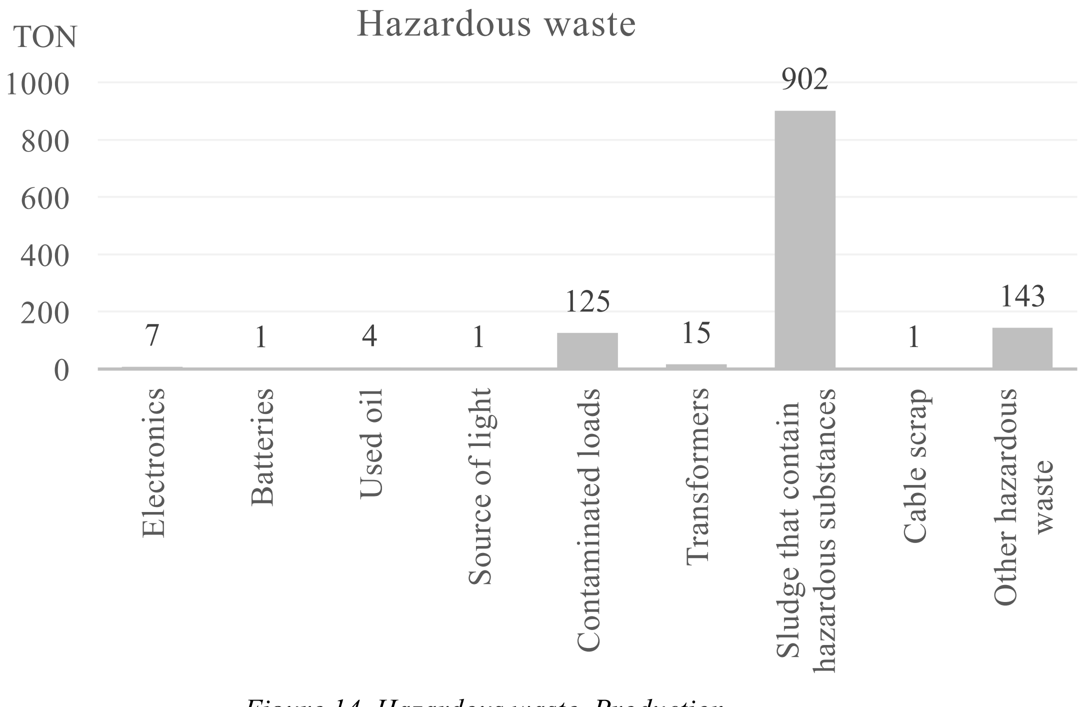

Figure 14. Hazardous waste, Production.

7.1.5 Distribution

The waste that is generated from the activities that are needed to distribute electricity, district heating, cooling and gas are compiled in the sector *Distribution*. A description of what each waste stream includes are presented in section 7.1.1-7.1.2.

For non-hazardous waste *Distribution* is the major cause of waste generation. The total amount of non-hazardous waste within *Distribution* in 2015 was 7616 ton, which to 96% consists of the waste stream *contaminated loads*, see Figure 15.

Figure 16 show the non-hazardous waste again but excluding *contaminated loads*. The figure show that *metals and scrap* dominates followed by *other non-hazardous waste, aqueous sludge,* and *non-combustible waste*. The waste stream *other non-hazardous waste* includes mainly combustible waste.

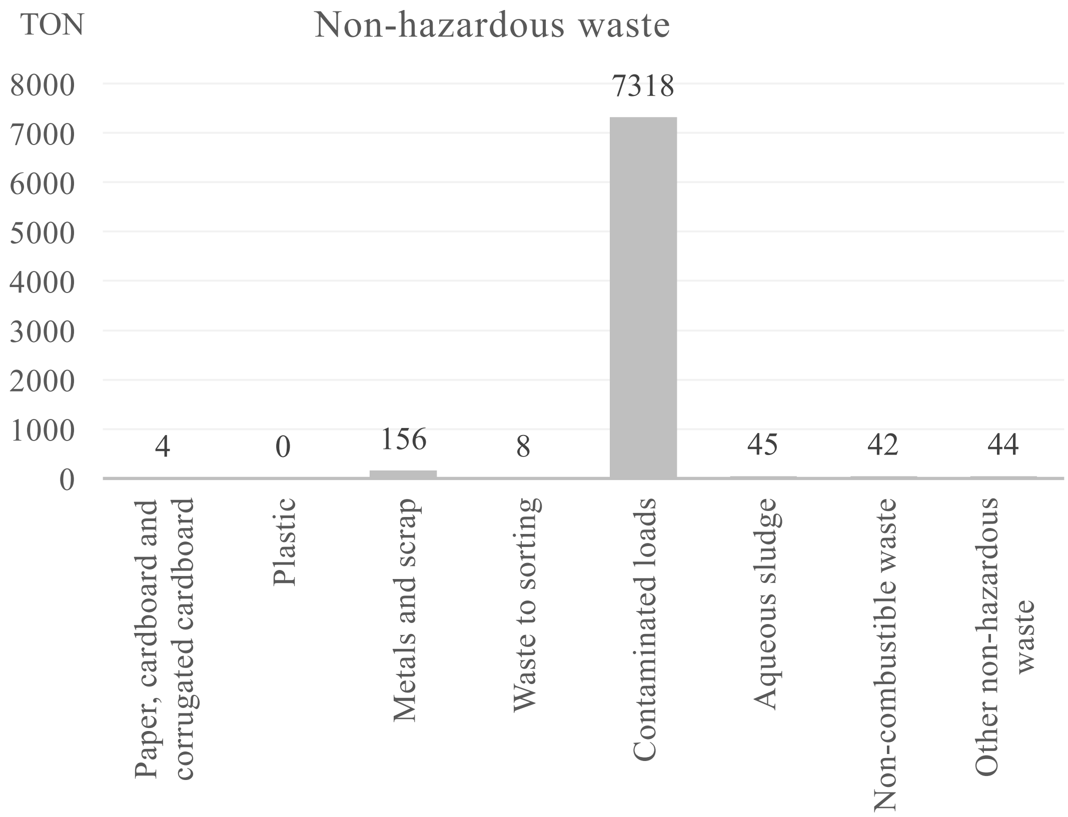

Figure 15. Non-hazardous waste, Distribution.

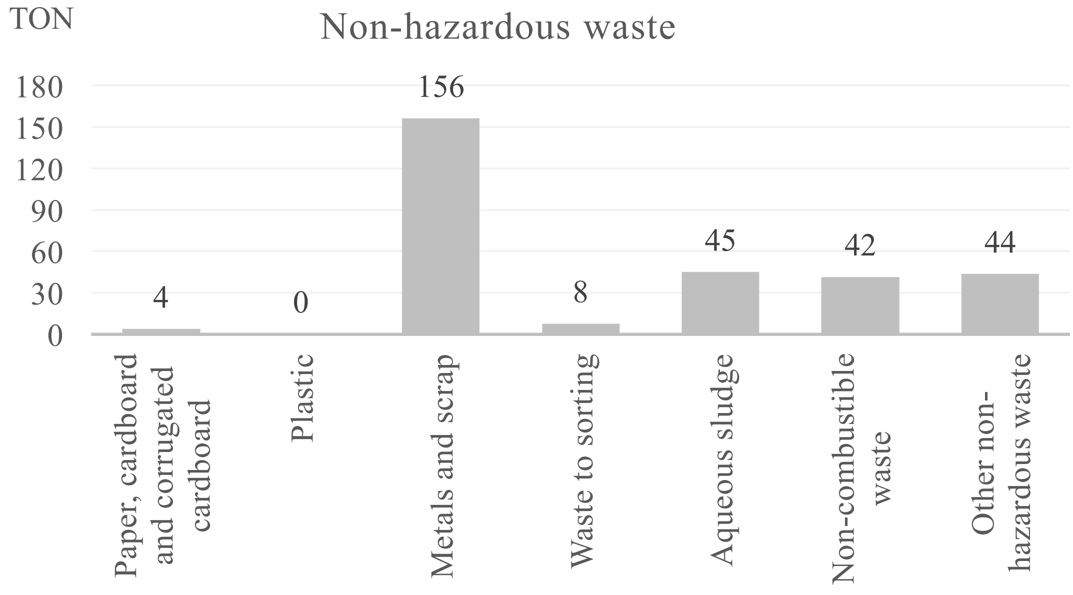

Figure 16. Non-hazardous waste Distribution, excluding contaminated loads.

The total amount of hazardous waste generated within *Distribution* in 2015 was 577 ton. *Contaminated loads* contribute to above 50%, were one of the major source is PAH-asphalt with a concentration of Polycyclic Aromatic Hydrocarbons (PAH) over 1000mg/kg. *Transformers* stands for around 30% of the total mass, see Figure 17. The waste stream *other hazardous waste* is one of the smallest in quantity and comprises oil, paint, aerosols etc.

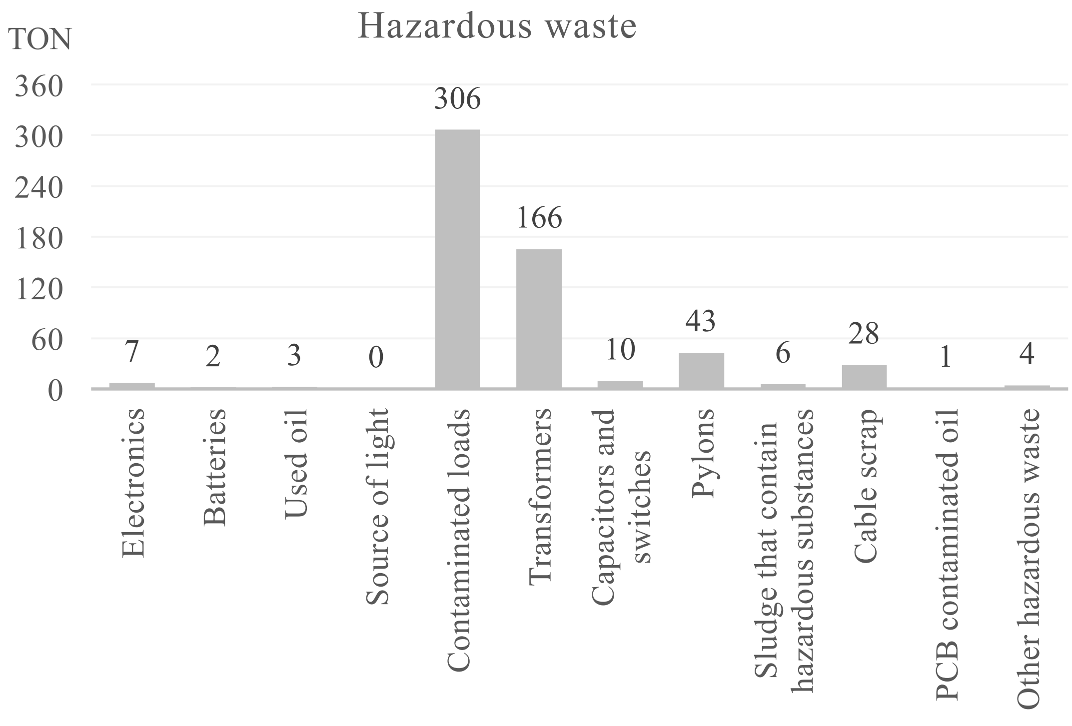

Figure 17. Hazardous waste, Distribution.

7.1.6 GothNet

The sector *GothNet* includes all waste streams that were generated within *GothNet*. The purpose of *GothNet* is to own and manage the city network.

The total amount of non-hazardous waste generated within GothNet in 2015 was 4.54 ton, where *paper, cardboard and corrugated cardboard* stood for 2.54 ton and *other non-hazardous waste* stood for 2 ton. The waste stream *other non-hazardous waste* contains the waste fractions combustible waste and wood. The total amount of hazardous waste generated were 1.68 ton, which only includes the waste stream *electronics*.

7.2 Framework for identification of prioritized waste streams

Phase 2.

This section presents a framework of how it is possible to identify which waste streams that should be prioritized to decrease the environmental impact from waste. The purpose with the framework is to present a list of waste streams that are most important to reduce towards lowering the environmental impact from waste. This framework does not set a limit for what a prioritized waste stream is, in contrast the framework illustrate how waste streams can be ordered based on the level of priority. The framework consists of three of Sweden's environmental objectives: *reduced climate impact*, *a non-toxic environment*, and *a good built environment*. How the framework can be used are presented further down in this section, the choice of aspects within the framework are presented in Chapter 6, section 6.2. An overview of the three steps in the framework and the aspects that should be consider within each step are presented in Figure 18.

1. Reduced climate impact

Identification of waste streams with the highest GHG emissions

2. A non-toxic environment

Identification of waste streams that contains *substances that should be phased out*

3. A good built environment

Identification of the share of the total mass for each waste stream and how the waste is treated

Result from the three parts of the framework presented in a list of waste streams to prioritize

Figure 18. Overview of the framework.

The results from the different steps are not weighted together to one final index, instead the results intend to present a list of waste streams that affect all or some parts of the framework and to what degree.

Before using the framework an identification and mapping of the waste streams are needed. The waste streams should be divided between hazardous and non-hazardous waste, the total quantity of waste per waste stream should be collected, as well as information regarding how the waste is treated. Thereafter the following three steps in section 7.2.1-7.2.3, and the concluding section 7.2.4 can be used to identify which waste streams that should be prioritized.

7.2.1 Reduced climate impact

This step identifies the waste streams with the highest $CO_{2\text{-eq}}$ emissions, hence should be prioritized.

Emissions of $CO_{2\text{-eq}}$ upstream (extraction and manufacturing) and downstream (waste management) can be retrieved from Sundqvist and Palm (2010) (Sundqvist and Palm, 2010). Emissions of GHGs arises from extraction of the raw materials that are used to produce products and during manufacturing of the products that after usage becomes waste, these stages in the life cycle are throughout the framework named *upstream*. Emissions from upstream used by Sundqvist and Palm (2010) were retrieved from various LCA studies. Emissions during waste management includes collection of waste, transport, and treatment, these stages in the life cycle are throughout the framework named *downstream*. Excluded in the calculations by Sundqvist and Palm (2010) are emissions during the use phase, i.e. in-between upstream and downstream. The climate impact from downstream is negative for some waste streams since the waste streams are recycled or incinerated for energy recovery and replace the use of virgin materials. For some waste streams, sludge etc., only downstream was included in the calculations by Sundqvist and Palm (2010) since the waste streams cannot be derived to a certain product or material upstreams.

The climate impact from downstream calculated by Sundqvist and Palm (2010) depends on how the waste is treated. The waste treatment used for the calculations by Sundqvist and Palm (2010) was retrieved from the Swedish Environmental Protection Agency (Naturvårdsverket, 2008). Where gaps occurred Sundqvist and Palm (2010) made assumptions on the distribution of waste treatments. Therefore, the result from using this step of the framework should be handled as an approximation and variations occur based on the different treatments of the waste. These variations are important to have in mind, but the purpose of using the framework is not to show exact numbers, in contrast the result should be used to perceive differences and compare magnitudes of waste streams.

Sundqvist and Palm (2010) presents the result in $CO_{2\text{-eq}}$/ton of waste for each waste stream. Multiply the emissions of $CO_{2\text{-eq}}$/ton by the total amount of waste within the company per waste stream in ton/year and present the result in $CO_{2\text{-eq}}$/year, for non-hazardous and hazardous waste. Table 7 and Table 8 show the climate impact for some common non-hazardous and hazardous waste streams respectively, presented by Sundqvist and Palm (2010). If more details and a larger variety of waste streams are needed a further extensive list is presented in the report by Sundqvist and Palm (2010).

Table 7. Climate impact presented by Sundqvist and Palm (2010) for non-hazardous waste streams.

Non-hazardous waste streams	Climate impact $CO_{2\text{-eq}}$/ton
Textile	17
Rubber	5.6
Batteries	5.5
Animal waste from processing of food and food waste	4.2
Plastic	3.4
Mixed non-differentiated materials	3.4
Metals	1.2
Glass	0.51
Paper and cardboard	0.17
Sludge from sewage treatment	0.08
Acidic, alkaline or saline waste	0.02
Mineral waste	0.01
Wood	-0.03

Table 8. Climate impact presented by Sundqvist and Palm (2010) for hazardous waste streams.

Hazardous waste streams	Climate impact $CO_{2\text{-eq}}$ /ton
Discharged equipment	24
Glass	7.6
Batteries and accumulators	6.1
Waste from chemical processing	4.4
Solvents	2.3
Mixed non-differentiated materials	1.6
Used oil	1.1
PCB-waste	0.18
Contaminated loads and dredged materials	0.15
Metals	0.12
Sewage sludge from industries	0.05
Waste from incineration	0.05
Acidic, alkaline or saline waste	0.02
Wood	-0.56

Compile the result

Compile the result in a table where the waste stream that has the greatest emissions of $CO_{2\text{-eq}}$/year is placed first i.e. this waste stream should be prioritized, followed by the waste stream that has the second greatest emissions of $CO_{2\text{-eq}}$/year at place number two, and so on.

7.2.2 A non-toxic environment

This step identifies the waste streams that may contain *substances that should be phased out,* and because of that should be prioritized.

Substances that should be phased out are substances that needs to be reduced because they cause certain health-, and environmental impacts (Kemikalieinspektionen, 2017a). One example is lead, that can cause damages to the nervous system, reduce the cognitive development and cause high blood pressure (Kemikalieinspektionen, 2015a).

Each waste stream needs to be studied to identify if they contain *substances that should be phased out*. There are different ways to accomplish this. In PRIO, developed by the Swedish Chemical Agency, *substances that should be phased out* are divided in five categories (Kemikalieinspektionen, 2017c), these categories can give a primary guidance regarding which substances that are of interests. The categories and examples of substances in each category are described further in the text, followed by examples of other ways to identify if a waste stream contains *substances that should be phased out*.

1. Carcinogenic, Mutagenic, and toxic to Reproduction (CMR)

It is common that fuel and raw materials for synthesis contains substances that may be Carcinogenic, Mutagenic or have effects on Reproduction. Gasoline is another product that contains carcinogenic substances. Creosote, chromium and arsenic in wood preservatives and waterproofing products are as well carcinogenic. Substances that affect the potential for reproduction are phthalates (softeners in PVC) and lead (paints and varnishes). (Naturvårdsverket, 2017b)

2. Endocrine disruptors

This category includes substances that cause disrupting effects on the endocrine system, which could lead to cancer or reproduction effects. No general criteria for endocrine disruptors exist but substances that are suspected to cause those effects are phthalates (primary used as softeners in PVC), chloroparaffins (cutting fluids for metal machining and softeners for flame retardants in plastics and rubbers), alkyl phenols (detergents, paints, glue, degreasers, pesticides and coolants), PBBs and PBDEs (flame retardants), bisphenols (used as raw materials for synthesis of other substances and in some plastics), pesticides and tributyltin compounds (paints for boats and in some preservatives). (Regeringskansliet, 2000)

3. Particularly hazardous metals: Cadmium, Mercury and Lead (Cd, Hg, Pb)

Cadmium, mercury and lead are all chemical elements and particularly hazardous metals. One negative impact from mercury is disruptive effects on the nervous system, while cadmium causes effects on the kidneys. Lead can, as mercury, cause damages to the nervous system but also reduce the cognitive development and cause high blood pressure. (Kemikalieinspektionen, 2015a) The use of cadmium, mercury and lead in electrical equipment and electronics are banned since 2006, but some electrical equipment and electronics that have not become waste still contains heavy metals (Naturvårdsverket, 2016b). Batteries that contain cadmium and mercury, over 0.002% and 0.0005% respectively, should since 2015 not be available on the market (Naturvårdsverket, 2016c). Waste that cannot be recycled and contain 0.1% mercury shall since 2015 be stored (Naturvårdsverket, 2016e).

4. Persistent, Bioaccumulative, Toxic/very Persistent, very Bioaccumulative (PBT/vPvB)

Persistent means that a substance is very poorly degraded in the environment. Examples in this category are PCB, DDT and brominated flame retardants. Bioaccumulation means that substances accumulate in the cells. (Kemikalieinspektionen, 2016)

5. Ozone-destructive substances

The ozone-layer in the stratosphere protects the earth from UV radiation from the sun. The UV radiation has the potential to cause cancer. Chlorine and bromine are chemical elements that are ozone-destructive and can be found in CFCs, HCFCs, halons, chlorinated solvents and methyl bromide. (Kemikalieinspektionen, 2015b)

Identify if a waste stream contains *substances that should be phased out*

The list below presents opportunities to search for information regarding if a waste stream, or the purchased products that becomes waste contains *substances that should be phased out*.

- Search in PRIO

In PRIO, it is possible to search for a chemical name, a product type or each of the five above-mentioned categories (Kemikalieinspektionen, 2017c). For example, search in PRIO for the first category: *Carcinogenic, Mutagenic, and toxic to Reproduction*, and a list of substances that can cause these effects is presented.

- Study the purchase

If the purchase of products within a company is well documented it is possible to use this information. For example, if one waste stream is *batteries*, study which *batteries* that were purchased. Contact the retailers of the specific *batteries* and ask for information regarding the chemical content in the *batteries*. Use PRIO and search if some of the chemicals are a *substance that should be phased out*.

- Search in the Swedish Chemical Agency's list of *particularly hazardous substances*

The Swedish Chemical Agency has developed a list of a bit less than 200 hundred *particularly hazardous substances* (Kemikalieinspektionen, 2017d), this list can be used to investigate if a certain substance should be given extra attention.

- Use the waste codes

Each waste stream is denoted by a waste code, i.e. a code that defines the waste. Appendix 4 in the Swedish waste regulation (2011:927) includes a list of waste streams and their waste codes. If the waste codes are provided, it is possible to search in Appendix 4 in the Swedish waste regulation to find a description of the waste stream. In some cases, it is expressed what a certain waste stream contains. For example, if a transformer contains PCB the waste stream receives a different waste code compared to a transformer that do not contain PCB.

- Use Table 9, which is compiled by the author of this master thesis

Table 9 shows examples of *hazardous waste* streams and which substances that they may contain. The Table can be used as a general description in absent of specific information. The first column shows examples of *hazardous waste* streams and the second column shows the result from a literature review of substances that each waste stream may contain.

Table 9. Identification of hazardous waste streams that may contain substances that should be phased out.

Hazardous waste streams	Identification of which substances that the hazardous waste streams may contain
Electronics	The use of Cd, Hg, and Pb in electrical equipment and electronics are banned since 2006, but some electrical equipment and electronics that have not become waste still contains the heavy metals (Naturvårdsverket, 2016b).
Batteries	Batteries that are available on the market should since 2015 not contain cadmium and mercury above 0.002% and 0.0005% respectively (Naturvårdsverket, 2016c).
Used oil	Substances that could cause CMR-effects are frequently found in crude oil or petroleum products (Naturvårdsverket, 2017).
PAH-asphalt	PAH is Carcinogenic (Kemikalieinspektionen, 2017).
Soil containing metals and oil	Based on the classification from the Swedish Environmental Protection Agency (Naturvårdsverket, 2009), the concentration of metals is likely to be above 2.5-500 mg/kg depending on which metals that the soil contains. For oil the concentration are likely to be above 15-1000 mg/kg. If the concentration are ≥ 1000 mg/kg this means that oil stands for ≥0.1% of the total mass.
Soil containing oil	The concentration of oil is likely to be above 15-1000 mg/kg (Naturvårdsverket, 2009). If the concentration is ≥ 1000 mg/kg it means that oil stands for ≥0.1% of the total mass.
Switches containing sulfur hexafluoride	Sulfur hexafluoride is a strong GHG (Naturvårdsverket, 2010).
Switches containing oil	Substances that could cause CMR-effects are frequently found in crude oil or petroleum products (Naturvårdsverket, 2017).
Switches containing asbestos	Asbestos is carcinogenic (Kemikalieinspektionen, 2017).
Pylons	Creosote impregnated (Kemikalieinspektionen, 2017) (carcinogenic) and copper, chromium, arsenic (CCA) in timber. Chromium and arsenic in wood preservatives and waterproofing products are as well carcinogenic (Naturvårdsverket, 2017).
PCB contaminated oil	PBT/vPvB (Kemikalieinspektionen, 2017)
Asbestos	Carcinogenic (Kemikalieinspektionen, 2017)
Paint, varnish, glue	Paint and varnish can contain lead compounds that effect the potential for reproduction (Naturvårdsverket, 2017).
Oil waste	Substances that could cause CMR-effects are frequently found in crude oil or petroleum products (Naturvårdsverket, 2017).
Toner cartridges	Toner contains carbon black (Naturvårdsverket, 2011).
Amines	Allergenic (Kemikalieinspektionen, 2017)
Solvents	May contain substances that causes CMR-effects (Kemikalieinspektionen, 2017c).
Cutting fluid	Can be carcinogenic (Kemikalieinspektionen, 2017).

Compile the result

Compile all waste streams that may contain *substances that should be phased out* in a table. Order the waste streams based on their total quantity in ton/year, i.e. place the waste stream with the largest quantity first, followed by the waste stream with the second largest quantity at place number two, and so on. Note that the total content of *substances that should be phased out* in each waste stream is disregarded, this result only compare the waste streams based on the total generation of waste per waste stream in ton/year. The waste stream placed first should be prioritized, followed by the waste stream placed secondly, etc.

7.2.3 A good built environment

This step identifies the *share of the total mass for each waste stream* and how the waste streams are treated, to evaluate which waste streams that should be prioritized.

Step 1

In step 1, calculate the *share of the total mass for each waste stream* compared to the total amount of waste generated. The calculations are made by dividing the quantity of each waste streams by the total amount of waste generated, Table 10 show an example of the calculations.

Table 10. Example of step 1, calculations of the share the total mass for each waste stream compared to the total amount of waste generated.

Waste stream	Quantity (ton)	Share of each waste stream
Metals and scrap	40	(40/100) = 40%
Glass	30	(30/100) = 30%
Food waste	20	(20/100) = 20%
Plastics	10	(10/100) = 10%
	Total: 100 ton	Total: 100%

Step 2

In step 2, the *waste hierarchy* in Figure 19 is used to understand which waste streams that circulate in closed loops. Place the waste streams in the waste hierarchy depending on how the waste is treated. For example, if the waste stream *metals and scrap* is recycled this waste stream is placed at *recycling* in the waste hierarchy.

In the waste hierarchy in Figure 19 one step is added in-between recycling and recovery, and another in-between recovery and disposal, namely: recycling/recovery and recovery/disposal, compared to the waste hierarchy presented in Figure 3 within Chapter 3. These two steps are added because it is common that some waste streams are disassembled and the components are treated in different ways. For example, the waste stream *electronics* can contain the two components metals and plastics, and these components may be treated in different ways. If metals are recycled and plastics are recovered, the waste stream *electronics* is placed at recycling/recovery in the waste hierarchy in Figure 19.

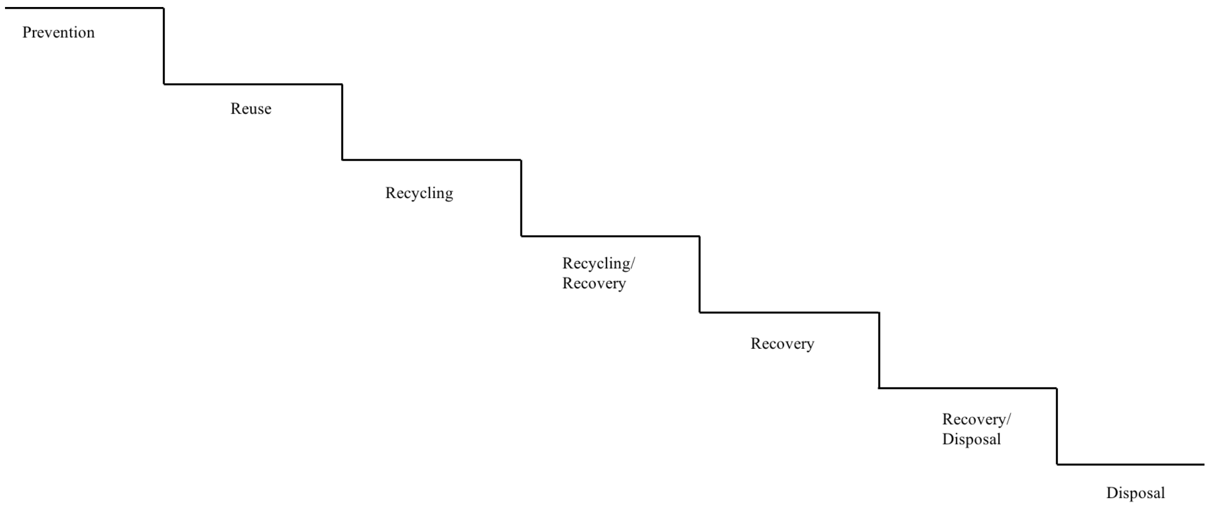

Figure 19. The waste hirerachy is based on the European Commission (2008), insert the waste streams depending on how the waste is treated.

Compile the result

This section describes how step 1 and step 2 are used to retrieve a list of which waste streams that should be prioritized.

Compile all waste streams in a table. The waste stream at the lowest level (disposal) of the waste hierarchy in Figure 19 is placed first, i.e. this waste stream should be prioritized, followed by the waste stream placed at the second lowest level (recovery/disposal) of the waste hierarchy at place number two, and so on.

If two waste streams are placed at the same level of the waste hierarchy for example at recycling, the waste stream with the largest share in percentage from step 1 is chosen to be prioritized before the second largest. For example, if the two waste streams *plastic* and *glass* both are recycled and therefore placed at the same level of the waste hierarchy (at recycling), step 1 is used to compare the share of each waste stream in percentage. If *plastic* has a share of 10% and *glass* 30% of the total mass, *glass* has the greatest share and is placed at number 1, i.e. should be prioritized before *plastic* that is placed secondly.

7.2.4 Identified prioritized waste streams

The last step of the framework is to compile the result from the three parts to identify if some waste streams should be prioritized based on all or two parts of the framework.

Compile the result from all parts of the framework in one table for hazardous waste and one table for non-hazardous waste. Table 11 show an example of a table presenting the result. The first column shows the order of the waste streams, the waste stream that should be prioritized is placed at number 1, followed by the second waste stream that should be prioritized at number 2 etc.

Table 11. Example of how the result can be presented.

	Reduced climate impact	**A non-toxic environment**	**A good built environment**
1	Plastic	*Metals*	Food waste
2	*Metals*	Contaminated loads	*Metals*
3	Non-combustible waste	Glass	Paper and cardboard
…	…	…	…

The result from the example in Table 11 show which waste streams that should be prioritized according to the three parts of the framework: *reduced climate impact, a non-toxic environment,* and *a good built environment.* For example, the table show that plastic should be prioritized based on a *reduced climate impact*, while food waste should be prioritized based on *a good built environment*.

From this compilation, it is possible to identify if a certain waste stream is among the most important waste streams to prioritize according to all or two parts of the framework. The example in Table 11 show that the waste stream *metals* is among the three most important waste streams to prioritize based on all parts of the framework. If the purpose is to reduce the overall environmental impact from waste, chose to prioritize the waste streams that are among the most prioritized waste streams according to all parts of the framework.

7.3 Identification of prioritized waste streams at Göteborg Energi

Phase 3.

The framework developed in phase 2 is used to identify which waste streams within Göteborg Energi that should be prioritized. Section 7.3.1-7.3.3 present the result for the three parts of the framework and in section 7.3.4 is the waste streams that should be prioritized listed. The result is discussed in Chapter 8.

7.3.1 Reduced climate impact

The result from the climate impact per waste stream in $CO_{2\text{-eq}}$/year is presented in Table 12 and Table 13 for non-hazardous, and hazardous waste streams respectively. The tables show the quantity of waste per waste stream and year in ton, and the emissions of $CO_{2\text{-eq}}$ per year for each waste stream. Which waste streams that should be prioritized are presented in section 7.3.4.

Table 12 show that the climate impact for non-hazardous waste streams is greatest for *contaminated loads*. *Other non-hazardous waste, metals and scrap,* and *waste to sorting* also have a high climate impact compared to the additional non-hazardous waste streams. Table 13 show that the climate impact from hazardous waste streams is greatest for *transformers*. *Electronics,* and *capacitors and switches* also have a high climate impact compared to the additional hazardous waste streams.

Table 12. Climate impact for the non-hazardous waste streams at Göteborg Energi.

Non-hazardous waste streams at Göteborg Energi	**Ton waste/year**	**Climate impact $CO_{2\text{-eq}}$/year**
Contaminated loads	8033	1205
Other non-hazardous waste*	168	570
Metals and scrap	274	315
Waste to sorting	38	130
Food waste	10	41
Ashes	434	22
Plastic	4	13
Aqueous sludge	167	13
Paper, cardboard and corrugated cardboard	58	10
Glass	16	8
Non-combustible waste	73	1

*Mainly combustible waste

Table 13. Climate impact for the hazardous waste streams at Göteborg Energi.

Hazardous waste streams at Göteborg Energi	Ton waste/year	Climate impact $CO_{2\text{-eq}}$/year
Transformers	181	4274
Electronics	18	427
Capacitors and switches	10	228
Contaminated loads	431	65
Sludge that contain hazardous substances	908	45
Source of light	1	35
Amines	14	23
Other hazardous waste*	4	18
Batteries	2	14
Solvents	5	11
Used oil	7	7
Cable scrap	30	4
Paint, varnish, glue	1	3
Sulfur containing waste and acids	17	0
PCB contaminated oil	1	0
Waste from incineration	9	0
Cutting fluid	21	-1
Oil waste	77	-4
Pylons	43	-24

*Asbestos, mercury, aerosols, toner cartridges, absorbents, and bases.

7.3.2 A non-toxic environment

In this step, only the hazardous waste streams within Göteborg Energi are studied. Table 14 show some of the hazardous waste streams within Göteborg Energi and information regarding which substances that they contain. The result is presented in Table 15, that show the hazardous waste streams within Göteborg Energi that may contain *substances that should be phased out* and each their quantity of waste per waste stream in ton/year. Which waste streams that should be prioritized are presented in section 7.3.4.

Table 14. Identification of hazardous waste streams that may contain substances that should be phased out.

Hazardous waste streams	**Waste fractions**	**Substances that should be phased out**
Batteries	Lead batteries	Pb
Source of light	Fluorescent	Hg (according to waste codes)
Contaminated loads	PAH-asphalt (>1000mg/kg) and soil contaminated with tar	PAH is carcinogenic (Kemikalieinspektionen, 2017) The concentration of PAH is ≥0.1%.
Transformers	Transformers that may contain PCB (according to waste codes)	PBT/vPvB (Kemikalieinspektionen, 2017). Göteborg Energi is phasing out all transformers that contain PCB (Björkman, 2017).
Switches	Switches containing sulfur hexafluoride (according to waste codes)	Sulfur hexafluoride is a strong GHG (Naturvårdsverket, 2010).
	Switches containing asbestos (according to waste codes)	Asbestos is carcinogenic (Kemikalieinspektionen, 2017).
Capacitors	-	Contain hazardous substances, but not PCB (according to waste codes).
Sludge that contain hazardous substances	The largest fraction is water containing hazardous substances from GoBiGas	The water that is generated within GoBiGas contains for example PAH and tar.
Cable scrap	Contain oil, coal tar or other hazardous substances	Coal tar is carcinogenic (Kemikalieinspektionen, 2017).
PCB contaminated oil	-	PBT/vPvB (Kemikalieinspektionen, 2017)
Other hazardous waste	Asbestos	Carcinogenic (Kemikalieinspektionen, 2017)
	Mercury	Hg

The result from Table 15 show that among all waste streams that may contain *substances that should be phased out*, a large quantity of *PAH-asphalt* was generated in 2015, followed by *oil waste*. The table show that only a small quantity of *mercury* and *switches containing asbestos* were generated in 2015.

Table 15. The hazardous waste streams that may contain substances that should be phased out, and the quantity of waste per waste stream in ton/year.

Hazardous waste streams at Göteborg Energi that may contain substances that should be phased out	**Ton waste/year**
PAH-asphalt (contaminated loads)	138
Oil waste	77
PCB transformers	44
Pylons	43
Cable scrap	30
Cutting fluid	21
Used oil	7
Solvents	5
Asbestos	3
Fluorescent	1
Lead batteries	1
PCB contaminated oil	1
Paint, varnish, glue	1
Switches containing asbestos	0
Mercury	0

7.3.3 A good built environment

This section presents the result from the calculations of the share of the total mass of each waste stream compared to the total amount of waste generated, step 1, and the result for how each waste stream is treated, step 2. Which waste streams that should be prioritized are presented in section 7.3.4.

Step 1

Table 16 and Table 17 show a list of the waste streams based on the share of the total mass, in percentage, for non-hazardous, and hazardous waste respectively. Table 16 show that *contaminated loads* stands for around 87% of the total non-hazardous waste generated, followed by *ashes* that stands for nearly 5% of the total mass. Table 17 show that *sludge that contain hazardous substances* and *contaminated loads* together stands for about 75% of the total amount of hazardous waste generated.

Table 16. Non-hazardous waste streams at Göteborg Energi and their share of the total mass of waste.

Waste stream	Percentage of the total non-hazardous waste
Contaminated loads	87%
Ashes	4.7%
Metals and scrap	2.9%
Other non-hazardous waste	1.8%
Aqueous sludge	1.8%
Non-combustible waste	0.78%
Paper, cardboard and corrugated cardboard	0.62%
Waste to sorting	0.41%
Glass	0.17%
Food waste	0.11%
Plastics	0.04%

Table 17. Hazardous waste streams at Göteborg Energi and their share of the total mass of waste.

Waste stream	Percentage of the total hazardous waste
Sludge that contain hazardous substances	51%
Contaminated loads	24%
Transformers	10%
Other hazardous waste	8.3%
Pylons	2.4%
Cable scrap	1.7%
Electronics	1.0%
Capacitors and switches	0.54%
Used oil	0.39%
Batteries	0.12%
Source of light	0.08%
PCB contaminated oil	0.06%

Step 2

All the waste streams are placed in the waste hierarchy depending on how the waste is treated, see Figure 20. The figure show that many of the non-hazardous waste streams are recycled while several of the hazardous waste streams are recovered, or disassembled to be recycled or recovered.

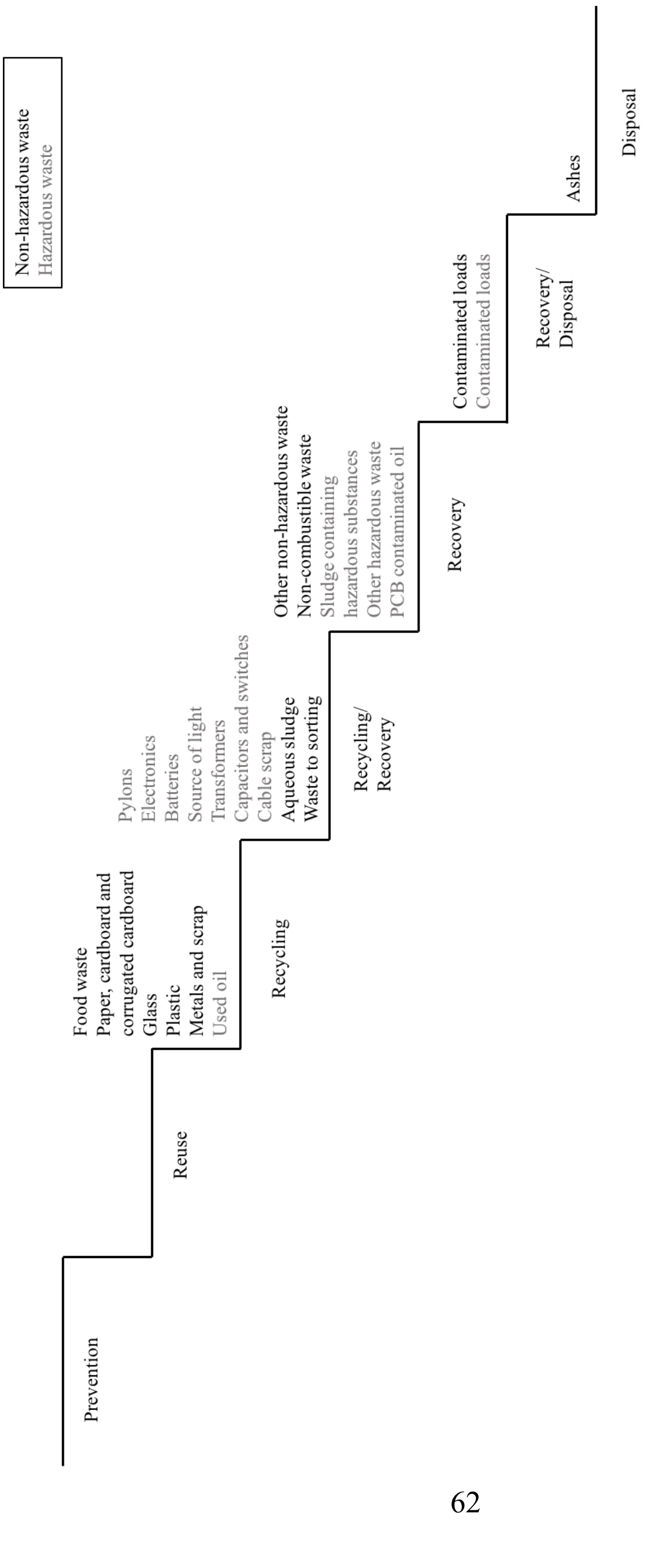

Figure 20. Show how each waste stream is treated. The non-hazardous waste streams are black, and the hazardous waste streams are gray. The waste hirerachy is based on the European Commission (2008).

7.3.4 Identified prioritized waste streams

The different parts of the framework give different results for which waste streams that should be prioritized. Table 18 and Table 19 show a compilation of which waste streams that should be prioritized based on the framework, for non-hazardous and hazardous waste respectively.

The result shows that the four non-hazardous waste streams that are among the six most important waste streams to prioritize for each part of the framework are:

- Ashes
- Contaminated loads
- Other non-hazardous waste
- Waste to sorting

Plastic, paper, cardboard and corrugated cardboard, and *glass* are three waste streams that all are among the four least important waste streams to prioritize according to Table 18. Note that some waste streams, for example *metals and scrap* and *non-combustible waste*, are important to prioritize according to one column i.e. one part of the framework.

Table 18. Prioritized non-hazardous waste streams.

	Reduced climate impact	**A good built environment**
1	**Contaminated loads**	**Ashes**
2	**Other non-hazardous waste***	**Contaminated loads**
3	Metals and scrap	**Other non-hazardous waste***
4	**Waste to sorting**	Non-combustible waste
5	Food waste	**Waste to sorting**
6	**Ashes**	Aqueous sludge
7	Aqueous sludge	Metals and scrap
8	Plastic	Paper, cardboard and corrugated cardboard
9	Paper, cardboard and corrugated cardboard	Glass
10	Glass	Food waste
11	Non-combustible waste	Plastic

*Mainly combustible waste, a small fraction of impregnated wood, painted wood and mixed waste.

Table 19 show that the result for each part of the framework differs. By using the outcome from all three parts of the framework, the result shows that the hazardous waste streams that are among the six most important waste streams to prioritize are:

- Contaminated loads (including PAH-asphalt)
- PCB transformers
- Other hazardous waste

The waste streams in the column *a non-toxic environment* differs from the other two columns. The reason is that for some waste streams only parts has the potential to contain *substances that should be phased out.* One example is the waste stream *contaminated loads* that contains different waste fractions where only one of them, *PAH-asphalt,* is identified to contain *substances that should be phased out.* Another example is *transformers,* that can be separated between *transformer containing PCB* and *transformers that do not contain PCB*. In the columns *reduced climate impact* and *a good built environment* are all *transformers* included, whereas for *a non-toxic environment* only the *transformers containing PCB* is included.

The result shows that the waste streams that are among the six most important waste streams to prioritize from two parts of the framework are:

- Sludge that contain hazardous substances
- Pylons

Table 19. Prioritized hazardous waste streams.

	Reduced climate impact	**A non-toxic environment**	**A good built environment**
1	**Transformers**	**PAH-asphalt (contaminated loads)**	**Contaminated loads**
2	Electronics	Oil waste	*Sludge that contain hazardous substances*
3	Capacitors and switches	**Transformers (PCB)**	**Other hazardous waste***
4	**Contaminated loads**	*Pylons*	PCB contaminated oil
5	**Other hazardous waste***	Cable scrap	**Transformers**
6	*Sludge that contain hazardous substances*	**Other hazardous waste****	*Pylons*
7	Source of light	Used oil	Cable scrap
8	Batteries	Fluorescent	Electronics
9	Used oil	Lead batteries	Capacitors and switches
10	Cable scrap	PCB contaminated oil	Batteries
11	PCB contaminated oil	Switches	Source of light
12	Pylons	-	Used oil

*Asbestos, mercury, aerosols, toner cartridges, absorbents, bases, cutting fluid, solvents, paint, varnish, glue, sulfur containing waste, organic and non-organic acids, amines, hazardous waste to incineration, and mixed oil waste.

**Cutting fluid, solvents, asbestos, paint, varnish, glue, and mercury.

7.4 Towards a circular economy

Phase 4.

The purpose of this section is to identify Göteborg Energi’s present contribution to a transition towards a circular economy, followed by a description of options for improvements that Göteborg Energi could implement to reduce the waste quantities or advance to other levels in the waste hierarchy.

7.4.1 Present situation

The study has earlier shown that some of the waste streams within Göteborg Energi are recycled and replace the use of virgin materials. Recycling of all components in a waste stream are more common for the non-hazardous waste compared to the hazardous waste streams within Göteborg Energi. The recycled non-hazardous waste streams identified in section 7.1 are: *food waste, paper, cardboard and corrugated cardboard, glass, plastic,* and *metals and scrap.* The recycled hazardous waste stream identified in section 7.1 is *used oil*.

Göteborg Energi exchange byproducts, energy and materials with industries in Gothenburg, a connection that can be termed industrial symbiosis. Industrial symbiosis is, as recycling, part of the strategies towards a circular economy. Industrial symbiosis is defined in Chapter 2 as an exchange of materials, energy and waste (Chertow, 2000), as well as other parameters such as knowledge and experience (Lombardi and Laybourn, 2012) between companies.

Figure 21 show Göteborg Energi’s connection to other industries within Gothenburg (Göteborg Energi, 2016). Within the dashed line are the activities of Göteborg Energi. Biological residues from forestry are used to produce biogas, heat and electricity. Ashes from the CHP plant Sävenäs is returned to forest land. Surplus heat from combustion of waste at Renova and surplus heat from various industries and the waste water treatment plant Gryaab are used to heat the water in the district heating system. Biofertilizer from production of biogas is returned to arable land. Biogas is produced within the waste water treatment plant Gryaab through biodegradation, i.e. digestion of sewage sludge. Göteborg Energi buys biogas from Gryaab and the biogas is upgraded in the facility Gasendal. The citizens in Gothenburg use the biogas, district heating and electricity that are produced.

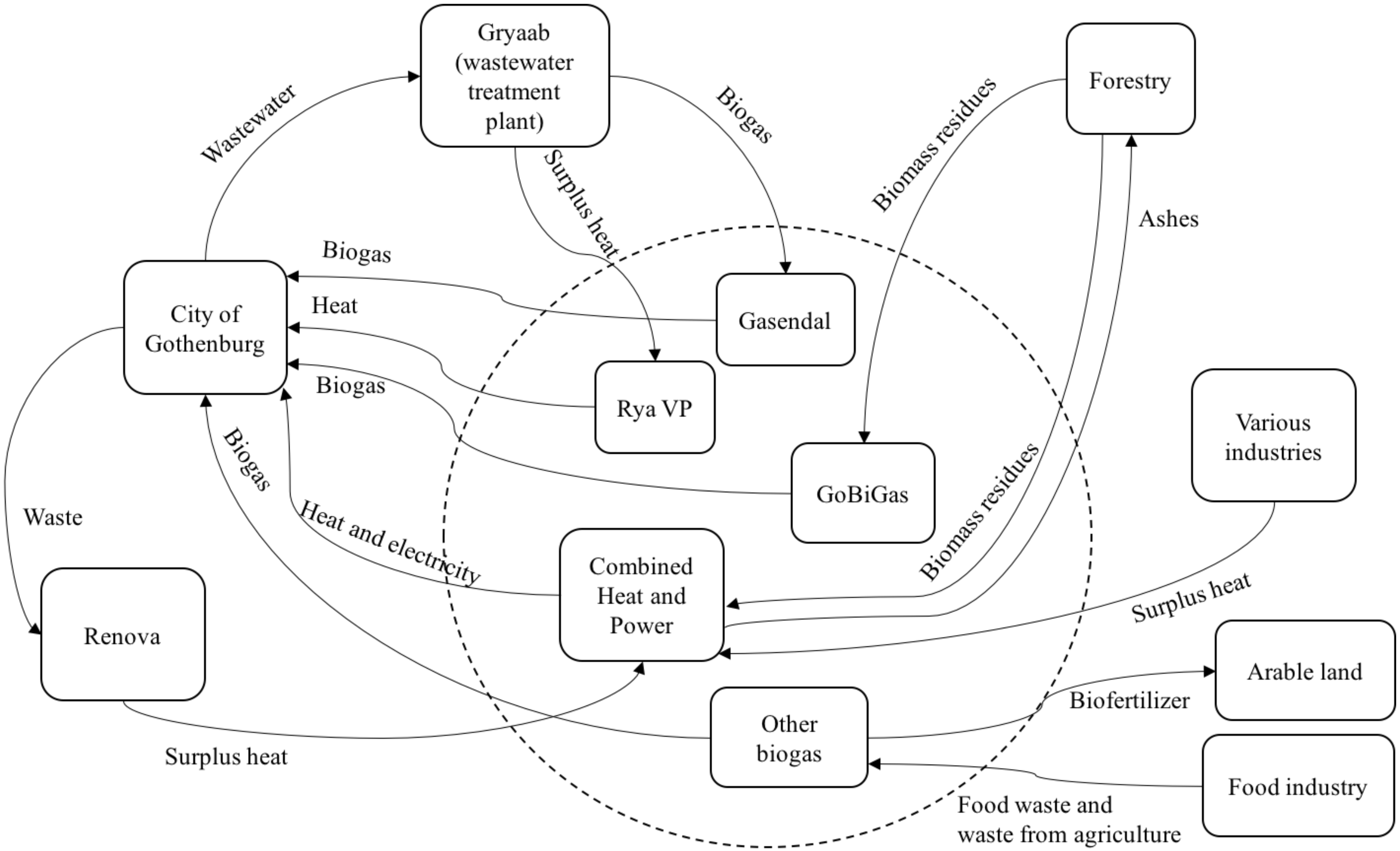

Figure 21. How Göteborg Energi exchange materials, energy and byproducts between other industries in Gothenburg, a connection that can be called industrial symbiosis. Based on Göteborg Energi (2016).

7.4.2 Possible improvements

This section provides examples for possible improvements that Göteborg Energi can implement to decrease the generation of waste and aim for circularity. The purpose is to present improvements for the waste streams that should be prioritized but also improvements that more easily can be achieved, the low hanging fruits. Actions for improvements vary between improvements early in the value chain (before waste is generated) and at the end of the value chain (after waste is generated). This study has identified some waste streams that should be prioritized, but it does not mean that these are the only waste streams where improvements are feasible. Improvements for other waste streams could be more economically beneficial or technically possible to change.

Prioritized waste streams

This section presents possible improvements for the identified prioritized waste streams at Göteborg Energi.

Some of the identified possible improvements for the prioritized non-hazardous waste streams that Göteborg Energi can implement are:

- Increased degree of sorting
- Improved information and education
- Increased recycling rate of recyclable materials
- Reduce the containers with *waste to sorting*

One of the national policy instruments that Göteborg Energi can promote is:

- Taxing unsorted waste

The result from section 7.3 show that the non-hazardous waste streams that should be prioritized are: *ashes, contaminated loads, other non-hazardous waste* and *waste to sorting*.

Waste to sorting and *other non-hazardous waste* can be managed in a way that increase the circularity through an improved degree of sorting. Stenmarck et al. (2014) describes policy instruments that can be implemented on a national level to increase the material recycling, namely: increase the requirements for sorting, increase the taxation of unsorted waste, and increase the information and education. Finnveden et al. (2013) also emphasizes that one policy instrument on a national level is to demand an increased recycling rate of recyclable materials.

Göteborg Energi can improve the recycling system by reducing containers with *waste to sorting*, which enables an increased level of sorting. The largest waste fraction within the waste stream *other non-hazardous waste*, is *combustible waste* which is incinerated for energy recovery. This study does not define how much of the materials in this waste fraction that could be material recycled instead, but the current quantity of *combustible waste* can probably decrease significant through better recycling. Stenmarck et al. (2014) suggests a political incitement to increase the taxation of unsorted waste. On a local level, Göteborg Energi can work proactive and educate the employees regarding which materials can be placed in *combustible waste*. Signs and information at the recycling areas on allowed components in *combustible waste* reminds the employees. The container with *combustible waste* can also be smaller compared to other containers, and placed at strategic positions.

Some of the identified possible improvements for the hazardous waste streams are: substitution and increased requirements on labelling of products that contain *substances that should be phased out*. For hazardous waste, *contaminated loads* (including PAH-asphalt), *other hazardous waste* and *transformers* are the waste streams that are among the six most important waste streams to prioritize according to all aspects presented in the framework. *Sludge that contain hazardous substances* and *pylons* are among the six most important waste streams to prioritize according to two out of three aspects presented in the framework.

PCB transformers and *pylons* are two of the products that Göteborg Energi already is substituting. The reason that they still appear in the waste statistics is because all products have not yet been substituted. Reducing the toxicity of materials is part of the road towards a circular economy. To reach a non-toxic environment, a policy instrument that can be implemented on a national level is to label all products that contain at minimum 0.1% of *substances that should be phased out* according to the criterions by the Swedish Chemical Agency (Finnveden et al., 2013). Göteborg Energi is at present working with phasing out hazardous chemicals and has developed action plans and targets to reduce the hazardous substances. Göteborg Energi can however increase the demand on their suppliers to provide the required information on the chemical content in the products. Some waste streams such as lead batteries, source of light (with a mercury content), and PCB contaminated oil, are not identified as the most critical from the result of using the framework. However, these waste streams contain *substances that should be phased out,* hence substitution is preferred.

Regarding *ashes* (non-hazardous), *contaminated loads* (both hazardous and non-hazardous) and *sludge that contain hazardous substances* (hazardous waste), no improvement possibilities are suggested. The reason is that *ashes* and *sludge that contain hazardous substances* are generated within the research and development project GoBiGas.

The non-hazardous waste stream *ashes* are dust that is captured through various filters used to purify the gases before they are released from the chimney. *Sludge that contain hazardous substances* are generated during cleaning of equipment within GoBiGas, and could be reduced through a more smoothly production without many starts and stops. Göteborg Energi is aware of the generation of waste at GoBiGas and constantly carrying the development forward. When the production of biogas works efficiently it is possible to improve the waste management and reduce the waste quantities. *Contaminated loads* are not studied further since the soil has been contaminated from other industrial activities during the past, and Göteborg Energi can only ensure that no more soil is contaminated and continue hiring waste contractors to treat the already contaminated areas.

Other identified improvements

This section presents other possible improvements that Göteborg Energi can implement and improve. The identified improvements are listed below and the following text describes each of them.

- Requirements on bought services regarding the chemical content in the used products.
- Improved purchase of products to buy for example non-toxic, long-lasting and recycled products.
- Increased communication and education within Göteborg Energi concerning recycling and prevention of waste.
- Increase the industrial symbiosis within Gothenburg to exchange for example materials, energy and knowledge.
- Arrange a workshop with the employees within Göteborg Energi to identify improvement possibilities to reduce the waste quantities and aim for circularity.
- Demand an improved feedback from the waste contractors regarding waste treatment and the environmental impact from waste.
- Implement a waste management plan that can show long-term goals, such as recycling rate and waste quantities.
- Prevent the generation of waste to incineration.
- Improvements at office areas to reduce the waste quantities.
- Flowcharts over the production facilities to picture the material and waste flows.
- Affect the consumers to decrease the consumption of energy.

Higher requirements on the services that are bought such as demand descriptions of what products and materials that have been used, demand quality and longer lasting products, can increase awareness, reduce the amount of waste, and hazardous substances used. Göteborg Energi buys services such as painting etc., the company performing the services use own bought materials and products. When a service is bought, extra attention should be given on *how* the hired companies take care of the used products. Göteborg Energi can request that the suppliers of services or products presents the chemical content as well as how the products are managed after usage. Göteborg Energi has currently requirements on chemical products, the next step is to increase the verification of chemical contents in goods.

The generation of waste can moreover be reduced through **an improved purchase of products.** It is recommended that Göteborg Energi develop an own guideline for the short-, and long-term purchase of products. Examples of aspects that certain guideline can include are specified further in the text. Criterions to think through before ordering new products are firstly, is there *really* a need? Could the products be repaired instead? Is it possible to borrow or rent the products? Secondly, increase the requirements for the products that are purchased: buy reparable and reusable products, buy material-efficient and non-hazardous products, and do not buy more than needed. (Göteborgs Stad, 2016a) The municipality of Gothenburg present an online education designed for managers and persons responsible for purchase. The education aims to prevent the generation of waste during purchase and in turn reduce the climate impact and increase the recourse efficiency. The above-mentioned criterions to think through at purchase along with additional ideas are presented in the online education, retrieved from the homepage of the municipality of Gothenburg. (Göteborgs Stad, 2017b) At purchase, a life cycle thinking and long term perspective should be applied. Products that have a longer lifespan should be preferred. A large portion of the emissions of $CO_{2\text{-eq}}$ arise upstream (Sundqvist and Palm, 2010), which means that those emissions could be reduced by an increased use of materials that have been recycled instead of using virgin materials, and prevent the generation of waste. An identification of companies selling recycled and long lasting products can be accomplished. A system for coordination of purchase can reduce the transportations. By choosing for example non-toxic, renewable and recyclable products in purchase it is possible to affect the market in a direction towards non-toxicity, resource efficiency and circularity.

Information and education can increase the knowledge regarding waste management and the environmental impact from waste. Efficient information explains what the receiver of the information should do and the effects of certain actions. In many cases, information need to be combined with other policy instruments. (Andersson et al., 2011) Change the business towards a circular economy incorporates a new mindset and habits for the employees. Employees can be educated to increase the awareness and knowledge regarding the gains with sorting and minimizing waste. An increased labelling of bottles and boxes can reduce the misunderstandings regarding what a certain bottle contains. Information on what waste fractions that are allowed in a specific container should be clear and updated. A review of the current routines can give knowledge regarding improvement possibilities and potential feedbacks can change the way employees think regarding waste management. Göteborg

Energi has recycling stations at the offices and signs for plastic, paper, food waste etc. Educating the employees is one way to increase the recycling rate, another is to provide signs for which waste fractions that should be sorted into for example *combustible waste*.

Industrial symbiosis is according to Lombardi and Laybourn (2012) along with exchange of materials and energy also sharing of knowledge and experiences. Enterprises and municipalities are in the same position as Göteborg Energi and a platform for sharing ideas and exchange experiences in a transparent manner can accelerate the transition towards a circular economy.

One possibility is to **arrange a workshop** with concerned employees within Göteborg Energi that aims to identify improvement possibilities and long term solutions to decrease the waste quantities. The employees at the various production facilities and offices within Göteborg Energi are well educated and have specific information regarding their part of the business and value chain, this information can be taken care of through arranging a workshop.

Göteborg Energi can demand **improved feedbacks from the waste contractors**. Make the loops as small as possible is one of the actions that can give both environmental and economic benefits (Ellen MacArthur Foundation, 2013). Improved feedbacks and statistics regarding total generation of waste and how the waste is treated can increase the awareness and follow-up within Göteborg Energi. An increased communication with the waste contractors could result in possibilities to exchange feedbacks and improvements.

It is recommended to implement a **waste management plan**, that can illustrate long-, and short term actions. The waste management plan can specify recycling goals, actions to prevent the generation of waste, improvements to aim for circularity etc. A yearly update of the waste management plan in relation to the yearly sustainability reporting makes it possible to follow up and improve the plan.

One of the paths towards circularity is to **prevent the generation of the waste streams that are incinerated** and instead increase the recycling rate. Some of the waste streams that are incinerated for energy recovery are: *PCB contaminated oil, combustible waste* and *other hazardous waste.* For *combustible waste* the first step is to increase the sorting of the waste. *PCB contaminated oil* and *other hazardous waste* are transported to Kumla for incineration. Stenmarck et al. (2014) describes some policy instruments that can be implemented on a national level to reduce the waste that are incinerated, such as: a maximum quote for how much waste that can be incinerated, taxing waste to incineration, and regulation for not incinerate unsorted or untreated waste. These policy instruments can work as incitements for decreasing the waste to incineration, and Göteborg Energi can be one of the companies that welcome this development.

Some of the identified improvements at **offices** are: replace disposal products with reusable, and encourage the use of plates instead of plastic boxes for lunch. The city of Gothenburg has published a report that describes how the generation of waste at offices can be prevented (Göteborgs Stad, 2016a), some of these practices can be applied within Göteborg Energi. The second largest waste stream within the sector *Support* is *paper, cardboard and corrugated cardboard*. Actions to prevent the generation of this waste stream is for example: implement double sided printing as standard and demand a personal conformation for printing (Göteborgs Stad, 2016a). One improvement possibility is to replace all disposable products within the company with reusable products. Another example is to provide reusable lunchboxes in the restaurant instead of the plastic-boxes that are used at present (Göteborgs Stad, 2016a). The employees should be encouraged to use plates instead of disposal boxes if sitting elsewhere in the building than the restaurant. Disposal products within the cafeteria can be replaced with reusable products, that are returned after usage.

Flowcharts over the processes and material flows in the production facilities can improve the understanding regarding where in the process that waste is generated and why. The flowcharts can show in-, and outflows of materials, energy, byproducts and waste. Together with statistics regarding waste generation they could give an overview of where in the process the greatest quantity of waste is generated and give an approximation regarding where improvements may contribute to greatest benefits. A proposal is to provide flowcharts in the environmental reports for each production facility.

A final improvement possibility is to **affect the consumers**. If the consumers reduce the consumption of electricity, district heating, cooling and gas, the generation of waste will consequently decrease.

8. DISCUSSION

The purpose of this Chapter is to discuss the result and method used in relation to the objectives, and provide options for further studies.

Circular economy is a growing concept and reports are continuously published in the subject. EU published an action plan towards a circular economy in 2015, and Sweden published a report in 2017 concerning how Sweden can reach a more circular economy. More reports will probably be presented, and hopefully include examples of improvements that enterprises can implement to prevent the generation of waste and work with loop-closing. The aim of this study is to be part of Göteborg Energi's transition towards a circular economy. Waste management is one of the fields that needs improvements to reach a non-toxic and resource efficient society.

Is there a need to redefine the definition of waste? During the literature review it was found that waste is defined in the EU Waste Directive (2008/98/EG) as an object or a substance that the user discard. In a circular economy, there is nothing called waste. Everything that someone discard could be used as a resource by someone else. If the aim is to reach a circular economy, why not redefine waste. The definition of waste could cover the objects and substances that, no matter what, cannot be used in another process or product because of for example hazardous properties.

The primary objective of this master thesis is to identify and map the waste streams within the value chain of Göteborg Energi. The result shows that 9274 ton non-hazardous waste and 1780 ton hazardous waste were generated during 2015. The main source of the non-hazardous waste is *contaminated loads* (around 87%) and for hazardous waste the main sources are *sludge that contain hazardous substances* and *contaminated loads* (together 75%). *Sludge that contain hazardous substances* and *contaminated loads* are not resources that are consumed and wasted compared to the other waste streams, i.e. they cannot be derived to a certain product in the phase upstream. The generation of contaminated loads is hard to prevent since the soil has been contaminated from industrial activities during the past. At present, contamination of soil should be prevented and the already contaminated areas should be treated as efficient as possible. *Sludge that contain hazardous substances* generated within GoBiGas could be reduced through a more efficient cleaning of equipment, and a more smoothly production without many starts and stops. Since GoBiGas is a research and development plant the focus has not been on reducing the waste quantities, and improvement can be studied when the plant is in full operation.

One of the most time-consuming parts of this study was to compile waste statistics and information regarding how the waste is treated. Improved statistics from the waste contractors reduce the time needed to compile information, and allow an increased follow-up and implementation of improvements at Göteborg Energi. The waste contractors are experts within waste management and have an important role in the transition towards a circular economy. The waste contractors were interviewed to understand how the waste streams are treated. It should be easy for companies like Göteborg Energi to recycle and reduce their waste quantities. If updated signs from the waste contractors are provided at the recycling areas it reduces the misunderstandings and allows the employees to increase the level of sorting. The waste contractors have as well a responsibility to increase the feedback regarding how much waste that they retrieve and how the waste is treated. It would be interesting to investigate which obstacles for an increased recycling rate that the waste contractors could identify. They have another perspective and can work proactive to inform their clients about options for improvements. Another actor that has an important role in the transition towards a circular economy and should be expert on prevention of waste is the producers. The waste contractors are responsible for downstream, after waste is generated, but the producers can affect how much waste that is generated and the content of renewable and recyclable materials as well as toxic components in the products.

In this study, a framework that cover three of Sweden's environmental objectives: *reduced climate impact*, *a non-toxic environment,* and *a good built environment* is developed. Before being able to identify which of the waste streams at Göteborg Energi that should be prioritized, one part of this master thesis was to investigate what aspects that should be considered when evaluating which waste streams that should be prioritized. The outcome is a framework that should be easy to use and give the user a list of in what order the waste streams should be prioritized, from an environmental perspective. The framework is divided into three parts. In the first part, a *reduced climate impact,* the emissions of $CO_{2\text{-eq}}$ from upstream and downstream per waste stream are calculated. In the second part, *a non-toxic environment,* the waste streams that may contain *substances that should be phased out* are identified. In the third part, *a good built environment,* the *share of each waste stream* and the *waste hierarchy* are used to understand which waste streams that circulate in closed loops and which waste streams that should be prioritized. The study suggests that if the aim is to reduce the environmental impact from waste, the emissions of $CO_{2\text{-eq}}$, the toxicity of the waste, and resource efficiency, should be prioritized.

The purpose of the framework was not to present precise numbers, rather compare the magnitude of the waste streams. Because of limited time, existing studies have been used within the framework. The framework could be developed to include an identification of *substances that should be phased out* in the non-hazardous waste streams. A more comprehensive study can include separate LCA-studies over each waste stream to calculate the precise emissions of $CO_{2\text{-eq}}$. This scope would increase the time needed to perform the study and it may be difficult to find all information regarding for example production of the products that eventually becomes waste and allocating the environmental impact between the waste streams during waste management.

The content of hazardous substances in products vary significant. A general identification of *substances that should be phased out* in the waste streams is used in many cases during this study. With statistics on the purchase of products it would be easier to make specific observations regarding the content of *substances that should be phased out* in each product, that eventually becomes waste. In this study, the share of *substances that should be phased out* in each waste stream was not calculated (for example, the share of lead in the waste stream *lead batteries*). The share can be retrieved by examine each waste stream to analyze the precise chemical content, a scope that would increase the time needed for performing the study and maybe take more time and effort compared to the value of the result. Hopefully, this study can be used as a guide for the further priority and work within the field of waste management for Göteborg Energi and companies that choose to use the framework.

The result from using the framework for the waste streams at Göteborg Energi shows that the non-hazardous waste streams that are among the sixth most important waste streams to prioritize based on the result from all parts of the framework are: *ashes, contaminated loads*, *waste to sorting,* and *other non-hazardous waste*. The waste stream *other non-hazardous waste* contains in majority the waste fraction *combustible waste*. One of the reason that the waste stream *other non-hazardous waste* should be prioritized is that the waste stream is incinerated and therefore placed at one of the lowest levels in the waste hierarchy. This waste stream has also one of the highest climate impact compared to other waste streams. The waste statistics show that a quite large quantity of the waste streams *paper, cardboard, corrugated cardboard* and *plastic* were generated within the sector *Support* compared to the other sectors. Based on own observations, the generation of these waste streams within the other sectors are probably in the same quantity or above the quantities in the sector *Support,* i.e. there is an unrecorded quantity. This is not shown in the statistics since these waste streams probably are sorted into the waste fraction *combustible waste*. If the level of recycling of recyclable materials increases these waste streams can replace the use of virgin materials instead of being incinerated as the present situation.

The non-hazardous waste stream *ashes* should be prioritized because they are disposed, but even though, from a climate perspective *ashes* are one of the least important non-hazardous waste streams to prioritize. *Contaminated loads* have a low climate impact per ton, and the reason that the climate impact per year are high compared to other waste streams is because a large quantity was generated in 2015. *Waste to sorting* contains a variety of materials such as plastic and metals, and should be prioritized because of a relatively high climate impact that arise from upstream during extraction and manufacturing. This study shows that if the generation of waste cannot be prevented, Göteborg Energi should firstly improve the recycling and reduce the waste streams *waste to sorting* and *combustible waste.*

The result show that only a few of the waste streams at Göteborg Energi are important to prioritize according to all parts of the framework, i.e. the waste streams that should be prioritized depend on the environmental objective that is valued highest. One example is the non-hazardous waste stream *metals and scrap* which is the third waste stream to prioritize according to part one of the framework a *reduced climate impact*, but lower in the list for part three of the framework *a good built environment*. This is a drawback from using the framework. The user of the framework needs to give attention to the waste streams that are not identified as waste streams to prioritize, but placed high in one part of the framework.

Plastic, paper, cardboard and corrugated cardboard, and *glass* are three non-hazardous waste streams that all are among the four least important waste streams to prioritize according to the framework. The characteristics of these waste streams are that they all circulate in closed loops, i.e. they are recycled and replace the use of virgin materials. The quantity of these waste streams is also relatively small compared to other waste streams within Göteborg Energi. Per ton, both *paper, cardboard and corrugated cardboard,* and *glass*, have low emissions of $CO_{2\text{-eq}}$ compared to other non-hazardous waste streams. *Plastic* on the other hand, is one among the three non-hazardous waste streams that have the greatest emissions of $CO_{2\text{-eq}}$ per ton, these emissions arise from upstream.

The hazardous waste streams that are among the sixth most important waste streams to prioritize based on all aspects in the framework are: *PCB transformers, other hazardous waste* and *contaminated loads. PCB transformers* should be prioritized because they contribute to a high climate impact upstream, and PCB is one of the substances that should be phased out. Transformers have a long life length compared to many other products within Göteborg Energi. The calculations of the climate impact exclude the use phase. By including the use phase, the climate impact from transformers might be smaller compared to the other waste streams, because of the long life length. A large fraction of the *contaminated loads* is deposited, the climate impact is on the other hand relatively low per ton.

The hazardous waste streams that are among the sixth most important waste streams to prioritize according to two of three aspects in the framework are: *sludge that contain hazardous substances,* and *pylons.* The climate impact per ton from *sludge that contain hazardous substances* is not high compared to other hazardous waste streams, but large quantities were generated during 2015. *Pylons* should be prioritized because they contain substances that should be phased out, and a share of them are incinerated. As mentioned earlier in the report, one of the improvement that Göteborg Energi is working with is to substitute *pylons* and *PCB transformers*. Therefore, one of the conclusions from this study is that Göteborg Energi has made the right priority.

It should be remembered that even if the mentioned waste streams are identified by the framework to be the most important waste streams to prioritize, other waste streams could be easier to prevent or implementation of improvements more feasible. It is therefore important to prevent the generation of waste in general and implement improvements for waste streams that not are identified as a priority as well.

The waste stream *other hazardous waste* contains many small waste fractions that separately have low climate impact, and quantity in ton. By adding all the waste fractions, the total environmental impact from *other hazardous waste* is significant. It can be questioned if the environmental impact should be calculated for the waste stream in total or if the environmental impact should be calculated for the different waste fractions individually.

When the framework was used for the hazardous waste, the waste streams within *a non-toxic environment* differ from the waste streams categorized in the other two parts of the framework. The reason is that for some waste streams only some parts have the potential to contain *substances that should be phased out.* One example is *transformers,* that can be separated into *transformer containing PCB* and *transformers that do not contain PCB*. In the other two parts of the framework *reduced climate impact* and *a good built environment* all *transformers* are treated as one stream, whereas for *a non-toxic environment* only the *transformers containing PCB* is included.

If Göteborg Energi aims to reduce their carbon footprint per ton of waste, discarded equipment should be prioritized. One of the conclusions from part one of the framework, a *reduced climate impact*, is that discarded equipment (electronics etc.) contributes to the greatest emissions of $CO_{2\text{-eq}}$ per ton. Discharged equipment usually contains components such as plastics and metals. The emissions of $CO_{2\text{-eq}}$ arise mainly during extraction of raw materials and manufacturing.

During this study, it became obvious that the non-hazardous waste streams are easier to deal with and identify the environmental impact from compared to the hazardous waste streams. One reason is that the non-hazardous waste streams often are “clean” flows and do not contain many different components, for example the waste streams *plastic, metals and scrap, food waste, paper,* and *cardboard and corrugated cardboard*. These waste streams are not disassembled at the waste contractors and treated in various ways and in most cases, do not need a primary treatment. While hazardous waste streams such as *electronics, source of light, batteries,* and *transformers* often need a primary treatment, the waste streams are usually disassembled by the waste contractors and the disassembled components are treated in various ways (one component can for example be recycled, while another component incinerated). In some cases, the waste contractors that are hired by Göteborg Energi retrieves the hazardous waste but transport it to another waste contractor which treat the waste.

The purpose with developing the framework and presenting which waste streams that should be prioritized were to guide Göteborg Energi in the choice of where improvements can give greatest gains from an environmental perspective. The improvement possibilities focus on the prioritized waste streams but also other improvements, the low hanging fruits. According to the waste hierarchy, waste should primarily be prevented. This study also concludes that the greatest benefits from an environmental perspective is through preventing the generation of waste and use of virgin materials. Waste can be prevented by prolonging the life length of products, for example: buy reusable instead of disposable products. This study shows that one improvement possibility is to work with the waste hierarchy and decrease the waste quantities in the lowest parts of the waste hierarchy, the waste that is disposed or recovered. Another important improvement is to reduce the toxicity of the waste. Göteborg Energi is phasing out all *pylons* and *PCB transformers*, other hazardous waste streams that need to be reduced are *PCB contaminated oil, asbestos,* and *mercury* etc.

One of the most important identified improvement possibilities is careful purchase. Through a careful purchase Göteborg Energi can reduce the use of hazardous substances, the waste quantities and the climate impacts. It is recommended to demand quality, long-lasting products, products without a content of *substances that should be phased out* greater than 0.1%, and always promote a long-term thinking. Possible improvements could possibly be easier to identify by studying the purchase of products and materials. It is recommended that Göteborg Energi demands an increased feedback regarding waste quantities and treatment for each waste stream from the waste contractors. An increased communication makes it easier to follow-up and work proactive. Another identified improvement is to take care of the knowledge and engagement within the company. Employees at various parts of the organization probably have ideas regarding feasible improvements, a suggestion is to arrange a workshop to catch all knowledge.

The study shows that Göteborg Energi should, from an environmental perspective, prevent the generation of the non-hazardous waste streams *waste to sorting* and *combustible waste* through better sorting. From a climate perspective, prevent the waste generation of electronics and electrical equipment. Göteborg Energi should increase the demand for: non-toxic products, improve statistics from waste contractors, implement policy instruments that demand an increased recycling rate of recyclable products, and implement policy instruments that decrease the amount of waste to incineration.

There is no solution or possible improvement that alone leads to a circular economy. The combination of improvements together with a changed mindset, increased willingness to do better and collaboration can make a difference. This master thesis is part of Göteborg Energi's effort towards reducing their waste quantities, being a role model, and aim for circularity.

8.1 Further studies

This section summarizes aspects that during this master thesis have been perceived as interesting topics to study further.

- The economic effects from the suggested improvement possibilities.
- Develop the framework and study if some of the non-hazardous waste streams contains *substances that should be phased out.*
- Focus on purchase, how can the inflows of products and materials be changed to reduce the waste quantities?
- Calculate the waste quantities per delivered kWh allocated per produced product. Based on the calculation communicate the reduction of waste per reduced kWh to the consumers.
- Develop indicators and key numbers to measure and follow-up improvements. For example: kilogram of waste per employee.
- Investigate if it is possible to compress some waste fractions such as paper and cardboard at the largest production facilities, and what benefits from an environmental and economic perspective that could be achievable. The waste quantities do not decrease but the volumes, which can result in reduced transportations.
- Study the possibilities to expand the industrial symbiosis between enterprises in and around Gothenburg.

9. CONCLUSIONS

This Chapter gives conclusions in relation to the objectives.

The study concludes that 9274 ton non-hazardous and 1780 ton hazardous waste were generated within the value chain of Göteborg Energi in 2015. *Contaminated loads* generated within the sector *Distribution*, contributed to 87% of the non-hazardous waste. For hazardous waste, *sludge that contain hazardous substances* generated within the sector *Production,* contributed to 51% of the hazardous waste. Göteborg Energi hires waste contractors to retrieve and treat the waste. Several of the non-hazardous waste streams are recycled, while the most common treatment for the hazardous waste streams are recovery or a combination of recovery and recycling.

The framework that are developed suggests that aspects that are important to consider when identifying which waste streams that should be prioritized are covered by three of Sweden's environmental objectives: *reduced climate impact*, *a non-toxic environment,* and *a good built environment*. For *a reduced climate impact* the emissions of CO_{2-eq} per waste stream are calculated. For *a non-toxic environment,* the waste streams that may contain *substances that should be phased out* are identified. Within *a good built environment,* the *share of one waste stream* and the *waste hierarchy* are used to identify which waste streams that should be prioritized.

The framework is used to identify which waste stream within Göteborg Energi that should be prioritized. The result show that the non-hazardous waste streams that should be prioritized are: *ashes, contaminated loads*, *waste to sorting,* and *other non-hazardous waste*. The hazardous waste streams that should be prioritized are: *PCB transformers, other hazardous waste* and *contaminated loads,* followed by *sludge that contain hazardous substances, and pylons.* In addition to the framework, the study show that electronics and electrical equipment have the highest climate impact per ton.

Göteborg Energi is, among others, working with industrial symbiosis, recycling many waste streams, and phasing out hazardous chemicals. From an environmental perspective, preventing the generation of waste is preferable. Some of the identified improvements that can be implemented at Göteborg Energi to reduce the waste quantities are: increased recycling rate of recyclable materials, improve the purchase of products to buy for example non-toxic and long-lasting products, verification of chemical content in products, demand an improved feedback from the waste contractors regarding waste treatment and the environmental impact from the waste streams, increased communication and education within the company concerning recycling and prevention of waste, and arrange a workshop to identify improvement possibilities to reduce the waste quantities and aim for circularity.

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APPENDIX

Appendix A

List of critical raw materials (European Commission, 2017).

- Antimony
- Beryllium
- Gallium
- Germanium
- Platinum Group Metals (PGMs)
- Phosphate Rock
- Borates
- Indium
- Heavy and light Rare Earth Elements (REEs)
- Chromium
- Magnesite
- Cobalt
- Magnesium
- Silicon Metal
- Cooking coal
- Natural Graphite
- Tungsten
- Fluorspar
- Niobium