Master’s thesis
Markus Benjamin Janitzek
Wrx360

Burning Money – Household Plastic Waste Recycling In Copenhagen


Academic advisor: Søren Bøye Olsen
Submitted: 01/10/15
Institutnavn: Institut for Fødevare- og Ressourceøkonomi (IFRO)

Name of department: Department of Food and Resource Economics (IFRO)

Author: Markus Benjamin Janitzek

Title / Subtitle: Burning Money – Household Plastic Waste Recycling In Copenhagen


Subject description: The aim of the thesis is to use a methodological approach to Cost Benefit Analysis (CBA), with the case of a circular waste management scenario in Copenhagen. The welfare economic potential of increasing recycling, by investing in the plastic waste management system and decreasing plastic incineration for the production of energy, is analysed. The results are compared to the CBA of a business as usual scenario, where no major increase in recycling is experienced and plastic waste continuous to be incinerated.

Submitted: 01. oktober 2015

Grade: X
Abstract

In accordance with the Waste Framework Directive and the National Plan for Resource and Waste in Denmark, the City of Copenhagen has set out different alternatives in order to decrease the amount of incinerated waste and increase the amount of recycling. The alternative that underlies this thesis is the household plastic waste management, where investments are made on a fine-sorting facility, that is able to recycle up to 70% of the plastic waste into the different plastic types. It is assumed in the model, that by the year 2033, there will be improvements in the technology of the sorting facility, which will lead to all the household plastic waste being recycled by the year 2045. The recycling rate is further increased through investments on the collection scheme of household plastic waste. Thus, by the year of 2045 there is no more waste incineration of household plastic waste. The baseline scenario on which the alternative scenario is held up, is a business as usual scenario, where there is not any decrease in the incinerated plastic waste, due to only a minor increase in recycling of plastic waste.

A welfare economic Cost Benefit Analysis (CBA) will be used as an economic tool in order to examine the two different scenarios- the baseline and the alternative one. Specifically, benefits to the environment, and the revenue gathered from recycling waste are interesting. The transportation and collection costs are higher in the alternative scenario, because there are larger investments in the waste management scenario, such as cost of bins and the costs of emptying the bins.

Comparing the results of the two scenarios, it is obvious that the revenue value of the alternative scenario is high. This means that the benefits from investing in the sorting facility are exceeding the costs, which will lead to a positive Net Present Value (NPV) at ca 390 million DKK. The difference between these two scenarios is at 740 million DKK, which shows that the NPV of the baseline scenario is negative, because there are not that many benefits to be gathered.

For the conduction of the thesis, a literature review for the plastic recycling has been undertaken in order to gather general information and have a better overview. Moreover, the thesis has been done with the collaboration of the Municipality of Copenhagen from where primary data and links to relevant secondary data for the CBA were gathered.
Preface

This project constitutes the master thesis of Markus Benjamin Janitzek in the Master in Science (MSc) program called “Environmental and Natural Resource Economics” at Copenhagen University – Faculty of Science. The thesis is credited to 30 ECTS-points over a period of 6 months. The thesis was conducted at the Institute of Food and Resource Economics, with Søren Bøye Olsen as academic advisor.

The thesis was established in cooperation with “The Technical and Environmental Administration” at the City of Copenhagen, and analyses the welfare economic potential of changing the waste management system in the direction of recycling more plastic waste from household in Copenhagen. This is done as an addition to the work City of Copenhagen is involved with in the cooperation within the Global Plastic Packaging Roadmap of the Ellen MacArthur Foundation. The thesis analyses the potential value of changing the plastic waste management system to a more circular system, where waste is not waste, but through investment in a fine-sorting facility is recycled and becomes a valued good. Focus of the thesis is on the management of plastic waste from households in Copenhagen. Data and information has been collected in cooperation with The Technical and Environmental Administration at the City of Copenhagen, however the content within this thesis are an expression of the author’s work and The Technical and Environmental Administration at the City of Copenhagen is not responsible for any claims.

The purpose of this thesis is to clarify and illustrate my abilities to construct and independently complete a study on an academic problem, which comprises data collection, processing and analysing of the results.

I would like to thank my academic advisor Søren Bøye Olsen for constructive meetings and discussions on my subject, as well as Morten Højer, Mette Skovgaard, and Martin Tilsted of the Technical and Environmental Administration at the City of Copenhagen. I would additionally like to thank Christoph Janitzek, Daniel Janitzek, Evdokia Roidou and Johan Winberg for giving great feedback on the thesis.
Content

ABSTRACT .............................................................................................................4

PREFACE ...............................................................................................................5

1 GENERAL INTRODUCTION ...........................................................................8

1.1 Background ....................................................................................................8

1.2 Problem statement ........................................................................................9

2 DEMARCATION ................................................................................................10

3 METHODOLOGY ..............................................................................................12

4 PLASTIC WASTE MANAGEMENT SYSTEM ..................................................13

4.1 Circular Economy – and the plastic packaging waste case: .................................13

4.2 Global Plastic Packaging Roadmap ..................................................................15


4.4 Plastic Waste Recycling Value Chain ...............................................................18

4.4.1 Type of waste and plastic ........................................................................18

4.4.2 Collection ................................................................................................19

4.4.3 Prevention and Re-Use ...........................................................................20

4.4.4 Sorting of Waste .....................................................................................21

4.4.5 Mechanical Recycling ...........................................................................21

4.5 Plastic type and products ..............................................................................24

5 ECONOMIC THEORY ......................................................................................25

5.1 Cost Benefit Analysis ....................................................................................25

5.1.1 Multi-Criteria Analysis ...........................................................................28

5.1.2 Cost Effectiveness Analysis .....................................................................28

5.1.3 Why not Multi-Criteria Analysis or Cost Effectiveness Analysis? ...............28

5.2 Welfare function and indifference curves ......................................................29

5.2.1 Cost Benefit Analysis as a test for increasing welfare .................................31

5.2.2 Applied Net Present Value ........................................................................32

5.2.3 Discount rate ..........................................................................................32

5.2.4 Descriptive Approach .............................................................................33

5.2.5 Prescriptive Approach .............................................................................33

5.2.6 Denmark’s choice of discount rate .........................................................36

5.2.7 Externalities .............................................................................................36
6 METHODOCAL APPROACH TO COST BENEFIT ANALYSIS, WITH THE CASE OF A CIRCULAR WASTE MANAGEMENT SCENARIO IN COPENHAGEN

5.3 Economic Valuation

5.3.1 Stated and Revealed Preferences

5.3.2 Benefit Transfers

5.3.3 Social Cost of Carbon

5.3.4 Standard Conversion Factor

6.1 Project definition

6.1.1 Baseline Scenario

Production of waste

SORTING (AT HOUSEHOLDS)

COLLECTION

SORTING (FACILITY)

TREATMENT & PROCESSING

6.1.2 Alternative Scenarios and choice

6.1.3 Alternative Scenario 1

Production

Sorting (Households)

Collection

Sorting (facility)

Treatment - Processing

6.1.4 Alternative Scenario 2

6.1.5 Alternative Scenario 3

6.1.6 Choice of scenarios

6.2 Identifying relevant project impacts

6.2.1 Geographical and Period Limitation

6.2.2 Assumptions

6.3 Physical quantification of relevant impacts

Collection

Sorting (Facility)

Treatment

Plastic Revenue

6.4 Monetary valuation of impacts

Collection

Environment
6.5 Discounting of costs and benefits................................................................. 77

6.6 Net present value test .................................................................................. 79
   6.6.1 Last step: Sensitivity analysis ................................................................. 81

7 DISCUSSION: ................................................................................................. 84

8 PERSPECTIVE ............................................................................................... 86
List of abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARC</td>
<td>Amager Resource Centre</td>
</tr>
<tr>
<td>BT</td>
<td>Benefit Transfer</td>
</tr>
<tr>
<td>CBA</td>
<td>Cost Benefit Analysis</td>
</tr>
<tr>
<td>CEA</td>
<td>Cost Effectiveness Analysis</td>
</tr>
<tr>
<td>CO₂</td>
<td>Chemical formula for Carbon Dioxide</td>
</tr>
<tr>
<td>D</td>
<td>Demand</td>
</tr>
<tr>
<td>DKK</td>
<td>Danish Kroner</td>
</tr>
<tr>
<td>EC</td>
<td>European Union</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GJ</td>
<td>Gigajoules</td>
</tr>
<tr>
<td>H₂O</td>
<td>Chemical formula for Water</td>
</tr>
<tr>
<td>HDPE</td>
<td>High-Density Polyethylene</td>
</tr>
<tr>
<td>Kg</td>
<td>Kilogrammes</td>
</tr>
<tr>
<td>Km</td>
<td>Kilometre</td>
</tr>
<tr>
<td>LDPE</td>
<td>Low-Density Polyethylene</td>
</tr>
<tr>
<td>MAC</td>
<td>Marginal Abatement Cost</td>
</tr>
<tr>
<td>MCA</td>
<td>Multi Criteria Analysis</td>
</tr>
<tr>
<td>MRS</td>
<td>Marginal Rate of Substitution</td>
</tr>
<tr>
<td>NIR</td>
<td>Near-infrared</td>
</tr>
<tr>
<td>NPV</td>
<td>Net Present Value</td>
</tr>
<tr>
<td>PE</td>
<td>Polyethylene</td>
</tr>
<tr>
<td>PET</td>
<td>Polyethylene Terephthalate</td>
</tr>
</tbody>
</table>

List of Figures

Figure 1 - Waste Management Hierarchy. Source: European Commission Environment (2015) ................................................................. 17
Figure 2 - Plastic Recycling Value Chain (Source: JRC, 2013) ................................................................. 19
Figure 3 - Application of plastics. Source JRC (2013) ................................................................. 25
Figure 4 - Baseline Scenario (Author created figure) ................................................................. 50
Figure 5 - Alternative Scenario 1 ................................................................. 54
Figure 6 - Quantity of Sorted Plastic Type in the alternative scenario, where a revenue can be gained ............................................................................................................... 71
Figure 7 - Revenue at the given year of recycled plastic ................................................................................................................................. 75

List of Tables

Table 1 Type of plastic and examples of application ................................................................. 24
Table 2 – Baseline Plastic Waste Quantity in total (not only households) (in tonnes) ................................................................................................................................. 49
Table 3 Characteristics of the alternatives ................................................................................................................................. 53
Table 4 - Share of plastic type in the total plastic waste quantity ................................................................................................................................. 58
Table 5 - Assumptions underlying the CBA ................................................................................................................................. 63
Table 6 - Truck Capacity (in tonnes) and emission of CO₂ (in kg/km/ton) ................................................................................................................................. 67
Table 7 Prevented CO₂ emission from recycling plastics (in kg/tonne) ................................................................................................................................. 68
Table 8 Benefits and Costs of the Baseline and Alternative Scenario ................................................................................................................................. 72
Table 9 Costs and benefits in 2015 and 2045; Emissions from Incineration and Recycling (in DKK) ................................................................................................................................. 76
Table 10 - Present Value of the different accounts in the CBA ................................................................................................................................. 78
Table 11 - NPV results of the Baseline and Alternative Scenario ................................................................................................................................. 79
1 General Introduction

1.1 Background

Since the establishment of the Ellen MacArthur foundation in 2010, their aim has been to promote the idea of a circular economy. A circular economy seeks to maintain the highest possible value as well as utility of materials, components and products at any time throughout its value chain, thus by design being recuperative. As a part of the initiatives promoted by of the Ellen MacArthur foundation and the World Economic Forum’s Circular Economy Initiative, Project Mainstream was created. One of the project’s main focus areas is the Global Plastic Packaging Roadmap that aims to solve problems related to the current state of global plastic packaging production and management. The production of Fast Moving Consumer Goods (FMCG) reached 288 million tonnes in 2012 and is presently growing by 9 % per year. This trend will continue with the population growth that is expected to reach 9 billion by 2030, with 3 billion new middle-class consumers worldwide. In the current linear economy of “take, make, dispose”, products and materials are not utilised to their maximum value, and the supply of FMCG, challenges the provision of resources in the future (WFD, 2008). Plastic production consumed 4-8% of the total oil produced per annum, which is one of the reasons why it is important to keep the value of the product, even after use. The European Commission introduced the Waste Framework Directive (WFD) in 2008, which gives the framework for deciding when a product is treated as waste, or as a secondary raw material, and considers the most valuable steps, in resource efficiency of plastic waste management. Prevention and reuse of plastic maintain the highest value of the material, followed by mechanical or chemical recycling. Energy recovery is the second least efficient option of waste disposal. In the 80’s Denmark has focused on the waste to energy option of waste management as a direct result of the widely used waste disposal practice of the 70’s, transporting waste to landfills leading to exhaustion of capacity. This shift in focus has manifested in 29 waste incineration plants by 2012 that processed 3,6 million tonnes of waste from households and enterprises (Dansk Affaldsforening et al., 2014). Considering the waste management hierarchy, the less efficient option of waste to energy missed a large potential of the resource, which could have been attained through the re-use or recycling thereof (WFD, 2008). The WFD was adopted into the Danish Nation Resource Plan, in 2012, followed by the Resource and Waste Plan for
Copenhagen City (KK, 2014). The target of these plans is to re-use or recycle at least 50% of household waste, where 22% should come from plastics. In accordance with the WFD and the National Resource plan, the city of Copenhagen has set a milestone in their Resource and waste plan (KK, 2014). The plan is to recycle 15,000 tonnes of total plastic waste, by year 2018, and continuously increase this amount in the future. This milestone thus aims to decrease the amount of waste incineration in Copenhagen and maintain the revenue from sorted plastic in Denmark, instead of exporting it to other countries such as Germany (KK, 2013). The plan states that the rising prices of material and resources generate a large potential to make the use of these resources more efficient. Thus, the primary goal is to increase recycling of plastic waste consequently decreasing incineration thereof, with the focus of reducing the environmental impact of waste, and thereby decoupling economic growth and the resulting stress on the environment (MST, 2014; KK, 2014). Currently, 90% of plastic waste is burned in incineration plants for energy, and only a minor fraction is sent to Germany for recycling as Copenhagen does not have a sorting facility of its own (City of Copenhagen, 2015; Larsen & Skovgaard, 2013). Therefore, the City of Copenhagen considers establishing a sorting facility and investing in the adjustment of the surrounding plastic waste management system, in order to achieve the objectives set out by the Waste and Resource Plan. This can also be considered as a step into the circular waste management of household plastic waste in Copenhagen.

1.2 Problem statement

The City of Copenhagen has set different initiatives, which seek to achieve the objectives of the National Resource Plan in their Waste and Resource plan. This thesis concentrates on the potential net benefits of restructuring the waste management system, to increase the recycling of plastic waste, whilst eliminating the incineration of plastic waste intended for energy production in the future, compared to a business as usual scenario. The alternative encompasses investments in the waste management system and the construction of a sorting facility that enables the sorting of plastics into the different plastic types, which can be sold on the plastic market. The CBA thus aims to discover if the project results in a welfare economic increase for society.

The aim of the thesis is to use a methodological approach to Cost Benefit Analysis, using the case of a circular waste management scenario in Copenhagen, in the form of a recycling solution.
by investing in a fine-sorting facility and thereby altering the waste management system. The potential costs and benefits to society from investing in such a system, where recycling of plastic waste from households is the main priority, are to be analysed by answering these sub questions:

- How can plastic waste be recycled?
- What is the value chain of post-consumer plastic waste from households?
- What is the plastic waste management system in the baseline and alternative scenario?
- What are the welfare economic consequences of the baseline and alternative scenario?

2 Demarcation

The CBA is based on an empirical case of recycling household plastic waste in the City of Copenhagen. This thesis analyses the welfare economic potential of investing in a sorting facility that can sort the collected plastic waste stream of households into the different types of plastic, to be sold on the plastic market. This analysis is conducted in order to find value of investing in such a system, by analysing the costs and benefits of the waste management systems accruing in the alternative scenario of increasing waste recycling, compared to a baseline scenario where the waste management system continuous as status quo, with a minimal increase in plastic recycling.

The analysis is based on theoretical foundation of CBA, concerning the current project and measures. Thus, the theory envelopes the relevant parts of welfare economic theory, discounting, and economic valuation used to find the unit prices in the model.

As the thesis is limited to the effects brought by household waste, it only takes into account 45% of the total plastic waste generation of the City of Copenhagen. Therefore, the full capacity of the waste management system is not taken into consideration. This also affects the operation of the sorting facility and the incineration plant. The efficiency of these plants are based on the capacity and input thereof. These factors partly decide the costs of operation, and eventually the profitability of the plants. By solely including one part of the waste management system, the outcome of the CBA on baseline and alternative scenario have to be interpreted accordingly.
Households bring a large amount of waste to recycling facilities/stations located at 38 different sites around the City of Copenhagen. However, due to the distance to these recycling stations, the collection rate of plastics at these stations is relatively inefficient and only a few percent of the potential plastic collection is achieved (MST, 2013). Due to the scope of the present thesis as well as the limitations in gathering data on the bring-system, recycling stations are not included in the analysis.

Another bring-system that is important to be mention, yet will not be included in the analysis, is the deposit-and-return system of PET bottles, which collects 95% of plastic bottles out of the waste collection system (Plastic Zero, 2013). As the deposit-and-return system is already well established, and the collection rate is meeting its potential, it is not at focus for the City of Copenhagen in increasing the recycling of plastic waste (City of Copenhagen, 2015). The total operation and treatment costs of the waste management system for household (i.e. in the form of fees), should reflect the total cost that the municipality has in operation of the system. This also applies for the charges that are included in the waste management system. For that reason, the expenses of the City of Copenhagen are estimated, with the correction of a deadweight loss.

Furthermore, the thesis includes a specific incineration plant throughout the baseline and alternative scenario of the thesis. Namely, Amager Ressource Center (ARC) is used as an example for waste incineration plant. The capital investment of the incineration plant is included as a sunk cost, and no further capital investments included. The inclusion of the incineration plant mainly concerns the cost of energy production, through a gate-fee and the operational costs, as well as the revenue gained from the sale of electricity and heat. It is assumed that the gap of missing quantity in the incineration plant will be replaced with imported waste. In reality, import of waste has been restricted in Copenhagen, in order to focus solutions on new technology, such as REnescience, and minimise the use of biomass. However, for the sake of the calculations, and in order to keep to display that the incineration plant has to substitute the missing plastic waste with another source of fuel, this assumption is included in the thesis. The energy production of the incineration plant is based on averages of the fuel consumption. Finding the exact figures on energy production would require a precise technical
concept in combustion and composition of the inputs in the given scenario, and therefore it is not within the scope for this thesis.

In reality, ARC is expected to open a modern state of the art incineration plant in 2017. This thesis does not include the new investment, for different reasons. One of the reasons is an issue concerning the large capacity of this incineration plant, as well as the added difficulty of having to find the necessary waste inputs, both challenges, which have not been solved yet. In addition, it is impossible to gather information on the plant, as it has not started operating yet.

3 Methodology

The thesis was conducted in cooperation with the City of Copenhagen. With whom the alternatives to the baseline scenario of plastic waste management from households were discussed. This resulted in the definition and demarcation of the baseline scenario, and the alternative scenario that are the focus of the CBA in this thesis.

Thus, primary data were gathered through meetings and discussion with the representatives of the City of Copenhagen, where their expertise and knowledge gave a great insight to and understanding of the Copenhagen waste management system. The primary data is used in the CBA, for example to establish the different costs related to the waste management system.

The primary data was complemented by secondary data. The City of Copenhagen referred to different projects or studies that had just been released by the different entities such as the incineration plant. Furthermore, other secondary data sources used for the CBA were from the Danish Environmental Protection Agency, the Danish Energy Agency, and the working group Plastic ZERO, which is a public private cooperation for avoiding plastics as waste in the future. Data was also gathered from consultancies such as COWI and Econet, however the author of this thesis, in cooperation with the City of Copenhagen, ensured that the data was assessed critically, before deciding if it could be used in the CBA.

The empirical foundation for the thesis is based on literature review of a number of peer reviewed articles within waste management, recycling, environmental economics and microeconomics. The empirical foundation includes different articles on the same topic in order
to assure a broader insight on the specific topic at hand and to allow a critical assessment of the relevant studies for the thesis.

Most of the articles are published in the recent years, as the development of plastic waste recovery is growing rapid. The thesis also includes secondary sources, mainly from reports of the Danish Energy Agency, Danish Environmental Protection Agency (EPA), and from the City of Copenhagen.

The social appraisal tool for projects, Cost benefit analysis (CBA) is used in order to analyse costs of establishing and operating a sorting facility and changing the waste management system in order to encompass more plastic recycling, in relation to the resulting benefits thereof. This CBA is carried out in an Excel spreadsheet following the guidelines of the Ministry of Finance’s official guide for CBA. In addition guidelines of the Danish Energy Agency were used for figures concerning the environment. The data on waste generation, sorting facilities, incineration plants, share of different plastic types and relevant unit prices are included in the spreadsheet and were gathered from the above mentioned literature review, desk research and information given by the representatives of the Global Plastic Packaging Roadmap work-group at the City of Copenhagen.

4 Plastic Waste Management System

4.1 Circular Economy – and the plastic packaging waste case:

The idea of a Circular Economy has been around the scientific world long before the establishment of the Ellen MacArthur Foundation. In 1966, Boulding K. had an alliteration of the resource use on earth and the waste it creates in the “economics of the coming spaceship Earth”. Here, he states that there is a need to regard earth as a closed economic system, where the linkage between the environment and economy should not be of a linear kind, and rather be a circular relationship. This would create a situation for both the economy and environment, which translates into a win-win, as there would be a closed-loop of materials in the economy (Boulding, 1966). Pearce and Turner (1990) explain the issue related to the still present linear
economy, where production is aimed to increase utility\textsuperscript{1} by producing consumer goods for the present and capital goods for future consumption.

In order to produce, there is a need for resources, which are the input to the economic system. The production of a good generates waste materials throughout the linear economy, however waste is not only produced through the economic system of humans, nature also has its waste production. The major difference is that natural system recycle their waste and convert it into useful components, e.g. leaves that are decomposed by organisms in order to become fertilisers for the growth of new plants and trees. The First Law of Thermodynamics can explain this process of creating waste, it states that energy or matter cannot be created or destroyed. What we use has to be released in some other form afterwards into the environmental system (Pearce & Turner, 1990).

Through recycling, the waste can be transferred, into new resources that can further production. However, there is still some waste that enters the environment, which can be explained by the Second Law of Thermodynamics. The economy produces products entropically, which means that they are composed of various complex mixture of materials. It puts a boundary to the closed system of the economy, as entropy gives the material dispersion, which equals the required steps of recycling in order not to produce waste (Pearce & Turner, 1990). Thus, in order to recycle waste, e.g. plastic waste, the entropy has to be decreased by adding energy to the system (Stein, 1998). Some materials are economically not feasible to recycle, as it would be too costly to gather the materials from the product. Others are technically not possible to recycle, such as such as energy itself. Capturing Carbon dioxide from combusted fuels would not create the burned fuel again (Gutowski & Dahmus, 2005).

Thus, the waste that cannot be recycled, or captured, is released in the environment, where the environment will recycle it to the amount that the assimilative capacity thereof allows. This is the ability of the environment to capture waste and convert it into harmless ecological products. However, if the environment draws upon exhaustible resources in order to recycle the waste, it is a finite quality of the environment. If waste generation exceeds the environmental assimilative capability, the utility of society will be affected negatively through e.g. pollution

\textsuperscript{1} See 5.2 Welfare function and indifference curves, for an explanation of utility.
and the related health risks (Bogner et al., 2007). An example would be the Gases emitted from landfill sites. These consist of carbon dioxide, methane, hydrogen sulphide and other gases, which have a negative effect on human health. Therefore, a circular economy aims, to overcome the barriers of recycling and minimise the waste production throughout the value chain of products.

The following chapter introduces the Global Plastic Packaging Roadmap, of the Ellen MacArthur Foundation and the World Economic Forum.

4.2 Global Plastic Packaging Roadmap

The aim of the “The Global Plastic Packaging Roadmap” is to become a guide for the circular economy design of plastic packaging and the connected plastic waste management in the cities. The current development of the guide is led by cities and leading consumer good companies, committed to a change of the current state. In the current state of a linear economy plastic packaging is created from virgin material and predominantly for single-use (WEF, 2015). For example, 93% of global Polyethylene terephthalate (PET) used for plastic packaging, especially for bottles, is produced on virgin material (fossil oil) (Ellen MacArthur Foundation, 2013). The goal of the plastic packaging roadmap is to change the packaging system into an effective packaging system based on re-use, recycling and the defined uses defined, valuable, biological or technical nutrients (ibid.)

The finalised roadmap will include a large range of starting points and needs, which then allows for widespread participation, which creates convergence and opportunities for innovation throughout the value chain of plastic (WEF, 2015).

In this thesis, the focus of the City of Copenhagen on recycling plastic waste from household, which includes plastic packaging will be analysed in a methodological approach to a CBA. The following chapter describes the development of EU and Danish towards a circular economy, where re-use is prioritised before disposal of waste.

4.3 EU Waste Directive Framework and the Danish National Resource Plan

In the 1980’s Denmark faced a problem with waste management. As a direct result of the widely used waste disposal practice of the 70’s, i.e., simply transporting all waste to landfills, the capacity of these landfills was eventually exhausted (Kjær, 2013). Consequently, throughout
the 80’s, landfills were being used at overcapacity. In order to solve this issue, the municipalities of the capital area jointly invested in the construction of waste incineration plants. By burning waste at these incineration plants, the pressure on landfills was decreased dramatically (DAKOFÅ, 2007). By 1995, the percentage of landfilled waste was reduced by 20% compared to 1985 and following the first national Waste plan in 1992. Followed by two national waste plans covering the periods of 1998 to 2004 and 2005-2008, progress showed that landfilled waste decreased to 4% in 2008. The increase in waste incineration was primarily covered by Vestforbrænding i/s (Vestfor), and Amager Resource Centre i/s (ARC), which are co-owned incineration plants by the municipality of Copenhagen. An added benefit to the reduction of landfilled waste, is that the energy produced by incinerating the waste can be utilized in the form of electricity and district heating, therefore presenting an alternative energy source to fossil fuel. The two largest incineration plants mentioned above were a result of investments in waste-to-energy. Their facilities produce energy and heat for the households of Copenhagen and around 75% of the waste in Copenhagen is currently incinerated in these two facilities (MST, 2014).

Since, there has been a shift in the hierarchy of the waste management chain, and instead of incinerating waste, re-use and recycling are prioritised.

In 2008, the EU commission released the EU waste legislation under the Waste Framework Directive (WFD), which set requirements for the management of waste within the EU. It encompassed the definitions and concepts of waste, recycling and recovery (WFD, 2008). Prior to the WFD, EU Member States had diverse waste management legislations and thus definitions of e.g. when to recycle plastic varied. As the name implies, the WFD lays down the framework for decisions on when waste is to become secondary raw material, which means that it is not waste anymore but has become a raw material for production again, and explains how to distinguish what is to be treated as true waste or as by-products of production/consumption. The targets of the WFD are a minimum overall 50% of weight re-use and recycling of waste from households (plastic, paper, metal and glass) and an increase to a minimum of 70% of weight of waste from construction and demolition. Furthermore, the waste should be managed by principles that do not harm human health or the environment (WFD, 2008).

After releasing the fourth national plan covering 2008-2010, it was estimated that with the developing trend of recycling from 2006 to 2010 that Denmark would not be able to fulfil the targets of the WFD (Kjær, 2013). Therefore, Denmark released the fifth national resource plan
in 2013, covering the years 2012-2018 (Kjær, 2013; Regeringen, 2013). This plan includes the initiatives on recycling of all household wastes, that would lead to a 50% overall recycling target. The plan states that the rising prices of material and resources generate a large potential to make the use of these resources more effective. Thus, the goal is to increase recycling and decrease incineration of waste, with the focus of reducing the environmental impact of waste, and thereby decouple economic growth and the resulting stress on the environment (MST, 2014). The national resource plan proposes initiatives aiming at increasing the recycling of waste in the municipalities. All responsibility as well as the power to make decisions on how to meet these goals, however, remains with the municipalities.

Figure 1 shows the top five priorities in closing the loop on waste, where post-consumer waste is collected, recycled and used to make new products, in order to gain more value of the material, as a resource. The figure shows a hierarchy from top to bottom, starting with the most valuable steps in resource efficiency of the waste management chain in the top (modified after European Commission of Environment, 2015):

- **Prevention**
- **Re-use**
  - Mechanical or Chemical Recycling
  - Energy Recovery
  - Disposal

*Figure 1 - Waste Management Hierarchy. Source: European Commission Environment (2015)*

Figure 1 clearly demonstrates that the highest priority of waste management is prevention of creating waste. This concept is followed by the idea of re-using waste, recycling material, incinerating waste to recover energy and lastly disposal of waste at landfills. The terms will be elaborated in the following chapter. The Danish national plan includes initiatives aiming at creating incentives in all five different priorities in the waste management hierarchy. However, the initiatives predominantly attempt to create incentives for waste prevention, re-use and recycling, as the national plan is to decrease incineration and disposal of waste (MST, 2014).

In relation to the present thesis, the Danish government has created initiatives for the development of new collection schemes in the municipalities, which helps the citizens sort their waste in different type of resources (organic, plastic, paper, metal etc.), in order to increase recycling thereof. This is furthered by an information campaign for the citizens of Denmark to
promote recycling at their homes. Another important aspect includes providing financial aid in the development of state of the art sorting- and treatment facilities, which is set to increase recycling and resource-efficiency of dry waste fractions, such as plastic (MST, 2013).

The present thesis primarily focuses on the priorities of recycling as well as energy recovery. The following chapter thus explains the different priorities of Figure 1, using the plastic recycling value chain.

### 4.4 Plastic Waste Recycling Value Chain

This chapter will commence with the general definition of plastic waste and the types of plastic is explained. Thereafter, the priorities illustrated in Figure 1 are elaborated.

#### 4.4.1 Type of waste and plastic

Plastic waste can be divided into pre-consumer waste, i.e. the waste created from the manufacturing of products, and post-consumer waste, i.e. the waste that is created through the plastic products used in the consumer market. Pre-consumer waste does not have impurities or only low levels thereof. Therefore, the pre-consumer waste is often already recycled internally at the production site or externally (at a recycling station), as it is economically feasible in order lower cost on resources. Post-consumer waste, more specifically household plastic waste, is the focus of this thesis, as it requires intensive treatment (Plastic Zero, 2013).

There are two general types of plastics, thermoplastics and thermosetting plastics. Thermoplastics, such as polyolefin (LDPE, HDPE, and PP) are plastics that soften when heated making them easy to mould into new products. Thermosetting plastics, on the other hand, deteriorate when heated after being hardened. Around 80% of plastics used worldwide are thermoplastics (Brems et. al., 2012). These plastics can be treated differently, and the following will explain the different methods, throughout the value chain of plastic recycling.

Figure 2 by JRC (2014) shows the value chain of plastic recycling.
Figure 2 shows that recycling of plastic waste can be divided into the operations of collection, sorting and separation, reprocessing (production of the secondary raw material) through mechanical or chemical recycling into the product manufacturing. These different operations affect one another, as the sorting technology is based on the type of collection, and the choice of sorting technology is important for the application of the plastic, due to the quality of the output. (Plastic Zero, 2013).

4.4.2 Collection

The waste collection system can roughly be divided into three main categories, namely mono-material collection, multi-material collection and mixed municipal solid waste (MSW) collection.
Mono-material collection is designed to gather a single specific source of separated waste product. A dominant example of such mono-material collection is the recycling of PET bottles, such as through the Danish “Pant” system (Larsen & Skovgaard, 2012).

The second category is, multi-material collection, and covers the separation of waste sources into their respective categories. This involves the consumer to separate the waste, so that the plastics are in different bins than the other household waste.

The final category, MSW collection, involves the collection of residual household and commercial waste. This type of collection requires the most treatment thereafter, as the plastics can be contaminated by non-plastic material components (e.g. organic materials) and other plastic components that could potentially negatively affect the quality of recycling and manufacturing (JRC, 2013).

4.4.3 Prevention and Re-Use

The global production of plastic, utilizes around 4-8% of the total oil produced per annum. This represents a significant figure, as plastics are used for a vast amount of applications in our society (Al-Salem et. al., 2009; Brems et. al., 2012; Stein, 1998). The advantages of preventing the production of novel plastic products and working towards increasing the re-use of plastic are twofold. The demand for oil in plastic production decreases, and thus the environmental impacts of CO2, NOX, and SO2 emissions are negated (Stein 1998, Brems et. al., 2012). In 2009, approximately 90% of the plastics produced derive from fossil fuels (Al-Salem et. al., 2009). Preventing production of novel plastic from fossil fuel (virgin plastic), or finding other solutions such as biodegradable plastic made of starch, corn sugar or other bio based material are necessary. As only 0,1-0,2 % of novel plastics are bioplastics, i.e. they are derived from starch, corn or sugar, which are renewable organic resources (Plastic Zero, 2013). In the past bioplastic, production was not feasible due to expensive technologies, which weakened the competitiveness to fossil fuel plastics. Furthermore, the price of sugar feed stocks, are further complicating the feasibility of in the production of bioplastics. Therefore, new technologies allowing for the use of non-food biomass in the production of bioplastics present an attractive way forward in preventing the production of fossil fuel plastics, if these show to be competitive on the market (Pei, Schmidt & Wei, 2011)
4.4.4 Sorting of Waste

Mechanical sorting, which is the most common form of sorting, involves the separation of plastics into the different types of plastic via a scanner (Panda et. al., 2010). At the central fine sorting facility, an infrared scanner (NIR) detects the different types of plastic polymer and automatically sorts the plastics according to their respective types. In order for the NIR scanner to work properly, the waste has to go through the NIR scanner in a single layer. Therefore, the plastic materials have to be separated, manually or via a vibration belt to ensure that foil and larger pieces do not cover smaller entities of plastic below. This raises the price of sorting, as it limits the throughput of the facility (Richard et al., 2011). Plastics can have very similar density, thus other types of sorting technologies, which analyse the plastic density, are not very efficient (ibid). NIR scanners achieve a sorting efficiency of about 90%, as the scanners are solely able to separate those plastics, which are visible. The machine can therefore not recognise black and coated plastic. However, by installing X-ray technologies, unwanted constituents can be separated from the plastics. Due to these before mentioned limitations, the sorting facility requires often requires preliminary manual sorting to roughly sort the materials before the mechanical sorting, as well as manual inspection after the sorting in order to ensure the quality and to attain a higher material quality of the sorted plastics (MST, 2014a).

4.4.5 Mechanical Recycling

Typically, the inputs for plastic product manufacturing are in the form of flakes, pellets or other types depending on the plastic being produced. Mechanical recycling is often referred to as secondary recycling, and is the most common method of recycling plastic waste in Europe with a share of 20,4 % of all recycled plastics (Brems et. al., 2012).

The production of plastic polymer from waste involves several steps, where the raw materials are processed chemically in order to produce the polymeric material, which meets the requirement of the desired application of the plastic. Specifically, additives of a various ranges are added in order to achieve the given characteristic of the plastic product. In order to be able to use recycled plastics as a substitute for virgin polymers, consideration of the end-use application of the plastic is crucial, as it markedly delimits the recyclability of plastics. Transparent products, for instance, can be gathered through a sorting technology; yet, they can be very difficult to collect from mixed colour inputs. Thus, in order to avoid any contamination of the transparent plastic production, closed loops of collection, such as deposit-return system of PET beverage bottles collection, which similar types of transparency, can be applied (Plastic
Zero, 2013). Notably, requirements for the conversion of recycled material that have been previously exposed to organic contaminants, such as food products, is especially strict (JRC, 2013; Plastic Zero, 2013). This principal concerns in respect to this are safety and health matters. Therefore, the intended future use and the origin of the input plastics to be recycled has to be align. For instance, if the recycled plastic is supposed to be used for food products then they need to originate from food applications (JRC, 2013). Contamination by organic waste can cause a hygienic problem, as bacteria can spread during the collection, storage, sorting and separation phase of plastic waste. However, this does not dramatically affect the quality of the product (the secondary plastic), as the organic waste does not affect the plastic composition in itself (ibid).

Nevertheless, it is important for the physical and chemical processing that the raw material is of the exact same composition in every process, as production of plastics is sensitive to even marginal deviations. One example is that the raw material can differ in their melting points depending on the composition thereof, which again can affect the quality of the produced plastics, with respect to their durability, functionality and strength. Furthermore, hazardous substances gathered through mixed plastic streams are problematic. Both of these factors can have consequences in relation to the safety of usages in medical equipment or automotive components. However, in less sensitive products, producers are able to limit the mentioned problem, by mixing secondary plastics with virgin plastics of the same type until they acquire the optimal compositions enabling a stable product (Plastic Zero, 2013).

Mixing of plastics of different types presents a trade-off, as it usually deteriorates the properties of the plastics and consequently the price of the plastic also decreases with the decreasing quality. An example is the mixing of polyethylene and polypropylene, which results in a plastic with lesser tensile strength, i.e. the stress the material can endure when it is pulled or stretched. This is the result of the immiscible characteristic of plastics. By adding other materials that improve the adhesion of the polymer interface the immiscibility can be decreased. These materials are often expensive, and due to lower demand on comingled products, it is often not economically feasible (Stein, 1998)

Lastly, it can be said that the secondary recycling often involves a down cycling, as the resulting granulates, are used for other products than the original plastic application, e.g. clothing materials Al-Salem et. al., 2009)
**Chemical Recycling**

Chemical recycling is a treatment option involving breaking down the chemical bonds of plastics waste into its constituents. This is often referred as tertiary recycling, or feedstock recycling, as the resulting gasses and oils can be used to create new plastics or other chemical feedstock such as fuels, oils and chars (PlasticsEurope, 2009; Al-Salem, *et. al.*, 2009). The production of fuels and plastics from chemical recycled feedstock has a high quality and there are therefore no limits to the application of the produced plastics. The treatment involves medium to high temperatures, where the bonds can be broken down through different methods. Pyrolysis is the breaking down of compositions at high heat treatment under oxygen-lean environment, hydrocracking uses high pressure of hydrogen and gasification involves the controlling of oxygen in the environment. Depending on the method used, the resulting material varies between polymers and can be in different phases, such as gas, solids or fluids. The advantage of chemical recycling is that mixed plastics can also be broken down and it is not restricted to clean plastics, contrary to mechanical recycling explained above (Panda, *et. al.*, 2010). Therefore, chemical recycling is suitable for mixed solid waste recycling, where the plastic waste streams are complex to recycle. However, an argument against using chemical recycling states that the methods are energy intensive and that significant amounts of gas emissions are created, which can be toxic (Gent, *et al.*, 2009). Unlike mechanical recycling, chemical recycling does not result in down cycling (transforming the material into products of lesser quality), as the produced feedstock can be used to obtain products of the same or similar quality. In the aspect of circular economy, this leads to an approach, which closes the loop more, than mechanical recycling does. Nevertheless, the technologies are still in the early stages are estimated to gain more importance on the recycling market in the future (Brems *et al.*, 2012)

**Waste-to-Energy**

The waste-to-energy step in the pyramid of plastic recycling, see Figure 1, involves the combustion of plastic waste, in order to generate electricity, steam, or process heat, most commonly in incineration plants. In Europe and in Denmark, this still presents the most common method of recovering post-consumer plastic waste. The Directive 2000/76/EC sets regulations and restrictions on incineration plants, chimney filters and ash processing, which has led them to become an environmentally sound option, since they today ultimately only release CO₂ and H₂O (Brems *et. al.*, 2012; Stein *et al.*, 1998). Whenever the alternative steps of
processing plastic waste are not applicable, e.g., due to mixed plastic waste streams, the waste-to-energy method presents a suitable as a solution to the waste management. From a thermodynamics point of view, the entropy increases when incinerating plastic, however the enthalpic value of the material is regained. This means that the combustion of the feedstock or the plastics is basically the same, with the difference that the polymer has had a higher value, by using the resource for its plastic application (Stein, et. al., 1998).

4.5 Plastic type and products

In the European Union, there were five types of plastic, which totalled 75% of plastic production, in the year 2010. These were Polyethylene (PE, 29%); Polypropylene (PP, 19%); Polyvinylchloride (PVC, 12%), Polystyrene (PS, 8%) and Polyethylene terephthalate (PET, 6%) (JRC, 2013). Table 1 presents specific application examples for the different types of plastic.

<table>
<thead>
<tr>
<th>Type of Plastic</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-Density Polyethylene (HDPE)</td>
<td>Garbagebins, Bottles, Pipes</td>
</tr>
<tr>
<td>Low-Density Polyethylene (LDPE)</td>
<td>Bags, sacks, Garbagebacks, flexible bottles (e.g. detergent)</td>
</tr>
<tr>
<td>Polypropylene (PP)</td>
<td>Margarincontainer, boxes, garden furniture</td>
</tr>
<tr>
<td>Polyvinylchloride (PVC)</td>
<td>Electronic cables, medicinal gear, credit cards, window frames, pipes</td>
</tr>
<tr>
<td>Polystyrene (PS)</td>
<td>Containers for food, package for eggs</td>
</tr>
<tr>
<td>Polyethylene terephthalate (PET)</td>
<td>Bottles, freezer trays, oven-proof trays</td>
</tr>
</tbody>
</table>

Source: Plastindustrien (web, n.d.)

The majority of plastic is used for packaging with 39%, followed by construction use with 21%. The category “others” covers diverse end uses such as furniture, medical devices, agriculture and other household goods (toys sport equipment etc.), see Figure 3. The data from APME (1999) showed that 73% of packaging is used in households, whereas the rest is consumed by the industry. The household packaging is mostly from Fast Moving Consumer goods, and not designed for reuse. In contrast, the packaging material for the
industry is designed for reuse and are often heavy plastic in the form of, e.g., crates, pallets, or drums, with a longer life span (10-15 years) (Bio Intelligence Service, 2008).

The following pie diagram (Figure 3) shows the main end-use applications of plastics:

![Pie chart showing the main end-use applications of plastics](image)

**Figure 3 - Application of plastics. Source JRC (2013)**

5 Economic Theory

5.1 Cost Benefit Analysis

The government, or public spender, has a budget constraint, which is financed by the taxes society has to pay, in order to maximise the utility of society. Therefore, whenever the public sector invests in a certain project, be it an implementation of a policy or regulation, or an improvement of “business as usual” activities, the decision has to be based on a political prioritisation. This includes the analysis of the consequences of the project (Finansministeriet, 1999). In order to secure a profound choice of resource allocation that benefits society, economic assessment tools such as the Cost Benefit Analysis (CBA) are helpful. Furthermore, CBA enables the analysis of whether resources can be used more efficiently by investing in a certain project (Norden, 2007).

CBA is a social appraisal of projects. It is a tool in decision-making, which weighs the cost and benefits throughout a given period in the future, of a current investment.

There are two main types of a CBA, the financial CBA (private) and the welfare economic CBA (social). The focus of a financial CBA is the flow of cost and benefits of the project itself, and not the entire economy, which is affected by implementation of said project (ADB, 1999). Thus, a financial CBA will analyse the added financial benefits and costs resulting from a project.
The important variables for this analysis are the balance, income as well as the sources and applications of funding (ibid.). On the other hand, the welfare economic CBA, used in this thesis, analyses the project from the perspective of the whole economy of society, or the economy demarcated in the analysis (Prokofieva & Thorsen, 2011). As a welfare economic CBA analyses the project from the perspective of the entire affected economy, which is in the scope of the analysis, it is possible to include market failures, such as externalities, which cannot be identified by the established commercial markets (Perman et. al., 2011). Therefore the following use of the acronym CBA, will refer to the welfare economic CBA.

The appraisal underlies the criteria of welfare economics, which will be explained in the following paragraphs.

The thesis will follow the structure of a CBA-based screening procedure shown by Prokofieva & Thorsen (2011):

1. Project definition
2. Identification of relevant project impacts
3. Physical quantification of relevant impacts
4. Monetary valuation of relevant impacts
5. Discounting of cost and benefit flows
6. Calculating the CBA indicators
7. Performing sensitivity analysis

The first step is to define the project. This creates the scaffold for the analysis, and establishes the foundation for finding the relevant project benefits and costs later in the process. Furthermore, the purpose of the analysis is devised, which enables the correct interpretation of the results. Then, the baseline scenario and the alternative scenarios of the project are described. The baseline scenario is the case, where prior activities prevail because the alternatives have not been implemented. The alternative scenarios are the cases where actions are undertaken, that lead to achievement of a specific objective. This will be done in chapter 6.1 of the thesis.

Next, after defining the project, the limits of the impacts that are of concern for the analysis have to be established. The resources used in the project, such as labour and financial investments, as well as the impacts on society which generate a positive or negative utility in the form of benefits and costs, respectively, are presented. Geographical boundaries of the
country to be analysed, and the preferences of the population, which are used for the analysis, both have to be reported, as these are the basis for the cost and benefits (Norden, 2007).

In this part of the CBA screening procedure, the positive and negative impact flows of a project along with the time of occurrence are presented. Since every input and output of the scenarios are typically presented in distinct units, such as e.g. tons of CO₂, MW/h, the comparability has to be secured by valuing the impacts in a common unit.

Having completed this, the next step of CBA commences, and the costs and benefits are valuated (chapter 5.3) in order to express the impact in monetary terms. Costs occurring before the project period of the analysis, yet still have an impact to the project are coined sunk costs. These are not included in the CBA, as they do not imply an opportunity costs to society. Also, there is no alternative to the cost, as it is already foregone the period to be analysed, which is important for the project decision. An opportunity cost is the value of an optimal alternative allocation of resources (Prokofieva & Thorsen, 2011).

In the next step of the CBA, the cost and benefits have to be discounted into their present value with the so-called discount rate. The discount rate is a widely discussed topic, where two dominant types, the prescriptive and descriptive approach, are argued by the two branches of economist to be the correct one to use. In chapter 5.2.3 the two types of discount rate and the Danish approach will be discussed.

After discounting the benefits and costs of the future to present values, the net present values give the result of the CBA. Chapter 5.2.2 in this thesis explains the formula of the Net Present Value (NPV).

After the CBA has been conducted, the sensitivity analysis ensures the quality of all assumptions made for the analysis and that no assumption is prone to bias. Therefore, the sensitivity analysis often includes different variations of the discount rate, specific inputs, prices, as well as the underlying assumptions. The sensitivity analysis can be done from variable to variable, or by grouping the variables that are changed.

Lastly, all results are discussed and a recommendation can be formed, based on the analysis. The underlying theory of the different steps will be explained in the following chapters.
As mentioned in the introduction, there are different tools for the social appraisal of a project. Examples are the Multi Criteria analysis (MCA) and Cost Effectiveness analysis (CEA), which will shortly be explained here.

5.1.1 Multi-Criteria Analysis

Unlike CBA, Multi-criteria analysis (MCA) is a tool based on non-monetary evaluation methods. The MCA differs from the CBA and CEA, as it utilizes objectives and criteria, which can be multidimensional, incomparable, incommensurable and conflicting (Omann, 2000). It is possible to use both quantitative and qualitative criteria, whilst analysing the co-benefits from a measure. Therefore, to perform a MCA, the definition on objectives and criteria for measuring the success of a decision need to be established. In a MCA, the different objectives are compared by weighting them, like in a CBA. However, this weighting system is decided by the stakeholder and analyst of the decision making team. They decide trade-offs to the project and the utility for the society of these different objectives. This approach can be challenging, especially when stakeholders have a different viewpoint of the objective at hand, and do not agree (Belton & Stewart, 2002).

5.1.2 Cost Effectiveness Analysis

In a cost effective analysis, the scenarios to be analysed, often mutually exclusive, are compared concerning the relative costs in relation to the achievement of the set goal (Finansministeriet, 1999). It measures marginal costs of achieving a target, and thus finds the project that achieves the objective most cost effectively, meaning with the lowest costs. Here, the consequences, meaning the effects of a project are not shown in monetary values, as it is the case of CBA.

5.1.3 Why not Multi-Criteria Analysis or Cost Effectiveness Analysis?

The analysis approach chosen for the present thesis is a welfare economic CBA analysis. This paragraph will describe the reasoning behind this decision.

The most obvious reason is that a MCA cannot show the effect on welfare of a given policy, as it is not based on a rationale such as the potential pareto improvement rule, unlike CBA. The pareto efficiency is the state, where resources are allocated in such a way that no individual can be made better off, without making at least another individual worse off. The potential pareto improvement rule is based on the Kaldor-Hicks criterion stating that a potential pareto improvement exists, if the beneficiary of a project can compensate the losers of the project.
whilst still being better off (Barr, 2012). If a MCA does not include an economic welfare objective, a decision based on a MCA could potentially be welfare decreasing and consequently the outcome could be that not following through with the decision would be preferable (Department for Communities and Local Government, 2009). Depending on the type of MCA, if it does not include an economic objective, it does not weigh the economic efficiency of a policy analysis, but rather emphasizes on the judgement of the decision making team and their weighting of the different performance criteria (Omann, 2000). The weighting of objectives is similar to the costs and benefits in CBA. However, in a MCA the final step of including the Willingness-to-pay (WTP) of society is not included. Therefore, MCA can potentially complement a CBA, as the analysis of a policy is undertaken on a different level. For this thesis, a MCA is not chosen, as the focus is on the economic benefit of a circular waste management scenario and other factors are not of importance.

The advantage of a CEA is most pronounced when the effects are partly or entirely impossible to quantify and thus the monetary value of the effect cannot be determined, which indicates the economic efficient use of resources. However, a CEA does not determine if the alternative scenario is better than the outcome of the baseline scenario, based on their impacts or effects on society (Balana, et al., 2011). A CBA attempts to answer this question, by showing whether the positive impacts (benefits) outweigh the negative impacts (costs) of the given scenario and by how much (ibid.). A CEA often includes only the cost criteria, which have a direct effect on the budget constraint. From a welfare economic viewpoint, the optimal analysis should take all the costs of society into account, e.g. non-monetary effects on the environment. Furthermore, it can be difficult to prioritise between two scenarios with the same cost-effectiveness, as these can have distinctive impacts, which are not shown (Finansministeriet, 1999).

As this thesis aims to analyse whether the alternative scenario of the Municipality of Copenhagen, will increase the welfare of society in comparison to the current baseline scenario, a CBA is a more appropriate decision-making tool to use. The main reason for this is that it enables the analysis of all effects, which have an impact on society.

5.2 Welfare function and indifference curves

In a perfect market, where property rights are clearly defined, consumers maximise utility, producers maximise profit, without asymmetric information and transaction costs are zero,
society aims to distribute market or non-market goods in a way that individuals cannot improve their utility without rendering another individual worse off. This is the concept of Pareto optimal allocation of society’s resources (Christensen, 2008; Perman, et. al., 2011).

\[ V = \int dt \Delta(t) N(t) u(c(t)) \]

*Equation 1 - Social Welfare Function*

Equation 1 is the social welfare function that social planners aim to maximise (Greaves, n.d.), the different parameters which are \( \Delta(t) \) the discount factor for utility at a given time “t”, “N” the population size, “c” the consumption per capita. Lastly, “u” implies the utility function for an individual.

The term utility refers to the preferences of individuals and describes the behaviour of consumers, revealing their choice in goods and services. A way of illustrating utility is by utility curves. The maximization of utility occurs, when the utility maximizes the use of the budget of the individual. Figure 4 below shows the Utility curves and budget constraints.

The graph depicted in Figure 4 presents the quantity of the first good on the x-axis and gives the quantity of the second good on the y-axis. The different utility curves U1- U3 are examples of the inexhaustive amounts of utility curves a consumer can have, where each curve represents the bundles of goods and services Y and X that give them the same utility along the curve. The slope of the curves is given by the marginal rate of substitution, which is the amount of good y the individual is willing to give up for good x. The formula is given by \( \text{MRS} = \frac{\Delta y}{\Delta x} \) (Varian, 2010). This means the utility in the right side of the top curve is higher compared to the curve.
closer to the origin. The explanation for this is that these consumers are never content. In an attempt to maximize utility within the budget constraints, an individual, will strive towards obtaining the bundle denoted at the point \((Q_y, Q_x)\). Here the budget constraint is tangential to the indifference curve. Thus, at this point, the slope of the budget constraint is equal to the marginal rate of substitution \((MRS)\) and the consumer’s marginal utility per unit of income is equal for the two goods (Varian, 2010). The utility curves are convex, due to the negative substitution effect, which implies that an increase in prices for a certain good, e.g. due to a tax, the individual will seek to other substitutes that are less expensive. In effect, this leads to the individual consuming a bundle available at a lower indifference curve, since the budget constraint is closer to the origin (price increase equals a decrease in income) \((ibid.)\).

### 5.2.1 Cost Benefit Analysis as a test for increasing welfare

CBA is based upon the intertemporal variant of the potential compensation, meaning a potential pareto improvement, which entails that a compensation should not actually be paid, however the gained possibilities should allow for such compensation. 

As the municipality of Copenhagen is the entity investing in the management of plastic packaging waste, it is clear that a social welfare of society is the one that has to be increased. However, it is difficult, close to impossible, to measure the utility of society with the different variations thereof ex ante or ex post. Therefore, it is simplified by acknowledging the fall or increase in total consumption as a result of a change in total net benefit to the individual (Perman et. al., 2011). A consumption loss of society translates to less utility expressed in monetary terms, and thereby negative net benefits.

$$W = \sum_{t=0}^{T} \frac{1}{(1+r)^t}C_t$$

*Equation 2 - Weighted Sum of Consumption*

Equation 2 shows that, the weighted sum of consumption \(C_t\) over time \((t)\) at different discount rates \((r)\) is equal to welfare \(W\). It follows that the weighted sum in the change of consumption is the same as the change in welfare. Thus, if the right hand side of Equation 2 is positive, the project should go ahead, since \(\Delta W>0\) means that the project is welfare enhancing. It is possible to show the utility as welfare, through the concept of a social welfare function, which entails that welfare is non-decreasing in the utility of the individuals. For example, in a society
comprising only of two people, given the utility of person A, the social welfare cannot decrease, if the utility of person B were to rise, and vice versa. (Perman et. al., 2011).

The efficiency criterion for the CBA is called the net present value test. In order to weigh the effects of a given scenario, in monetary terms, and compare it to an alternative scenario over time, a NPV) test is used, which will be explained in the following (ibid)

5.2.2 Applied Net Present Value

The primary assumption behind a CBA is that all consequences from a project can be shown in gains and losses in monetary terms. For example, if a market failure cannot be correctly valued, then a CBA would be incomplete and consequently the results cannot be interpreted as definitive, and should instead be considered indicatively. A project should go ahead, if the discounted net benefits over “T” periods, lead to a positive net present value, which is shown in below (Equation 3). This equation is strikingly similar to Equation 2; however consumption is shown as net benefits, which is the general formula for NPV (Perman et. al., 2011).

\[
NPV = \sum_{t=0}^{t=T} \frac{NB_t}{(1+r)^t} > 0
\]

Net benefits, are the difference between benefits and costs. The time span for the appraisal of a project ends only, when all the impacts cease and therefore not when the project stops serving the purpose it is intended to. However, most social planner chose to end the time span of the CBA, at the point where the investments life time (e.g. a power plant) has ended. As such, the time span for NPV tests (explained below) is many years in the future, which applies to the environmental impacts in particular. The estimated costs and benefits that will accrue in the future are presented as their present value through discounting, which will be explained in the following chapter.

5.2.3 Discount rate

Discounting has many serious implications for the intergenerational equity (Bruce, Lee & Haites, 1996) The NPV test being sensitive to the discount rate used as is evident when observing the formula used (Equation 3) (Perman et. al., 2011). If the discount rate is negative, the future is valued higher than the present, meaning impacts happening in the future will have
higher weighted value compared to impacts happening the present. Contrarily, a positive discount rate would mean that the present is valued higher than future impacts. If the discount rate has a high value, current projects are preferred, which would give environmental projects a disadvantage, as these tend to have impacts in the future.

There have been disagreements about the proper use of discount rate in economics. Especially, with respect to accounting which parameters should be included, as is the case with parameters such as the future economic growth per capita and the scarcity of environmental goods. This has led to two approaches dominating the field. The first is the prescriptive approach, which includes ethical considerations and the second is termed the descriptive approach, which roots in the decisions made by both government and individuals. In the following the prescriptive approach will be described more detailed, and the descriptive approach will be touched briefly.

5.2.4 Descriptive Approach

The social discount rate under the descriptive approach is derived from both current rates of return as well as economic growth rates. The descriptive approach focuses on the opportunity cost of capital. Using this approach the social planner chooses the investments, which lead to maximum total consumption. In this case, should the return of the investment be lower compared to alternative investments, these alternatives should preferably be chosen, as this would increase the welfare of both future and current generations. The preferences and actions of society constitute the social welfare function, which should be used for the intertemporal choices for future generation. Specifically, the aim of the descriptive approach is to maximise the economic resources of future generations, while giving them the responsibility to decide the resource allocation in the future (Bruce, Lee & Haites, 1996).

5.2.5 Prescriptive Approach

In the prescriptive approach, the market rate is considered a poor indicator for the trade-offs that society has to make, especially due to the difficulty of transferring income to future generations. Thus the discount rate, also called the social rate of time preference (SRTP) is based upon the Ramsey equation (Equation 4), which is derived from maximising the social welfare function, Equation 1(Arrow, et. al., 2008).
In the Ramsey equation the social discount rate is composed of three parameters, namely the discount rate on utility, which is the time preference of society ($\delta$), consumption elasticity of utility ($\eta$) and the growth rate of consumption ($g$). The right side of the equation shows that an investment at a given rate of the time preference in a society added to the growth rate of consumption and the elasticity thereof will leave the social welfare unaffected. The Ramsey equation indicates that the consumption rate and utility rate are variable, whereas the utility rate is given by the parameter of time preference, which is an exogenous factor. The consumption rate is an endogenous factor, which is determined by the aggregated discounted utility, given a positive time preference that maximises the present value of utility (Greaves, n.d.). When given the growth rate $g$, an extra unit of consumption in the next period has to be discounted by the term $\eta g$, which is the diminishing marginal utility of consumption (Arrow, et. al., 2008). The purpose of discounting is to find the appropriate balance between future welfare and present welfare. Thus, if the utility discount rate of time ($\delta$) is positive, $\delta > 0$ then it can be substituted by a high elasticity of marginal utility ($\eta$), which is the inverse of the intertemporal elasticity of substitution indicating the willingness to substitute consumption over time. Buchholz & Schumacher (2008) state that if an extreme case reveals that there is no time preference, meaning $\delta = 0$, then the Ramsey equation could be fulfilled by having $\frac{r}{g} = \eta$. This zero discount rate, or no time preference in the discount rate equation, eliminates the discrimination of future generation. Ramsey originally supported this idea, yet now argues that it is unethical to discount the utility of future generations because we do not know what their utility will be (Arrow, et. al. 2008). Stern argues for a rate at 0.1, because it includes the rate of extinction of the human race, which gives a value to human life, as populations will not exist 1000 years from now (Stern, 2006). Arrow argues that due to the fact that investment in the present will give greater consumption possibilities in the future, the time preference should be positive (Bruce, Lee & Haites, 1996). Consumers in society constantly make this trade-off between consumption today and the future. Mostly, individuals prefer consuming today compared to a possible consumption in the future. Thus, in order to make them indifferent between the choices, the quantity of future consumption has to be higher, than the present quantity. The discount rate reflects this time
preference, which indicates the quantity needed to make a consumer indifferent between these possibilities (Bruce, Lee & Haites, 1996).

Cowen (2001), who also discussed the correct interpretation of intergenerational time preference, states that the discount rate can be seen as a comparison between interpersonal utility between generations. Thus, the choice is likely to be one of ethics, which could indicate that a no time preference $\delta = 0$ is correct, but it requires more analyse than the world of ordinary welfare economic can allow.

This shows that the consumption possibility of future generation has strong implications on the time preference too. The reason being, that the future generations are wealthier due to the growth rate of consumption. This can be the case if technological progress continues to grow at the rate of the last century, resulting in a doubling of the living standards every thirty years (Bruce, Lee & Haites, 1996). This leads to higher values of $\eta$, which leads to diminishing marginal utility of consumption that increases more rapidly with an increase in consumption (Arrow, et. al., 2008). Therefore, economists have argued for different rates of consumptions, which ultimately reflects the sacrifice the current generation has to make in order to transfer their income to future generations. This sacrifice is also called the inter-temporal inequality aversion.

The prescriptive approach concludes that the discount rate should be derived from an ethical consideration of society’s trade-off between consumption across generations. Furthermore it concludes that the SRTP will be lower than the market interest rate, due to limitations in transfers across generations. Lastly it concludes that the shadow price of capital should be applied to adjust for the costs of investments.

Critiques of the prescriptive approach state that the discount rate often is to low, which results in high opportunity costs of capital. Lomborg (2001) argues against low discount rates at the basis of investments, specifically for climate change mitigation, since projects in developing countries offer higher rates of return, and therefore presents a superior use of resources. The counter argument is that there are no alternatives to investments, as society cannot set aside investments in the next centuries (Bruce, Lee & Haites, 1996).
5.2.6 Denmark's choice of discount rate

In Denmark, a political decision determined that the discount rate should use a declining discount rate for the social appraisal of projects and is explained in a guideline by the ministry of finance (Finansministeriet, 1999). The Danish Ministry of Finance has set a real discount rate (corrected for inflation), which accounts for the run time of the project. The discount rates to be used are 4% for a project going between 0 and 35 years, 3% for projects between 36-70 years, and 2% for projects longer than 70 years. Thus, as this project has a lifespan of 30 years, the analysis will calculate with a discount rate of 4% (ENS, 2013). There are two different branches of economists use this approach to discounting, but base it on different assumptions. The first branch, base the declining discount rates on the extended Ramsey rule, however shocks to a growth rate of consumption per capita which is correlated positively over time. The economist add a precautionary term to the Ramsey rule that is large in absolute value for long time spans. This leads to a decreasing discount rate (Arrow et al. 2008).

Weitzman (1997) developed the other branch of literature. He demonstrates that a decreasing discount rate structure today is justified by the uncertainties of future discount rates. This is the so-called Expected Net Present Value (ENPV) approach. He states that discounting with an uncertain, decreasing “certainty-equivalent” discount rate, should be the same as discounting with a constant but uncertain the discount rate (Weitzman, 1998, Arrow et al. 2008).

It is apparent that discount rates, which have pivotal implication in a CBA, are a hotly debated topic in the scientific world and therefore it will undergo a sensitivity analysis in this thesis. As mentioned prior, discount rates are used to discount the values of cost and benefits of marketed and non-marketed goods. The non-marketed goods will be discussed in the following chapter.

5.2.7 Externalities

The conditions underlying an ideal competitive economy are perfect information, complete markets and perfect competition. Should these not be met, society is said to be in a state of economic inefficiency. Specifically this means that market failures exist, which can be externalities, and that the pareto optimal allocation does not hold anymore. In real life economies, this is often the case. An externality exists, when decisions in consumption or production by one agent affect the utility or profit of another unintentionally and the impact on
this agent is not compensated accordingly (Perman et. al., 2011). This is the case of externalities, which can be either positive or negative. If a positive externality is present, the market would produce too little in relation to requirements of allocative efficiency, and by contrast, if the externality is negative (e.g. emission from a plant or facility), the market would create too much of the economic bad concerning economic efficiency (Varian, 2010). As an example of a negative externality would be the fact that part of the plastic waste is burned in an incinerator, which leads to the emission of greenhouse gases, including CO₂, which can be categorised as pollution (negative externality). As externalities can have a great impact on the result of a CBA, it is important to estimate the value thereof and to include it in the analysis.

![Diagram](Figure 5 - Negative Externalities of a producer [Source: Boundless.com, 2014, modified by author]

In the case of this thesis, plastic material represents a negative externality, as soon as it declines to be waste. In Figure 5 the individual demand (D) is the social benefit of the good. “S” gives the supply curve. Thus, the market is at equilibrium in point E*, given by the quantity q1 and price p1. However, similarly to the external cost (EC), the social cost curve (SC) is higher than the supply curve. This therefore is the direct effect of the negative externality, which is not internalised by the producer. By internalising the externality, the optimal market situation O* at a higher price “p2” and a lower quantity “q2” is achieved. Different economic regulation and policy measures, such as command-and-control policy and market base policies, respectively, can attain this optimal market situation. Command and control instruments can, for example,
set a legislative regulation on the allowable emission by producers in a specific sector. However, this can lead to distortionary effects on the market. A Pigouvian tax on the other hand, can be considered an optimal tax, because it provides a price on the right to pollute, thereby including this externality into the economic market. A Pigouvian tax does not create distortionary effects on the market, whilst still creating a revenue for the government. However, it is important to emphasize that this is a theoretical tool, as it is limited by the difficulty of determining the correct price for the given externality that leads the market to generate the optimal quantity of the externality. In a market, where there are no transaction costs and property rights exists or are given to the affected parties, the Coase Theorem claims, that the affected parties will bargain in order to find an optimal solution (efficient) for the resource allocation. This would eliminate the externality without the interference of regulators (Perman, et. al., 2011). Due to the scope of this thesis, further discussion of these measures will not be included.

The strategy of a CBA is to give monetary values to the different impacts and effects resulting from the implementation of a given scenario, including market failures. Benefits are the increase in quantity or quality of goods and services, which generate positive utility to society. Costs are the decrease in quality or quantity of goods, which lead to a decrease in utility or an increase in the price of the good. For a CBA it is important to both identify the market and non-market goods, if these affect the human needs and wants (Prokofieva & Thorsen, 2011).

A CBA also applies to investments that are not of capital nature, such as implementation of new policies. The important factor for a CBA to be applicable, the nature of the change has to be relatively marginal, with respect to the economy. As such, the absolute terms of an investment can be high; nevertheless, it would still be a minor part of total investment (Perman et. al., 2011).

Through different monetary valuation methods, the monetary value of environmental impacts are captured and considered with ordinary inputs and outputs, such as labour and goods respectively (ibid).

The costs and benefits have to be measured in the same value system, in order to be comparable. Thus, the physical quantities of change, such as a decrease in emission due to less incinerated plastic waste must be valued in monetary terms.
These impacts can be part of the economic market, such as the trade with recycled plastic after the process thereof or it can be impacts, which are not described in the market. By implementing a desired and non-desired project, effects in the location of impact are generated.

In the case of plastic waste management market failures are present in the form of externalities. In contrast to a CBA, commercial or private appraisals often do not include these impacts. This potentially leads to an understatement of project costs in the financial decision-making, as e.g. the cost to society of resulting pollution through burning of plastic in waste incineration plants, would not be included in the financial analysis. Furthermore, the positive effect of the scenario can also be included in a CBA, e.g. the decrease in landfills and decrease of incineration of plastics (Perman et al, 2011).

Both panel (a) and (b) present salary on the y-axis and hours worked on the x-axis. The positively sloping line $L^S$ is the labour supply curve, measured in hours of work supplied. The top horizontal line in panel (a) and panel (b) gives the salary before taxes. Both panels assume a constant income, and that output of labour is produced with a constant return to scale. Based on these assumptions, in a competitive market, the marginal product of work is not dependent on the amount of hours worked (Fielder, 2011). Panel (a) presents the proportional tax, where a tax with the size of “t” is imposed on the labour market, resulting in a wage after tax line below the original wage line. Panel (b) presents a progressive tax, where the wage after tax line is equal to wage level before tax. However, with increasing work hours, the tax increases, and the wage after tax decreases stepwise until it reaches the maximum tax (Fielder, 2011). The deadweight loss resulting from the different tax forms in panel (a) and panel (b) are given by the triangle at the labour supply. This illustrates the amount of social loss due to a loss in production, which can be explained by a shift from $H_0$ to $H_1$. The two figures also show that the deadweight loss depends on the marginal rate of the tax and that the tax revenue decreases with the progressive tax, because the average tax rate is lower. This includes a loss of produced goods, in the form of wage, and leads to less hours available for the labour supply.

It is the elasticity of consumption, meaning the change in quantity generated by a change in price, which gives the size of the deadweight loss due to taxation.

$$\varepsilon = \frac{p}{q} \frac{\delta p}{\delta q}$$

*Equation 5 - Elasticity of Consumption (Varian, 2010)*
If the consumption is elastic, then the consumer can effortlessly change their consumption, which leads to a higher tax burden. The relationship between goods is also a factor that influences the scale of the tax burden, percentage point change in the price of another good. The formula is the same as before, however concerns the prices of one good (\( P_Y \)) and quantity (\( Q_x \)) of another (Atkinson & Stern, 1974).

\[
\varepsilon_{X,Y} = \frac{\delta Q_X}{\delta P_Y} \frac{P_Y}{Q_X}
\]

*Equation 6 - Cross-Price Elasticity (Atkinson & Stern, 1974)*

If the elasticity is negative, it means that the goods are complementary, and the price increases of one good will lead to a decrease in demand of the other good. Two goods are termed substitutes the demand for one good increases as a direct result of a price increases in a second good. Note that at this point, the elasticity is positive. If the elasticity is zero, the goods are independent from another.

If a taxed good is in fact a substitute of another good, then consumers will switch over to the untaxed substitute. This leads to a larger tax burden, since there is a smaller production that can be taxed (Atkinson & Stern, 1974). The same also applies to labour, if the work is considered one good and leisure (not working) is another good, it follows that high elasticity results in people choosing the substitute, i.e. more leisure. The reason for this is that their marginal return on labour has diminished, resulting in a larger deadweight loss. Contrarily in a situation where the elasticity is low, e.g. people with little income who are dependent on the same amount of income, their behaviour is not affected as much, and there will not be a large change in deadweight loss as a result (*ibid.*)

These examples show that there is a marginal cost to society induced by a tax, which as explained before will be at 20% of the investment cost in this thesis (ENS, 2013a).

The next chapter focuses on the economic valuation of non-market goods.

### 5.3 Economic Valuation

#### 5.3.1 Stated and Revealed Preferences

Economic valuation methods can be used to estimate the monetary values of the goods and services of those, which are not traded in a market, e.g. externalities. There are different valuation methods, which all have their strengths and weaknesses. However, there are two
general differences in valuation methods, which are stated preferences (SP) and revealed preferences (RP). Stated preferences constitutes cases where the value of a market or non-market good is estimated by revealing the choices made by a population, the willingness-to-pay (WTP) the willingness-to-accept (WTA), or when a population shows its preferences in another way, e.g., in a survey, where the results are analysed in order to yield a measure of value. Examples are the contingent valuation method, a survey-based method, where the total utility of individuals is estimated, through a hypothetical scenario where a change in a good or service occurs. This has been criticised by economists, as they distrust the rational of people’s decision and their choice in WTA and WTP (Bateman et. al., 2002).

On the other hand, methods of revealed preferences analyses the effects of an externality on the market of another marketed good. This method can be challenging to apply since a relation between these markets does not always exist (Bateman et. al., 2002). Two examples of revealed preferences are travel cost method or hedonic price method. The former shows the alternative cost of individuals traveling to a certain area and thereby reveals their willingness to pay to receive the benefit of the good, e.g. their willingness to pay to enjoy a park. The hedonic price method is used to estimate the economic value for environmental services or ecosystems, such as a park or lake based on the price of the marketed good, as these are related to the different characteristics of the specific good. The hedonistic price method tries to value these characteristics of a good, such as room number and size of a house. The variation in housing prices can then be explained by the value attached to the different characteristics (WTP of people), e.g. two similar houses have different housing prices, where the only difference in characteristics is the proximity to a lake of one of the houses. The main assumptions behind the hedonic price method are utility maximisation, given the income and a free market, where perfect information on housing characteristics exist. Furthermore, there are no moving costs or transaction costs, as these would lead away from the different characteristics, which are important to establish (Taylor, 2003)

Willingness to pay is the amount an individual is willing to pay for a service or good in order to receive the good or service, or avoid receiving an undesired good or service. Willingness to accept shows the amount needed in compensation for an undesired good, or the amount needed to sell a good or service (Horowitz & McConnell, 2002). Individuals tend to overstate their WTA, because these individuals value a prospective gain higher, especially if these individuals
have the property rights on the status quo. This is due to the endowment effect, which states that people give higher value to things they have ownership over (Graves, 2002). In comparison, WTP is dependent on the income of an individual. In cases where the individual suffers a loss, individuals tend to not overstate their willingness because a loss in income is valued higher than a potential gain (Horowitz & McConnell, 2002). Therefore, the general trend in studies comparing the two is that WTA is higher compared to WTP, and this difference becomes more pronounced, when the good is a non-market good. Horowitz & McConnell (2002) found the mean WTA/WTP ratio is 7.2 based on 201 observations in 45 studies. The reason for this is the substitution and income effect. If the goods do not have a good substitution in consumption and there is a small income effect (non-marketed good), then the disparity between WTA and WTP is higher than the opposite case where substitutions to the consumption are present (Horowitz & McConnell, 2002). Yet, well designed surveys aim to discover strategic/biased answers, and to identify any outliers which are not representative of the true WTA & WTP of the population. The net sum of WTA and WTP gives the total economic value (TEV). Depending on what economic value arises, TEV can be divided into the non-use and use value. The non-use value is the willingness to pay for a good, despite no possibility or plans of actually having real use of the good being present. The different non-use values are categorised in altruism, bequest, and the existence value. Altruistic value is the concern for a goods existences for others in the current generation and future generations respectively. Existences value is the WTP for knowing that a good exists somewhere, without plans for anybody to have a use of it including the individual itself. Bequest value differs from the existence value in the sense that future generations should have the possibility to use the good. The use values are the WTP of actually using a product or having the option to use a product in the future. The understanding of the diverse types of values is of importance to find the correct value for preferences of individuals in the project being analysed. Therefore, depending on the type of value being determined, the valuations method can vary.

Due to limitations of scope, this thesis does not make use of these methods in order to find the benefits and costs to society of the externalities of a change in the waste management system. Therefore this matter was only briefly touched upon in this chapter. In this thesis, costs and benefits are estimated through benefit transfers, which will be explained in the following paragraph.
5.3.2 Benefit Transfers

Benefit transfers (BT) refers to the transfer of already existing non-market values (benefits or costs) of previous studies or projects, which are used for the CBA of the project at hand. As other methods such as contingent valuation can be costly and time consuming, BT can be a good alternative method since it takes already existing values into the analysis. However, as the study site from which values are transferred can potentially be based on a different context than the one of the project to be analysed, it is important to be critical with the validation of transferred values (Bateman, et. al., 2002). Thus, BT works increasingly better with increasing similarity of the context. It is also important that the original values are based on a high quality study that is accurate concerning the characteristics of the study site. Differences in characteristics of the study site and policy site lead to transfer of unfitting values in an unadjusted BT.

The disparity in context can, e.g. be apparent in socio-economic characteristics important for the population (different culture and WTP of individuals), the general base of the study site and policy site, market conditions at the different sites, as well as access to alternative good or service options (Bateman, et. al., 2002; Pearce, Atkinson & Mourato, 2006). Most often, study sites and policy sites are not similar in the before mentioned variables, which is the reason why the values have to be adjusted. Thus, divergent baselines and durations of the project, can lead to biases because the origins are different (different foundation of the data). Also, inflation is an important variable which has to be taken into account. If the alternative goods and services differ, it implies that there is a different price level of these goods, ceteris paribus (Bergstrom & Taylor, 2006).

In order to strengthen the estimates (or acknowledge the uncertainty) a high/low bound estimate can be given, multiple studies can be used for the benefit transfer, or a benefit transfer function can be used to combine different studies with meta-analysis. With this respect it is crucial that measures are held in the same units and prices. If for example studies from other countries are included, then the economy of the relevant origin study has to be compared with the project site, and corrected by the Purchasing Power Parity (PPP) (Pearce, Atkinson & Mourato, 2006).

Thus, in order to decrease so-called transfer error, which is the difference in percent between the results based on the transferred benefits, as well as primary valuation error, different methods of BT can be applied. Both have their advantages and disadvantages. The income
adjusted Benefit Transfer, adjusts for income and the change in WTP due to elasticity of income. Similarly, to an unadjusted BT, it still fails to capture most of the differences in characteristics, except for the socio-economic aspects. The WTP function transfer adjusts the all-available factors including income, according to their effect on WTP. The coefficient for marginal change in WTP of the different factors adjusts the BT. However, it is a demanding method to use, and therefore it might defeat the initial purpose of BT being a simple and timesaving method. Lastly, there are simple meta-analysis as well as meta-analysis methods. The former takes the average values from studies and weights them by their distribution around the mean (high dispersion equals low weight). Meta-analysis is the most complex and time-consuming version of BT, where whole functions are transferred from different studies. These studies are used to analyse the variation in WTP, which can be used for the WTP of the study site.

The advantage of this type of BT is that it can process the variables used to gather the WTP at the study site and whilst also including the characteristics of the study site (Bateman et al, 2002; Pearce, Atkinson & Mourato, 2006)

5.3.3 Social Cost of Carbon

The social cost of carbon (SCC), describes the marginal damage created by releasing an additional ton carbon to the environment. The discounted present value of the social cost of carbon, shows the change in utility, given current consumption. The correct value of the social cost of carbon is widely disputed amongst economists. Theoretically speaking, the optimal cost of carbon should have a price, which balances the benefit of decreasing carbon emission with the abatement cost (Nordhaus, 2007). For governments, a ratified social cost of carbon means that they have a shadow price to carbon, which they can use to minimise the inconsistencies in policy appraisals. The social cost of carbon is lower when there are tighter emission targets, due to a smaller effect on climate change (Price, Thornton & Nelson, 2007).
Figure 6 shows the marginal abatement cost (MAC) and the social cost of carbon, given the assumptions of perfect information, and a rational policy maker. The y-axis represents the cost of tonnes of carbon and the x-axis signifies the strategy chosen that will lead to a certain amount of atmospheric concentration (in ppm) of carbon. With increasing cost of abatement, the atmospheric concentration of carbon decreases, since it becomes more costly to reduce another unit of emission. The impact on social cost of carbon emission is rising, as it has higher quantities of emission have a greater impact on society, e.g. through the consequences of climate change. The optimal social cost of carbon is a situation, as explained before, where the social cost of carbon equals the marginal abatement cost. If this level is identified, policy makers can, in theory, create the optimal abatement pathway. In practice, the assumptions often do not hold due to imperfect information, as there are always uncertainties involved with the emission and the social cost of carbon (DECC, 2009).

Scientific uncertainties are related to the uncertainties about the impacts of the different emissions on the future and present environment. These also involve low-probable worst-case scenarios, led on by global warming (ibid.). Economic and policy uncertainties include the assumptions of economical nature, such as the value of the loss of life, the growth rate of economy and emission (which are important for the valuation of monetary values of externalities). The judgement of ethical value, refers to the discussion in chapter 5.2.5. under prescriptive approach. The discount rate is important for the value accumulated over time (ibid.).
A paper by Tol from 2005 describes the diversity in the estimations of the social cost of carbon over the years. Tol gathered 103 estimates from 28 published studies, and formed a probability density function. The 95th percentile, representing only those 5% of the values are above this threshold, is at $350/ton carbon. The mean is a 93$/ton carbon and the median is a 14/tC (Tol, 2005).

A major challenge in finding a consensus on a social cost of carbon lie is based on the uncertainties behind the calculations. Guo et. al. (2006) categorises these into three branches: scientific uncertainties, economic and policy uncertainties, and ethical value judgments. Stern and his working group, found a social cost of carbon at $85 per tonne of CO₂ in 2000-prices, based on the assumptions used in the model (Nordhaus, 2007). This report, led on a wave of criticism, as assumptions on the prescriptive discounting and uncertainties on economy and climate change were mentioned (Varian, 2006; Taylor 2006). This shows that the social cost of carbon has been a hot topic in economics and there is no consensus on the correct figure. The EU has established an Emission Trading System, which is a Cap-and-Trade type economic tool. Certain markets, such as Aviation, Transport, Energy Production, are given a limited amount of quotas, depending on the acceptable level of CO₂ set in the market. The companies involved can acquire these quotas in order to release emission through production. The point of the social planner is to find the amount of quotas that would lead to a price of carbon, which reflects the social cost to society (DECC, 2009). The thesis will not go further in depth with the ETS system and quotas, as it would be out of the scope for this thesis. However, it has to be noted, that the incineration plant, and the transport of products is regulated by the quota market. Inspired by the UK, the Danish Government has set out a target-based approach as well. In the Climate Plan, the SCC rises with the amount of initiatives that are implemented to reduce emissions (KEB, 2013). Thus, the Climate plan sets MAC = SCC over all t= 1, 2, …..n, which is the optimal level from Figure 6 (DECC, 2009). Based on the initiatives in the climate plan, the social cost of carbon, at 989 DKK/ ton CO₂eq., which will be used in this thesis for the analysis. This represents the estimated shadow price of sorting plastic waste to avoid incineration thereof. The estimation is further based on a 45% sorting of plastic from the residual waste. The Energy Agency explains that the high social cost of CO₂ is explained by the high cost related with the substitution waste with other inputs for the incineration plant, as well as the high operation cost of the sorting facility.
Furthermore, the Energy Agency uses a low price on the sale figure of sorted plastic (only 200 kr/ton sorted plastic). Therefore, the social cost of carbon is uncertain and will undergo a sensitivity analysis, to analyse the variation caused by this variable.

5.3.4 Standard Conversion Factor

Another important economic impact is the standard conversion factor. The prices used in a CBA reflect the willingness to pay of the consumers. Yet, the producers use a different price, when they pay for a production good, also due to the taxes added to the price for consumers. Thus, the calculation price of the producers needs to be established, which is levelled to the consumer paid price. This represents the purchase price of the goods that could have been attained by using the resources alternatively leading to the same welfare value of the missed consumption goods.

The standard conversion factor is a method to capture the market and purchase price of the lost consumption goods, and is technically calculated as the relationship between GDP and GDP at factor cost. This has been around 32,5% in the recent years, which will be used in this thesis for the prices (Web MST, 2005; ENS, 2013a)

6 Methodical approach to Cost Benefit Analysis, with the case of a circular waste management scenario in Copenhagen

This part of the thesis is a methodical approach to Cost Benefit Analysis on the case of waste plastic management from households in Copenhagen. Underlying this CBA approach are the different steps mentioned, which will be applied on the information gathered from meetings and discussion with representatives of City of Copenhagen and other studies, with comparable results for an unadjusted benefit transfer. In cooperation with the City of Copenhagen, the frame for this analysis was set, and the resulting assumptions underlying the analysis. The following chapters present the physical impact of the baseline and alternative project, followed by the costs and benefits thereof. Then the results of the CBA are presented, after the discounted values are presented. A sensitivity analysis verifies and stress’ the assumptions of the CBA. Lastly, the approach of plastic recycling is set in perspective with the circular economy potential of the alternative scenario. It has to be noted that the purpose of this CBA is solely to point out the
potential of recycling plastic waste from households. This means that it does not take the full potential in the plastic waste stream recycling into consideration. This can have an effect on the NPV, as the investments are not scaled accordingly, e.g. due to difficulties in calculating the relationship between treatment costs in the sorting facility and the processed waste\(^2\). Therefore, the present values of the analysis show the potential of recycling household plastic waste. To begin, the next chapter will describe the project definition

### 6.1 Project definition

The case of this thesis is the analysis of an alternative management scenario to the 2015 plastic packaging waste management status quo situation. It was mentioned that the WFD sets a target of 50% recycling of household waste by the year 2020. Furthermore, it is stated that at least 22% should result from recycling of plastic waste. The Danish government has included this target in their National Resource Plan, which elaborates on the initiatives that give municipalities the option to find the best solution on achieving the objectives of increasing waste recycling. The city of Copenhagen has therefore set a milestone in their Resource and waste plan 2018, to the recycle 15,000 tonnes of total plastic waste, by year 2018 (KK, 2014).

The first part of the CBA will define the baseline scenario (business as usual scenario). The baseline scenario describes the business as usual scenario, given the investments and the management system that were implemented prior to 2015. This scenario therefore does not have any mayor investments, but rather shows what would happen, if the City of Copenhagen follows a business as usual management scenario for household plastic waste. Thereafter the alternative scenarios will be introduced, which have been considered by the City of Copenhagen as a possible solution to achieving the objectives of the resource and waste plan. The last part of this chapter argues the choice of alternative, which is to be analysed.

---

\(^2\) It is known that an increase in processed waste at the sorting facility decreases the treatment cost, as it gets closer to operating on full capacity. Yet, the City of Copenhagen did not have the information on this correlation. All the different cost for treatment of the different materials entering the facility, are included in the price, therefore it is not possible to make a distinction on the cost of treating plastic waste. Therefore, it is assumed that the price is constant at the target set by the sorting facility. This can be argued to be their optimal treatment costs, when operating at full capacity.
6.1.1 Baseline Scenario

The baseline scenario will be explained according to the different relevant steps of the plastic value chain, production of waste sorting (at households), collection, sorting (at facility), treatment and processing.

Production of waste
Thirty percent of Copenhagen cities waste is generated from commercial waste, 45% from demolition and construction waste, whereas 25% out of the total 827,000 tonnes waste is household waste. This total amount does not include residues of energy production and wastewater treatment. Out of the total amount of waste, 309,000 tonnes was plastic waste in Denmark, in 2010 (Larsen & Skovgaard, 2012). In order to estimate the amount of waste in Copenhagen, the City of Copenhagen has scaled the total amount of plastic packaging from household and housewares through the number of inhabitants, whilst the plastic from the commercial industry and construction are scaled according to the number of workplaces. This resulted in an estimated amount of approx. 36,000 tonnes of plastic generated in Copenhagen, see Table 2, and additional 5,000 tonnes of contaminated or toxic plastic, e.g. from medical institutions (Larsen & Skovgaard, 2012).

<table>
<thead>
<tr>
<th>Source of plastic</th>
<th>Generated</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packaging household</td>
<td>13,173</td>
<td>38%</td>
</tr>
<tr>
<td>Packaging industrial</td>
<td>10,854</td>
<td>31%</td>
</tr>
<tr>
<td>Building/construction</td>
<td>2,754</td>
<td>8%</td>
</tr>
<tr>
<td>Automotive</td>
<td>1,782</td>
<td>5%</td>
</tr>
<tr>
<td>Weee</td>
<td>2,754</td>
<td>8%</td>
</tr>
<tr>
<td>Housewares</td>
<td>941</td>
<td>3%</td>
</tr>
<tr>
<td>Others (furniture etc.)</td>
<td>5,022</td>
<td>14%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>36,389</strong></td>
<td><strong>89%</strong></td>
</tr>
</tbody>
</table>

Note: *The table does not include agriculture waste, which was part of the original estimation. The original estimation was based on waste from all of Denmark. As this thesis only concerns the City of Copenhagen, it is safe to assume that there is no agricultural waste.
** City of Copenhagen noted that only around half of the automotive waste amount should be included.
Table 2 indicates that not all the plastic waste sources are from households. The city of Copenhagen (2015) estimates that households generate around 45% plastics of the total in Copenhagen.³ (City of Copenhagen, 2015)

Thus, Copenhagen households produced 16,375 tonnes of waste in 2010. Over the past years, the quantity of residual waste production Denmark has been declining. At the same time, the share of plastics in the residual waste is growing by an estimated 1% each year, thus by the year 2015, the amount of plastic waste from households has increased to 17,210 tonnes. By the year of 2045, the projected amount of plastic waste from households is 23,197 tonne. This is illustrated in Figure 4.

³ In accordance to the notice on waste (BEK nr 1309 af 18/12/2012), private enterprises have to make their own arrangements regarding the collection of separated and recyclable waste (Larsen & Skovgaard, 2012). The municipality solely makes the options of waste management available for enterprises, however, will not manage the collection thereof, due to conflicts with market competitiveness. The thesis will only concern the household produced waste, therefore the waste produced by companies will not be included in the analysis (Retsinformation, 2015)
SORTING (AT HOUSEHOLDS)

There are around 20,000 villa households (single-storey households) and 260,000 multi-storey households in Copenhagen (KK, 2015), with an expected growth of the population by 100,000 at year 2025. This leads to an increase in apartments in Copenhagen, with is calculated at 330 per year, with no increase in single-storey homes.

Households have different options to sort their plastic waste, such as a bring–system, where the waste is brought to a recycling station, or making use of the deposit-pand system for PET bottles. Due to the fact that the prior is not very efficient, and the latter already well established, the baseline scenario concentrates on the residential plastic waste (RPW) fraction, which is collected kerbside and transported to a bundling station or an incineration plant (ARC) (MST, 2013).

The waste at households is gathered in 140 litre bins at single-storey homes and for multi-storey homes there is one 660 litre bin per 55 apartments. At the start of the baseline scenario, some households had established some form of sorting of hard plastics, which amounts to 1,000 tonne in 2015 (City of Copenhagen, 2015; KK, 2014). This amount will increase 1% per year, equal to the general plastic growth, because the municipality has not implemented any other measures before the year 2015 that would increase this amount (City of Copenhagen, 2015). The rest of the waste gathered at the households which equals 16,210 tonnes is set to be collected and transported to the incineration plant, which will be explained in the following.

COLLECTION

Plastic waste is not collected in a separate system, and unlike other countries, such as Germany, there is no producer responsibility or added cost on weight of waste produced, in .e.g. plastic packaging. (Larsen & Skovgaard, 2012; Jakobsen & Kristoffersen, 2002). The producer of the waste does not bear the cost of the waste collection, and instead the households have to pay a yearly fee on waste management, which covers the costs of collection and transportation. This fee is not used for the analysis, instead the existing system costs is used, because this is the amount that is paid by the municipality and eventually the amount that households have to cover with the fee. As these are unit costs, the total cost of collection and transport changes with the projected amount of waste that has to be handled, throughout the period of the analysis, which makes the estimation of the costs simpler, than having to calculate the change in fee for consumers. The collection of the waste is managed by an estimate of five compact trucks with a capacity of 6 tonnes, with two employees each (City of Copenhagen, 2015). The actual used
capacity on the collection trips averages 5 tonnes. The average distance for the transportation is 35 km, to the households and back to the pre-sorting facilities or incineration plant (MST, 2013). This sums to 120,472 km driven by these trucks in year 2015.

The baseline scenario also involves the transportation of sorted hard plastic at the pre-sorting facilities in Copenhagen to Germany. The receiving facility in Germany is responsible for the transport; however, as the transport has an effect on the environment through emissions, the average kilometres will be included in this analysis. The average distance is 230km to the nearest facility in Germany (MST, 2013). With the 1,000 tonnes of sorted plastics, and a truck capacity of 25 ton, this amounts an estimated yearly distance of 9,200 km. (City of Copenhagen, 2015).

**SORTING (FACILITY)**

All the source-sorted plastics is gathered at pre-sorting facilities, where the waste is packaged into bundles of 660 litres, to ease the transport to the facility in Germany. The City of Copenhagen has to pay a gate-fee per tonne of plastic delivered to the facility in Germany. At the facility in Germany, the waste is sorted into the different types of polymer, to be sold as raw material to plastic producers on the global market (City of Copenhagen, 2015). However, this process will only be included until the gate-fee has been paid, because from that point forward the waste is not included in the waste management of the City of Copenhagen anymore. The energy consumption of these facilities are not included in the baseline scenario case. Thus, there is no revenue to be gained from exporting the plastic waste to Germany.

The unsorted residual waste, is send to the incineration plant where the waste is sorted for metals and other valuables and then treated.

**TREATMENT & PROCESSING**

The last step of the value chain is the value that the plastic waste attains throughout the management system. For the baseline scenario, this results in the incineration for the purpose of energy generation, which eliminates the recycling possibility of the resource (KK, 2014).

Generally, around 10% of total waste in incineration plants is plastic waste (City of Copenhagen, 2015; Tilsted, 2015; Larsen & Skovgaard, 2015). This percentage is also underlined by the fact, that around 90% of household plastics are incinerated in the baseline
scenario, in 2015. This equals an amount of 16,210 tonnes of plastic, which generates around 6,646 Mwh electricity and 122,550 GJ heat for the district heating.

6.1.2 Alternative Scenarios and choice

Political directions from EU and the Danish government require a change in the Danish waste management system. An example of this is the 2008 EU Waste Framework Directive, which states that “by 2020, the preparing for reuse and the recycling of waste materials such as […] plastic […] shall be increased to a minimum of overall 50% by weight” (EU, 2008; WFD, 2008). Furthermore, the Danish National Resource Plan, which launched in year 2013, aims to double the amount of recycled waste, from MSW (MST, 2013). During the meetings with the City of Copenhagen, three alternatives to the baseline were proposed and considered a step in the direction of complying with the directive and the adaptation of the Danish National Resource Plan by the City of Copenhagen. In the following, the alternatives will be described, thereafter a choice for the CBA of this thesis is made.

The three alternatives are shortly introduced in the following Table 3, as an overview.

<table>
<thead>
<tr>
<th>Action</th>
<th>Alternative 1</th>
<th>Alternative 2</th>
<th>Alternative 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment</td>
<td>Fine Sorting Facility</td>
<td>REnescience Plant</td>
<td>Central sorting at the incineration plant</td>
</tr>
<tr>
<td>Collection</td>
<td>Sorted kerb-side</td>
<td>Unsorted kerb-side</td>
<td>Unsorted kerb-side</td>
</tr>
<tr>
<td>Outcome</td>
<td>Plastic sorted in types, sold on the plastic market.</td>
<td>Biogas and biopulp, respectively for fuel and fertilisation. Plastic flakes for sale on plastic market</td>
<td>Mixed plastics sold on plastic market.</td>
</tr>
</tbody>
</table>

6.1.3 Alternative Scenario 1

The first alternative scenario concerns investments, which enable a higher efficiency in recycling, as a way to achieve the goals of the EU Waste Framework Directive and the National Resource Plan.

For instance, the alternative scenario aims to recycle 15,000 tonnes plastic waste in total by the year of 2018 (also including commercial waste). The share of household plastic will be around 20%. By the end of year 2025, the aim is to increase total recycling of Copenhagen Plastic
waste to 30,000. In the CBA used in the thesis, the objective is corrected to 33,138 tonnes of waste, due to the projection of 1% growth of plastic waste per year.

This thesis concentrates on the development of the recycled plastic waste streams for households that aim to achieve this objective (KK, 2014; City of Copenhagen, 2015).

The major differences to the baseline scenario is visible in the year 2018, when the construction of the sorting facility has ended and the operation of the facility begins. The investment in a sorting facility allows the fine sorting of plastics into different types of polymers, to enable reselling of the plastic.

The waste management chain included in the first alternative scenario are as follows.

Production

The production of plastic waste in the alternative scenario is equal to the baseline, because the analysis does not include any investments that generate incentives in order to change the behaviour of producers or consumers, in order to reduce the production of waste. This means, that there is an estimated 17,210 tonnes of plastic waste generated by the households of Copenhagen in 2015. The figure below shows the waste management system for alternative scenario 1.
Sorting (Households)
The first alternative scenario primarily aims to improve the collection rate\(^4\) for recyclable plastics from households compared to the baseline scenario. The percentage of the theoretical potential of waste that is collected results in the actual potential of collection of the waste stream (MST 2011a; MST 2012).

In order to increase the collection rate, municipalities have to invest in a different collection scheme. At single-family housing, the municipality will install 4-compartment bins, with a volume of 240 litre, leaving the household with the responsibility to sort the waste into plastic, metal, paper and cardboard. Multi-storey housing in the city will have 660 litre bins, which are for plastic only (MST,2013; City of Copenhagen).

A Swedish study by Econet in Lund revealed that only 43% of the plastic waste is actually sorted at households, the rest is collected in the residual waste (MST, 2013). This is due to the fact that it is a challenge to motivate the citizens to sort their waste at kerb side. Additionally it can be explained by citizens being unsure on the correct division between the different types of waste materials. Citizens lacking the knowledge of which plastics should be sorted can partially explain this or how clean the plastic should be. Some simply might not understand the necessity of sorting waste, because it is believed that all waste is mixed after sorting and incinerated (Pedersen, 2014). In order to increase the efficiency of household sorting, the alternative scenario includes an information campaign, set out by the City of Copenhagen. The campaign aims to motivate and illustrate the potentials of recycling to citizens. Furthermore, it involves informing inhabitants on the correct way to recycle and make them aware of issues, such as mixing different waste types can decrease the actual potential of recycling (MST, 2013; KK, 2012). The report of the Danish EPA works with the aim to achieve an efficiency of 60% for the collection of plastic waste from households (MST, 2013). In the alternative scenario 1, the household sorted material should be 100% by 2045, which is given by a linear increase in recycling over the period. In this regard, there is not a better projection available, as the development on plastic waste recycling is uncertain in the future, and the only real marker is the year 2018 and 2025, which is part of the Copenhagen Resource and Waste Plan (KK, 2014; MST 2011a; MST 2012).

\(^{\text{4}}\)The percentage of the theoretical potential of waste that is collected. The collected amount is the actual potential (MST 2011a; MST 2012).
City of Copenhagen, 2015). After sorting the waste, it has to be collected by waste management operators.

Collection
The waste from households is collected 24 times per annum for single-family and multi-storey housing, respectively (City of Copenhagen, 2015). Depending on the year of the project period, the waste is transported to different locations. Before the sorting facility is operational, 2015-2017, the collected sorted plastic waste at households is transported to a pre-sorting facility, which bundles the plastics into 660 litre packages that are transported from Copenhagen to Germany for fine sorting of the plastic waste. In the years 2018-2045, the household sorted plastic waste is transported to a newly constructed fine sorting facility, which sorts the plastics into the different types of polymers. Compact trucks handle the transportation with a capacity of 6 tonnes, averaging around 5 tonnes of plastic waste per transport. The estimated distance of a trip to households and back to the pre- or fine-sorting facility is 35 km\(^5\). Based on these estimates, the total distance in year 2015, is identical to the distance in the baseline scenario at 120,472 km. As the calculation is based on, the total generated plastic waste and the capacity of the trucks. The estimated distance to Germany is equal to baseline scenario, at 9,200 km in 2015. The following two years, the sorted plastic amount increases, thus the transport to Germany as result also increases. In 2016, the estimated distance is 18,400 km and in 2017 it is estimated to be 20,240 km. The large increase is a consequence of the almost doubling of the waste recycling quantity collected at households, which then is send off to Germany.

Sorting (facility)
Similar to the baseline scenario, all the source-sorted plastics is gathered at pre-sorting facilities, where the waste is packaged into bundles of 660 litres, to ease the transport to the facility in Germany in the year 2015-2017. The City of Copenhagen has to pay a gate-fee per tonne of plastic delivered to the facility in Germany. The facilities sort and sell the plastics, however as mentioned under the baseline scenario, the CBA only includes the process until the point of the gate-fee.

\(^5\) The same distance as in the baseline scenario.
From 2018 onwards, the investment in a sorting facility is the main difference between the alternative one and the baseline scenario.

As soon as the facility is operational, in the year 2018, it will lead to a shift in the waste management of plastic. There will be a progress in the share of recycled material away from the incineration of plastics (City of Copenhagen, 2015). The facility will sort the plastics according to type and subsequently aim to remove the plastics from any contaminants, such as biodegradable materials, when possible. As mentioned in the plastic value chain chapter, currently the sorting facility cannot run at 100% efficiency, due to issues such as the current technologies, NIR scanner, not being able to recognise all the plastics. Martin Tilsted (2015) from the City of Copenhagen mentioned in a correspondence that out of the 100% plastic waste from households transported to German sorting facilities, only around 35-40% of the output is actually recycled. This is partially due to the purity of the sorted material. The report developed by the Danish Environmental Agency, mentions that including the plastic that is mechanically sorted for PE, PET and PP, the total yield of around 68-91% with a purity of around 78-94%, a figure which is lower for plastic types such as PS (MST, 2015). Together with the city of Copenhagen, it is assumed that a state of the art sorting facility could achieve a sorting efficiency of 70%, which is applied in the calculations of the CBA (City of Copenhagen, 2015). The machines at the sorting facility have a lifetime of 15 years. It is assumed that the machines bought after the current machines have expired, will increase the sorting efficiency to 100% due to improvements of technology at the time, or improvement in product design of plastic products, which facilitate the recycling process by e.g eliminating black coloured plastics. (City of Copenhagen, 2015). A study by ARC on the inputs from household waste, revealed the share of the different polymers entering the incineration plant (Econet, 2015). Table 4 below represents these figures, corrected for the 30% sorting inefficiency and the input of LDPE, which was not presented as a share in the paper by ARC. The input of LDPE (soft plastic), was estimated to be around 50% of all plastic waste by the City of Copenhagen (2015). For the period 2033-2045, the percentage of polymer types sorted at the facility is higher, because the sorting efficiency has increased to 100%.
### Table 4 - Share of plastic type in the total plastic waste quantity

<table>
<thead>
<tr>
<th>Type of plastic</th>
<th>Percentage of waste Germany (2015-2017*)</th>
<th>Percentage of waste 2018-2032</th>
<th>Percentage of waste 2033-2045</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDPE</td>
<td>9%</td>
<td>7%</td>
<td>11%</td>
</tr>
<tr>
<td>PET</td>
<td>12%</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>PP</td>
<td>17%</td>
<td>15%</td>
<td>21%</td>
</tr>
<tr>
<td>PS</td>
<td>3%</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>LDPE</td>
<td>0</td>
<td>35%</td>
<td>50%</td>
</tr>
<tr>
<td>Unsorted waste</td>
<td>60%</td>
<td>30%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Note: The percentages do not sum to 100% due to rounding up.

*The percentage of waste that goes to Germany is the same as in the baseline scenario.

Source: Corrected values according to sorting efficiency and inclusion of LDPE, original percentages from the study by Econet, 2015.

The unsorted waste (30% period 2015-2030), can either be unrecognisable plastic types or other material that has been wrongly sorted at the households, such as rubber or different types of metal scraps. The waste that is not sorted at households or the sorting facility will be incinerated, the sorted waste will be sold on the plastic market, as explained in the following paragraph.

#### Treatment - Processing

After the plastic waste is separated into the different types of polymers, it is sold on the plastic market, where the resulting granulates or flakes from the sorting facility are bought by different types of companies that use plastic in their produce plastic products or use plastics in other products such as clothing materials (MST, 2013). It is assumed that all sorted plastic is sold on the plastic market.

The 30% unsorted waste is sent to the incineration plant and processed for energy production. In the following two paragraphs, alternative 2 and alternative 3 are briefly described. Thereafter the choice between all three alternatives is made.

#### 6.1.4 Alternative Scenario 2

The second scenario is based on unsorted residual waste, which is collected kerb side. The waste is subsequently transported to the new “REnescience” facility. REnescience has been in development since 2004, and the technology used enables sorting of waste, into the diverse categories to utilize primarily for the production of biogas, for recycling as well as a smaller fraction to be used as fuels. This is made possible by enzymes, which are able to locate and sort 4-5 times as much organic material out of the unsorted waste, compared to what the households
would be able to do mechanically. The unsorted MSW is wetted and heated the optimum temperature and environment for enzymatic reactions to take place. These enzymes produce a liquid of the biodegradable waste that allows for separation of the non-degradable waste (such as plastic). This system does not require a shredder and it has a high capture rate of the different types of waste. The Bioliquid can be used for biogas production or the production of other chemicals. The non-degradable parts, such as plastics and metals, can be further sorted into the various types and are further recycled. Plastic foils can also be captured and can be used in the production of new plastics, in order to reduce the use of fossil resources (REnescience, 2015). There are some uncertainties regarding the REnescience alternative and the use of the products generated by the process of treating the waste. One question raised concerns the use of the biopulp created by the organic processing, for fertilizing agricultural land. Currently, the law states that only organic waste material is allowed as a fertilizer. Since biopulp is categorised as residual waste it is not cleared for such purpose, which has a negative effect on the economy and the de facto potential of REnescience facilities (MST, 2013). Furthermore, there are still doubts about the purity of recycled plastics produced by the enzymatic treatment process. The purity of the plastics is pivotal for the resell value as well as the possibility to sell granulates or flakes on the recycled plastic market. Consequently, the City of Copenhagen still requires more information and research on the potential of such facility, given by the testing facility coordinated between DONG Energy and ARC. Nevertheless, it can potentially become possible to implement such a solution in the future (MST, 2014b; City of Copenhagen, 2015).

6.1.5 Alternative Scenario 3

The third alternative includes an investment in a sorting facility, most likely a station with a NIR scanner, at the incineration plant. In this alternative, waste is not sorted at kerbside, and is transported as mixed waste to the incineration plant. Here, the NIR scanner will sort the waste into the different types of waste. The municipality is still unclear how this centralised sorting facility would work, and the implementation of the project would be difficult, as the arrangements for future incineration, plants have already been made6 (City of Copenhagen, 2015).

---

6 This regards the construction of a large incineration plan by Amager Ressource Center. However, due to the scope of the thesis as well as limitations in retrieving data on the facility, it is not included in the analysis.
6.1.6 Choice of scenarios

The different alternatives are all interesting with regards to achieving the objectives set by the WFD, and the Danish National Plan. Even about the circular plastic waste management case, the alternatives aim to close the loop, by increasing the value of the resource throughout the value chain and turning waste into a good, by utilising it for recycling, or production of energy (WEF, 2015).

Alternative 2 involves an investment in a new technology, which has not yet proven to be efficient for plastic waste recycling (City of Copenhagen, 2015). As explained earlier, the production cycle of plastic is sensitive to any sort of contamination, due to the strict laws of plastic use. A recycled plastic used for food products, has to derive from plastics that were previously also used for the same purpose (JRC, 2013). Thus, there is a chance that an enzyme bath might contaminate the plastic. Therefore, the quality of the raw material after recycling could be too low in order to sell it for a good price on the market for recycled plastics, or even disqualifying it for the recycled plastic market. Nevertheless, it is interesting that REnescience introduces the prospect of combining the waste sorting and treatment facility with the production of biogas for electricity and fuel. Yet, the testing facility is currently running on a preliminary basis. Further results have to show, whether it a feasible process and compatible with a large scale.

Alternative 3 is difficult to implement in reality. It is an add-on for the new incineration plant in Copenhagen set to open in 2016. Since the plant is already in its construction phase, changing the plan also has implications on the set budget for the power plant. Therefore, it was only briefly discussed with the representatives at the City of Copenhagen (City of Copenhagen, 2015).

To sum up, alternative 2 seems to be an innovative measure to establish a circular waste management structure, yet it still has to be proven that the system is fully functional and applicable for the sorting of plastic waste for recycling and the production of biofuel or gas. However, of all these alternatives, alternative 1 is the most realistic scenario to be implemented in the near future by the municipality, because it is a system that is more readily available and could the sorting facility could start operation in a few years after construction (ibid.).
The next section will identify the relevant project impacts of the first alternative scenario to be analysed. Also, all assumptions of this thesis will be stated, in order to create the frame of the CBA.

6.2 Identifying relevant project impacts

This chapter concerns the limitations of the CBA and will cover geographical framing of the impacts that are taken into consideration, the time horizon of the projects to be analysed and the assumptions that underline the calculations of the CBA.

6.2.1 Geographical and Period Limitation

The analysis of the waste management programme is based in Copenhagen, and will also be the geographical limitation of the CBA. However, externalities, such as emissions of incineration plants, have an effect on society and the environment, but do not necessarily solely concern Copenhagen. The reason for this is that emissions, e.g. CO$_2$, are transboundary and the emission can therefore affect other geographical areas than the externality production site. However, the effects of emissions can be crucial for the decision between choosing the baseline or an alternative scenario. Møller et. al. (2000) argue that it is generally accepted that the national emissions, causing negative externalities in other countries should be included in a CBA. Even though the emissions might not directly affect the area of Copenhagen, they are relevant in the Danish accounts of emission and pollution and included in the targets for the Danish Climate Plan (Regeringen, 2013). Therefore, the emissions of the project will be included in this CBA.

The time horizon for a CBA can be vital to the resulting net present value of the different alternatives. The reason for this is the discount rate, as well as the inclusions of all the generated costs and benefits of both baseline and alternative scenario (Finansministeriet, 1999). Most CBA frequently use the period that equals the economic lifetime of the specific capital investment, which is also the case in this analysis (ibid.). The project period is 30 years, from 2015 to 2045, corresponding to the period of depreciation of the investment in the new sorting facility.

6.2.2 Assumptions

As the CBA is not able to include all the impact factors and other aspects on the effect on society, in the baseline as well as in the alternative scenario, reasonable assumptions are stated,
which limit the CBA to the scope of this thesis. If the assumptions are expected to have a major effect on the outcome of the CBA, e.g. by creating a bias, then a sensitivity analysis based on the assumptions can give certainty to the outcomes and conclusion.

The following Table 5 gives the assumptions of the baseline and alternative Scenario.
<table>
<thead>
<tr>
<th>Assumption</th>
<th>Used assumption/ figure</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General Assumptions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discount rate</td>
<td>4%</td>
<td>Finansministeriet, 1999</td>
</tr>
<tr>
<td>Standard Conversion factor</td>
<td>1,325, used to convert all factor prices into market prices.</td>
<td>Ens, 2013a</td>
</tr>
<tr>
<td>Inflation</td>
<td>1,015</td>
<td>Finansministeriet, 1999</td>
</tr>
<tr>
<td><strong>Waste Stream</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastic production</td>
<td>Plastic production is not included in the thesis. Only the waste management part of plastic is considered in the analysis.</td>
<td>City of Copenhagen, 2015</td>
</tr>
<tr>
<td>Yearly plastic waste increase</td>
<td>1% increase per year</td>
<td>MST, 2015</td>
</tr>
<tr>
<td>Share of household</td>
<td>45%</td>
<td>MST, 2015; Larsen &amp; Skovgaard, 2012</td>
</tr>
<tr>
<td><strong>Transportation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average capacity use, 5 tonnes out of 6 tonnes for the collection of waste in Copenhagen. The trucks going to Germany are full 25 tonnes.</td>
<td>City of Copenhagen, 2015</td>
<td></td>
</tr>
<tr>
<td><strong>Incineration Plant</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Prices</td>
<td>Prices used are market prices for consumers given before tax and are projected by the Danish Energy Agency.</td>
<td>ENS basisfremskrivning sept. 2012</td>
</tr>
<tr>
<td>Substitution</td>
<td>In the alternative scenario, the gap of waste in the incineration plant, created through increased recycling, is substituted by import of waste, from other countries or a regional import within Denmark.</td>
<td>MST(2013); MST(2015)</td>
</tr>
<tr>
<td>Incineration Plant</td>
<td>The capital investment of the incineration plant is not included, as these appear as sunk costs. The reason being that the plant existed before the initial phase of the project.</td>
<td>Finansministeriet, 1999</td>
</tr>
<tr>
<td>New incineration plant?</td>
<td>Investment in the new plant of ARC is not included, due to practical reasons of not being able to gather the data of its characteristics and because it would not change the comparison between the two scenarios, as the investment would be implemented in both the baseline and the alternative scenario.</td>
<td>City of Copenhagen, 2015</td>
</tr>
<tr>
<td><strong>Recycling of Plastic</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorting Efficiency</td>
<td>In the baseline scenario, and in the years of 2015-2017 of the alternative scenario, the sorting efficiency of the Germany facility is estimated to be 49%. From the year 2015- 2030, the thesis assumes a sorting efficiency of 70%. In the 2033-2045 the sorting efficiency is at 100%, due to investment in new state of the art machinery at the sorting facility.</td>
<td>City of Copenhagen, 2015</td>
</tr>
<tr>
<td>Market</td>
<td>It is assumed that all of the sorted plastics at the facility are sold on the recycled plastic market.</td>
<td>Own assumption, together with the City of Copenhagen</td>
</tr>
<tr>
<td><strong>Environment</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indirect emissions</td>
<td>The emission caused indirectly through consumption of energy from the sorting facility, is not included in the calculation of the cost or benefit to the environment.</td>
<td>Own assumption, together with the City of Copenhagen</td>
</tr>
<tr>
<td>Type of emission</td>
<td>Only CO₂ is included in the analysis. Other types of emissions include SO₂, CH₄, NOₓ and other particulates, which will not be included in this CBA. The reason being that incineration of plastic mostly leads to CO₂ emissions.</td>
<td>Own assumption, together with the City of Copenhagen</td>
</tr>
<tr>
<td><strong>Tax</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost for waste management- consumer</td>
<td>The alternative scenario will initially raise the cost for consumers, to get their waste collected and handled. However, it is assumed that this cost will fall again after only a short period, where the benefits of the system can be collected.</td>
<td>City of Copenhagen, 2015</td>
</tr>
</tbody>
</table>
The above table shows, the general assumptions underlying the CBA, which are set by the Ministry of Finance. These secure the comparability of results between other projects, and sets the scaffold for the economic properties. The other assumptions are specific to the different accounts of the waste management scenario. For example, for the sake of the CBA it is assumed that the missing waste from incineration plant is substituted by imported waste of organic matter. The substitution of waste at the incineration plant leads to the incineration of an equal amount of waste in both scenarios. This implies that the incinerated substitute waste, is CO\textsubscript{2} neutral\textsuperscript{7} and therefore it leads to a reduction in emission, due to a decrease of incinerated plastic waste (Guendehou et. al., 2006). Import of waste has an increasing trend in Denmark, especially in the years 2011-2013 (MST, 2015a). The waste statistic by the Environmental Agency (MST, 2015a) indicates that this is directly related to the increase in recycling from household waste, which decreases the amounts of waste being incinerated that has to be compensated. Therefore, it is plausible to assume that this trend will continue. However, it has to be noted that in reality the City of Copenhagen has made a decision in 2012, that all waste import for the incineration plants in Copenhagen should be restricted, in order to prevent unnecessary use of biomass and to promote new technologies in the waste management chain (e.g. REnescience) (Ebbesen & Lønborg, 2012). The CBA uses a cost of imported waste equal to the gate fee at the incineration plant. The assumption further might be discarded because the CBA does not include the added cost of transporting the waste, as well as other costs, which need to be considered. The increased cost of waste incinerated at the plant, could potentially make the essential difference between the alternative scenario increasing utility of society or not (MST, 2015a).

Furthermore, it is assumed that all the sorted plastic is sold on the plastic market. The amount of sold plastic strongly depends on the price of virgin resources for the primary production of plastics. Given a lower price on oil, the recycled plastics are more difficult to sell, due to their higher price in comparison to virgin plastics. However, oil prices have fluctuated strongly over the recent years, which lead to an uncertainty on the price of oil and consequently virgin plastics in the future. Contrarily, the price of recycled plastics is not affected by the price of oil (Wrap.

\textsuperscript{7} It has to be noted that the CO\textsubscript{2} neutrality of biomass incineration is debated among scientists. The reason being that the neutrality depends on a variety of factors which affect the carbon flux. Some of these are the type of biomass (agriculture plants or woody mass from forest), the management and procurement of the biomass, how it is transported to the location of incineration, the technology used for incineration and the period of regrowth (Bracmort, 2015)
Therefore, as long as companies have the necessary stream of plastic waste to continue their sorting of plastic (ibid.)

The unsorted plastic waste is burned for energy in the incineration plant.

Another critical assumption concerns not including the production of plastic waste. Therefore the possibilities of the social planner to influence the recycling of plastics is limited to the management thereof and incentives to decrease plastic production/consumption at producer, retailer or consumer level cannot be included.

Furthermore, as the City of Copenhagen does not manage the waste streams of enterprises, the thesis only accounts for household plastic waste. The figures in the analysis therefore do not show the full potential of plastic waste recycling in Copenhagen. Therefore, the sensitivity analysis will further analyse the significance thereof to the result of the CBA.

6.3 Physical quantification of relevant impacts

In this chapter, the relevant impacts in the CBA will be analysed and quantified. The relevant impacts of the two scenarios will be given under the different steps of the waste management chain.

The following analysis does not include waste production, as there are no physical impacts relevant for this thesis, and therefore begins with the sorting at households (MST, 2015).

Sorting (Household)
In the alternative scenario, citizens experience both advantages and disadvantages from the project. The disadvantage includes new waste bins, which have to be located at their single-storey family house and the multi-storey housings. One disadvantage is that this takes away space from the garden and backyard. Also, especially during higher temperatures in summer, the containers heat up they can potentially emit unpleasant odours, which decreases welfare of the households. Another disadvantage of sorting waste is given with the opportunity cost, or cost of lost time. This indicates the cost that citizens have when using their time to sort the waste into the different bins, which could have been allocated more efficiently for the individual (OECD, 2008).

On the other hand, it can also be argued, that not all citizens see it as a cost to recycle but rather benefit from the fact that they are doing something good for the environment. These benefits of some citizens could outweigh the costs of others. There are no current data on the opportunity cost of citizens’ time use to sort their plastic waste. Also, no data is available describing the benefits of recycling attained by other citizens. Therefore, it is difficult to make an estimate of this impact for the CBA (MST, 2013). If this impact was argued to be important for the outcome of the CBA, a stated preference analysis, explained in chapter 5.3.1, could capture these preferences of the citizens by e.g. sending out surveys. Furthermore, environmental projects by the Environmental Agency of Denmark generally do not include these type of costs in their analysis (ibid).

Nevertheless, in order to secure that household’s sort waste in both scenarios, the City of Copenhagen has set out an information campaign. In both scenarios, the campaign is run in the years 2015 and 2016, and for the alternative scenario it is repeated in the years 2027 and 2028. The campaign attempts to nudge households into the direction of increasing their sorting efficiency and general quantity of sorted plastics. Since this, theoretically, is a means by the social planner to lead the consumer into an optimal situation for society, the cost of the campaign, does not generate any distortion or excess burden (ENS, 2013a).

The Municipality of Frederiksberg launched an information campaign in the beginning of 2014, which runs for a few years into the future. The focus of the campaign is especially to increase the consistency of households in their sorting habits. 90% of households answer that they are content with sorting their household plastics yet the collection rate still is not high. Thus the campaign emphasizes the communal effort to sorting waste, that increases the sense of right-doing for the households, which can increase the effort by those households which have not sorted to their full potential (Frederiksberg Kommune, 2013)

Collection
In both the baseline scenario and alternative scenario, the collection of transport affects the physical surroundings in different ways. Applying to the whole period of the baseline scenario and the first 3 years of the alternative scenario, the sorted waste at households is transported to Germany.
With the previously mentioned capacity of 25 tonnes, an amount of 1,000 tonnes sorted plastic waste and an average distance of 230km; these trucks are estimated to travel a distance of 9,200 km in 2015.

For the alternative scenario the quantity of sorted waste at households doubles in the first year. Therefore, the estimated distance of travel in 2016 is at 18,400 km.

The CO₂ emission of these trucks is presented in the below table (Table 6), including the CO₂ emission of the compact truck in Copenhagen, which collects local household waste.

<table>
<thead>
<tr>
<th>Capacity</th>
<th>CO₂ emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport Copenhagen</td>
<td>6</td>
</tr>
<tr>
<td>Transport Germany</td>
<td>25</td>
</tr>
</tbody>
</table>

Source: Plastic Zero (2013)

The transport of household plastics leads to emission of CO₂ through the burning of diesel. The report of Plastic Zero base their transport emission estimates on the EASEWASTE model, which is a model for environmental assessment of waste systems (Larsen & Skovgaard, 2013). Given the value of 0.09 kg CO₂/km/ton, the transport to Germany is estimated to emit of 20,700 kg CO₂ in 2015 in the CBA.

This shows that a truck of with a capacity of 6 tonne emits around 0.37 kg CO₂/km/tonne. With an average distance of 35 km, these trucks have to cover a distance of 120,472 km in year 2015, in order to collect all the plastic waste from households, in both scenarios. The CO₂ emission is estimated with these figures as follows.

\[
0.37 \text{ kg (CO}_2\text{ km/tonne)} \times 120,472 \text{ km} \times 6 \text{ tonne} = 267,449 \text{ kg CO}_2
\]

Equation 7 results in an emission of 267,449 kg CO₂ in both scenarios in the year 2015. As mentioned in the project definition, both scenarios are based on the same amount of plastic waste generated at the households. Therefore, the amount of plastic that has to be collected is the same. Additionally, the trucks used are also assumed to be of the same type, therefore, the calculation of the emission is equal in both scenarios.

\[
\frac{10.476 \text{ (tonne waste)}}{6 \text{ (tonne capacity truck)}} \times 35 \text{ km distance} = 58.147 \text{ km}
\]
The transportation of waste, also includes external costs that represent the cost of noise, accidents and the wearing down of roads (COWI, 2010). These external costs are included in the analysis, as the inner city transport using trucks strongly affects the surrounding inhabitants and the transport on highways have to be maintained to support the traffic over the years. The next step in the value chain of plastic waste management is the sorting facility and the related impacts are presented in the following chapter.

Sorting (Facility)
The two alternatives differ in the amount of saved emission through recycling, as the amount of plastic that is recycled is less in the baseline scenario. The reduction of CO$_2$ of recycled plastics, sold for the production of new plastic products, depends on the different types of plastic polymers. The reason being that these have different emission outputs in their production from virgin resources (MST, 2013). Plastic Zero (2013) estimates, are shown in the following Table 7.

<table>
<thead>
<tr>
<th>Recycled plastic</th>
<th>Saved CO$_2$ emission through recycling</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE</td>
<td>-1,500</td>
</tr>
<tr>
<td>PP</td>
<td>-0,800</td>
</tr>
<tr>
<td>PS</td>
<td>-2,900</td>
</tr>
<tr>
<td>PET</td>
<td>-3,200</td>
</tr>
</tbody>
</table>

Based on the figures in Table 7, and the percentage of different waste types that are successfully sorted at the facility.

In the baseline scenario, the saved emissions in 2015 amounts to 747 tonnes CO$_2$ and in 2045 it has only increased to 1,007 tonne CO$_2$ in saved emissions. The reason for this minor increase in the whole period is the rather conservative projection of increase in plastic waste recycling in the baseline scenario. Additionally, the actual recycling rate of around 40% at the German sorting facilities further decreases the potential amount of CO$_2$ savings through recycling.

The CO$_2$ savings for the alternative scenario are calculated in the years 2015, 2018 and 2045. The input share of the plastic type and CO2 savings of the specific plastic type, respectively Table 4 and Table 7 is used together with amount of sorted plastic wastes from households in the given year:
As can be seen from the above equations, the saved emissions in the alternative scenario are estimated to be 747 tonnes \(\text{CO}_2\) in year 2015, 3,643 tonnes in year 2018 and 43,123 tonnes \(\text{CO}_2\) in year 2045. The difference in \(\text{CO}_2\) savings can be explained by the different sorting efficiencies throughout the years and the quantities of sorted plastic waste. The sorting in year 2015, is similar to the baseline scenario, The sorting efficiency is at 70% in year 2018, but by the year 2045, the sorting efficiency is expected to have increased to 100%, resulting in all plastic actually being recycled.

\(\text{CO}_2\) savings are not only gained through the substitution of virgin plastics with recycled plastics. The following chapter concentrates on the impacts of the incineration plant in the two scenarios.

**Treatment**

Another source of emission is generated when burning plastics in incineration facility for the production of energy. The burning of one tonne plastic leads to an emissions of 680 kg \(\text{CO}_2\) emissions in a modern state of the art incineration plant, that produces electricity and heat. This underlines the fact that the main emission in waste incineration plants originates from the burning of plastics (Plastic Zero, 2012). The incineration plant produces 0.41 Mwh electricity per ton waste, and as a side product it produces 7.56 GJ heat per tonne waste (MST, 2013). In the baseline scenario 16,210 tonne plastic waste is incinerated in the year 2015 and 21,849 tonne plastic waste in the year 2045.

The alternative scenario recycles a larger amount of plastic waste and as a result, a smaller quantity of plastic waste is send to the incineration plant directly. In 2015, the amount of plastic in the incineration plant equals 16,210 tonnes, at the year 2030 it amounts to 12,674 tonne plastic. Bear in mind that this only concerns plastic waste from households. It is challenging to sort some types of plastics, e.g. due to the colour, size, or the purity of the household plastics,
which make them either too costly to sort, or simply unsuitable to sort, due to the limitations defined by law for the application of recycled plastics. Therefore, the decrease in plastic waste going to the incineration plant, in the alternative scenario, can be considered a lower target. From the year 2033-2045, the sorting technology is assumed to have improved to 100%. The CBA assumes new state of the art technology in the future, however, other initiatives such as incentivising to develop plastic designs that are targeted at recycling would also increase the sorting efficiency of the facility (Dolbey, 1997).

As a result the amount of plastic incinerated decreases drastically. In the year 2031 it has already decreased to 8,891 tonnes and in the year 2045 no plastics are incinerated anymore.

As mentioned before, the plastic waste that is missing from the incineration plant in comparison to the baseline scenario is substituted with imported organic waste.

The plastic that is recycled does not solely have a positive impact on the environment. The following chapter describes the revenue that can be attained by recycling plastic waste.

Plastic Revenue
The major difference from the baseline to the alternative scenario is the trade with the recycled plastic waste. In the baseline scenario and 1,000 tonnes plastic waste is transported to sorting facilities in Germany, where around 40% is sold on the plastic market (limited by the sorting efficiency). The revenue is not presented under the baseline scenario, because it is not linked to the economy of the society of Copenhagen. In the alternative scenario, the same applies for the first three years, where the sorted plastic waste is transported to Germany. The operation of a sorting facility from year 2018 enables the sorting in Denmark. The increase in efficiency at year 2033 is based on the investment in state of the art technology. Furthermore, the Information campaign possibly also impacts the collection rate at households, decreasing impurities at source, which then decrease the amount of non-plastic materials at the sorting facility. Innovations in product design could also lead to the higher efficiency in sorting. The quantity of sorted material in the alternative scenario are presented in Figure 6.
The growth in the sorting of plastic, is dependent on the amount of plastic that is collected at the households for recycling. The percentages mentioned in Table 4 are obvious in the above figure. LDPE is the highest sorted plastic type in the sorting facility. Thereafter is the amount of unsorted plastic, which will be send to the incineration plant. The lowest amount of plastic is the Polystyrene. At the year 2033 the increase in sorting efficiency is visible, with the rise of the all the graphs, and the end of the unsorted plastic graph. Overall, creates positive effects for the society, since the benefits from selling the plastic waste is kept within the City of Copenhagen (unlike the baseline scenario). The plastics are traded on the recycled plastics market, where prices depend on the quality of the good and the type of polymer. The prices used in this thesis will be defined in the chapter of monetary valuations of impacts.

6.4 Monetary valuation of impacts

In this chapter, the benefits and costs of the different steps of the plastic waste management value chain are described. The data was retrieved via desk-research and discussions with the representatives of the City of Copenhagen. The following table (Table 8) presents the benefits and costs that are involved in the analysis of the baseline scenario and alternative scenario. This
chapter will specifically analyse the accounts on the collection and transport, plastic revenue, as well as the environment, since these have the largest impact on the outcome of the CBA.

Table 8 Benefits and Costs of the Baseline and Alternative Scenario

<table>
<thead>
<tr>
<th>Account</th>
<th>Baseline Scenario</th>
<th>Alternative Scenario</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sorting (Household)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of Bins</td>
<td>Constant budget of: 350,000 DKK every 10 years</td>
<td>City of Copenhagen, 2015</td>
<td></td>
</tr>
<tr>
<td>Transportation &amp; Collection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation Cost - Copenhagen</td>
<td>2.65 DKK/km*</td>
<td>MST, 2013</td>
<td></td>
</tr>
<tr>
<td>Externality cost of transport</td>
<td>2.43 DKK/km</td>
<td>MST, 2013</td>
<td></td>
</tr>
<tr>
<td>Transport cost Germany</td>
<td>220 DKK/ton*</td>
<td>MST, 2013</td>
<td></td>
</tr>
<tr>
<td>Collection Cost</td>
<td>25 DKK/ collection***</td>
<td>City of Copenhagen, 2015</td>
<td></td>
</tr>
<tr>
<td><strong>Sorting of Plastic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gate-fee for Sorted Waste Germany</td>
<td>450 DKK/tonne*</td>
<td>n.a.</td>
<td>City of Copenhagen, 2015</td>
</tr>
<tr>
<td>Treatment Cost pre – or Sorting Facility**</td>
<td>0.137 million DKK* for pre-sorting facility</td>
<td>2.13 million DKK per year for sorting facility</td>
<td>City of Copenhagen, 2015; MST, 2003</td>
</tr>
<tr>
<td>Capital Cost sorting facility**</td>
<td>1.06 million DKK every 10 years*</td>
<td>Approx. 25 million DKK in construction and approx. 40 million in machinery every 15 years*</td>
<td>City of Copenhagen, 2015</td>
</tr>
<tr>
<td>HDPE revenue</td>
<td>1800 DKK/tonne*</td>
<td>MST, 2013</td>
<td></td>
</tr>
<tr>
<td>PET revenue</td>
<td>2000 DKK/tonne*</td>
<td>Larsen og Skovgaard 2012</td>
<td></td>
</tr>
<tr>
<td>PP</td>
<td>2000 DKK/tonne*</td>
<td>Larsen og Skovgaard 2012</td>
<td></td>
</tr>
<tr>
<td>PS</td>
<td>1700 DKK/tonne*</td>
<td>Larsen og Skovgaard 2012</td>
<td></td>
</tr>
<tr>
<td>LDPE</td>
<td>2800 DKK/tonne*</td>
<td>Larsen og Skovgaard 2012</td>
<td></td>
</tr>
<tr>
<td><strong>Incineration Plant</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gate-fee for Incineration Plant (without tax)</td>
<td>245 DKK/Tonne*</td>
<td>COWI, 2013</td>
<td></td>
</tr>
<tr>
<td>Electricity price in 2015 (without tax)</td>
<td>486 DKK/ Mwh</td>
<td>ENS, 2013</td>
<td></td>
</tr>
<tr>
<td>Heating price in 2015 (without tax)</td>
<td>475,88 DKK/ Mwh</td>
<td>DTU, 2010</td>
<td></td>
</tr>
<tr>
<td>Information campaign</td>
<td>45 DKK/home*</td>
<td>50 DKK/ home*</td>
<td>MST, 2013</td>
</tr>
<tr>
<td><strong>Environment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport CO2-emission cost</td>
<td>0.082 DKK/ kg CO2</td>
<td>0.082 DKK/ kg CO2</td>
<td>Larsen &amp; Skovgaard, 2013</td>
</tr>
<tr>
<td>CO2-emission Cost (incineration, or saving through recycling)</td>
<td>0.989 DKK/ kg CO2</td>
<td>0.989 DKK/ kg CO2</td>
<td>ENS, 2013a</td>
</tr>
</tbody>
</table>

Note: *Value given as factor price, has to be corrected with the standard conversion factor to attain the market price, which is assumed to give the WTP of the consumers.

Collection
Throughout Copenhagen, the plastic waste is gathered in 24,727 bins in total. These bins have to be replaced every ten years (MST, 2013). The municipality carries the cost of the investment in bins and replacement of the bins. The cost of these bins is based on the budget of the City of Copenhagen, which is 350,000 DKK, corrected with the standard conversion factor, it results
in 463,750 DKK for the exchange of bins (City of Copenhagen, 2015). The budget has to be corrected with the standard conversion factor in order to gain the market price, as the budget only presents the factor price of the good and thereby does not represent the WTP of society. The investment in the bins is financed by tax money; therefore, the final figure has to be corrected for deadweight loss. The transport of the waste has to be added as well, which costs, 2.65 DKK/ km (ibid.). Compact trucks manage the collection of household waste, with an average capacity use of 5 tonnes. The trucks have to collect 17,210 tonnes of waste in 2015, in both scenarios. Given their capacity of 5 tonnes, and an average distance of 35 km, this leads to a cost of 423,009 DKK in year 2015 and 570,152 DKK in year 2045 in both scenarios. This cost is included in the calculation of the deadweight loss. The following emptying costs cost represents all the costs encountered by the waste collection companies. These include the operation costs (maintenance, labour) as well as the capital costs. The cost is lower at the baseline scenario, due to less emptying of bins. The cost remains constant over the years, assuming that the marginal income of emptying more bins over the years remains the same. The cost is corrected for the standard conversion factor. The cost is 4,313,151 DKK in the baseline scenario and 6,625,000 DKK in the alternative scenario. This is included in the calculation of the deadweight loss. For the transport to Germany, the 25 tonne trucks have to drive around 230 km. The CBA of the Danish Resource Plan concluded that the cost of transport to Germany corresponds to 220 DKK/ tonne. Additionally, a gate fee is paid at the sorting facilities in Germany in order for them to accept the plastic waste. This fee usually correlates with the production costs per tonne. Another important calculation for the collection and transport of plastic waste is the externality cost of transport. This is calculated by the km driven times the externality cost at 2.45 DKK/km. For the baseline scenario, the external cost of transport in 2015 is 324,268 DKK, and in 2045, it is 683,925 DKK. For the alternative scenario, the cost is at 324,628 in 2015 and 635,402 DKK in 2045. The reason why the cost is lower for the alternative scenario is that there is no transport to Germany after year 2017. The sorting facility and the revenue of recycled plastic are of great importance for the result of the CBA. These revenues are explained in the following.
Plastic revenue:
The plastic revenue is only relevant for the alternative scenario, as the sorted waste is transported to Germany in the baseline scenario.

A study by Econet (2015) was made on the incineration plant of ARC to evaluate the composition of waste streams that were incinerated. The relevant share of plastic types is given in Table 4. In the years 2015-2017 there is no revenue, because the sorted waste is sent to Germany. Waste that enters the sorting facility is sorted with 70% efficiency in the years 2018-2032. Thereafter, technological progress and improvements in plastic designs will enable 100% sorting efficiency, which can be achieved by the investment in new machinery by the year 2030. Thus from 2033-2045 the sorting efficiency has increased by 30%. There are different factors that affect the market price of sorted plastics.

The operational cost of sorting facilities are high, which consequently leads to increased prices due to a highly variable cost in the facilities, since the treatment cost depends on the utilized capacity of the machinery.

The price also strongly depends on the quality of the plastic that is sorted. In the alternative scenario, the plastic prices are given for finely sorted plastics, i.e. sorted into different types of plastics. This increases the price of the good. Facilities are often constructed to deliver a certain quality of the different polymers, e.g., 92% purity of PE, in order to secure a share on the market. If the quality should change, due to a change in input plastic composition, then the facilities risk being unable to sell their output. In order to secure that the facility gains revenue, the lower quality plastic can be sold at a significantly reduced price to clients that run the material through another facility to reprocess the materials. Other measures to increase the quality of output plastic could include the augment the use of manual labour to sort the materials. This however which increases the treatment costs. Alternatively, treatment facilities can invest in purification measures, which would increase the capital costs. All the above are examples of the circumstances that treatment facilities operate under (MST, 2014a)

Additionally, the oil and gas price has affects the demand of recycled plastics. The price of virgin plastics follows the trend of the oil prices, which weakens the competitiveness of recycled plastics as they do not have any cost advantage.

The plastic prices shown, are the prices that are paid by material dealers in 2012, and they represent the average based on different platforms (MST, 2013). In this analysis, the price has
been adjusted to real terms. The revenue gathered at the sorting facility is the main driver of the alternative scenario, and Figure 7 demonstrate the results of the yearly calculations on sold recycled plastic trade.

![Figure 7 - Revenue at the given year of recycled plastic](image)

The above figure illustrates that the revenues are relatively high. To some extent this can be due to the assumptions on which the model base. The high sorting efficiency, including the sale of all plastic outputs on the market, can be argued, considering the previously mentioned difficulties of defining parameters that influence the recycled plastics market. Nevertheless, recycled plastic has a large potential for profit. The assumptions are also plausible, as future technological development and appropriate consumer behaviour, in addition to a recyclable friendly plastic product design, can establish the means to achieve the depicted potential revenue of selling recycled plastics (City of Copenhagen, 2015). The following paragraph shows the benefits to society by improving the environmental account.

Environment
In this chapter the impacts on the environment are given a monetary value, in order to attain the benefits to society, from e.g. emission savings. Table 8 presents the costs of CO₂ in the transport sector and the recycling of plastics. These values are then multiplied into the CO₂ emissions or savings that the two scenarios create.
Transportation presents a minor share of costs to society due to CO\textsubscript{2} emissions. In the year 2015, the costs of emissions from transport in Denmark and to Germany are at 23,836 DKK. This value increases to 31,503 DKK in year 2045, because a larger amount of waste will have to be collected and transported in the waste management system. With respect to the costs of emission of the alternative scenario in the transport sector, the costs for the years 2015 and 2045 are comparable, with only a slight increase from 22,043 DKK to 29,710 DKK for 2015 and 2045 respectively. The emissions generated from the incineration plant as well as the savings from recycling plastics have a significant impact on the NPV of the environmental account in the CBA. The following table presents the benefits of recycling plastics and costs of incineration at the time for the two scenarios.

| Table 9 Costs and benefits in 2015 and 2045; Emissions from Incineration and Recycling (in DKK) |
|-----------------------------------------------|----------------|----------------|
| **In DKK**                                    | Baseline Scenario | Alternative Scenario |
| **Year**                                      | 2015            | 2045            | 2015            | 2045            |
| Incineration Plant- emissions generated       | -10,901,779     | -14,693,951     | -10,901,779     | +15,600,407     |
| Recycling- emissions saved                    | +738,981        | +996,034        | +738,981        | +42,648,759     |

Note: Negative values imply costs, positive values are benefits, e.g. due to CO\textsubscript{2} savings.

Table 9 shows that the emissions saved from the recycling of plastics in the alternative scenario are increased in 2045, when compared to the baseline scenario. The benefit of recycling plastics is given by the difference between savings of primary production, and the emission that is saved when recycling\textsuperscript{10}. The undiscounted benefit in year 2015 is at approximately 1 million DKK which increases to 42.6 million DKK by year 2045. This increase is mostly due to the major increase in sorting efficiency that eliminates plastic being incinerated at the sorting facility. Therefore, a higher quantity of plastics can be sorted and recycled, potentially substituting the production of virgin plastics on the market (MST, 2012).

\textsuperscript{10} It should be mentioned that an estimated 15,000 tonnes of recycled plastic, would save 22,500 tonnes of CO\textsubscript{2} emission simply due to the decrease in the production of new plastics based on virgin resources. Eliminating one tonne of novel plastics reduces the usage of oil and gas by 1.5 tonnes (KK, 2012). This is generally the value that the benefit of recycling plastic represents, including the environmental costs of production (e.g. for energy costs and transport).
The emissions from the incineration plant are also interesting, as the production of energy, by assumption, is identical in the two scenarios. This is exemplified when comparing the costs in year 2015 in both scenarios, where the cost is around 10 million DKK. However, as it is assumed that the plastic removed from the incineration plant is substituted by CO$_2$ neutral waste or biomass, the alternative scenario experiences a benefit of 15 million DKK from emissions savings in the year 2045. Compared to the costs in the baseline scenario for the same year, the difference is at almost 30 million DKK.

As the benefits and costs given in the chapter of monetary valuation are not comparable between the years, these have to be discounted. Therefore, the discounted values are presented in the following chapter.

### 6.5 Discounting of costs and benefits

With a discount rate of 4%, the following values for the different posts were calculated\textsuperscript{11} by applying equation Equation 3. In doing so, the values of the specific year were transferred to the starting period of the project, in order to compare the results throughout the period as current values of the project. As expected, the environmental effects have a high positive net present value. The reason for this might be the low discount rate, which makes benefits in the far future not lose as much values as the would with a high discount rate. The next chapter presents the NPV for all the different accounts in the CBA analysis.

---

\textsuperscript{11} If interested, the discounted values for a given year can be found in the Excel file.
As evident from the results presented in Table 10, there is a great difference between the environmental impact in form of costs to society in the baseline scenario and benefits to society in the alternative. The alternative scenario has an NPV that is approx. 740 million DKK higher than the baseline scenario. The reason is that the alternative scenario assumes carbon neutral emissions.
substitution of the lost input due to plastic recycling. This shows that the revenue from the plastic recycling results in a large NPV at ca. 600 million DKK. The baseline scenario does not have any account that have such a high NPV, which is why the net costs leads to a negative NPV overall.

The NPV of the incineration plant is close to equal, due to the assumption that the import of substitute fuel equals the gate fee of waste in the baseline scenario. A sensitivity analysis will secure if this does not bias the alternative scenario positively. Looking at the “transport and collection” account leans towards the baseline scenario, mainly because the information campaign in the alternative scenario is more expensive, due to a larger effort on recycling.

On the environmental account the alternative scenario has a NPV of ca. 220 million DKK, due to the fact that the recycling of plastic waste leads to high emission savings. However, the fact of substitution of waste that is carbon neutral in the scenario also factors into it. The saved emissions from the incineration plant equal to 108 million DKK, which would be different if it was assumed that other types of waste would be substituted for the recycled plastics.

6.6 Net present value test

Adding the calculated previous costs and benefits with the discounted present values, gives the net present value. A positive net present value translates to a welfare increasing project. By contrast, a negative net present value translates to a decrease in welfare, as the present values of future costs outweigh the benefits.

Table 11 is a summarised version of Table 10 and shows the NPV for the two scenarios on the main accounts of the analysis

<table>
<thead>
<tr>
<th></th>
<th>NPV- baseline scenario</th>
<th>NPV – alternative scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorting Facility</td>
<td>-</td>
<td>-193.094.617</td>
</tr>
<tr>
<td>Pre-sorting Facility</td>
<td>-5.097.633</td>
<td>-2.516.174</td>
</tr>
<tr>
<td>Incineration Plant</td>
<td>2.228.433</td>
<td>2.228.433</td>
</tr>
<tr>
<td>Transportation and Collection</td>
<td>-150.378.945</td>
<td>-240.052.651</td>
</tr>
<tr>
<td>Environment</td>
<td>-196.726.111</td>
<td>217.906.769</td>
</tr>
<tr>
<td>Revenue Plastic</td>
<td>-</td>
<td>603.875.653</td>
</tr>
</tbody>
</table>
Table 11 shows that the NPV of the alternative scenario is about 660 million DKK higher than the baseline scenario. This means that investing in the sorting facility, has the potential to increase the welfare of society by 380 million DKK. This increase can mainly be credited to the benefits achieved through the revenue of recycled plastics and the emissions savings thereof. The baseline scenario, where plastics are incinerated for energy throughout the scope of the project, has a substantially negative NPV, because the baseline scenario does not experience any real benefits throughout the period of analysis. As an example, the account “environment” results in a negative NPV at -200 million DKK. The reason for this is likely to be that there are no real improvements to the environment in this case, as well as the CO2 shadow price, given by the Danish Climate Plan initiatives, is very high (ENS, 2013a). Comparing the NPV of investing in the recycling of plastic with continuing the plastic waste management system as in the baseline, reveals a superior NPV in the alternative scenario, with 228 million DKK compared to the baseline, which again translates to an increase in welfare.

These results are confirmed by the literature and studies that focus on the recycling of plastic waste (Brems, et. al., 2012; Stein, 1998; MST, 2013; City of Copenhagen, 2015). However, the results have to be interpreted with care, as the frame of the CBA is a snapshot of the whole plastic waste management system. For example, the thesis only focuses on the accounts of plastic waste created by households, therefore a large amount of plastics are not considered. Furthermore, the capacity of the systems have not been taken into consideration. This can especially have an effect on the incineration plant in the alternative scenario, e.g., if the substitution of the decrease in waste entering the plant, leads to higher costs in the alternative scenario. On the other hand, the potential benefits of recycling plastics can be greater, as the pool of plastic waste in City of Copenhagen is higher, when other entities (such as business) are included. Nevertheless, the revenue of recycled plastic depends on the global demand for plastics and the price of virgin plastics. Therefore, the true potential of plastic waste recycling is not shown in this analysis. However, the results show that by sorting plastic waste, it is transformed into a good to society.

In order to test the bias of some of the arguments mentioned before, the last step of the CBA, the so called sensitivity analysis has to be conducted. The following chapter focuses on that analysis based on some of the underlying assumptions of the CBA.
To sum up, the NPV of the alternative scenario is greater than the baseline scenario. However, due to the limitation of the thesis, it cannot be concluded that the investment should be made in the new incineration plant and the change of the plastic waste management system. In order to acquire such conclusion, it is necessary to have a higher detail level in the factors in the CBA, such as including the efficiency of capacity use of the different plants and the cost of substitution of fuel for the incineration plant.

6.6.1 Last step: Sensitivity analysis

A sensitivity analysis has to be conducted in a CBA, since it is impossible to predictions with a perfect foresight. Thus, there are uncertainties to the values assigned to impacts. The base case of the CBA include the most plausible estimates and the sensitivity analysis show how the net benefits change with the change in assumptions. This means that if the net benefits value does not change throughout the different assumptions implied in the sensitivity analysis, the analysis is said to be robust (Boardman et. al., 2011). As it is not feasible to change all the assumptions behind the estimates in this model, there are different approaches to a sensitivity analysis that analyse the results for potential biases. Partial sensitivity analysis is one method and involves changing one main, or more specifically one relatively “highly uncertain” assumption, while holding all other assumptions constant. If there are no significant differences between the NPV from the sensitivity analysis and the original NPV after changing a parameter, then it can be concluded that this assumption does not affect the result significantly. Contrarily, if changing one parameter has an effect on the resulting NPV, then it is important for the result, and the assumption behind that parameter should be further analysed or reflected upon. Other types of sensitivity analysis are also available, however, in the following part, this thesis will make use of the before mentioned partial sensitivity analysis.

Assumption “discount rate 4%”

In the theory behind the discount rate, it was discussed that the Ministry of Finance has set the discount rate to be declining over different periods. In order to assure that the discount rate,

12 Another sensitivity analysis is called the best/worst case analysis, where a subset of assumptions are changed in order to establish a worst and best case scenario of the CBA (Boardman et. al., 2011).
does not have a detrimental effect on the outcome of the analysis, the lower discount rate of 3% and the higher discount rate of 5% will be analysed in this part of the sensitivity analysis.

<table>
<thead>
<tr>
<th>Account</th>
<th>3 % discount rate</th>
<th>5 % discount rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Alternative</td>
</tr>
<tr>
<td>Sorting Facility</td>
<td>-</td>
<td>-211,814,242</td>
</tr>
<tr>
<td>Pre-sorting Facility</td>
<td>-5,700,164</td>
<td>-2,519,932</td>
</tr>
<tr>
<td>Incineration Plant</td>
<td>-9,268,068</td>
<td>-9,268,068</td>
</tr>
<tr>
<td>Transport and Collection</td>
<td>-164,852,167</td>
<td>-265,096,198</td>
</tr>
<tr>
<td>Environment</td>
<td>-223,189,950</td>
<td>279,811,419</td>
</tr>
<tr>
<td>Revenue Plastic</td>
<td>-</td>
<td>737,876,180</td>
</tr>
<tr>
<td>Total NPV</td>
<td>-384,474,213</td>
<td>550,045,228</td>
</tr>
</tbody>
</table>

Based on this sensitivity analysis it can be concluded that given the assumptions underlining the model that the discount rate does not change the potential of obtaining a positive NPV for the alternative scenario. The baseline scenario remains negative, due to no real source of revenue. Recyclables would be a valid option for the baseline scenario, yet these end up as a gate-fee cost in the deliverance at the facilities in for example Germany.

Assumption “only household plastic waste”:
Both the alternative and baseline scenarios were demarcated to plastics generated from households waste. Thus, a large amount of plastic is not considered for the analysis. The analysis thus starts with a quantity of approximately 38 000 tonnes of plastic. If this was a dynamic model, the treatment costs for the sorting facility would decrease as well, due to the
better use of the available capacity. However, since this thesis employs a partial sensitivity analysis strategy, only the amount of waste is changed in the CBA. The argument is that there is a potential for an additional 30,000 tonnes of waste in year 2015, which could be sorted and sold for a value. Therefore, the analysis has been reconstructed, as to include and project the waste generation of all Copenhagen entities. This leads to a waste amount of 51,549 tonnes in year 2045. The amount of recycled waste increases with an average of 1,685 tonnes per year. It is assumed that the types of plastic share, the prices and the sorting efficiency are the same compared to the main CBA. With this taken into consideration, the revenue generated from plastic, assuming that the waste is sold on the plastic market, leads to the following result.

If all the recycled waste of the Copenhagen is included, the NPV of the alternative scenario will be much greater than the baseline scenario, which will be very negative due to the higher environmental costs.

Assumption “substitution of waste incineration plant – same cost of inputs”

The cost of the imported waste material seems to have an effect on the NPV, as the profitability of the substitution to close the gap created by the recycling of plastics decreases the NPV of the incineration plant. A “what if “ analysis shows that only a high cost of the imported material (2,346 DKK/ton) would result in a NPV of zero for the alternative scenario.

Therefore, it can be concluded that the price of imported waste has a significant effect on the potential net benefits gained from recycling. However, the price is required to be sufficiently high in order to eliminate the potential NPV observed in the main CBA fully. The results on the accounts of the incineration plant therefore do not bias the overall results of the NPV.

Furthermore, the treatment cost is not easy to calculate, due to the companies not willing to give the information and it being based on the amount of plastics and metals that enter the system. Thus, there is no cost the sole account of one tonne plastic.
7 Discussion:

The purpose of the CBA was to present the potential of recycling of plastic as step towards a circular economy, where the value of a product's life cycle is raised. This included the investment in a fine sorting facility, where outputs of sorted plastics are traded on the plastic market for a benefit to society through environmental and economic accounts. The environmental benefit is generated through substitution from virgin plastics to recycled plastics, which decreases the use of fossil resources for the production of virgin plastics. The economic benefit is gathered by the market price of the recycled plastics, which are in direct competition to the virgin plastic. It was expected that the NPV of the alternative would be positive and in relation to the baseline scenario show a high potential of being beneficial to society, given the assumptions behind the analysis. However, some factors, which will be discussed in the following, can possibly have an influence on the actual potential of plastic recycling from households and the profitability to society.

Recycling of plastics is one of the possibilities to increase the value of the life cycle of plastics. However, recycling of plastics is only one solution in the large interconnected field of the life cycle of plastics. Ellen MacArthur’s objective is to promote and strengthen the idea and possibility of implementing, and restructuring the life cycles of products into a circular economy (Ellen MacArthur foundation, 2012). The following paragraph shows the issues involved, focusing solely on the recycling of plastics, and leads up to the innovation and value that is to gain from creating a circular loop that encompasses not only the municipal system of waste management, but also the producer, retailer and consumer of plastic products.

There are different issues that elude from only concentrating on the plastic management system, specifically the sorting and recycling of plastics. One of these is the capacity of the sorting facilities, which in this example was set to be at 50,000 tonnes capacity per year. With the plastic waste from both households and companies, the capacity would first be reached by the year 2045, according to the model used in this paper. It stands out that the increase in the treatment cost by facilities is inversely correlated with the amount of material put through the machines (Larsen & Skovgaard, 2013). This is due to the high capital and operating costs of the sorting facilities that require large amounts of plastics to be sorted, in order to pay these costs. Besides expensive machinery, the treatment costs of these facilities are also high, due to the energy consumption of operating the machines. There is a direct conflict between recycling and investing in waste to energy solutions. The model described in the thesis aims to recycle.
all the plastics, without taking into consideration whether this scenario would actually be the
optimal solution for the waste management scenario as a whole, as the model e.g. describes
using the plastic originally designated for the incineration plants. In the EU paper on circular
economy it is described that it is important not to stress recycling as the only option, without
considering other means of decreasing landfill. The argument is that the waste hierarchy sets
the right frame for waste management, with regards of attaining the highest value of the material
This, together with the difficulty that the market and legislation sets high demands for the
recycled plastics, makes it difficult to gain value on all the output material. There are different
output markets behind the different plastic types. These have different requirements of the
plastic, as the producer requires identical inputs to the production of plastic products, in order
to secure the stability and quality thereof.
Large importers of plastic, such as China, have increased the demands on the quality of the
material that they receive, which puts pressure on the sorting facilities. A German and Austrian
sorting facility also show the difficulties of current recycling facilities. The German sorting
facility is dependent on the market situation, and works with a rejection of between 5-15% of
the general amount of output. In addition to the sorting efficiency, this can also leads to a high
amount of sorted plastics not being sold on the plastic market. This again leads to a deficit in
the finances of the company. The Austrian sorting facility focuses on certain type of plastics,
in order to secure the purity and quality part of their output, and make their production more
efficient. However, this leads to around 60% of the plastics that enter the facility to exit as
unsorted waste being send to incineration plants for the production of energy (Plastic ZERO,
2013).
Moreover, even legislation sets a barrier, for specific types of recycled plastics, especially for
the use of recycled plastics for applications in direct contact with food (JRC, 2013). The
potential of many recycled plastics is lost due to the fact that they have to be used for non-food
applications instead. Washing of the pellets or flakes can secure some of the purity, but not all.
Plastic foils for packaging, or plastic films, are easy to clean. This is true for the thin layer
plastics, where contamination is too costly to remove from the plastics.
The above-mentioned difficulties of sorting plastics show that it is not always suitable to use
this method for all the different plastic waste. Therefore, other means of handling the waste
should be considered in the discussion.
8 Perspective

All this leads to the argument of creating a life-cycle driven circular economy. It strives to find solutions and cooperation between the affected parties of the life cycle chain, in order to optimise and maximise the value of the plastics. However, this is only one step in the life cycle of plastics.

In relation to Circular Economy, it can be seen that plastic waste management, and the recycling of plastics alone, given the possibility of trading the recycled plastics, has an enormous potential in benefitting society. This is also what the Ellen MacArthur Foundation (2012) and the World economic forum (2015) concludes. This thesis was a snapshot of the circular economy. In order to fully grasp the potential of a circular economy, it is important to start at the top of the waste hierarchy (Figure 1 - Waste Management Hierarchy. Source: European Commission Environment (2015)). The successful global or even European change to a circular Economy requires stability for Consumer and Producer. As the manufacturer cannot influence the products, as they produce for a global market, and countries have different requirements. Therefore

The data and references used in the CBA are mostly retrieved from ministries or consultancies. These type of papers are usually not well referenced, although they do build upon academic literature. A large part of the analysis was built on the opinions and knowledge of experts of this field. This is satisfactory for the purpose of the present analysis, however should a CBA be set up that stands as a decision tool for social planners, it is important to make use of a larger span of reviewed literature. Additionally, some factors were not included in the analysis, due to the limitations of scope in the thesis. For example, it would have been interesting to gain the WTP of citizens to increase recycling in Denmark.
9 References:


Bio Intelligence Service, (2008). *Study to analyse the derogation request on the use of heavy metals in plastic crates and plastic pallets, for DG ENV*. [online] Available at:


Boundless.com, (2014). *Negative externality*. [image] Available at:


COWI, (2013). *Plastafhængig affaldsafgift. Københavns Kommune*. [online] COWI. Available at:


City of Copenhagen, Højer M., Skovgaard M., Tilsted M. 2015. Cooperation with the City of Copenhagen. Included Meetings, Dialogues, Discussions throughout the process of writing the thesis.

Cowen, T. (2001). *What is the Correct Intergenerational Discount Rate?*. Professor of Economics. George Mason University


Kompetencecenter For Affald. 1st ed. [ebook] København: DAKOFA. Available at:


http://eprints.lse.ac.uk/12761/1/Multi-criteria_Analysis.pdf [Accessed 29 Sep. 2015].

Dolbey R. (1997); Rapra Review Reports, Expert overviews covering the science and technology of Rubber and Plastics. Vol. 8, Number 12, 1997


Energistyrelsen [ENS], (2013a). Beregningsmetode til samfundsøkonomiske omkostninger ved virkemidler i klimaplan [ebook] Energistyrelsen. Available at:


World Economic Forum (WEF), (2015). Project MainStream – a global collaboration to accelerate the transition towards the circular economy Status Update. 1st ed. [ebook]
World Economic Forum in collaboration with the Ellen MacArthur Foundation and McKinsey & Company. Available at: