Impacts of increased plastic recycling in Sweden-

A quantitative study of the environmental, social and economic impacts of increased plastic recycling in Sweden

AIDA ESMAILZADEH DAVANI 2018
MVEK02 EXAMENSARBETE FÖR KANDIDATEXAMEN 15 HP
MILJÖVETENSKAP | LUNDS UNIVERSITET

Impacts of increased plastic recycling in Sweden

A quantitative study of the environmental, social and economic impacts of increased plastic recycling in Sweden

Aida Esmailzadeh Davani

2018

LUNDS UNIVERSITET

Aida Esmailzadeh Davani
MVEK02 Examensarbete för kandidatexamen 15 hp, Lunds universitet
Intern handledare: Leonidas Milios, IIIEE, Lunds universitet

CEC - Centrum för miljö- och klimatforskning
Lunds universitet
Lund 2018

Abstract

The rapidly growing, global plastic production and the waste generated as an effect of this is associated with countless environmental problems. As this sector continues to expand, so will the problems. Further complicating is the fact that currently only a small proportion of plastic is being recycled or re-used. A majority of the recyclable plastic in the EU and in Sweden is instead being incinerated for energy recovery. To increase plastic recycling, a new EU target was set in 2018. The target aims to recycle 55% of the plastic packaging waste by 2030.

The purpose of this study is to quantify the environmental, social and economic impacts of increased plastic recycling in Sweden. This will be done by assessing the GHG-emissions, jobs generated, and costs associated to the collection, transport, sorting and recycling of plastic waste. The results of the impact assessment can be used to predict the best future pathway for Sweden to achieve the new EU target.

The quantification is enabled by using a modified version of a plastic waste management flow model, developed for Plastic Recyclers Europe. Based on the results, the best future pathway can be determined through a scenario analysis. Three different target scenarios are examined. In the first scenario the aim is to reach the EU target of 55%. In the second a "no export" condition applies, and in the third a ban on energy recovery of recyclable plastics is applied. Scenario 3 results in the highest reduction of GHG-emissions as well as the highest generation of jobs. Thus, this scenario is the most long-term sustainable option as it encourages a more circular economy. However, due to the magnitude of change needed to achieve this, a large economic investment is needed. A gradual adaptation using different strategies and policy instruments will be necessary.

Keywords: Plastic recycling, energy recovery, incineration, Sweden, scenario analysis.

Contents

Introduction

Global plastic production

With a rapidly increasing world population and an even higher rate of consumption, a significant amount of waste is being generated. Plastics serve a particularly big problem, since the manufacturing of these products have serious environmental impacts as most plastics are fossil based and produced from crude oil and natural gas (Palm & Myrin, 2018, p. 10). These sources are finite and impact the environment negatively during the extraction, production and utilization processes (Neufeld et al., 2016, pp. 13-15). Therefore, it is of high interest to make sure that the plastic that is currently on the market is being recycled to its full potential, not only through an environmental perspective but also in sustainable development as a whole.

The first fossil-based plastics were produced during the beginning of the 1930s, at that point the plastics produced were primarily PVC and a few other types of plastics. Since then there has been a comprehensive expansion of the plastic industry, and today there are over 700 types of plastics on the market (Fråne et al., 2012, pp. 14-18). This vast variety of plastics has numerous distinct functions and is used in nearly all economic sectors worldwide (Hestin et al., 2015, p. 4). Its applications vary from packaging, bottles, building insulation, car parts and electronic devices etc. This industry is constantly growing and reaching new production peeks every year, with Asia (China in particular) being the largest producer, followed by Europe as the second largest. In 2015, 322 million tons of plastic were produced worldwide, and an even higher production rate was reached in 2016 when the plastics production totalled up to 335 million tons (Plastics Europe, 2017, pp. 16-17). The plastic production is predicted to double by year 2036 and quadruple by year 2050 (Neufeld et al., 2016, p. 10). This will in turn result in an even higher waste generation.

Environmental impacts

The extraction of the crude oil needed to produce plastics can cause significant stress on the ecosystem due to the magnitude exploitation associated to it. This could be in the form of deforestation, erosion or contamination of water and soil as a result of oil spill and leakage from drilling (O'Rourke & Connolly, 2003, pp. 593-594). An oil spill, depending on its severity, can cause huge impacts coastal and marine flora and fauna.

There have been cases in the past where marine and coastal wildlife has died due to ingestion of crude oil (Epstein et al., 2002, p. 23). Furthermore, an oil spill on land can cause contamination of soil and ground water, which in turn can cause problems related to agriculture and drinking water supply (Epstein et al., 2002, p. 23).

The leakage of plastic waste into the environment also has significant impacts and is currently widely debated. It is the source of massive pollution of terrestrial ecosystems and marine ecosystems, in particular (Neufeld et al., 2016, pp. 7-8) (Li et al., 2016, p. 334). Currently there is approximately 150 million tonnes of plastic in the oceans, and every year 8 million additional tonnes of plastics are dumped into the oceans. This could be compared to one garbage truck emptying its entire content into the ocean every minute (Neufeld et al., 2016, pp. 7-8).

Due to the chemical structure of plastic, its degradation is a very slow process and can take over a century. During the degradation the plastic is fragmented into smaller pieces known as macro- and microplastics (Li et al., 2016, p. 335). These are hazardous because they can easily be ingested by marine fauna. The plastic can then work its way up the food chain and increase in concentration as larger animals feed on lower trophic levels (Eriksen et al., 2014, p. 2).

If the plastic production quadruples until 2050, like it is predicted to do, it will lead to even more problems in the future. This, in combination with the massive leakage of plastics into our oceans and the generally non-existent or very slow degradation and consequently the large accumulation over time, could lead to a scenario where by 2050 there could be more plastics than fish (by weight) in the oceans (Neufeld et al., 2016, pp. 14–15).

European plastic production and legislation

To regulate plastic recycling, the EU have implemented several legislations including recycling targets. Packaging and packaging waste is regulated by European Parliament and Council Directive 94/62/EC which states that 22,5% of the total plastic packaging waste has to be recycled no later than 31 December 2008. In 2015 the European Commission presented a new proposal (COM (2015) 596 final), amending EU Directive 94/62/EC. The proposal suggests new recycling targets for 2030. In April 2018 this proposal was ratified by the European Parliament. The targets which were decided on were slightly lower than the ones originally proposed. The new recycling target for plastic packaging waste is 55% for 2030, compared to 22,5% which is the current target (Palm & Myrin, 2018, p. 22-23) (European Council, 2018a). In May 2018 the targets were officially adopted by the European Council, and within two years the EU member states will implement these targets into their national legislation (European Council, 2018b).

As a member state of the EU, Sweden is obliged to comply with EU Directives. The Waste Framework Directive (2008/98/EC) is the main EU- constitution related to waste. A very central part of the directive is the EU Waste Hierarchy (see Figure 1), which specifies how waste should be treated and most importantly in which order the different ways of treatment should be prioritized (Michanek & Zetterberg, 2012, pp. 342-347). The emergence of waste should at first hand always be *prevented*, once waste has been generated it should in first hand be *reused*, then *recycled*. Thereafter it should be *recovered for energy purposes* and finally, as last instance, the waste should be *disposed* (Michanek & Zetterberg, 2012, pp. 342-347).

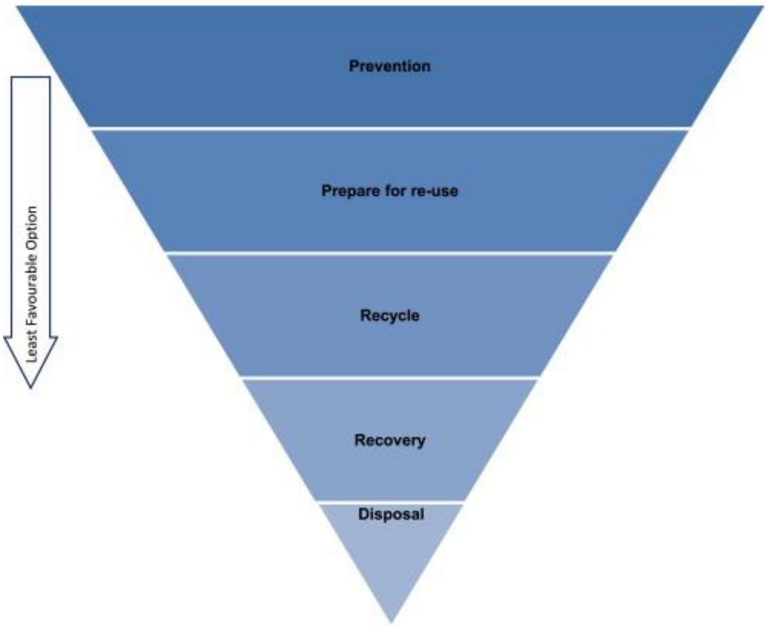

Figure 1. The EU Waste Hierarchy
Order of prioritized treatment from most favorable option to least favorable option. *Illustration:* Papargyropoulou et al., 2014, p. 108.

The European plastic production was estimated to 60 million tons in 2016, where packaging accounts for the largest market sector (see Table 1) (Plastics Europe, 2017, pp. 22-23). Out of the total amount of produced plastic only ca 31% was recycled in the EU, the rest was deposited into landfills (ca 27%) or incinerated to produce energy (Plastics Europe, 2017, p. 29). Even though the recycling trend in the EU is increasing, compared to the two other methods, landfilling and energy recovery is still the first or second instance in many countries within the EU (Plastics Europe, 2017, pp. 32-33).

Table 1. Distribution of European plastic production

European plastic production shown in percentage of main sector (Plastics Europe, 2017, pp. 32-33)

Market sector	Share
Packaging	ca 40%
Building and Construction	ca 20%
Automotive	ca 10%
Electrical and electronics	ca 6%
Household, leisure and sports	ca 4%
Agriculture	ca 3%
Others (incl. furniture, medical residue etc.)	ca 17%

In 2015 the European Commission initiated the "Circular Economy Action Plan", an initiative that aims to encourage economic circularity in the EU (European Commission, 2018). The action plan was later followed by "A European Strategy for Plastics in a Circular Economy" (COM (2018) 28 final). The main purpose of this strategy is to increase plastic recycling in the EU and consequently decrease leakage of plastic waste in order to achieve a more circular economy and sustainable society (European Commission, 2017, p. 5-9). The concept of circular economy emphasises reuse and recycling of resources in order to conserve material and energy. Instead of having a linear system where products are produced and then disposed of as waste, the circular economy aims to "close" these systems into a closed loop to preserve resources (Huysman et al., 2017, p. 46). Plastic is one of the areas that is still in need of more work to increase its circularity. This is primarily due of the fact that little amount of the total plastic waste is recycled, due to leakage into natural systems (European Commission, 2017, p.5) (Neufeld et al., 2016, pp. 7-8).

Swedish waste management and legislation

Swedish municipalities are responsible for managing the collection of household waste. Packaging waste however, and therefore also plastic packaging waste, falls under producer responsibility (2014:1073). This means that it is the producers' responsibility to make sure that all plastic packaging waste that they have placed on the Swedish market is collected and then treated (Fråne et al., 2014, pp. 51-53). Every person who handles packaging waste is by law (2011:927) §24 required to separate these from other waste types. A majority of the Swedish plastic producers and importers are a part of Förpackning- och tidningsinsamlingen (FTI AB), who is the company responsible for operation and collection of plastic packaging under producer responsibility (2014:1073) (Avfall Sverige, 2017, p. 20). FTI AB has approximately 6000 unmanned *bring sites* across Sweden where households can dispose of their plastic packaging waste. The bring sites consists of separate containers that are emptied on a regular basis and then transported to sorting facilities contracted by FTI AB (Fråne et al., 2014, pp. 52-54).

Kerbside collection is another alternative for collection of plastic waste (Fråne et al., 2014, p. 55). They consist of separate vessels for the different waste types, including one for plastic packaging waste. The kerbside collection is operated by the municipalities, in some cases they are contracted by FTI AB and in other cases they are under agreement with the producers. Since the producer responsibility still applies, the municipalities receive compensation for the collection of the plastic waste (Fråne et al., 2014, pp. 54-56). The municipalities often run *recycling centres* for the disposal of larger plastic items such as furniture, only a small amount of these are recycled due to limitations in recycling capacity in Sweden (Fråne et al., 2014, p. 58). Electronic waste classified as Waste Electrical and Electronic Equipment (WEEE) is separated from other types of plastic waste due to producer responsibility SFS 2005:209. El-Kretsen, in collaboration with producers and municipalities across Sweden, is responsible for the collection and treatment of WEEE (Fråne et al., 2012, pp. 25-28).

PET-bottles are collected and treated in a separate system, according to (2005:220), which states that all bottles containing beverages, excluding products containing a certain amount of dairy or fruit juice, must be deposited into a *Deposit system* (Fråne et al., 2014, pp. 57-58). The actor responsible for the deposit system is Returpack AB. Returpack AB has a list of approved reverse vending machines that any store in the retail food market can purchase. As a member of Returpack AB, the stores are then given financial compensation for deposit, handling fees etc. (Fråne et al., 2014, pp. 57-58) (Returpack AB, n.d.a).

When plastic waste is collected from bring-sites, kerbsides or through recycling centres it is transported to sorting facilities where the plastic is, for example, processed as follows: It is put through a rough initial sorting- and baling process (Olofsson, 2014, p. 67), transported to recycling facilities where the plastic is further sorted and separated from each other depending on type of plastic. This procedure can be done through various approaches e.g. separation of soft and hard plastic via centrifugation, separation of plastics with different densities through flotation or through infra-red radiation (Olofsson, 2014, pp. 27–29). The sorted plastic is then processed, usually mechanically, into smaller flakes (Olofsson, 2014, pp. 27–29). The plastic can also be further processed into a more homogenous compound known as granules (Carlsson, 2002, p. 17). Swerec AB is the main actor in Sweden when it comes to recycling of plastic. They receive 53 000 tonnes of plastic (48 000 tonne plastic packaging waste, 5000 tonnes of other plastics) (Ruther, pers. comm), and out of this about 20% is lost in the sorting process due to material being wrongly sorted at the source. In total only 50% of the collected plastic packaging is transported to Swerec AB, the rest is exported to recycling facilities in Germany. This is due to the fact that Swerec AB do not currently have sufficient capacity to handle more plastic waste (Fråne et al., 2012, p.

23). FTI AB is currently in the process of building a brand-new recycling facility that is said to be able to handle a substantially higher amount plastic waste than Swerec AB can today (FTI AB, 2018).

PET-bottles from the deposit system, however, are treated separately from other kinds of plastic. They are transported by Returpack AB to their own sorting facility in Norrköping and then they are recycled at Cleanway AB, a recycling facility that lies in conjunction with their sorting facility (Cleanaway, n.d.a).

According to the only comprehensive plastic waste flow analysis in Sweden, conducted by SMED, 900 000 tonnes of plastic were introduced to the Swedish market during 2010 (Fråne et al., 2012, pp. 14-15). Furthermore, the report states that 26% of the total post-consumer plastic generated in Sweden is recycled, 58% is incinerated to produce energy, 14% is used for fuel production in the cement industry and the final 2% is deposited into landfills (Fråne et al., 2012, pp. 7-8). The packaging sector has a higher recycling rate at 49% (Milios et al., 2018, p. 3). Although Sweden is currently surpassing the existing EU target, there is still a long way to go to reach the proposed target for 2030. A change of the way plastic is currently being handled in Sweden will be necessary to increase the current recycling rate.

In a study conducted by Hestin et al. (2015) for Plastic Recyclers Europe, the impacts of an increased recycling rate in the EU were examined. They found that replacing virgin plastics with recycled plastics could result in 6,5% less greenhouse gas (GHG) emissions from the EU plastics industry by 2020 and 11,5% less GHG-emissions by 2025 (Hestin et al., 2015, p. 35). The social impacts in the form of employment in EU were also substantially high, with nearly 50 000 direct, and over 75 000 indirect jobs by 2020 and 80 000 direct jobs and 120 000 indirect jobs by 2025 (Hestin et al., 2015, p. 43). The investment costs required is approximately 0,7-1,3 billion EUR per year (Hestin et al, 2015, p. 40).

These numbers show that economically it might not be completely sustainable but environmentally and socially it is. But since these results are based on the scale of the EU, they do not represent Sweden accurately. A full quantification of impacts from increasing plastic recycling is currently missing in Sweden.

Scope and question formulations

The scope of this project is to quantify the potential impacts of increasing plastic recycling in Sweden. This will be done through an environmental (GHG-emissions), economic (costs) and social impact assessment (jobs generated). The quantification can then aid authorities in making well-informed and better decisions when designing future plastic waste management systems (regarding the waste streams above), by showing them the potential benefits of increased plastic recycling in Sweden. This can in turn contribute to achieve a circular economy. Considering the results of the waste flow model and impact assessment, potential future pathways in plastic waste management will be identified and qualitatively assessed.

Question formulations

- Is it environmentally, socially and economically sustainable, in terms of reduction of GHG-emissions, employment and costs, to increase plastic recycling in Sweden?

- Which future waste management scenario would be the most beneficial pathway (in terms of reduction of GHG-emissions, employment and costs) for Sweden to achieve high plastic recycling and achieve EU targets by 2030?

Method

The model and limitations

The quantification of recycling impacts will be enabled by using a plastic waste management flow model, developed for Plastic Recyclers Europe. This is the model used in the previous study released by Plastic Recyclers Europe (2015). Since I am conducting a similar study, the same model will be used. However, I will use a modified version of the model with Sweden-specific data (see Appendix 2).

The model enables a full quantification of the lifecycle of plastics. The steps included in this study, and therefore also the model, is the initial *collection*, the following *pre-treatment/sorting*, *transportation* to recycling facilities and finally *recycling* of the collected material, *energy recovery or landfilling*. Consequently, the complete lifecycle of plastics is NOT considered in the model, as the initial steps such as the production of plastics, placing it on the market and the consumption is not included (Hestin et al., 2015, p. 8). Furthermore, there could also be additional steps e.g. more transports and sorting, which the model also does not consider (Hestin et al., 2015, p. 17).

In practice the model was fed with key data, such as costs for operation, collection and transportation, employment data and GHG-emission data, and the model output will enable an environmental, social and economic impact assessment (Hestin et al., 2015, pp. 17-18). However, since these terms are very wide and include a whole range of aspects, this study will be limited to only reduction of GHG-emissions, number of jobs generated and costs (Hestin et al., 2015, pp. 17-18). All costs that were apprehended have been recalculated to EUR using a conversion rate of 1 EUR=10.15 SEK, to match the existing EU data in the model. This is the average exchange rate for the last three months (February 2018, March 2018 and April 2018).

Data Collection

The data gathering was of quantitative nature and done through an online literature search, as well as expert interviews through phone calls and emails sent to authorities that hold the data needed to conduct a full quantification of the environmental, economic and social impacts of increased recycling in Sweden. The data needed for the quantification were costs, employment numbers, distances and weights related to the collection, transport, sorting and recycling of plastic. To get an overview of the data, a data protocol was constructed before the gathering was initiated. The complete data protocol and full calculations for all the data points that required further work can be found in Appendix 1.

The online literature search was mainly conducted through the search engines Google Scholar and LUBsearch, in order to find relevant literature. The search words used were "plastic recycling", "plastic recycling Sweden", "waste management Sweden", "incineration plastic" etc. The search was done in both Swedish and English to make sure that no relevant literature was lost. Most of the information used in the thesis were retrieved from reports released by actors such as Plastic Recyclers Europe, IVL Svenska Miljöinstitutet, Avfall Sverige, Svensk Miljöemissionsdata, Nordic Council of Ministers etc. Many of the reports were given to me by my supervisor and some of them were found on the web pages of the various actors.

In order to collect the data that could not be retrieved from literature, expert interviews with different authorities connected to the plastic waste industry were done. Only questions about the specific data were asked (see table 1-4). To find the data related to the collection of plastic waste FTI AB was contacted. This is the corporation responsible for the operation and collection plastic packaging (Avfall Sverige, 2017, p. 20), and therefore hold relevant statistics related to this. Stena recycling was contacted about the data related to sorting of plastics. They have a filial in Eslöv that receives plastic packaging waste from municipalities and therefore should have relevant data related to sorting. The data related to recycling was given by Swerec AB, the main actor in plastic recycling in Sweden (Fråne et al., 2012, p. 23).

Furthermore, Returpack AB and Cleanaway AB was contacted about the data related to PET-bottles. Returpack AB is the organization responsible for the operation of the return system, and Cleanaway AB is the recycling facility connected to Returpack AB (Cleanaway AB, n.d.a). To gather the information related to ELV-cars numerous actor were contacted. Ådalens, a haulage contractor, gave information about cost and approximate distances of collection of ELV-cars and Stena Metall gave approximate numbers related to fragmentation of ELV-cars, as they are the biggest actor in Sweden in this sector (Jensen et al., 2012, pp. 22–23).

Some of the data was not possible to get a hold of, mostly due to company confidentiality. Swerec AB, Returpack AB and Cleanaway AB could not give any information about cost of operation for sorting and recycling processes. The only information they could contribute with on this matter was their annual report. This became the basis for the calculations of these data points (see Appendix 1). FTI AB, Stena Recycling AB and El-Kretsen could not contribute with any information related to transport, sorting, collection or employment. Since there is currently no Sweden specific data to be found in literature on these matters, EU averages from the previous study conducted by Hestin et al. (2015) for Plastic Recyclers Europe was used.

Scenario Analysis

In order to conclude the best future pathway for plastic waste management in Sweden, different future scenarios will be explored. Scenario analysis is a method used to help understand the impacts of the different scenarios. By comparing them, the optimal future pathway may be identified. Scenario analysis does not set out to predict the future, it is simply a tool to explore and compare different future pathways (Duinker & Greig, 2007, p. 209). Furthermore, it helps decreasing errors such as over-and underestimation. This is prevented since the chosen scenarios will act as boundaries for the speculation, these boundaries will also enable us to discover even more possible pathways, which might have been harder to discover without this approach (Schoemaker, 1995, p. 27).

In this study, three different future scenarios set in 2030 will be explored. This specific year is chosen because this is the year in which the revised EU target at 55% for recycling of packaging waste needs to be achieved (European Council, 2018). Each future scenario will be compared to a Business-As-Usual (BAU) scenario also set in 2030, these will then be analysed and compared based on GHG-emissions, costs and jobs generated in order to determine the best future pathway for Sweden.

The following three scenarios will be compared to the BAU scenario, all of which are set in 2030:

1. Scenario where Sweden fulfils all targets set by the EU.

2. Scenario where Sweden fulfils all targets set by the EU, including an extra scenario where Swedish export of plastic is limited

3. Scenario where Sweden fulfils all targets set by the EU, including an extra scenario where there is no energy recovery of recyclable plastics.

Results

The following diagrams (Figure 2-4) show the reduction of GHG, number of created jobs and average costs and revenues as a result of an increased plastic recycling in Sweden. All three scenarios displayed in the graphs take place in 2030, which is the year the revised EU target at 55% for recycling of packaging waste needs to be achieved (European Council, 2018).

Environmental impacts

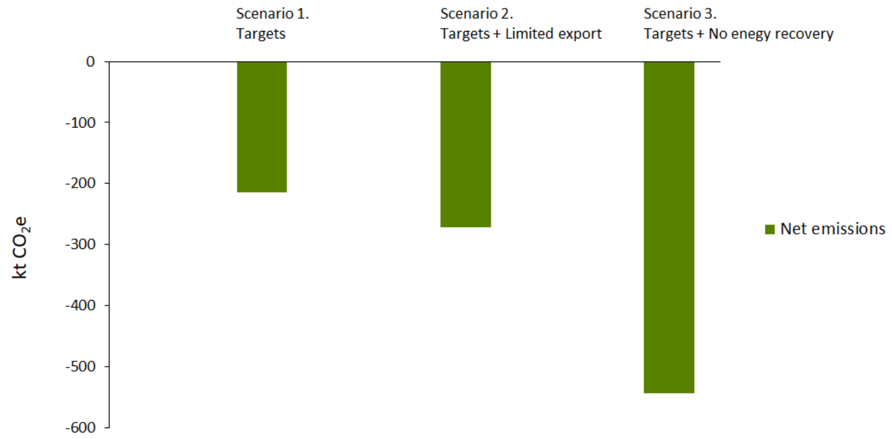

Figure 2. Net GHG emissions
Comparison of net reduction of GHG-emissions (kilo-tonne CO_2 equivalents[1]) of three examined scenarios, compared to the BAU scanerio.

The highest reduction of GHG-emissions, compared to BAU, were given by scenario 3 (ca 542 kt CO_2e) Scenario 2 (ca 272 kt CO_2e) and 1 (ca 215 kt CO_2e) show a substantially lower GHG reduction compared to the BAU scenario.

[1] A CO_2 equivalent is a unit used to equate different types of greenhouse gases that have different strength and make them comparable.

Social impacts

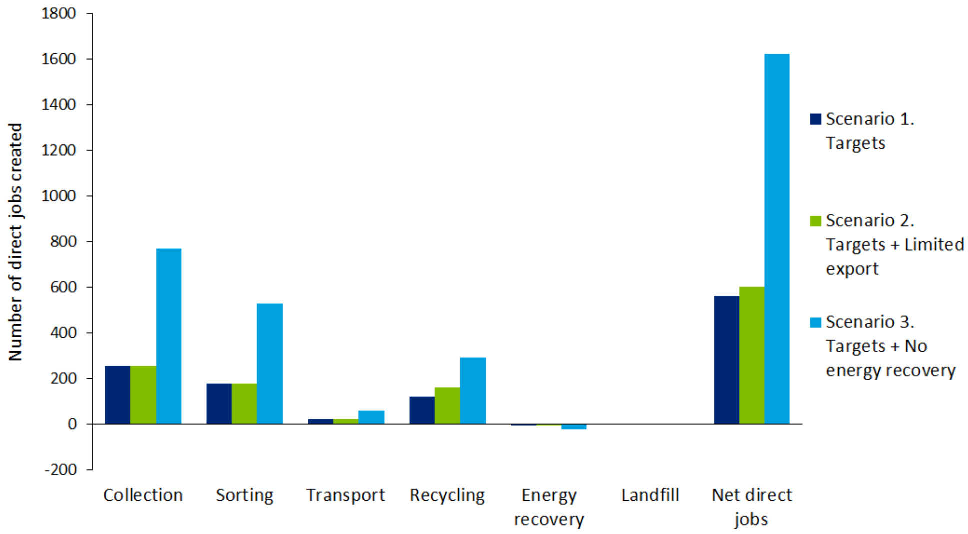

Figure 3. Number of direct jobs
Comparison of the number of direct jobs[2] generated from the three examined scenarios, compared to the BAU scenario.

Figure 3 show that scenario 3 results in the highest generation of net direct jobs at ca *1621* direct jobs, compared to the BAU scenario. Scenario 2 show the second highest generation of net direct jobs at *601* direct jobs, followed by scenario 1 with the lowest generation of net direct jobs at *560* direct jobs. Scenario 3 also has the highest number of jobs created in each section of the value chain (collection, sorting, transport and recycling), and has the highest number of jobs lost in the sections; energy recovery and landfill. Scenario 2 and 1 are relatively even in the respective sections, except for recycling.

The number of indirect jobs[3] can be calculated using a factor of 1,5. The factor is based on previous reports and is quite conservative, in order to give a genuine picture without exaggeration (Hestin et al, 2015, p. 42). Using this multiplier, the

[2] Jobs directly connected to the plastic value-chain e.g. transport, sorting and recycling (Hestin et al., 2015, pp. 40-42).

[3] Jobs that are generated because the plastic industry purchases services and goods for other kinds of industries and this results in employment indirectly (FOE, 2010, pp. 7-8).

number of indirect jobs for scenario 3 is ca 2430, scenario 2 results in ca 902 jobs and scenario 1 generates ca 840 indirect jobs. **This means that the total number of jobs created is for scenario 3 is ca 4050 jobs, ca 1503 jobs for scenario 2 and ca 1400 new jobs for scenario 1.**

Economic impacts

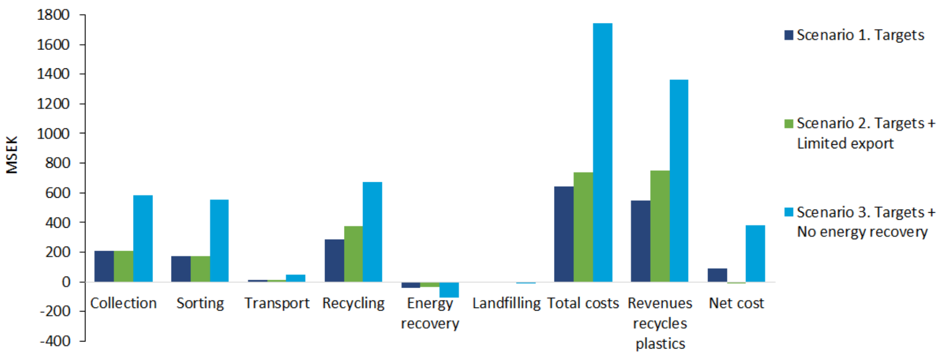

Figure 4. Average costs
Average costs for each section of the value chain of plastic recycling and the revenues of recycled plastic, compared to the BAU scenario.

Figure 4 show that scenario 3 show the highest net cost at ca *379 MSEK*, compared to the BAU scenario. Scenario 1 result in a considerably lower net cost at ca *93 MSEK*, compared to BAU and finally scenario 2 results in a profit of ca *12 MSEK* compared to the BAU scenario.

Discussion

Scenario comparison

In the following section the impacts of the different scenarios will be compared and examined more closely, to determine the best future pathway for Sweden.

1. Scenario where Sweden fulfils all targets set by the EU.

2. Scenario where Sweden fulfils all targets set by the EU, including an extra condition where Swedish export of plastic is limited

3. Scenario where Sweden fulfils all targets set by the EU, including an extra scenario where there is no energy recovery of recyclable plastics.

Environmental impacts

According to the results in figure 2, the highest reduction of GHG emissions (compared to the BAU scenario) was given by scenario 3 (ca 542kt CO_2e). Scenario 2 (ca 272kt CO_2e) had the second highest GHG reduction, followed by scenario 1 (ca 215kt CO_2e).

Scenario 1 is the scenario where Sweden fulfils the revised EU target for plastic packaging waste at 55% by 2030. No further effort is made. Therefore, it is not surprising that this pathway generates the lowest numbers compared to scenario 2 and 3, which both has extra conditions that contributes to the net GHG reduction.

Scenario 2 includes reaching the target at 55% in 2030, as well as a limit on export (European Council, 2018). Currently about 90 000 tonnes of plastic (out of 900 000 tonnes) is exported for recycling to primarily Germany, China, Hong Kong and the Netherlands (Fråne et al., 2012, pp. 34, 70). The reason for the relatively high export is because the of the limited capacity for treatment of plastic waste in Sweden. Swerec AB is the main actor in recycling of plastic waste and they handle approximately 53 000 tonnes of plastic waste per year (Ruther, pers. comm.). This is only a fraction of the total amount of plastic on the Swedish market. The new recycling facility that is being built by FTI AB will most likely help reach the new EU target, as less plastic packaging waste will be exported and instead treated in Sweden (FTI AB, 2018). This will also contribute to less transportation, which in turn results in less GHG-emissions.

Scenario 3 entails reaching the target as well as a ban on energy recovery of recyclable plastics. This scenario, as mentioned above, resulted in the highest reduction of GHG corresponding to about 10% of the total emissions of Skåne during 2015[4] (Andersson et al., 2017, p. 87). This is not surprising as plastic is a fossil-based product and therefore contains considerable amounts of CO_2 (Palm & Myrin, 2018, p. 10). A ban on energy recovery of recyclable plastics could consequently help to avoid a substantial amount of GHG-emission. Furthermore, banning energy recovery of recyclable plastic is a way of decreasing the linearity of the plastic waste sector and increasing its circularity. Not only is this crucial to fulfil the "Circular Economy Action Plan", it is also essential for the entire plastic industry (European Commission, 2017, p. 5-9). Since plastic waste is fossil fuel based it is not sustainable to keep extracting more crude oil in order to satisfy the constantly growing plastic industry (Neufeld et al., 2016, p. 10). Not only will the oil reservoirs eventually be depleted, but a constant production of virgin plastics will continue to cause even more damage to the sensitive ecosystems surrounding the reservoirs (Epstein et al., 2002, p. 23). In addition, it could cause even further leakage of plastic waste into the natural systems, which could be disastrous considering the recent forecast by World Economic Forum claiming that there could be more plastic than fish (by weight) in the oceans by 2050 (Neufeld et al., 2016, pp. 14–15).

A ban on energy recovery of recyclable plastics could potentially be a step forward in solving some of these problems. Banning energy recovery of recyclable plastic means increasing the recycling of the plastics that are already on the market, which in turn could result in less usage of virgin plastics. To meet the growing plastic demand, the plastic waste that is lost through leakage will become important. Actors within the plastic sector will therefore be motivated into making decisions that will counteract leakage e.g. using less single-use plastics such as those used for packaging, which Palm & Myrin, (2018) argues is a waste of resources (Palm & Myrin, 2018, pp. 18-19).

A complete ban on energy recovery of recyclable plastic is not be something that can be implemented rapidly and will most likely require gradual adaptation. This could be done through implementing economic instruments such as taxes. In 2002 a tax on co_2-emissions from incineration was implemented, but these were later taken away to ensure that biofuel could compete with fossil fuels (Finnveden et al., 2007, p. 5). An effective way to decrease energy recovery of recyclable plastics in Sweden would be to re-implement a carbon dioxide tax specifically for incineration of recyclable plastic, alternatively taxing recyclable plastic that is going to incineration by weight (Finnveden et al., 2007, p. 5). This would increase the prices of incineration of recyclable plastic, and if the tax is high enough it might no longer be profitable to produce energy and

[4] See calculation P in Appendix 1

heat this way. Consequently, this could favour the plastic recycling industry as it will become more beneficial to recycle and re-use, which both are one of the first instances in the EU waste hierarchy. This could in turn increase competitiveness in the field, which could fuel the recycling industry even more (Finnveden et al., 2007, p. 5).

However, it is important to note that some plastics are of lower quality and therefore recycling of these might not be very beneficial since they can most likely not be used in production as substitution of virgin plastics. When dealing with these kinds of plastics a trade-off is needed to determine whether it is more advantageous to recycle or to burn them. Keep in mind that the energy recovery produces district heating, which Sweden uses to great extent. Thus, before a complete ban on energy recovery of recyclable plastics is implemented, it is important to have the technology that allows for high quality recycling in place. This is important because once the plastics are not used for energy recovery, some other energy source, e.g. fossil fuels, will take its place.

Social impacts

An increase of recycling of plastic waste, could potentially lead to more job opportunities throughout the whole plastic value chain (collection, sorting, transport and recycling) (Hestin et al., 2015, pp. 40-41). According to figure 3, the scenario that generated the highest number of net jobs, including indirect jobs, is scenario 3 (4050 jobs), followed by scenario 2 (1502,5 jobs) and then scenario 1 (1400 jobs). When looking at scenario 2 and 3 in figure 3, there was slight variation in the specific sections of the value chain, but overall scenario 2 generated more jobs than scenario 1.
Scenario 3 generated considerably more jobs in total, compared to the other two scenarios. The explanation for this is that it is the only scenario that bans energy recovery of recyclable plastics. The incineration process in itself does not require much manpower, compared to recycling that usually involves more steps in the value chain, as well as more transportations between different treatment facilities (Olofsson, 2014, 27-19; Carlsson, 2002, p. 17; Hennlock et al., 2015, p. 14).

Scenario 2 has a limitation on export, which does not really increase recycling in itself. Sweden has significantly more infrastructure for energy recovery compared to recycling, with Swerec AB being the only major facility in Sweden (Fråne et al., 2012, p. 23; Finnveden et al., 2007, p. 6). A limitation on export might therefore not be enough to increase the recycling rates to the same level as scenario 3 would because it still enables the possibility of energy recovery of recyclable plastics, which is why it has a lower total job generation. Scenario 1 only entails reaching the 55% recycling target, which of course requires more recycling than today, but it allows energy recovery of the remaining recyclable plastic, which is why this scenario also predicts fewer jobs than scenario 3.

The jobs generated in scenario 1 are only due to the target. The extra condition in scenario 2 generate some additional jobs because more plastic must be treated nationally rather than internationally. Finally, scenario 3 has a ban on energy recovery of recyclable plastics, which is the reason this scenario resulted in the highest number of jobs.

Economic impacts

Achieving higher plastic recycling in Sweden will not only require a remodelling of the way plastic is treated today, but also policy instruments and above all a rather large initial economic investment (Hennlock et al., 2015, p. 14). In the three examined scenarios in Figure 4, scenario 3 show the highest net cost at ca *379 MSEK* (compared to BAU) as well as the highest costs throughout the plastic value chain (collection, sorting, transport and recycling). This is not surprising, as this the scenario that will require the biggest transformation compared to the present situation. Today an astonishing high amount of recyclable plastic is being incinerated to produce energy, rather than recycled. According to the plastic waste flow analysis conducted by Fråne et al. (2012), approximately 58% of the total plastic waste is incinerated to produce energy and only 26% is recycled (Fråne et al., 2012, pp. 7-8). When looking at plastic packaging specifically, the recycling rate is slightly higher, at 49%, but still not as high as it could be (Milios et al., 2018, p. 3).

Why such a disproportionally high amount of plastic is incinerated has to do with the fact that Sweden has an overcapacity of incineration facilities, compared to recycling facilities (Finnveden et al., 2007, p. 6; Corvellec & Bramryd, 2012, p. 1726). Even compared to other European countries, Sweden has one of the highest rates of incineration (Corvellec & Bramryd, 2012, p. 1726). One of the reasons why so many incineration facilities are being built in the first place is because burning plastic of plastic is much cheaper than recycling, since it requires less man power and does not involve as many steps as recycling (Finnveden et al., 2007, p. 6; Hennlock et al., 2015, p. 14). Furthermore, most solid waste incineration plants in Sweden produce both power and heat, which is distributed as district heating in Sweden. This means that not only is incineration cheaper, it also generates an income for those who burn and the sell the energy (Fråne et al., 2012, pp. 28).

A ban on energy recovery of recyclable plastics therefore means that there needs to be a drastic increase in recycling infrastructure in Sweden. There need to be more and bigger recycling facilities with higher capacity than today. This why scenario 3 has a much higher investment cost than the other scenarios do. Today a lot of money is instead invested in building even more incineration facilities (Corvellec & Bramryd, 2012, p. 1726).

Scenario 1 (ca *93 MSEK*) had almost three times as low net cost as scenario 3, compared to BAU. Like previously mentioned, this is not surprising, as this scenario only aims to increase the existing recycling rate of plastic packaging from 49%, to the new 55% target (Milios et al., 2018, p. 3). Even though changes need to be done to get there, it does not involve any major transitions, like scenario 3.

Scenario 2 had a net cost of ca *-12 MSEK,* (compared to BAU, meaning that the recycling is profitable and can generate a profit of ca 12 MSEK. The biggest difference between these two scenarios are the cost of recycling and the revenues generated, which were both higher for scenario 2. All other steps in the value chain were quite similar in cost. Scenario 2 aims to limit export, meaning that the plastic waste that would have otherwise been exported to countries like Germany and China, is instead treated in Sweden. Therefore, the cost of recycling is higher than scenario 1, where the export stays the same (Fråne et al., 2012, pp. 34, 70). A limited export also results in more revenues from the sale of the recycled plastic, since more plastic waste is treated inbound rather than abroad, where the countries the plastic is being exported to profits.

Sources of error

When conducting this study some error sources could be identified. During the data collection there were some difficulties finding a few of the data points. This was mainly due to company confidentiality but also due to difficulties getting a response on time from the actors contacted. The missing data points were instead replaced with EU averages from the previous study conducted by Hestin et al. (2015) for Plastic Recyclers Europe, marked in bold in table 1-4. This means that there is a certain level of uncertainty in the results and therefore they might not be fully accurate for Sweden.

Conclusions

After a close examination of the environmental, social and economic impacts of each of the scenarios, both advantages and disadvantages can be identified. One scenario that stands out however is scenario 3. It shows the highest GHG reduction as well as the highest numbers of employment. On the other hand, it also has the highest cost. Scenario 2 also shows quite good promise, although the GHG reduction and employment rates are not as high as scenario 3, it has zero investment cost and generates a profit. Scenario 1 show the least amount of promise due to its lower values and the fact that it only increases recycling to a certain extent. It does not give incentive to further recycling.

When comparing scenario 1, 2 and 3 through an environmental point of view, scenario 3 is the strongest candidate. Not only because of the high results, but also because banning energy recovery of recyclable plastics encourages a more circular way of thinking, this can in turn decrease plastic waste in a long-term perspective as well as the usage of virgin plastics, which benefits the environment. Scenario 1 also encourages recycling, but only until the target is reached. The remaining recyclable plastic may therefore still be subject to energy recovery. This is also true for scenario 2. A limited export condition will not guarantee recycling of the plastics, due to limited recycling infrastructure in Sweden. This counteracts the circularity of the plastic value chain. In addition, it also does not provide further incentives for sorting and recycling capacity expansion, or further improvement in sorting- and recycling technology.

Scenario 3 is also the best option in a social perspective, as it generates the highest amount of jobs, which in turn benefits the society. In an economic perspective however, it is the most expensive alternative, which might be problematic. It is important to emphasize that this study did not include the full lifecycle of plastics (steps included are: collection, pre-treatment/sorting, transportation, recycling, energy recovery and landfilling). If the full lifecycle was considered in this study, it would most likely result in even higher costs for the examined scenarios.

A ban on energy recovery of recyclable plastics allows more focus to be placed on recycling and re-use, and ultimately a more sustainable future where fossil fuel is slowly phased out. The high initial cost is therefore an investment worth making as the long-term benefits could be substantial. However, it is important to first make sure that the technology required for high quality recycling in place. This is important because if plastics are not used for energy recovery, fossil energy source could take its place.

To reach scenario 3, policy instruments such as taxes could be of aid. Scenario 2 could be used as a tool, where limiting export could be a first step towards an increased recycling and eventually a circular economy. Moreover, the profits generated from the recycling system in scenario 2 could also be used to invest in more recycling infrastructure.

In conclusion, scenario 3 would be the most beneficial pathway for Sweden to achieve high plastic recycling and achieve EU targets by 2030, as it is the most long-term sustainable option.

Future studies in what types of policy instruments would be the most effective alternatives to phase out energy recovery of recyclable plastics is needed. It would also be of interest to explore other types of environmental, social and economic aspects of an increased plastic recycling in Sweden, as this study was limited to only GHG reduction, number of jobs generated and costs. Since plastic pollution of the oceans is major problem today, it could therefore be interesting to examine the effects of an increased recycling in Sweden on this matter. The results could in turn be used to strengthen the conclusions drawn in this study and help show the benefits of banning energy recovery of recyclable plastics.

Acknowledgements

I would first of all like to thank my supervisor Leonidas Milios for giving me the opportunity to take on this project. I would also like to thank him for all the help and valuable advice he has given me along the way. I would also like to thank the people in the plastic sector who have kindly answered my questions during the data gathering.

References

Agriculture and Energy Statistics Unit (SCB). 2017. Electricity supply, district heating and supply of natural gas 2016. Agriculture and Energy Statistics Unit (SCB), Örebro. 73 pp.

Andreasson, M. 2018. Returpack AB, mats.andreasson@returpack.se

Andersson, S., Arvelius, J., Verbova, M., Ortiz, C., Jonsson, M., Svanström, S., Gerner, A. and Danielsson, H. 2017. Metod- och kvalitetsbeskrivning för geografiskt fördelade emissioner till luft under. Sveriges Meteorologiska och Hydrologiska Institut, Norrköping. 89 pp.

Avfall Sverige. 2017. Svensk Avfallshantering. Avfall Sverige, Malmö. 37 pp.

Carlsson, A. 2002. Kartläggning och utvärdering av plaståtervinning i ett systemperspektiv. IVL Svenska Miljöinstitutet AB, Stockholm. 67 pp.

Carlsson, K. Stena Recycling AB, 010–4458501

Cefic, ECTA, 2011. Guidelines for Measuring and Managing CO2 Emission from Freight Transport Operations. Cefic, ECTA. 18 pp.

CEWEP. 2016. CEWEP Country Report 2016 - Sweden. The Confederation of European Waste-to-Energy Plants (CEWEP).8 pp.

Cleanaway PET Svenska AB. n.d.a. About Us. [http://www.cleanaway.se/about-us/]. Accessed 29 April 2018.

Cleanaway PET Svenska AB. n.d.b. URRC Process. [http://www.cleanaway.se/urrc-en-gb/]. Accessed 21 May 2018.

Corvellec, H. and Bramryd, T. 2012. The multiple market-exposure of waste management companies: A case study of two Swedish municipally owned companies. Waste Manage. 32: 1722-1727.

Duinker, P.N. and Greig, L.A. 2007. Scenario analysis in environmental impact assessment: Improving explorations of the future. Environ Impact Assess Rev. 27: 206–219.

Epstein, P.R., Selber, J., Borasin, S., Foster, S., Jobarteh, K., Link, N., Miranda, J., Pomeranse, E., Rabke-Verani, J. and Reyes, D. 2002. A life cycle analysis of its health and environmental impacts. The Centre for Health and the Global Environment, Harvard Medcial School, Boston. 73 pp.

Eriksen, M., Lebreton, L.C., Carson, H.S., Thiel, M., Moore, C.J., Borerro, J.C., Galgani, F., Ryan, P.G. and Reisser, J. 2014. Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. PLoS One. DOI 10.1371/journal.pone.0111913.

European Commission. 2017. A European Strategy for Plastics in a Circular Economy. European Commission. [http://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy-brochure.pdf]. Accessed 18 April 2018.

European Commission. 2018. Implementation of the Circular Economy Action Plan. [http://ec.europa.eu/environment/circular-economy/index_en.htm]. Accessed 21 May 2018.

European Council. 2018a. EU ambassadors approve new rules on waste management and recycling. [http://www.consilium.europa.eu/sv/press/press-releases/2018/02/23/eu-ambassadors-approve-new-rules-on-waste-management-and-recycling/]. Accessed 27 April 2018.

European Council. 2018b. Circular Economy: New rules will make EU the global front-runner in waste management and recycling. [http://europa.eu/rapid/press-release_IP-18-3846_en.htm]. Accessed 23 May 2018.

Finnveden, G., Björklund, A., Reich, M.C., Eriksson, O. and Sörbom, A. 2007. Flexible and robust strategies for waste management in Sweden. Waste Manage. 27: 1–8.

FOE. 2010. More jobs less waste: Potential for job creation through higher rates of recycling in the UK and EU. Friends of the Earth, London. 53 pp.

Forsman, J.A. Ådelans, 0612-12419

Fråne, A., Hultèn, J., Sundqvist, J.O. and Viklund, L. 2017. Framtida avfallsmängder och avfallsbehandlingskapacitet. Sveriges Meteorologiska och Hydrologiska Institut, Norrköping. 60 pp.

Fråne, A., Stenmarck, Å, Gíslason, S., Lyng, K., Løkke, S., zu Castell-Rüdenhausen, M. and Wahlström, M. 2014. Collection & recycling of plastic waste: Improvements in existing collection and recycling systems in the Nordic countries. Nordic Council of Ministers, Copenhagen. 133 pp.

Fråne, A., Stenmarck, Å, Sörme, L., Carlsson, A. and Jensen, C. 2012. Kartläggning av plastavfallsströmmar i Sverige. Sveriges Meteorologiska och Hydrologiska Institut, Norrköping. 75 pp.

Gibbs, A., Elliot, T., Thomas, V., Ballinger, A., Hogg, D., Gentil, E., Fischer, C., Bakas, I. and Ryberg, M. 2014. "Development of a Modelling Tool on Waste Generation and Management" Appendix 1: Baseline Report. European Commission. 632 pp.

Hennlock, M., zu Castell-Rüdenhausen, M., Wahlström, M., Kjær, B., Milios, L., Vea, E., Watson, D., Hanssen, O.J., Fråne, A. and Stenmarc, Å. 2015. Economic Policy Instruments for Plastic Waste: A review with Nordic perspectives. Nordic Council of Ministers, Copenhagen. 118 pp.

Hestin, M., Faninger, T. and Milios, L. 2015. Increased EU plastics recycling targets: Environmental, economic and social impact assessment. Deloitte.

Huysman, S., De Schaepmeester, J., Ragaert, K., Dewulf, J. and De Meester, S. 2017. Performance indicators for a circular economy: a case study on post-industrial plastic waste. Resour. Conserv. Recycling. 120: 46–54.

iContainers. n.d. Get your instant ocean freight quote. [https://www.icontainers.com/]. Accessed 22 May 2018.

Jensen, C., Felix, J., Söderman, M.L., Alongi, S. and Skenhall, T.R. 2012. Utvärdering av förändrad demontering och återvinning av uttjänta fordon i Sverige. IVL Svenska Miljöinstitutet, Stockholm. 61 pp.

KI. 2016. Miljö, ekonomi och politik 2016. Konjunkturinstitutet, Stockholm. 151 pp.

Kosior, E., Churchward, G. and Closed Loop London. 2004. Development of a Food Grade PET recycling Process – Literature Review and Feasibility Study. The Waste & Resource Action Programme (WRAP), Banbury. 35 pp.

Li, W.C., Tse, H.F. and Fok, L. 2016. Plastic waste in the marine environment: A review of sources, occurrence and effects. Sci. Total Environ. 566: 333–349.

Michanek, G. and Zetterberg, C. 2012. Den svenska miljörätten. Iustus Förlag AB, Uppsala. 554 pp.

Milios, L., Christensen, L.H., McKinnon, D., Christensen, C., Rasch, M.K. and Eriksen, M.H. 2018. Plastic recycling in the Nordics: A value chain market analysis. Waste Manage. DOI 10.1016/j.wasman.201803034.

Monier, V., Hestin, M., Thonier, G., Pasquier, O., Tissot, I. and Chiorozas, C. 2014. Étude prospective sur la collecte et le tri des déchets d'emballages et de papier dans le Service Public de Gestion des Déchets. ADEME, Angers. 30 pp.

Neufeld, L., Stassen, F., Sheppard, R. and Gilman, T. 2016. The New Plastics Economy: Rethinking the Future of Plastics. World Economic Forum, Geneva. 36 pp.

Olofsson, J. 2014. Materialåtervinning av förpackningar och tidningar - Kartläggning och klimatnyttoanalys baserat på två fallstudier. Miljö- och Energisystem Institutionen för Teknik och samhälle, Lunds tekniska högskola, Lund. 118 pp.

O'Rourke, D. and Connolly, S. 2003. Just oil? The distribution of environmental and social impacts of oil production and consumption. Annu Rev Environ Resour. 28: 587-617.

Ottosson, T. Cleanaway AB, 011-190486

Palm, E. and Myrin, E.S. 2018. Mapping the plastics system and its sustainability challenges. Department of Environmental and Energy Systems Studies, Lund University, Lund

Papargyropoulou, E., Lozano, R., Steinberger, J.K., Wright, N. and bin Ujang, Z. 2014. The food waste hierarchy as a framework for the management of food surplus and food waste. J. Clean. Prod. 76: 106–115.

Plasticker. 2018. Market Report Plastics – April 2018. [https://plasticker.de/preise/marktbericht3_en.php?id=178]. Accessed 21 May 2018.

Plastics Europe. 2017. Plastics – the Facts 2017. An Analysis of European Plastics Production, Demand and Waste Data. Plastics Europe, Brussels. 44 pp.

Returpack AB. n.d.a. Customers and Partners. [http://pantamera.nu/om-oss/returpack-in-english/customers-partners/]. Accessed 28 April 2018.

Returpack AB. n.d.b. Pantstatistik. [http://pantamera.nu/pantsystem/statistik/pantstatistik/] Accessed 18 May 2018.

Returpack AB. 2018c. Årsredovisning för Returpack – PET Svenska AB – Räkenskapsåret 2017. Returpack AB, Norrköping. 19 pp.

Ruther, C. Swerec AB, charlotte.ruther@swerec.se.

Schoemaker, P.J. 1995. Scenario planning: a tool for strategic thinking. Sloan Manage. Rev. 36: 25 p.

Swerec AB. 2017. Årsredovisning och koncernredovisning för räkenskapsåret 2016. Swerec AB, Lanna. 25 pp.

Waste Care. n.d. Balers and Recycling. [https://www.wastecare.com/Products-Services/Balers/aboutbalers.htm]. Accessed 22 May 2018.

WEEE. 2006. Actual results and figures of the collective WEEE systems in Europe. [www.orgalime.org/sites/default/files/I_Willem_Canneman3.ppt]. Accessed 5 May 2018.

Legislation

A European Strategy for Plastics in a Circular Economy, COM (2018) 28 final.

EU. 2008. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives, OJ L 312, 22.11.2008, p. 3–30. [http://data.europa.eu/eli/dir/2008/98/oj]. Accessed 15 April 2018.

EU. 1994. European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste, OJ L 365, 31.12.1994, p. 10–23. [http://data.europa.eu/eli/dir/1994/62/oj]. Accessed 27 April 2018.

Proposal for a Directive of the European Parliament and of the Council amending Directive 94/62/EC on packaging and packaging waste, COM (2015) 596 final.

SFS 2005:209. Förordning (2005:209) om producentansvar för elektriska och elektroniska produkter.

SFS 2011:927. Avfallsförordning.

SFS 2014:1073. Förordning om producentansvar för förpackningar.

Appendix 1

Data

The following tables are a compilation of the data gathered during the data collection. The data points represent costs, employment numbers, distances and weights related to the collection, transport, sorting and recycling of plastic waste. The data marked in bold are EU average data from the previous study conducted by Hestin et al., 2015 for Plastic Recyclers Europe.

Table 2. Collection
Sweden specific data related to collection of plastic waste. The asterisk indicates that the data has been reworked and the calculations can be found in the section "Data calculations".

Categories	Collected data	Source
Collection		
Cost: Door-to-door collection	**2568 SEK/tonne**	**Hestin et al., 2015, p. 23***
Cost: Bring sites	**1127 SEK/tonne**	**Hestin et al., 2015, p. 23***
Cost: Recycling centres	**497 SEK/tonne**	**Hestin et al., 2015, p. 25***
Cost: Return system	18000 SEK/tonne	Returpack AB, 2017*
Employment: Door-to-door collection	**40 FTE**[5]	**Hestin et al., 2015, p. 23**
Employment: Bring sites	**21 FTE**	**Hestin et al., 2015, p. 23**
Employment: Recycling centres	**9 FTE**	**Hestin et al., 2015, p. 25**

[5] Full-time equivalent (FTE) is a unit used to equate the work load of employees that work a different number of hours per week. FTE is calculated by dividing the average number of hours worked per employee with the number of hours of a full-time employee.

Employment: Return system	**21 FTE**	**Hestin et al., 2015, p. 23**

Table 3. Recycling, transport, sorting and the deposit system
Sweden specific data related to the recycling, transport and sorting of plastic waste, and the deposit system. The asterisk indicates that the data has been reworked and the calculations can be found in the section "Data calculations".

Categories	Collected data	Source
Recycling		
Cost of operation of recycling facilities	1633 SEK/tonne	Swerec AB, 2016*
Cost of operation of recycling facility for PET bottles	4973 SEK/tonne	Kosior et al., 2004, p. 26; Plasticker, 2018; Olofsson, 2014, p. 27*
Employment in recycling facilites per 10 000 tonne sorted waste	10 FTE per 10 000 tonnes	Ruther, pers. comm.; Ottosson, pers. comm.*
Cost of construction for new recycling facility	250 000 000 SEK	FTI AB, 2018
Transport		
Cost of transport for recycling in Sweden	**152 SEK/tonne**	**Hestin et al., 2015, p. 27***
Cost of transport for recycling in Germany	**152 SEK/tonne**	**Hestin et al., 2015, p. 27***
Cost of transport for recycling in China	284 SEK/tonne	Waste Care, 2018; iContainers, 2018*
CO2-emissions for shipping of one container to China by sea	8,4 gCO2/tonne-km	ECTA, 2011, p. 9
Sorting		
Cost of operation of sorting facilities	**1940 SEK/tonne**	**Hestin et al., 2015, p. 26***
Emplyment in sorting facilities per 10 000 tonne sorted waste	**17 FTE**	**Hestin et al., 2015, p. 26**
Cost for construction of new sorting facility in Sweden	**5126 - 8242 SEK/tonne**	**Monier et al., 2014***

Table 4. End-of-life vehicles (ELV), incineration and WEEE
Sweden specific data related to end-of-life vehicles, incineration and Waste Electrical and Electronic Equipment (WEEE). The asterisk indicates that the data has been reworked and the calculations can be found in the section "Data calculations".

Categories	Collected data	Source
End-of-life vehicles (ELV)		
Average cost of collection of ELV	620 SEK/tonne	Bil Sweden, 2015, pp.7–9; Forsman, pers. comm*
Average cost of dismantling or shredding of ELV	350 SEK/tonne	Carlsson, pers. comm.
Average revenues from ferrous material	2500 SEK/tonne	Jensen et al., 2012, p. 23
Average revenues from non-ferrous material	13260 SEK/tonne	Jensen et al., 2012, p. 23*
Cost of landfilling ELV shredder waste in Sweden	800 SEK/tonne	Jensen et al., 2012, p. 56
Incineration		
Average cost of incineration	524 SEK/tonne	CEWEP, 2016, p. 8*
WEEE		
Average cost of collection and recycling	**3756 SEK/tonne**	**WEEE Forum, 2006***

Table 5. Electricity sources
Percentages of source energy in Sweden (SCB, 2016, p.7).

Categories	Collected data
Electricity sources	
Hydro power	40,47 %
Nuclear power	39,7 %
Conventional thermal power	9,59 %
Wind power	10,15 %
Solar power	0,09 %

Data calculations

A. Cost: Door-to-door collection

$$253\ EUR/tonne \cdot 10{,}15 \approx 2568\ SEK/tonne$$

B. Cost: Bring-sites

$$111\ EUR/tonne \cdot 10{,}15 \approx 1127\ SEK/tonne$$

C. Cost: Recycling centres

$$49\ EUR/tonne \cdot 10{,}15 \approx 497\ SEK/tonne$$

D. Cost: Return system

- 20 282 tonne PET-material year 2017 (Returpack AB, n.d.b)

- From Returpack AB's annual report (Returpack AB, 2018c)
    - Variable costs
        - Raw material and basic necessities: 1 110 247 000 SEK
        - Other external costs: 58 134 000 SEK
        - Other variable costs: 1 245 000 SEK

    - Write-offs
        - Machines and other technical facilities: 0 SEK

Total: 1169 626 000 SEK

- Cost of deposit (Andreasson, pers. comm.)
    - 0,89 SEK per small PET bottle, 367 million small bottles
    - 1,79 SEK per large PET bottle, 267 million large bottles

$$(0{,}89 \cdot 367000000) + (1{,}79 \cdot 267000000) = 804560000\ SEK$$

- Actual cost:

$$1169626000 - 804560000 = 365066000\ SEK$$

$$\frac{365066000\ SEK}{20282\ tonne} \approx 18000\ \ SEK/tonne$$

E. Cost of operation of recycling facilities

- 48 000 tonne plastic packaging sorted and washed (packaging)
- 5 000 tonne other types of plastic are grinded into flakes (e.g. toys etc.)
- Total: 53 000 tonne plastic waste (Ruther, pers. comm.)

- From Swerec AB annual report (Swerec AB, 2017)
  - Variable costs
    - Raw material and basic necessities: 32 580 000 SEK
    - Other external costs: 17 310 000 SEK
    - Personnel costs: 28 670 000 SEK
    - Write-offs: 7 960 000 SEK
    - Other variable costs: 44 000 SEK

Total: 86 564 000 SEK

$$\frac{86564000}{53000} \approx 1633\ SEK\ per\ tonne$$

F. Cost of operation of recycling facility for PET bottles

- Cleanaway AB uses a recycling process called URRC (Cleanaway AB, n.d.b).
  - Cost of URRC process: < 501 to 660 EUR/tonne (Kosior et al., 2004, p. 26).
  - Considering the price range of virgin PET prices over the past three years (April 2016-April 2018) (Plasticker, 2018), the new cost for the URRC process is <548 to 680 EUR/tonne. Due to technical advances since the report written by Kosior et al. (2004) report was released, the process of URRC can be assumed to be cheaper than it was then, and therefore the lower cost in the spectrum is assumed, and not an average → 548 EUR/tonne.

$$548\ EUR/tonne \cdot 10.15 \approx 5562\ SEK/tonne$$

- 15% of PET-bottles end up in Swerec AB. They have a cost of operation of 1633 SEK/tonne (see calculation E) (Olofsson, 2014, p. 27)
- Remaining 85% goes to Cleanaway AB and through the more expensive URRC Process

$$(1633\ SEK/tonne \cdot 0{,}15) + (5562\ SEK/tonne \cdot 0{,}85) \approx 4973\ SEK/tonne$$

G. Employment in recycling facilities for PET bottles

- 33 FTE
- 28 700 tonne plastic year 2017 (Ottosson, pers. comm.)

$$\frac{33\ FTE}{28700\ tonne} = 0{,}00114983\ FTE\ per\ tonne$$

$$0{,}00114983 \frac{FTE}{tonne} \cdot 10000\ tonne \approx 12\ FTE\ per\ 10000\ tonne\ recycled\ plastic\ waste$$

Employment in recycling facilities

- 41 FTE
- 48 000 tonne plastic packaging sorted and washed (packaging)
- 5 000 tonne other types of plastic are grinded into flakes (e.g. toys etc.)
- Total: 53 000 tonne plastic waste (Ruther, pers. comm.)

$$\frac{41\ FTE}{53000\ tonne} = 0{,}00077358\ FTE\ per\ tonne$$

$$0.00077358\ FTE\ per\ tonne \cdot 10000\ tonne \approx 8\ FTE\ per\ 10000\ tonne\ recycled\ plastic\ waste$$

- **Average employment in recycling facilities**

$$\frac{8\ FTE + 12\ FTE}{2} = 10\ FTE\ per\ 10\ 000\ tonne\ recycled\ PET\ bottles$$

H. Cost of transport of recycling in Sweden

$$15\ EUR \cdot 10{,}15 \approx 152\ SEK/tonne$$

I. Cost of transportation of recycling in Germany

$$15\ EUR \cdot 10{,}15 \approx 152\ SEK/tonne$$

J. Cost of transport of recycling in China

$$25\ EUR \cdot 10{,}15 \approx 254\ SEK/tonne$$

K. Cost of operation of sorting facilities

$$191{,}1\ EUR \cdot 10{,}15 \approx 1940\ SEK/tonne$$

L.

$$505\ EUR \cdot 10{,}15 \approx 5126\ SEK/tonne$$
$$812\ EUR \cdot 10{,}15 \approx 8241\ SEK/tonne$$

M. Average cost of transport for recycling in China

- First, the "typical" size and volume of a bale of collected and sorted plastic waste was determined using "commercial" info from a baler in the US: 400lbs/cubic yards - 600lbs/cubic yards (PET or PE) (Waste Care, n.d.)
  →Average: 500lbs/cubic yard
  → 1 cubic yard = 0,764555m^3

$$\frac{500lbs/cy}{0{,}764555m3/cy} \approx 653{,}97lbs/m3 \approx 296{,}63kg/m3$$

- Average prices for a trip from Europe (Hamburg or Rotterdam) to China (Shenzen or Hong Kong) (iContainers, n.d.):
  - 40FT (67m^3) container: 550 EUR (assuming large containers are used.

$$296{,}63kg/m3 \cdot 67m3 \approx 19{,}874\ tonne$$

$$\frac{550\ EUR}{19{,}874\ tonne} \approx 28\ EUR/tonne$$

$$28\ EUR/tonne \cdot 10{,}15 \approx 284\ SEK/tonne$$

N. Average cost of collection of End-of-Life Vehicles (ELV)

Average weight of cars:

$$\frac{1248{,}64\ kg + 1322{,}49\ kg + 1309{,}16\ kg}{3} = 129{,}43 \approx 1{,}29\ tonne$$

(Bil Sweden, 2015, pp.7–9)

Cost of toing car is approximately 800 SEK/car. This cost includes fuel and driver for a distance of around 3 miles[6] (Forsman, pers. comm.).

Average cost for toeing a car per tonne:

$$\frac{800\ SEK}{1{,}29\ tonne} \approx 620\ SEK/tonne$$

O. Average revenues from the sales of recyclable materials from End-of-Life Vehicles (ELV)

Non-Ferrous metal:
Stainless steel: 10000 SEK/tonne
Mangan-rich steel: 2800 SEK/tonne
Copper: 40 000 SEK/tonne
Brass: 2500 SEK/tonne
Aluminium: 11000 SEK/tonne
TOTAL: 66 300 SEK/tonne

(Jensen et al., 2012, p. 23)

Average:

$$\frac{66300\ SEK/tone}{5} = 13260\ SEK/tonne$$

P. Emissions: Skåne compared to scenario 3

- Scenario 3: ca 542kt CO_2e
- Skåne (2015): 5800kt CO_2e

$$\frac{542}{5800} \approx 0{,}1 = 10\%$$

---

[6] Swedish miles: 1 mile=10 km

Appendix 2

The following model baseline assumptions and calculations were compiled by Leonidas Milios.

Plastic waste management model baseline assumptions and calculations

The baseline of plastic waste management and plastic waste flows in Sweden is based on the investigation by SMED (Svenska MiljöEmissionsData) conducted by Fråne et al., published in 2012, using as a reference year of investigation the year 2010 (Fråne et al., 2012). SMED is a consortium of public institutions in Sweden with the aim of collecting and developing skills regarding the long-term emission statistics in the areas of air and water pollution, and waste and hazardous substances generation. Members of the consortium are the Swedish Environment Institute (IVL), the Swedish Statistics Agency (SCB), the Swedish Agricultural University (SLU), and the Swedish Meteorological and Hydrological Institute (SMHI). The report 'Mapping of plastic waste streams in Sweden' (Fråne et al., 2012) presents the most comprehensive mapping of plastic waste flows in Sweden so far, and it contains rich contextual information that satisfy nearly all baseline data requirements of the plastic waste management model developed in this study. The data used in the model can be found in the summary of the report, in a table form (Fråne et al., 2012, p. 11).

Plastic waste generation by waste stream

The SMED (2012) report provides quantitative data on plastic waste generation and management by source. 'Manufacturing' and 'Medical' plastic waste is out of the scope of this study, so they are not modelled, and we did not use the respective amounts of plastic waste found in the SMED report. Without these two waste fractions, the breakdown of post-consumer plastic waste generation used in the model is presented in Table 6. Amount in tonnes is rounded as in the report.

Table 6. Share of plastic waste generation, by waste stream

WEEE: Waste Electrical and Electronic Equipment; ELV: End of Life Vehicles; B&C: Building and Construction

Ref. year 2010	Packaging	WEEE	ELV	B&C	Agricultural	Other	TOTAL
Proportion of post- consumer plastic waste	61%	7%	4%	9%	4%	16%	100%
Post-consumer plastic waste (tonnes)	299000	34000	18000	43000	18000	81000	493000

Plastic waste collection mode differentiation

In the case of household waste, the data is broken down according to collection method. In the model, we distinguish between the different modes of collection according to the data found in the SMED report. 'Sorted plastic packaging' is mainly attributed to 'bring site' collection, as 'kerbside' collection was not widely developed at the time of the study. 'Plastic packaging in the residual waste' is attributed to the 'kerbside' collection system in the model. 'Sorted deposit bottles' corresponds to the 'Deposit' system of collection in the model. Further, we have attributed a share of the 'Services' plastic waste to commercial post-consumer packaging, using the percentage defined by Plastic Recyclers Europe (Hestin et al., 2015, p. 15). For the waste stream 'Other plastic waste' in the model, we included the data 'Other plastics in the residual waste' (kerbside collection) and 'Bulky waste' (delivery to recycling centres) from the SMED report. There is a separate mention in the SMED report about 'Plastic packaging in the sorted food waste', which we integrated into the 'kerbside' plastic packaging waste collection in the model. The rest of the waste streams in the SMED report correspond 1:1 to the defined categories of the model, so the attribution of data to respective categories is self-evident.

Plastic waste treatment by waste stream

SMED (2012) also specifies the plastic waste treatment in each waste stream, and this breakdown is used in the model to define the treatment shares of plastic waste by waste stream in the model baseline (Table 7).

Table 7. Share of plastic waste generation, by waste stream

The 'Total' treatment rate in the last row is a weighted average taking into account the share of each waste stream in the total plastic waste generation (see Table 6).

Ref. year 2010	Collection for recycling rate	Incineration rate	Landfilling rate
Packaging	37%	63%	0%
WEEE	43%	44%	13%
ELV	0%	67%	33%
B&C	0%	100%	0%
Agriculture	89%	11%	0%
Others	4%	96%	0%
Total	29,13%	68,75%	2,11%

In Table 7, the column 'Collection for recycling' refers to the amounts of plastic waste collected and sent to recycling. However, the actual recycling is lower as a certain percentage of plastic is rejected in the subsequent processes (sorting and recycling), which is then redirected to other treatment options (most notably, incineration). This particularity is important in calculating the environmental impacts of plastic recycling, but it has little or no effect when calculating the economic and social impacts.

Plastic waste imports and exports

The SMED (2012) report presents data regarding imports and exports of plastic waste. However, it does not specify countries of origin and destination, and waste stream and plastic waste type. For this reason, we used the international trade databases 'UN comtrade' and 'Eurostat comext' to triangulate the data and identify the missing information. Plastic waste corresponds to CN8 code 3915, which is further subdivided to plastic waste type, 391510 for polymers of ethylene (PE); 391520 for polymers of styrene (PS); 391530 for polymers of vinyl chloride (PVC); 391590 for polymers of propylene (PP) etc. The data proved to be very consistent across all databases, which gives a strong indication of good quality data. We extracted data time series (2010-2015) and concluded that the type of waste traded, and the partner countries remained relatively stable. About 25% of exports had Hong-Kong and China as destination, while the remaining 75% was trade was among EU partners with Germany being a dominant end market (30%-35% of the exports). A slight change over the years was observed with trade in EU shifting from earlier partners Netherlands and Belgium to later partners Poland and Lithuania, at the same percent of exports (15%-20%). In terms of modelling, this change has no effect, since the distance and mode of transport are relatively the same. For imports, Norway consistently accounts for over 90% of imports of plastic waste to Sweden for the whole period 2010-2015. The projection of imports and exports of plastic waste in the model are represented by a percentage of the amount compared to the total plastic waste generation in Sweden. In this assumption, the percentage of exports and imports in kept constant for all future scenarios. For example, if the export of PET bottles for recycling is 8% of the total plastic waste generated in Sweden in 2010, then the percentage of export of PET bottles for recycling in 2030 will be 8% of the total plastic waste generated in Sweden in 2030. This is an inherent assumption of the model, since it is not possible to predict actual amounts of plastic waste traded in a hypothetical situation in the future.

Projections of future plastic waste generation

For calculating the future plastic waste generation in Sweden, we used the baseline data from Table 6 and applied the annual growth rates proposed by the Swedish National Institute of Economic Research (Konjunkturinstitutet) in the report 'Environment, economy and policy 2016' (KI, 2016). The growth rates are based on the general equilibrium model EMEC, which is use by the Swedish government for long-term projections of the economy for policy development reasons. These projections have been criticised by another report from SMED (2017) for being too 'gross' and not accounting for possible waste prevention measures that would take place in the meantime and keep the growth rates at lower levels. However, in this study we will use the growth rates by KI for a number of reasons. Firstly, we ran time series (2008-2015) analyses on statistical data on waste generation (from Eurostat and SCB) for 'Total waste generation', 'Packaging waste generation', and 'Municipal waste generation', and concluded that the projections by KI are valid, especially concerning plastic waste. When analysing 'Total waste' and 'Municipal waste' generation the trend was practically flat, with very low growth rate, which made us doubt the projections by KI. However, the trends in packaging waste in general, and plastic packaging waste in particular, were strongly correlated with the rate 2,4% proposed by KI. Taking into account that packaging waste consists 61% of the total plastic waste, and that it is the waste stream with the most significant influence in the model, we decided to keep the original projections by KI and the EMEC model for all waste streams in the model. Table 8 presents the future amounts of plastic waste generated in 2030 which form the basis of calculations for the scenarios in this study.

Table 8. Annual growth rate of waste generation and future waste amounts, by waste stream
WEEE: Waste Electrical and Electronic Equipment; ELV: End of Life Vehicles; B&C: Building and Construction

	Packaging	WEEE	ELV	B&C	Agricultural	Other	TOTAL
Post-consumer plastic waste (2010) (tonnes)	299 000	34 000	18 000	43 000	18 000	81 000	493 000
Annual growth (%)	2,4%	2,5%	2,5%	2,6%	1,0%	2,4%	-
Post-consumer plastic waste (2030) (tonnes)	480 474	55 713	29 495	71 848	21 963	130 162	789 656

Targets applied in the model scenarios for 2030

The targets set in the scenarios of this study are either specifically targeting waste plastics or refer to a certain waste stream (e.g. WEEE) which can contain mixed materials. The targets identified derive from existing legislation or draft proposals by the European Commission. Where specific targets for a waste stream were not found in legislation, targets by material or waste stream were determined by adapting to good practices and/or voluntary targets by the industry. Table 8 lists the targets, stating the source and the rationale behind the specific targets selection.

Table 9. Plastics recycling targets for 2030, by waste stream
WEEE: Waste Electrical and Electronic Equipment; ELV: End of Life Vehicles; B&C: Building and Construction.

Target	2030	Source
Packaging recycling	55%	COM(2015) 596 final, target for plastic packaging.
WEEE recycling	50%	Directive 2012/19/EU, weighted average of the different targets by WEEE categories. The rate presented here represents the share of plastics in WEEE that needs to be recycled for reaching the overall target in the Directive. For calculation method, please see the report conducted by Hestin et al. (2015) for Plastic Recyclers Europe. In the Plastic Recyclers Europe report this share is calculated at 45% for 2020, but in this modelling study we assume a gradual progression of the target to 50%.
ELV recycling	30%	Directive 2000/53/EC, based on plastic content in ELV. The rate presented here represents the share of plastics in ELV that needs to be recycled for reaching the overall target in the Directive. For calculation method, please the

		report conducted by Hestin et al. (2015) for Plastic Recyclers Europe
B&C recycling	30%	No target, legal or voluntary, was found for this waste stream, and therefore we assume a 30% target in line with other waste streams (e.g. ELV and Agri.), as a measure of good practice and ambition within the construction sector.
Agricultural recycling	30%	Voluntary industry target, set at sectoral level by Swepretur - an industry association for manufacturers, importers and retailers of silage film, plastic bags and horticultural foil.
Other plastic waste recycling	7%	Plastic content in municipal soled waste (except packaging waste) that needs to be recycled for achieving the revised municipal waste target of 60% by 2030 (COM(2015) 595 final). For calculation method, please see the report conducted by Hestin et al. (2015) for Plastic Recyclers Europe.

WWW.CEC.LU.SE
WWW.LU.SE

Lunds universitet

Miljövetenskaplig utbildning
Centrum för miljö- och klimatforskning
Ekologihuset
223 62 Lund