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Economic and environmental impacts of reprocessing household plastic waste at Øra, compared to transport and reprocessing in Germany

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Renewable Energy

Preface

This Master's thesis represents my final work of the M.Sc. in Renewable Energy at the Norwegian University of Life Sciences. Ole Jørgen Hanssen served as primary supervisor, and Cecilia Askham from Ostfold Research (Østfoldforskning) was secondary supervisor.

This 30 ECTS Master's thesis is part of the science project SirkulærPlast, where Cecilia Askham is project manager. SirkulærPlast connects design and product developers with producers of recycled raw materials and plastic products. Sharing of knowledge between actors along the value chain of recycled plastic products aims to eliminate today's barriers of use, and increase use of Norwegian plastic waste in Norwegian industry. See Ostfold Research's home page for further information.

During my years at NMBU, I have developed a deep passion for waste management and utilization. With electives about waste management and technology, and working part time with waste management in my hometown and in Ostfold Research, I had a desire to end the Master's studies researching within this field. During the spring, experienced people from the waste industry have shared their knowledge, making the work even more interesting. The opportunity to use this Master's thesis as influencer to decision makers within Norway's waste management industry was a major motivation. I hope to have used other's and my own time and resources efficiently to end up with useful results presented in understandable manner.

I want to thank my strong support group for all help and support during the semester. First, my primary supervisor Ole Jørgen Hanssen and secondary supervisor Cecilia Askham, for frequent assistance and engagement from start to end. Next, I must award all the skilled people who used their spare time providing me with valuable information; Vegard Rogn from IVA, Per Skjevik from Protec Scandinavia, Lars-Petter Eriksen from Sikoplast, Fredrik Hellström from Frevar, Rudolf Meissner and Robert Bartel from IVAR, and Stein Dietrichson from D&D Consult. Without their expertize I would not have been able to achieve this level of success. Finally, I want to thank my parents for cheer and support throughout this semester.

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Abstract

Since the early 19-hundreds, plastics have been a valuable product for humans. Production has expanded throughout decades, leading to increased volumes of plastic waste. Insufficient treatment of plastic waste leads to numerous disadvantages for environment and humans. To minimize the negative effects, and sustain the value of the resource, plastic recycling is necessary. Reprocessing of plastic waste, including washing and extrusion, is a central part of this. As Norwegian household plastic waste is currently exported to Germany for this retreatment, research of running a plastic reprocessing plant in Norway was of interest.

This study included two analyses investigating if a plastic reprocessing plant should be established at Øra in Fredrikstad, or if Norway should continue exporting household plastic waste to Germany. Data from two machine suppliers were compared in terms of costs and resource consumptions. First, a Net Present Value (NPV) analysis was conducted, including installation and 20-years operation of a facility at Øra. Secondly, an environmental analysis calculated and compared green house gas (GHG) emissions of two scenarios: (1) Operation of a plastic reprocessing plant at Øra, and (2) transport of plasic waste from Øra to Germany, including similar retreatment process in Germany. By using Life Cycle Assessment methodology, total green house gas emissions over the projects life time was presented, with use of different electricity mixes in both countries.

Both the economic and environmental analyses showed net benefits of reprocessing household plastic waste at Øra. Best option resulted in a NPV of NOK 41,821,700, and net saving of CO_2-equivalents during the life time between 15,304 - 72,914 tonnes. The NPV was most sensitive to change in plastic input amounts and variable costs, and the environmental analyses presented electricity mix as most decisive factor.

Sammendrag

Siden tidlig på 19-hundretallet har plast vært en verdifull ressurs for mennesker. Produksjonen har ekspandert over generasjoner, som har ledet til økte mengder plastavfall. Utilstrekkelig behandling av plastavfallet leder til flere ulemper for miljøet og befolkningen. For å minimere de negative effektene, samt bevare verdien til ressursen, er plastresirkulering nødvendig. Etterbehandling av plastavfall, inkludert vask og ekstrudering, er en sentral del av denne prosessen. Ettersom norsk husholdningsplast i dag blir eksportert til Tyskland for etterbehandling, har undersøkelse om drift av et etterbehandlingsinlegg i Norge vært av interesse.

Denne studien inkluderte to analyser som undersøkte om et etterbehandlingsanlegg for plast burde bli etablert på Øra i Fredrikstad, eller om Norge burde fortsette å eksportere husholdningsplasten til Tyskland. Data fra to maskinleverandører ble sammenlignet, basert på kostnader og ressursforbruk. Først ble en nåverdianalyse gjennomført, som inkluderte installering og 20-års drift av et anlegg på Øra. Deretter ble en miljøanalyse utført, som beregnet og sammenlignet drivhusgass-utslipp fra to scenarier: (1) Drift av et etterbehandlingsanlegg for plast på Øra, og (2) transport av plastavfall fra Øra til Tyskland, inkludert tilsvarende etterbehandling i Tyskland. Ved bruk av livsløpsanalyse som metodeverktøy, ble totalt utslipp av drivhusgasser over anleggets levetid presentert, ved bruk av ulike elektrisitetsmikser i begge land.

Både den økonomiske analysen og miljøanalysene viste fordeler ved å etterbehandle plastavfallet på Øra, fremfor transport og behandling i Tyskland. Beste alternativ viste en nåverdi på NOK 41,821,700, og en netto besparelse av CO_2-ekvivalenter over anleggets livsløp mellom 15,304 – 72,914 tonn. Nåverdien var mest sensitiv for endringer i mengder plast behandlet, samt variable kostnader, mens miljøanalysen viste valg av elektrisitetsmiks som mest utslagsgivende faktor.

Table of Contents

Table of Figures

Table of tables

Table of equations

List of abreviations

EFSA	European Food Safety Authority
ENTSO-E	European Network of Transmission Systems Operators for Electricity
EU	European Union
GHG	Greenhouse Gas
HDPE	High Density Polyethylene
HPW	Household Plastic Waste
IPW	Industrial Plastic Waste
IRR	Internal Rate of Return
LCA	Life Cycle Assessment
MSW	Municipal Solid Waste
NIR	Near Infrared
NOK	Norwegian Kroner
NPV	Net Present Value
PET	Polyethylene
PP	Polyprophylene
ROAF	Romerike Avfallsforedling
VC	Variable Costs

1 Introduction and background

The world population uses more resources than Earth can reproduce over time. With an estimated population of more than nine billion people in 2050, immediate action is necessary to preserve the limited resources Earth provides (United Nations 2017). Countless products we use today are made of scarce, non-renewable resources, such as fossil fuels, minerals and metals. Unfortunately, most scarce reserves end up as waste after the product has served its main function.

This “take-make-dispose” approach is called a linear economy, and is unsustainable with today’s increasing resource consumption and waste amounts. In a linear economy, virgin resources are extracted to make a product, and after use the product ends as waste for incineration or disposal. Statistics by the World Bank estimate a world generation of municipal solid waste (MSW) from urban cities to 2.2 billion tonnes each day from year 2025. 10% of the municipal waste is plastic – or potentially 22 million tonnes every day from the world’s cities. The expected recycling rate is as low as 20 %, not much lower than today’s recycling rate in the European Union (EU) (Hoornweg & Bhada-Tata 2012).

Within the EU-27, Norway and Switzerland, there are significant differences in the levels of recycling, energy recovery and landfill of plastic waste. With an yearly generation of plastic waste of 28.5 million tonnes in the EU, less than 30 % are collected for recycling (European Commision 2017; Villanueva & Eder 2014). Moving towards a sustainable society, waste must be considered a resource, and the rate of recycling increase. By changing the economy from linear to circular, minimal amounts of resources are disposed.

In a perfect circular economy, waste is eliminated. When life time of a product ends, the product is reused, or components or materials are handled as a resource in new products (The Ellen MacArthur Foundation 2013). Recycling of waste is a way to increase life time and functionality of a resource, yet today’s recycling rate in Norway is lower than the goals nationally and at the EU level.

As a member of the European Economic Area (EEA/EØS), Norway is obliged to follow the EU’s waste framework directive, which has a MSW recycling goal of 50 % within 2020. 46 % of MSW were recycled in the EU in 2015, above Norway’s recycling rate at 38 % of MSW in 2016 (Eurostat 2017; SSB 2018e) . To increase the recycling rate in Norway, it was on the 27th of February 2018 adopted by the parliament that all plastic and food waste from the Norwegian households and industry must be recycled (Sølsnæs 2018). There are several reasons why recycling of especially plastic waste is beneficial.

The majority of monomers used to make plastics, such as ethylene and propylene, are made of fossil hydrocarbons mixed with additives to improve material properties and performance. Fossil hydrocarbons are molecules consisting of hydrogen and carbon, derived from natural gas processing and crude oil refining. As this feedstock is limited in nature, taking millions of years to regenerate, plastics should be recycled to safeguard the resource (Khan Academy 2018; Thompson et al. 2009; U.S. Energy Information Administration 2017). Plastic products using recycled plastic compared to virgin material, also show significant reduction in energy consumption, climate change impact and fossil depletion.

A recent LCA study compared production of recyclates in Denmark by virgin plastics. Storm (2017) demonstrated that energy consumption of producing 1 tonne of recycled PE/PP was up to 11 % of virgin plastic energy consumption. Climate change impact from recycled PE/PP was up to 18 % of virgin PE/PP, and fossil depletion only up to 6,5 % of virgin material of same polymers. Use of virgin material in plastic production should be limited due to less energy consumption, climate impact and fossil depletion. Additionally, plastic astray from inadequate plastic handling leads to several environmental problems.

Fossil hydrocarbons accumulate, rather than decompose in landfills and natural environment. It can break down to small pieces, such as micro and nano plastic particles. Only thermal treatment by combustion or pyrolysis eliminates plastic completely. Micro and nano plastic in natural environments leads to long-term issues for plants, animals and humans. Fish, birds and other animals mistake plastic for food, resulting in plastic affecting the food chains both on- and off-shore. Humans, being on top of the food chain, also ingest plastic particles by eating animal meat (Brink et al. 2017; Geyer et al. 2017). Consequences of plastic in both animal and human body are under investigation, yet research already indicates that harmful effects can occur. Plastic in living organisms influences the cytotoxicity of particles to cells and tissues. Polymers are also linked to effects on biological responses in humans, such as inflammation, genotoxicity, oxidative stress, apoptosis and necrosis, are also coupled (Wright & Kelly 2017). Accumulation of plastic serves harmful effects for natural environments. Moreover, incineration of collected plastic also leads to environmental and health issues.

Plastic incineration without proper flue gas treatment can release toxic pollutants. Pollutants, such as dioxins and halogens, can be destructive to human health, and damage the central nerve system, lead to heart deceases and cancer, and aggravate respiratory ailments (Verma et al. 2016; World Health Organization 2016). Plastic recycling can on the other hand prevent these negative consequences.

Pollution of plastic to natural environments, and health effects related to incineration, can be prevented through functional plastic recycling systems and governmental regulations. Sufficient recycling systems reveal more plastic for new plastic production, lowering need of virgin raw material. However, the plastic market is not necessarily demanding recycled plastic.

Demand for recycled plastic in Europe count 6 % of total plastic demand, where lower quality is a fundamental barrier to use of recycled raw material (European Commision 2017). Pivnenko et al. (2015) investigated factors affecting quality in plastics recycling, where polymer cross contamination, presence of additives, non-polymer impurities and polymer degradation were quality influencers. In a survey by the European Plastic Convertors Association (2017), almost 60 % of the respondents found it hard or very hard to find supply of recycled plastic with adequate quality. Another study of the Nordic plastic market found that a fragmented plastic market results in lack of both supply and demand of recycled plastic (Milios et al. 2018). Impurities in recycled plastic also limit new product possibilities, such as current regulatory framework limits use of recycled plastic in food packaging.

Packaging in contact with food follows strict legal framework at European level. Due to food safety, food contact materials are defined on basis of scientific work done by the European Food Safety Authority (EFSA). EFSA's framework regulations, covering packaging, machinery and kitchenware, says no food contact material must transfer constituents into food at levels that endanger human health, or produce unacceptable changes in food composition or properties. Accepted recycled plastic materials are primarily offcuts from plastic production which has not been in contact with food yet, and plastic waste from food contact materials (Moliner & Verdejo 2017). When packaging consisted of 59 % of plastic production in the EU in 2015, the food packaging restrictions can inhibit demand of recycled plastic significantly (European Commision 2017).

There are many benefits linked to using recycled plastics instead of virgin material for plastic production. Virgin material are made of non-renewable resources, which should be used carefully. Using recycled plastic reduces fossil depletion and energy consumption significantly. Using plastic waste as a resource moves the economy from linear to circular – a more sustainable society. Plastic astray and burning lead to numerous negative environmental effect. Plastic fragments enters food chains, threatening animals and human health. Burning plastic release toxic pollution, also dangerous to humans and other living organisms. Anyhow, even if plastic is recycled, next reprocessing steps require additional energy and resource use. Today, the next required processing step of Norwegian HPW takes place abroad.

After plastic is collected and sorted into different plastic fractions, the plastic must be reprocessed before it can be used as raw material in new plastic production. Currently it is no operating plastic reprocessing plant in Norway. Historically, sorted HPW has been send to Swedish, Finish and German reprocessing facilities. Today, almost all HPW is exported to Germany, except small amounts sent to Finland (Hjorth-Johansen 2018). Norwegian plastic producers using recycled plastic material in their plastic production must import reprocessed polymers. Norway's export and import of recycled plastic could be avoided with a reprocessing plant located in Norway. Avoided transport trigger curiosity of environmental benefit of installing a reprocessing plant in Norway. Furthermore, supplementary factors can also lower environmental impact of reprocessing in Norway rather than Germany.

Norwegian electricity has a different energy resources than Germany's. As post-consumer plastic reprocessing is highly energy consuming, even equal electricity consumption of reprocessing in Norway and Germany can have significant differences in green house gas (GHG) emissions (IVA 2018; Skjevik 2018). The Norwegian electricity-mix (el-mix) is based on energy produced in Norway, where renewable energy from hydro (96 %) and wind (2 %) consisted of 98 % of power supply in 2016 (Olje- og energidepartementet 2018). Germany has on the other hand a high amount of non-renewable energy in their energy mix. The German energy mix, consisting of 85 % non-renewable energy, will likely have higher emissions than similar process in Norway (AG Energiebilanzen 2017). Nevertheless, both countries are part of transmission grids with electricity supply from other countries with different energy carriers. This effect increases GHG-emissions from processes in Norway, and lowers emissions from treatments in Germany.

Reduction in GHG-emissions due to less transport and use of greener electricity can constitute of a substantial amount during life time of a plant. Research of GHG-emissions comparing a plastic reprocessing plant located in Norway and in Germany, was therefore desirable. A LCA-analysis give a comprehensive research result, and was therefore a preferred method.

However, building a reprocessing plant require a feasible financial profile, especially if a private actor is contractor. Exploration of a reprocessing plant build in Norway could be financially profitable without subsidies, was main motivation to conduct an economic analysis. If the economic analysis showed a positive result, it could be of interest to entrepreneurs, potential investors and lenders.

Results from both the LCA and economic analyses can influence decision makers, working as motivation to conduct both analyses. If the LCA supports reprocessing in Norway, and the economic analysis discourage it, it can lead to further analyses discovering social benefits/disadvantages of reprocessing in Norway. Social benefits can further prompt governmental funding of a reprocessing facility. The research can also highlight information which was earlier intransparent.

This research was conducted in relation to the research project SirkulærPlast. Coordinated by Østfoldforskning (Ostfold Research), SirkulærPlast aims to gain more knowledge about market conditions for recycled plastic. SirkulærPlast connects actors along the value chain of plastic products, whose located in the Oslofjord area. The project aims to create a competence bank about recycled plastic, in order to avoid barriers to use of recycled plastic as raw material in plastic production, and increase use of Norwegian plastic waste into Norwegian industry (Østfoldforskning 2018). As treatment of sorted HPW is an important part in the value chain of recycled plastic, my research was a linking part in the science project.

Location of reprocessing facility within Norway will also affect both the LCA and economic analyses. A new central sorting plant outlined at Øra in Østfold, called Østfold Avfallsforedling (ØAS), makes Øra an interesting location of a plastic reprocessing plant. The reprocessing plant's immediate proximity to ØAS could serve several benefits: The reprocessing facility has direct access to waste streams from ØAS, avoiding extra transport of plastic waste. Loss from plastic reprocessing can also go back directly to ØAS. Less transport reduces GHG-emissions, saves costs, and reduces spill of plastic during transport (M.Karlsson et al. 2018). Additionally, Øra is located at the South-East coast of Norway, offering easy transport access of plastic waste from other places in Norway and/or nearby countries. Providing easier access to plastic markets in nearby countries can avoid reprocessing of plastic where electricity is less green. Furthermore, all SirkulærPlast-partners located in the Oslofjord area centralize value chain actors to this part of Norway. Encouraged communication between actors can optimize production, supporting Øra as location for reprocessing of plastic waste. The beneficial synergies between ØAS and other value chain actors, as well as and geographic location, were the main reasons why Øra was used as location for the reprocessing plant in this study.

2 Scope and research questions

The main scope of this Master's thesis was as follows:

What are the environmental and economic impacts (benefits and/or disadvantages) of installation and operation of a plastic reprocessing plant at Øra, compared to transport of sorted HPW for reprocessing in Germany?

Research questions associated with the main scope:

1. Which washing and extrusion line combination results in highest Net Present Value over a 20-years life time?

2. What is the minimum amount of HPW processed per year to give a positive payback of costs over the project's lifetime?

3. How sensitive are the results of chosen alternative with regard to economy, and what are the most sensitive factors?

4. What is the net potential saving in GHG for a HPW processing plant located in Norway, compared to transport and processing in Germany, over 20-years life time?

3 System

3.1 Reference Scenario

This Master's thesis investigated two scenarios, referred to as the Reference Scenario and Scenario 1.The Reference Scenario presented today's proposal of sending sorted HPW from ØAS, to the reprocessing plants in Germany currently reprocessing the Norwegian sorted plastic waste. It also included the retreatment process in Germany. LCA-analyses was conducted for this scenario. HPW amounts transported and reprocessed equaled the amounts in Scenario 1, as well as resource consumption during reprocessing, expressed in the next chapter. The Reference Scenario is further explained in Chapter 5.4.4.

3.2 Scenario 1

Installation and operation of a plastic reprocessing plant at Øra was conducted in Scenario 1. Both NPV- and LCA-analyses were performed for this scenario. The reprocessing plant location in Scenario 1 was assumed next to ØAS at Øra. ØAS will process household waste from the municipalities in Østfold, except Hvaler, Aremark, Rømskog and Rakkestad, reaching out to above 280,000 inhabitants (SSB, 2018). The planned central sorting plant, was projected with the same type of central sorting technology as Romerike Avfallsforedling (ROAF), using Near Infrared (NIR) scanners. Input in the reprocessing facility was bales of sorted HPW from ØAS with ROAF's plastic quality.

The plant was projected for sorting HPW of the polymer fractions HDPE, PP and PET. These polymer types were chosen due to sales price and availability. The treatment processes was for simplicity split into two lines; a washing line and an extrusion line. As mentioned, input to the washing line was bales of sorted HPW from ØAS. The washing line shreds and cleans the plastic, producing plastic flakes stored in silos. Flakes can be sold as raw material to plastic producers, to a higher price than plastic bales of the same polymers, but a lower price than plastic pellets. Due to absence of demand for PET pellets, this fraction has a negative market value (Meissner 2017). Hence, recycled PET was projected sold as flakes in Scenario 1, ending the reprocessing after the washing line. Clean HDPE and PP flakes sorted separately are input in the extrusion line. The extrusion line produce HDPE and PP pellets sold in big bags on the plastic market.

Transport of sorted plastic waste between ØAS' sorting plant and the reprocessing plant was expected to be minimal, as both the reprocessing plant and ØAS was projected located at Øra (Hellström 2018). Possible transport of materials between the two facilities was therefore not included in Scenario 1.

With a short distance between ØAS and the plastic reprocessing facility, sorted HPW would likely not be transported in bales, but rather more resource efficiently, for instance by a conveyor belt as IVAR will use (Meissner 2017). However, input in Scenario 1 was bales of plastic waste, as the system should be able to receive sorted plastic waste from other plants where it is transferred in bales.

Based on recommendations from suppliers, the system was designed to process 1,200 kg HPW/hour and operate 7,000 hours/year, resulting in processing 8,400 tonnes HPW/year. This amount was assumed being accessible from ØAS. Yet, with about 280,000,000 inhabitants in the ØAS-area, the expected amount from ØAS cover between 22 % - 50 % of plastic input during life time of the facility. Remaining amounts would in pracice be covered by IPW, or HPW from other municipalities. This research assumed only HPW was received, to project for "worst case"-scenario. HPW was considered "worst case" compared to IPW as it contains more impurities which results in a more comprehensive washing treatment.

The rate of HDPE, PP and PET was based on today's composition received at Frevar, the energy recovery plant at Øra, and ROAF. The whole process was projected within same building. Due to possibility of temporary storage after the washing line, there was no direct connection between the lines. Suppliers evaluated to provide equipment for Scenario 1 were referred to as Option A and B in this paper, since certain data was confidential.

4 Functions of plastic and state of the art

"Plastics", or "polymers", are wide terms, including materials composed from elements such as carbon, oxygen, hydrogen, nitrogen, sulfur and chlorine. Plastics are generated when groups of atoms used to make unit cells, called monomers, are combined with secondary chemicals to achieve special functions. Thermoplastics, characterized as meltable, are formed when the connections of atoms result in long chains. If the connection of carbon atoms form two or three-dimensional networks, thermoset plastics are formed, which are not meltable.

The plastic polymer input in the reprocessing facility at Øra were HDPE, PP and PET. Information about the three polymers processed in the facility is necessary to understand origin and areas of use in new plastic products (American Chemistry Council 2018; Selke & Culter 2016).

HDPE is a relatively stiff material, with excellent resistance to many solvents and chemicals. The polymer has high tensile strength, meaning the capacity of material to resist tensile loads without fracture (Selke & Culter 2016). The characterizations make HDPE suitable for packaging household products and industrial chemicals, such as bottles for juices and detergent (Villanueva & Eder 2014).

PP is especially suited for hot-fill liquids, as it has a high melting point. PP's moisture transmission is low, and has good chemical resistance and strenght. The polymer is used in flexible and rigid packaging for food and other consumer products, additional to larger parts for auto industry (Villanueva & Eder 2014).

PET is an excellent barrier to moisture, oxygen and carbon dioxide (CO_2), making it common for beverage bottles and other consumer containers. It is resistant to most solvents, and has capability of hot-filling. PET is often used in clothing, nicknamed polyester. In 2015, almost three times as much PET was used for textile production than for packaging worldwide (Villanueva & Eder 2014; Worrell & Reuter 2014). Reprocessing HDPE, PP and PET can use different technologies.

The machines delivered by the suppliers serve similar technologies, but have often different characteristics and system setups. When projecting a plastic reprocessing plant, it is necessary to understand the system technology. However, this research will not focus on, or compare, different technology setups. Information about the technology, mainly based on the system delivered by Option B, is presented in the appendix, Chapter 10.1.1-

4.1 State of the art of plastic reprocessing facilities

It was limited information of costs of instalment and operation of reprocessing facilities in Norway. First, Norway has no operating plastic washing and extrusion facility today, meaning no operating experience. Second, actors within the field are naturally restrictive to give this information open available to the public. However, one facility in Stavanger is under construction and another private actor has developed a fulfilled project plan and financial model. Even though none of the businesses have operating practise yet, their data have been valuable in this study.

The facility under construction, owned by IVAR, is the first recycling plant in Norway with central sorting of HPW, additional to washing and extrusion. The plant is projected to start operating in the end of 2018, with an estimated total cost of 476 million NOK in 2013-kroner value, approximately 533 million NOK in today's kroner value (IVAR 2017; SSB 2018c). The plastic reprocessing machinery includes two parallel washing lines and one extrusion line, delivered by the contractor Amut, with subcontractors for individual components. The plant will produce regranulat of the polymer fractions LDPE, HDPE and PP, with an estimated output of 58 %, 77 % and 68 % respectively (Bartel 2018). Flowchart of HPW reprocessing at IVAR is illustrated in Figure 1.

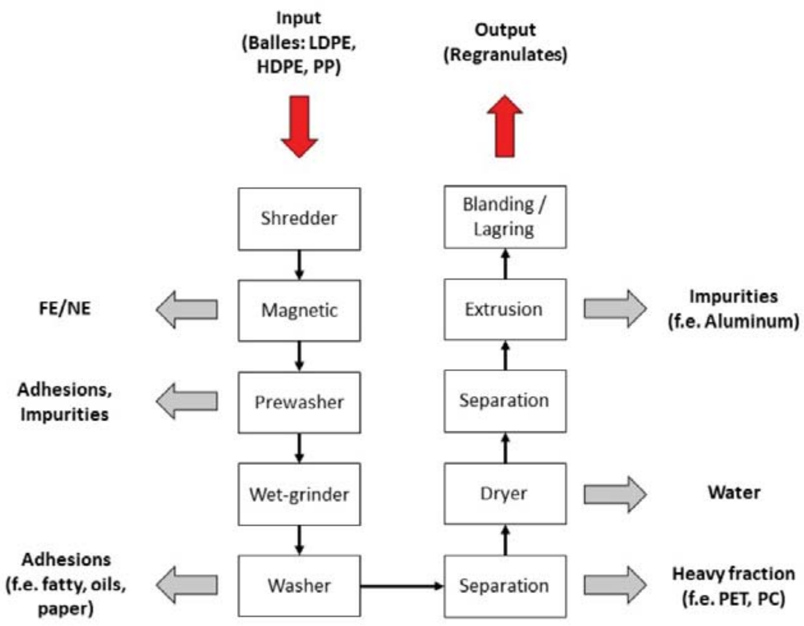

Figure 1: Flowchart of IVAR's washing and extrusion process (Bartel 2018)

The investment cost of the IVAR-facility includes both central sorting and plastic reprocessing. Without being able to access investment costs separated for their reprocessing machinery, their investment costs can not be used further in this research.

Project specific factors, such as location, input amounts per year, resource consumption during operation, etc, determine the financial budget. No cost analysis was performed earlier based on same project specifications as in Scenario 1. However, studies of the Norwegian business planning a similar reprocessing plant increase the quality of the economic analysis in this study. A life cycle inventory investigating resource consumption during reprocessing can indicate energy and water demand.
Franklin Associates (2011) reported energy and water consumption from six HDPE and four PET post-consumer plastic reprocessing facilities. Total energy demand of reprocessing post-consumer HDPE bales to pellets and PET from bales to flakes, was 554 kWh/t and 311 kWh/t respectively. Washing line processing HDPE used 1,5 m^3/t, while 1,3 m^3/t was used for PET.

5 Data and method

5.1 Data collection

Data used in the analyses was based on information from an outlined reprocessing facility in Norway, and European suppliers of plastic recycling processing equipment. The suppliers were contacted to retrieve information about prices of the necessary reprocessing machines, with their operating energy and water demand. Most suppliers shared general information, but this information was not detailed enough to use in the analysis. However, a few actors provided valuable information about machine prices, energy and water demand.

Industrivekst Vang (IVA) is a Norwegian firm planning a reprocessing plant processing household and/or industrial HDPE and PP, and has been one of the primary data sources in this research. Project manager Vegard Rogn shared detailed information about their financial model, and energy and water demand of projected machines. Their data was gathered by experienced Norwegian and German consulting firms, and was used in this studies' economic analyses and LCA-analyses.

Protec Scandinavia is a Norwegian supplier of plastic recycling machines and systems, and one of the businesses cooperating with IVA. They provided this study with system design for washing and extrusion, and machine cost estimates with the same suppliers as projected for IVA. The washing equipment was planned to be delivered by the German company Herbold, and the extrusion machines by the Austrian company Erema. Data from Protec Scandinavia is used in the economic analyses.

The German machine supplier Sikoplast also offered a system design for washing and extrusion, with corresponding prices, energy and water demand. The data was used in both the economic and environmental analyses.

IVAR also shared parts of their financial model. Their financial model has primarily been used as a comparison tool for operating costs and sales variables.

5.2 Economic analysis theory, method and assumptions

Different methods can be used in estimating a project's profitability. One of the most common calculation methods is NPV-analysis, which has been used in this study (Bredesen 2015).

NPV is defined as the value of a future cash flow over the entire life time of an investment, discounted to the present. In 2012, Berg et.al concluded in a study that NPV was the most used profitability of investment method among 200 of Norway's largest companies. 80 % of the 200 businesses used it often, very often or always. NPV is used in public Norwegian services, developed and/or operated by private actors (Offentlig-privat samarbeid (OPS)), supporting use of the method in this research (NHO 2014; Regjeringen 2018a).

There are several reasons why NPV is the most popular method. NPV maximises the shareholder's fortune, accounts inflation, risk and all other relevant economic information (Bredesen 2015). This makes the NPV-method a suitable tool to for investment analysis. NPV is calculated with the following equation:

$$NPV = -CF_0 + \sum_{t=1}^{n} \frac{CF}{(1+i)^t}$$

Equation : Net present value (Bredesen 2015)

The investment cost is defined as CF_0, n is the life time of investment in years, and CF is cash flow in year t. i represents the depreciation rate. Positive NPV supports acceptance of a project. Any private actor investing in or running the reprocessing facility, is dependent on a positive financial budget over the project's life time. No actor wants to lose money and time invested in a project, or get a too low payback. A NPV analysis is therefore crucial to ensure a profitable project, as well to convincing investors to support the project.

5.3 Method and assumptions

The economic analyses started with comparing data from the suppliers, based on machine costs and their electricity and water use. Different supplier of the two lines were optional. The resource consumption between the machine options differed, resulting in varying operating electricity and water costs. Due to this, a NPV-analysis of the four possible combinations of washing and extrusion lines from Option A and B were performed. The NPV-analyses was performed for Scenario 1. As the

Reference Scenario refers to no implementation of a reprocessing plant, an economic analysis of this scenario was not carried out in this research. Simplifications of the analysis was made due to limited received information and time.

CF_0 were divided into machine cost required for the washing line and the extrusion line, additional to other pre-production costs. Machine system designer provided with the equipment costs of all components necessary for both lines. The machine component costs were subtracted and presented in second year of construction period (year 2021). With equipment imported from Germany and Austria, the VAT is refunded from the exporting countries, of 19 % and 20 % respectively. Yet, Norwegian VAT of 25 % of original machine cost must be added (European Commision 2018; SSB 2018d). Machine costs presented in the economic analyses include Norwegian VAT of 25 %.

IVA has provided several investment costs, yet based on larger input volume. Pre-production cost were proportionally reduced from IVA's cost to this research's input volume. Pre-engineering and project development cost was assumed equal as IVA's, as input volume was considered to not impact project planning notably. Transport and installation of equipment cost per machine line was same as IVA's. More comprehensive investment cost analyses for the specific location should be carried out in an extensive economic analysis.

CF was a product of yearly incomes subtracted costs, all in nominal numbers with 2 % yearly increase. 2 % increase was based on Norway's inflation goal, and price index of services, labour in industry, and rent of commercial property (Norges Bank 2018a; SSB 2017b; SSB 2018a; SSB 2018f). Nominal, running prices were necessary for correct tax calculations. CF was presented per year and not by the respective month they occur, including all costs and income current year. Income was the product of expected output of the plastic fractions each year and respective predicted price. Income tax of 23 % of the result was included (Regjeringen 2018b). Using income alone does not give an accurate representation since yearly costs must be considered.

Yearly running cost was a product of several project specific factors. Data according transport and gate fee of loss, building and warehouse rental, machinery to warehouse leasing, water treatment and fresh water costs, and costs of full-time employees, were based on IVA's unit calculations. IVA's estimates were given per unit, and were then customized to Scenario 1. It was assumed that all water used in the washing line was cleaned. Warehouse size was projected to 2,500m^2 and reprocessing facility to 2,000m^2.

3-4 full-time employees were needed with the given size of facility (Skjevik 2018). The plant was projected with 4 full-time employees in operation period. Administrational cost were assumed 10 % of personnel cost. Personnel and administration costs were assumed to include costs related to establishment and maintenance of customer relations and marketing, additional to manpower needed for running the facility. Further investigation of shift arrangements at the facility was not included.

Price of household HDPE, PP and PET bales bought from ØAS was an outcome of market price, further expressed in Chapter 5.3.1. Electricity cost was a product of energy consumption per ton, plastic amount processed given year, and electricity price in given year. Future electricity price estimates used in analysis are uttered in Chapter 5.3.2. Maintenance costs of equipment are usually high, as metals, rocks and other impurities tear the machinery, resulting in frequently replacement of elements (Skjevik 2018). A relatively high maintenance cost of 10 % of machinery capital expenses was used in the analysis, to expect a longer life time of equipment.

The machinery was considered group D in Norwegian tax depreciation, resulting in a balance depreciation of 20 % each year (Skatteetaten 2017; Skatteloven §14-43 1999). This means the rest value of machines in year X were 80 % of value year X-1. Depreciations are part of cash flow (CF) in NPV-analysis, and reduce taxable income. The rest value final operating year was assumed equal as scrap value of the machines. The scrap value would equal depreciation basis in tax statement, resulting in no sales tax of the scrap value.

Life time of the equipment was set to 20 years, as the machines can likely operate for 15-20 years, depending on maintenance (Skjevik 2018). With a construction period set to two years, the analysis period was 22 years in total. Scenario 1 did not include reconstruction of machines and/or storage hall in order to limit the scope of this study.

The depreciation rate (i) reflects a weighted cost average. i included minimum required rate of return, often based on risk and uncertainty of the project, and/or expected return of investment in alternative spending. Risk was connected to Scenario 1, as well as future income and costs were uncertain. To compensate for risk of losing money, a high i of 10 % before tax was used in the economic analyses

(Bredesen 2015). Equation 2 was used to estimate the depreciation rate after tax. i is still the depreciation rate before tax, and s is the income tax, resulting in a depreciation rate after tax (r) of 7.7 %.

$$r = i * (1 - s)$$

Equation 1: Depreciation rate after tax (r) (Bredesen, 2015)

In a fulfilled economic analysis, i would also be based on rate of debt, private equity and investor support. A sensitivity analysis with i as variable was conducted. As this research excluded a finance plan in order to limit the scope, a sensitivity analysis varying i was conducted, which is valuable for potential contractor.

Internal rate of return (IRR) is not part of a NPV-analysis, but is calculated using same CF. IRR is the value of i when NPV is zero, and can predict the likelihood of profitability and financial strength of the project. With IRR above a project's i, the project can better withstand elements of risk and uncertainty, since the project to a certain level can tolerate higher CF_0 and/or lower CF than calculated, without resulting in negative NPV. IRR was calculated to back the results.

In order to limit the scope, the economic analyses was not as comprehensive as a potential contractor's business model should cover. Investor and bank offers for financing are necessary to complete the financial budget, as well as more detailed cost prognoses customized to location. Location of facility determines cost of rental, procurement and installation of power supply, water supply and treatment system, to the industry area. Further research of these costs should be performed in an adequate analysis. However, a cost reserve percentage was included in the analysis to compensate for potential exclusion of cost elements. Due to uncertainty in the economic analysis, an estimation of how NPV changes with variation in central variables was conducted, and is expressed the Sensitivity Analysis and Discussion chapter.

5.3.1 Plastic prices

The plastic price is highly important for the economic analyses, as it determines income and profit of the project. The price of sorted post-consumer plastic bales, flakes and pellets is a result of supply and demand on the international plastic market. Recycled plastic suitable for several new products has greater demand, resulting in a higher price. A greater demand applies to purer fractions and transparent and light plastics. Plastic can be recoloured to a darker colour, but the colour cannot be converted from dark to light, leading to more areas of use for light coloured plastic (Andersen 2015). Price of recycled plastic also correlate with the price of virgin plastic material.

Recycled plastic is a less sought material for plastic production than virgin material, because of lower quality in terms of impurities and smell. The virgin material works as a price ceiling for recycled plastic, but without reaching the same price level if quality is lower. The recycled plastic price follows the fluctuations in the oil market, but the timing and movement vary by type and grade of resin and region produced (Blanchard et al. 2015).

Future predictions of the oil market price can give an idea of coming plastic prices, but experts disagree in oil market forecasts. Some predictors suggest a peak soon after 2025, while others expect the global oil demand to continue to grow until 2040 (The Oxford Institute for Energy Studies 2018). Because of experts' disagreement on future oil market trends, the future plastic prices used in this research were not based on future oil market predictions, but rather historic plastic prices.

The Plasticker internet platform (Plasticker.de) publishes final average monthly prices in Europe for recycled plastic bales, flakes and pellets, with historic prices up to 60 months (five years) back. Currently above 28 000 users from 130 countries are registered in the market place (Bundesverband Sekundärrohstoffe und Entsorgung e.V. 2018).

Estimation of future prices of HDPE and PP pellets and bales, and PET flakes and bales, was necessary to conduct the economic analyses. Five years historic prices available at Plasticker were used to estimate these price elements, assuming exchange ratio of Euro (€) to NOK of 9.1 based on historic and current prices, and price increase of 2% each year (Norges Bank 2018b). However, data of all fractions were not available at Plasticker, such as price of HDPE bales. To predict future prices of HDPE bales, prices of HDPE pellets were used, reduced with 28 %, or the average rate between PP bales and PP pellets the past 60 months.

5.3.1.1 HDPE price

The five-year historic price level of HDPE pellets range from a peak of 1.06 €/kg in October 2013, to a minimum value of 0.75 €/kg in December 2017. This is graphically presented in Figure 2 below. Considering the historic prices, a future fixed price for HDPE pellets of 850 €/t was used in the economic analyses, corresponding 238 €/t for HDPE bales. The blue line in Figure 2 shows the assumed price of HDPE pellets the past 60 months. The polynomial trendline demonstrates a decreasing price tendency. Prices of HDPE bales are expressed with the orange line, assuming the average price ratio of PP bales/PP pellets of 28 % throughout the five years period.

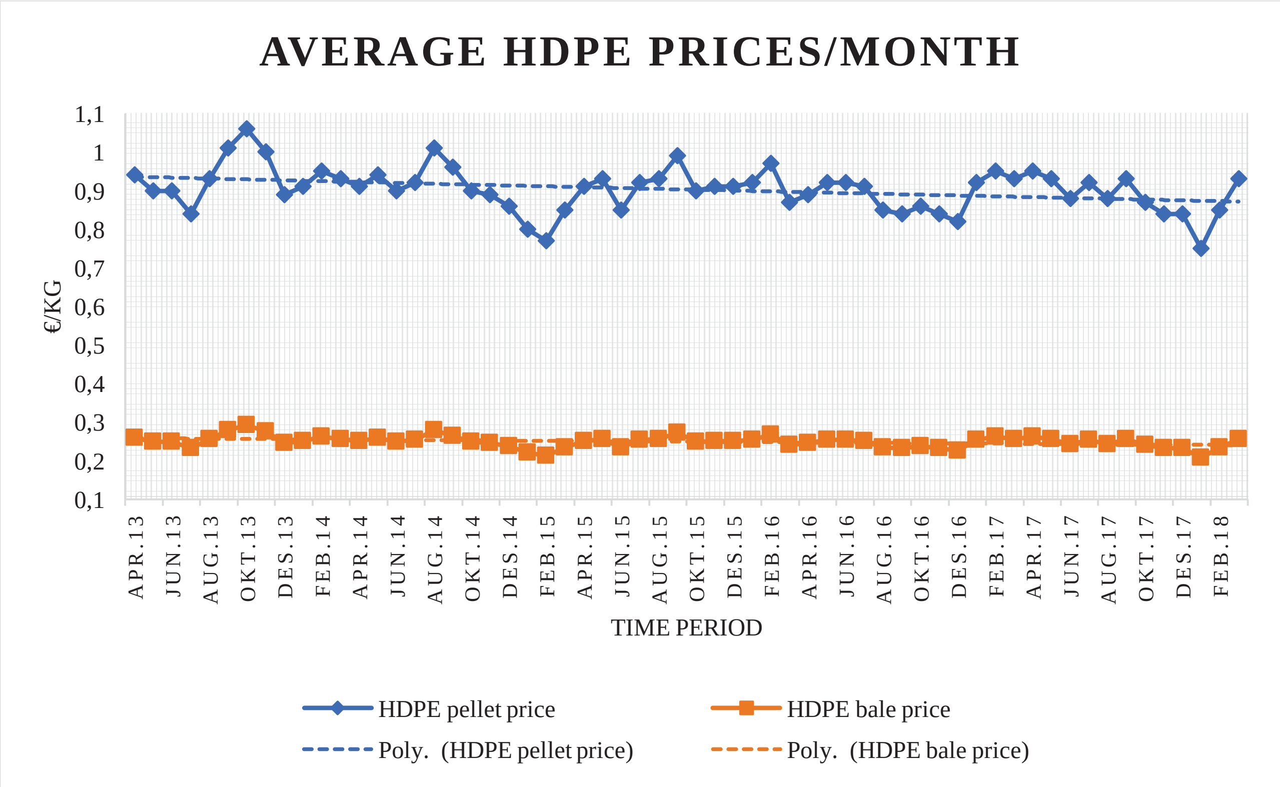

Figure 2: Historic prices of HDPE pellets with polynomial trendline. Assumed prices of HDPE bales as 28 % of HDPE pellets prices.

5.3.1.2 PP price

Figure 3 shows the average price of PP pellets and bales. The PP pellets polynomial trendline shows a decreasing price tendency. The range is from a maximum of 1.05 €/kg in October 2013, to a bottom of 0.73 €/kg in January 2017. With a time lag, the prices of bales followed same fluctuations, and had a peak in of 0.33 €/kg in February 2017, and minimum in May 2016 of 0.15 €/kg. A fixed price of 800 €/t for PP pellets and 200 €/t for PP bales were used in the economic analyses of PP pellets.

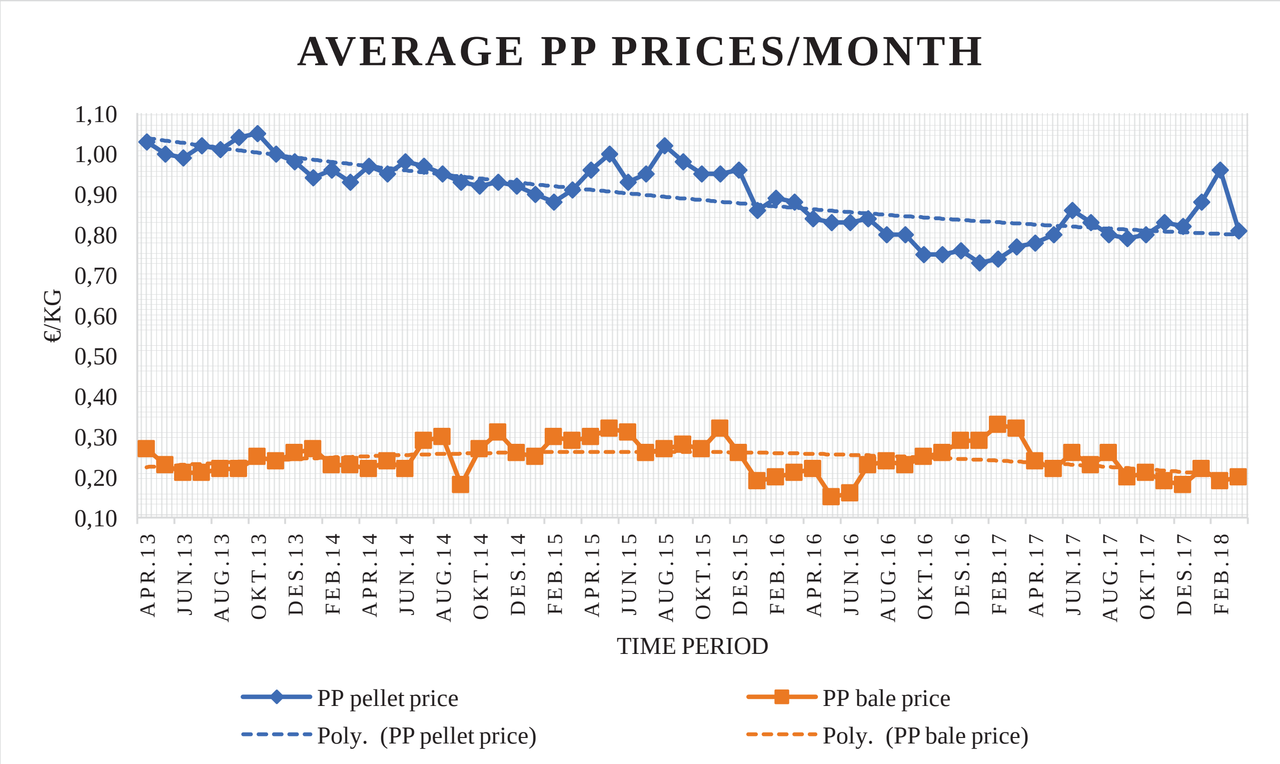

Figure 3: Historic prices of PP pellets and bales, with polynomial trendline.

5.3.1.3 PET price

Figure 4 shows historic prices of PET flakes and bales. The prices of PET flakes have decreased from 0.60 €/kg in April 2013 to 0.32 €/kg in February 2018. PET bales' price had similar fluctuations, but with a top in January 2015 of 0.25 €/kg to a bottom in October 2018 and January 2018 of 0.11 €/kg. A fixed price of 350 €/t was used in the economic analyses of PET flakes, while a price of 150 €/t was used for PET bales.

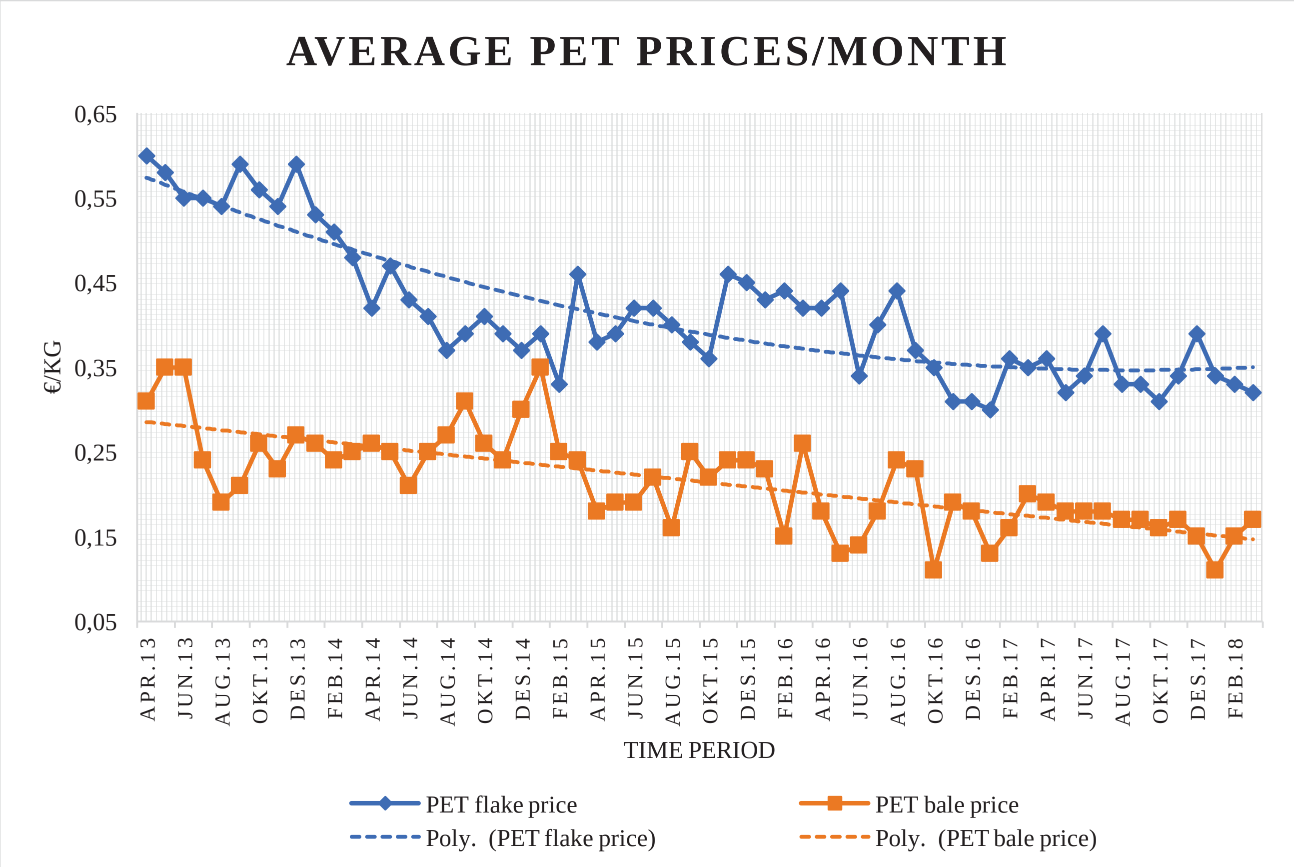

Figure 4: Historic prices of PET flakes and bales, with polynomial trendline.

5.3.2 Electricity price

The electricity price affects the running costs significantly, and should be predicted with minimal error. The electricity price in Norway is a result of the supply and demand in the Nordic electricity market, where cost of coal is price driver. Furthermore, the price is impacted by different factors in Norway and the Nordic countries, such as political restrictions in EU with incorporation in EØS, as well as the EU's common CO_2-quota system.

The Norwegian Water Resources and Energy Directorate (NVE) has estimated the future electricity price until 2030. From year 2017, NVE predicts a real price increase of 0.06-0.07 NOK/kWh from 2017 to 2030. The estimated increase is mainly a result of assumption of a tightened CO_2-market, which results in higher costs for coal and gas power plants (Amundsen et al. 2017). With an average electricity price of 0.23 NOK/kWh in 2017, 0.07 NOK/kWh constitutes of a yearly increase over 13 years to 2.06 %, additional to inflation.

Norway is divided into five price zones. Øra lies in zone N01, often experiencing higher prices because of greater population density increase the demand (Amundsen et al. 2017). The average spot price in N01 was 0.291 NOK/kWh in 2017 (Nord Pool 2018). A linear increase in electricity price of 2.06 % was used in the analysis over the project's life time (NVE 2018).

According to "Forskrift om særavgifter", Chapter 3-12, recycling plants are not exempted to pay tax on electricity (Finansdepartementet 2018). Grid rent and consumer fees per kWh was added to the electricity price in the economic analyses. Grid rent includes taxes, such as electricity tax, VAT and Enova-support (SSB 2018b). Grid rent fee including taxes was 0.546 NOK/kWh in 2017, and the consumer fee was 0.163 NOK/kWh in the same year (SSB 2018b). An assumption of a combined fee of 0.71 NOK/kWh during the life time was used in the economic analyses. The electricity price development is presented in Figure 5.

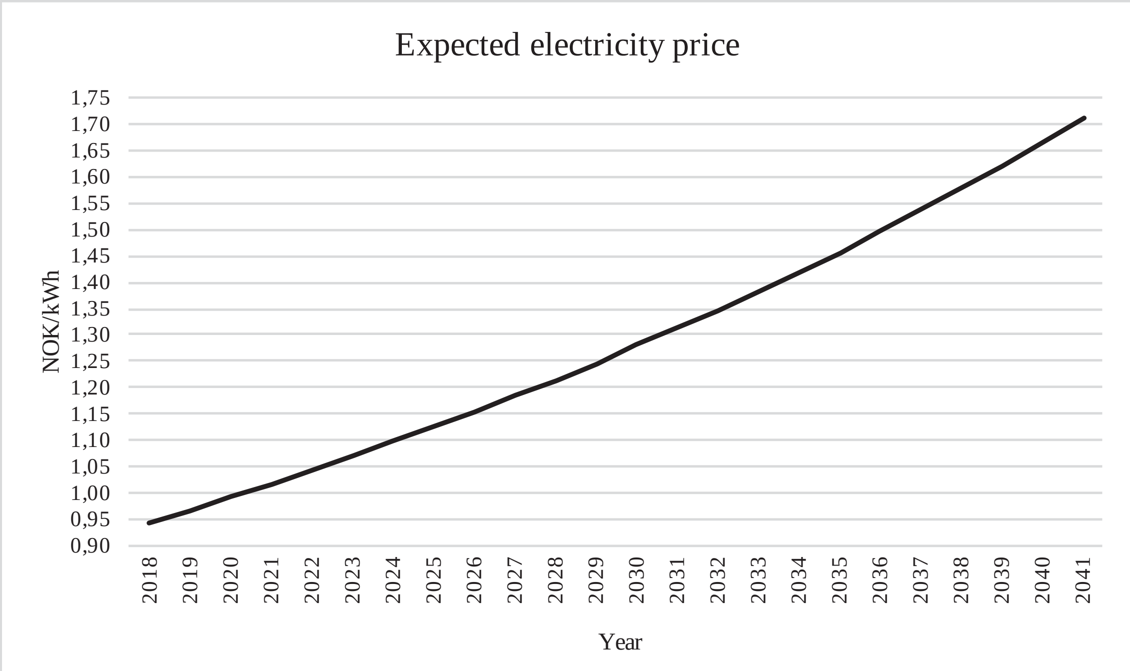

Figure 5: Expected electricity price including grid rent and consumer fee, used in the economic analyses.

5.3.3 Sensitivity analysis

Deciding if a project should be carried out or not is based on a set of assumptions of key variables. Examples of the key variables are sales price and quantity, investment and operating costs, and life time of the project. NPV is based on the most accurate value of the variables. Though, risk analysis is an important part of the economic analysis of a project, where sensitivity analysis is commonly used.

Sensitivity analysis is a tool to calculate how the NPV would vary with change in one variable, assuming all other variables remain constant. This highlights risk in the project, as it shows which variables who have the greatest effect on the NPV. Future cash flow is more uncertain than present cashflow. Therefore, the performed sensitivity analysis highlighted the change in NPV with a 25 % increase and decrease in four variables: Amount of plastic input, plastic prices, investment cost and variable costs (VC). The sensitivity analysis results is presented in Chapter 6.3, together with the payback time of the project. The change in NPV with a discount rate after tax between 4 % to 14 % is presented in Discussion.

5.4 Life cycle assessment theory, method and assumptions

A life cycle assessment follows the input products from raw material extraction from natural resources, through production and use, to disposal - a "cradle-to-grave" impact evaluation (Curran 2015). This LCA will calculate environmental impacts of Scenario 1 and the Reference Scenario.

LCA consist of several steps leading to calculation of the environmental impacts of a system. First, the product studied and purpose of the LCA are presented in the scope section. Secondly, inventory analysis informs about construction of the LCA, resources used in life cycle, and emission calculations. The third section determines potential environmental impacts from resources used in the processes and emissions during the processes. Impacts are classified and characterized. Finally, impacts are weighted on the same scale to define the environmental impact of the processes (Curran 2015). To be able to compare the LCA with other studies, the four steps must follow certain guidelines.

There are a series of international standards and guidelines for LCA. Leading standards are ISO 14040, which considers principles and framework of an LCA, and ISO 14044, which specify requirements and guidelines for carrying out an LCA (Goedkoop et al. 2016). The LCA-analysis in this research followed ISO 14040/44.

LCA can be carried out with different software, such as OpenNexus, openLCA, and GaBi. This analysis was performed in SimaPro 8.4.0, due to experience with this software, and with the available database NexusDB@158.39.185.138. "Østfoldforskning LCA 2017" and Ecoinvent 3.4 libraries were used as they were considered most updated and appropriate for this study.

Purpose of the analysis was as follows:

1. To perform an inventory in treatment process of post-consumer plastic waste, from washing to extrusion, in Norway and Germany.
2. To perform an inventory from export and import of plastic from Norway to Germany.
3. To run the scenarios with different electricity mixes.
4. To compare the scenarios with respect to environmental impact
5. To identify the largest environmental impacts contributions in the life cycle

Ostfold Research's LCA 2017 methods were used in all analyses.

5.4.1 System boundary

Determining geographic boundaries factors, such as electricity grid, technology used, and transport distances, is a crucial step in a LCA. Wider boundaries result in more complex systems, which can contribute positively as the environmental impact estimations are presented in a comprehensive context. However, detailed data for a project can be difficult to access, and generic and unspecific data increase the uncertainty of the results. The system boundaries in an LCA should therefore be carefully chosen.

This LCA-analysis involved reprocessing of sorted HPW of the polymer types HDPE, PP and PET, including washing and extrusion. Environmental impact results from the two analyses were combined and compared in quantitative terms (Curran 2015). Operating procedures in the reprocessing plants in Norway and Germany were assumed to be identical. This included use of the same amount of electricity for light and heating of facility, hours of operation, maintenance, etc. Reprocessed HPW as end-product in the systems has the function as raw material for new plastic production. The system avoids plastic waste for disposal, and substitutes use of virgin material for new plastic production. However, this avoided burden will not result in a net difference between Scenario 1 and the Reference Scenario, and was therefore not included in this study.

The system in Scenario 1 and the Reference Scenario starts from bales of sorted HPW of HDPE, PP and PET are received at the facility, excluding environmental impacts from production, use and central sorting. Output from the systems are PET flakes and HDPE and PP pellets. Even if PET's reprocessing ends after the washing line, it was assumed that the same PET amount follows into the extrusion line. This means that the only losses for PET are output from the washing process, which reduces input to the extrusion line. This is further expressed in Chapter 5.4.9.

5.4.2 Reference Scenario

The Reference Scenario was based on current plans for ØAS; central sorting at Øra with plastic export to Germany for further processing. The company Hubert Eing receives 44 % of Norway's unsorted HWP, Tönsmeier 31 %, and Umweltdienste Kedenburg 25 % (Hjorth-Johansen 2018). The transport distances from Øra to those recycling plants are 1175 km, 992 km, and 1012 km respectively, resulting in a weighted average distance of 1077 km. The type of lorry affects the environmental impact of transport significantly.

The reference flow of HPW-transport was *1 tonne-kilometre (tkm)*. The unit refers to the transport of 1 tonne the distance of 1 km. The total environmental impact was calculated by multiplying the impact from 1 tkm with 1077 km, and the total number of tonnes processed during the life time.

"Bring" is currently the contractor for transport of HPW from Norway. Bring's international rail specialist confirmed Euroclass VI lorries are used in exportation, with a loaded weight about 25-28 metric tonnes. The Euroclass for vehicles is a standard with a maximum acceptance of emissions to air per km – a higher Euroclass number refers to a newer registered vehicle, with less pollution per km driven. Euroclass VI is the highest class available for heavy diesel vehicles, with registration year from 2013/14 (NAF 2018). The type of lorry used in the analyses was referred to in SimaPro as; transport, freight, lorry >32 metric ton, [RER].

Several companies using recycled plastic as raw material in their plastic production are located in Norway. With no granulate supply in Norway, Norwegian plastic producers must import recycled plastic from abroad. Import of regranulat is not included in this LCA, but is further deliberated in Chapter 7.

Flowchart for the Reference Scenario is presented in Figure 6.

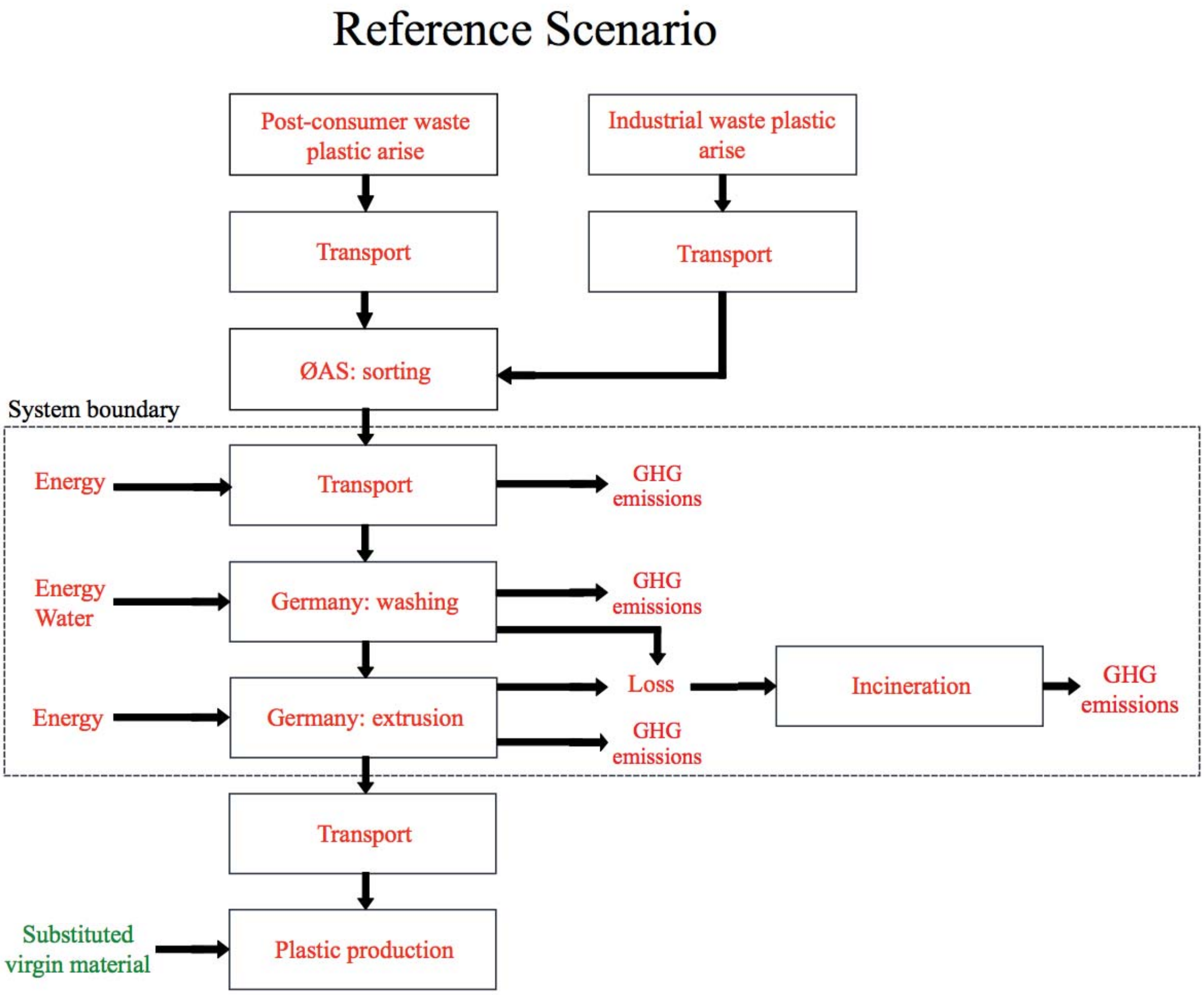

Figure 6: Flowchart for the Reference Scenario

5.4.3 Scenario 1

Scenario 1 presents reprocessing of plastic waste at Øra, where two out of the four machine combination alternatives were studied. One of the alternatives presented GWP during the life time with chosen machine combination, and is presented in Chapter 6.4. The other alternative showed GWP during the life time by using the machine combination with another resource consumption. This scenario analysis expressed the difference in GWP with unequal resource demand, and is further deliberated in the Discussion chapter. Own processes representing the washing and extrusion lines were created in SimaPro, based on data from the system suppliers. An overview of the processes are given in Chapter 10.4. The flowchart for Scenario 1 is presented below.

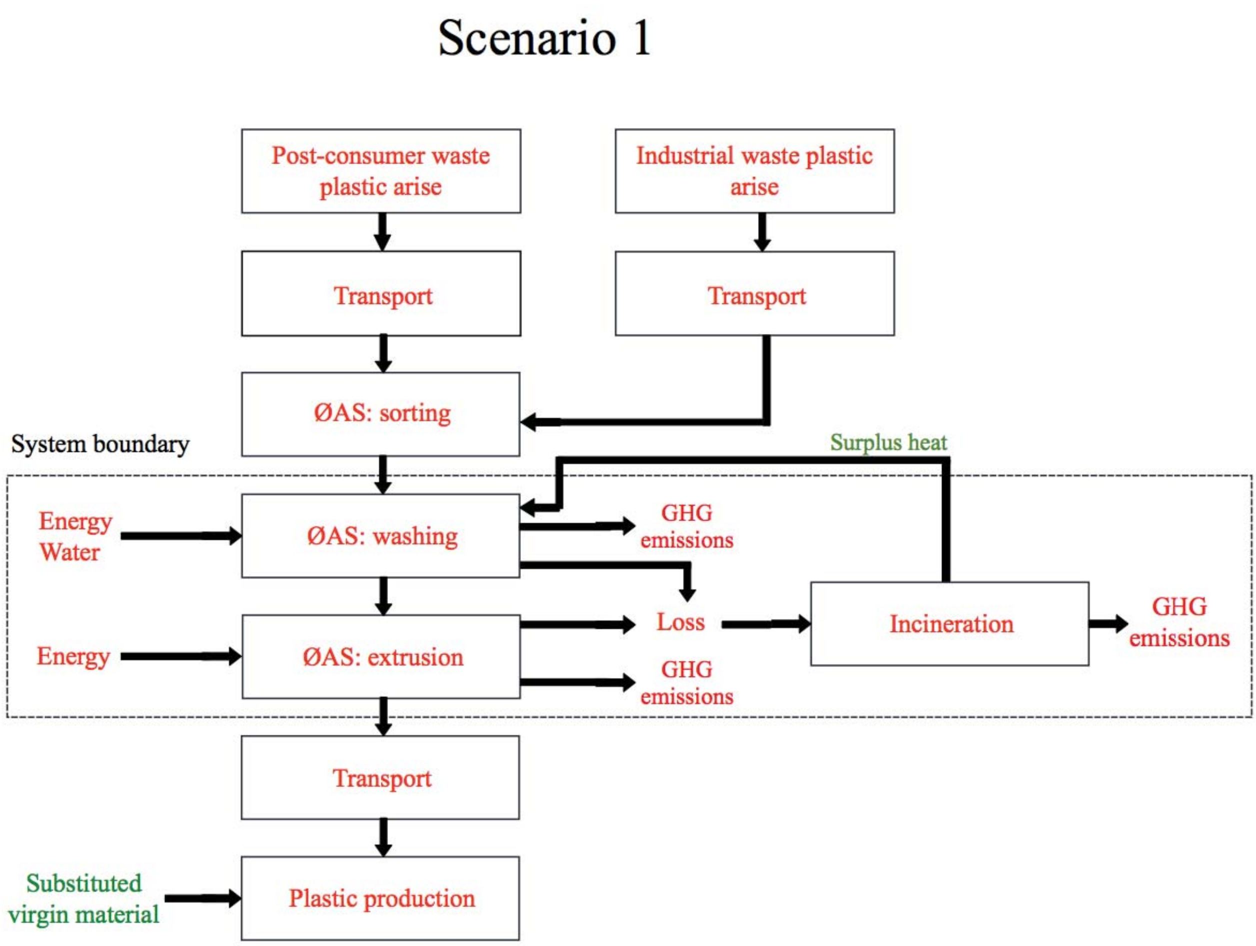

Figure 7: Flowchart for Scenario 1

5.4.4 Functional unit

As environmental impacts from systems are expressed in quantitative terms, a functional unit is needed for the analysis. The estimated environmental impact from the LCA was connected to processing of the functional unit of HPW.

The functional unit used for the retreatment process was *1 tonne* of sorted HPW. As the waste industry generally refers to this unit, it is a natural choice for the analysis. The functional unit refers to 1 tonne with expected proportion of HDPE, PP and PET received at ØAS. The total environmental impact of the systems was calculated with the environmental burden results per functional unit, multiplied by number of tonnes processed during life time.

5.4.5 Impact category

The environmental impacts considered in this LCA were results of resources used in the processes, and treatment of losses from the processes. In order to limit the study, climate change was the only evaluated imact category. There are several reasons why this category was considered suitable for the analyses.

Emission of GHG, such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), results in global warming. The gases prevent incoming thermal radiation to reflect back to the atmosphere, and lack of reflection leads to disturbed balance between energy absorbed and emitted by Earth. More energy absorbed by Earth than reflected results in temperature increase and global warming. GHG-impacts are weighted in SimaPro as CO_2-eq. Gases contributing to global warming potential (GWP) are used to convert emissions of individual processes to CO_2-eq. CO_2 naturally count 1 CO_2-eq., while CH_4 count 25 and nitrous dioxide 298 CO_2-eq. in a 100-year perspective (IPCC 2007). All processes in the analyses result in emissions of GHG, thus using climate change as an environmental impact category was then a natural choice (Curran 2015; Schab 2017)

5.4.6 Electricity mix

The el-mix used in the treatment processes in Norway and Germany can have significant impact on the results. The national el-mixes available in SimaPro were used for both scenarios; Norwegian el-mix for Scenario 1, and German el-mix for the Reference Scenario. Both processes retrieved the el-mix from "Electricity country mix, Medium voltage, Market" in SimaPro.

The newest versions available for Norwegian and German medium voltage (1kV to 24kV) electricity mixes are in Ecoinvent 3.0.1.0, valid for year 2014, based on statistics same year. The end date was set to 31.12.2017, with last update 08.06.2015 for both el-mixes. The dataset included electricity inputs produced in the given country, from imports with transformation to medium voltage, transmission networks, direct emissions to air (sulphur hexafluoride, SF6) and electricity losses during transmission. The basic source was IEA. 2017. IEA World Energy Statistics and Balances. OECD iLibrary, eISSN: 1683-4240, DOI: 10.1787/enestats-data-en. (*market for electricity, medium voltage DE* 2017; *market for electricity, medium voltage NO* 2017).

Nevertheless, both Norway and Germany are part of international transmission grids with supply of electricity produced in connecting countries with varying energy carriers, already expressed in Chapter 0. Using the national el-mix can then give an incorrect result. By using the national el-mix, Scenario 1 (Norway) can expect better result in terms of lower CO_2-emissions than reality, and the opposite in the Reference Scenario (Germany). A scenario analysis where the national el-mixes were replaced with the energy mix, ENTSO-E (European Network of Transmission Systems Operators for Electricity), was therefore conducted (Ecoinvent 2016).

ENTSO-E is a market group, consisting of "market of markets", in version 3.0.0.1. Losses and relevant exchanges, such as transport and transport infrastructure, were not included. The end date was 31.12.2017. ENTSO-E consisted of el-mixes from eleven countries and one market group, namely; Denmark, Estonia, Finland, Great Britain, Ireland, Iceland, Lithuania, Latvia, Malta, Norway, Sweden and UCTE market group. UCTE is an outdated geographically entity, consisting of el-mixes from 24 other European countries, used before ENTSO-E. ENTSO-E is a continuation of UCTE, where the mentioned eleven countries' el-mixes were added. As both Norway and Germany were included in the ENTSO-E market group, it was relevant scenario analysis for the LCA results (*market group for electricity*, *medium voltage ENTSO-E* 2017).

5.4.7 Energy demand

The machines used in the washing and extrusion processes had a specific energy consumption per tonne HPW processed. Data from providers of Option A and B were used to make own processes in SimaPro for the washing line and extrusion line separately. The reprocessing facilities in Germany currently receiving the Norwegian HPW did not respond with resource demand for the retreatment, resulting in assumption of the same energy and water demand of machinery in both Norway and Germany. Energy consumption of 300 kWh/t in the washing line were given from both suppliers. The extrusion line consumed 200 kWh/t in Option A and 350 kWh/t in Option B (IVA 2018; Sikoplast 2018; Skjevik 2018)

Trial test results from same supplier as Option B were provided by IVA. The tests were carried out by their machine suppliers abroad, for washing and extrusion separately. Bales of HDPE and PP from ROAF were input in the washing trial tests, and included both cold and warm wash using caustic soda, which System 1 was designed to use. The extrusion trial tests used a combination screw, with a smaller size model than Option B provides. The trial tests from extrusion of HDPE and PP separately gave electricity demands of 247 kWh/t and 353 kWh/t respectively. As Scenario 1 processes more PP than HDPE, this can lead to a lower energy consumption in practice than the given data of 350 kWh/t. However, a worst scenario was chosen, where the electricity consumption for extrusion of 350 kWh/t was used for Option B machinery. The energy consumption level is also supported by previous research by Franklin Associates (2011).

5.4.8 Freshwater

Freshwater was a key resource in the washing process. A general water demand per tonne processed HPW for both scenarios was used. Data from suppliers presented a water demand of 1m^3/t HPW for Option A and 2 m^3/t for Option B.

Use of 3-4 % caustic soda (NaOH), or other chemicals, is common in the washing process to remove impurities (Sikoplast 2018). This research assumed the same type and amount of chemicals used in both Norway and Germany, resulting in no net difference between the systems. Impact of using chemicals in the washing process was therefore not included.

5.4.9 Process losses

The input bales of HPW will always contain impurities. The assumed proportion of losses used in the LCA-analysis were based on the trial test data from IVA.

Results from washing of bales of PP, and HDPE medium cans and bottles, were used to estimate expected losses in the washing process. The average of the PP and HDPE losses in the reprocessing were used to assume the losses for PET. A total weighted average loss, based on input amounts of HDPE (21 %), PP (38 %) and PET (41 %), was used in the washing and extrusion processes created in SimaPro.

Impurities from the washing processes were separated into paper/fines and sinking material in the trial test results. Sinking material was assumed to be a mix of other plastics. The trial tests showed a washing loss of 22.5 % paper/fines, and 7.8 % of sinking material. Loss from the extrusion process revieled the loss of 2.5% to contain mainly aluminium. Uncertainty is connected to the results, as moisture was included in the weight of the impurities, and some of the impurities might have been present before the trial tests. The losses can then potentially be lower in reality, but the mentioned loss proportions were still used in the LCA-analysis to assume worst scenario.

Table 1 below shows the mass flow through the reprocessing plant used in the LCA. Loss treatment from washing and extrusion was included in the LCA. 225 kg paper/t HPW was treated as waste paperboard for municipal incineration. Plastic wastes for municipal incineration consist of 78 kg/t HPW. 17 kg aluminium/t HPW was treated as scrap aluminium for municipal incineration.

Table 1: Mass flow of reprocessing 1 tonne HPW

Input washing	Loss washing	Output washing/ Input extrusion	Loss extrusion	Output extrusion
1 tonne	Paper/fines: 22.5 % = 0.225 tonne	0.697 tonne	Aluminium: 2.5 % = 0.017 tonne	0.680 tonne
	Plastic wastes: 7.8 % = 0.078 tonne			

5.4.10 Cut-off

The systems are theoretically infinitely large. Plastic pellets are produced by machines, and these machines are produced by machines needing other machines, materials, and so on. The cut-off criteria based on negligible contribution to masses or costs was necessary to make inventory possible (Curran 2015). Another cut-off criteria can be infrastructure, such as buildings and equipment to manufacture the product.

Mentioned infrastructure was not included in the LCA-analyses. As the analyses presents nett difference in emissions of CO_2-eq. between the Reference Scenario and Scenario 1, there was no need for further cut-off.

5.4.11 Inventory analysis

The flowcharts in Figure 6 and 7 show the technical system model and system boundaries. The relevant mass and energy flows were considered, which was electricity and water use, and treatment of losses.

6 Results

This study was conducted to answer the main scope with associated research questions. As presented in Chapter 3, the scope with this Master's thesis was as follows:

What are the environmental and economic benefit or disadvantage of installation and operation of a plastic reprocessing plant at Øra, compared to transport of sorted HPW for reprocessing in Germany?

Research questions were addressed to substantiate and answer the main scope. Results connected to each research question are presented.

6.1 Research question 1

Which washing and extrusion line combination results in highest Net Present Value over a 20-years life time?

Table 2 below shows investment costs including VAT and energy requirement of the washing and extrusion line from Option A and B.

Table 2: Scenario 1: Investment cost, energy requirements, and energy costs during life time for Option A and B

Process	Element	Option A	Option B	Unit
Washing line	Machinery cost	57 330 000	30 712 500	NOK
	Electricity consumption/ton	300	300	kWh/t
	Fresh water consumption/ton	1	2	m^3/t
Extrusion line	Machinery cost	76 440 000	29 859 375	NOK
	Electricity consumption/ton	200	350	kWh/t

Costs of Option A machinery were drastically higher than Option B. The high extrusion line cost of Option A was because two lines were needed, processing HDPE and PP separately. Extrusion machinery in Option B uses a combination screw, resulting in one extrusion line running HDPE and PP in separate batches.

The washing process required the same amount of electricity in the three options, but the amount of fresh water per tonne differed. Option A required 1 m^3/t, while Option B demanded 2 m^3/t. In the extrusion line, the electricity consumption varied between Option A and B. During the life time of the facility, the different resource requirements during operation impact the NPV.

As combination of the washing and extrusion line from Option A and B were possible, an analysis of the four possible combinations was conducted. In Alternative 1 – 4 presented below varied the machine costs, and electricity and water costs during the life time. All other costs were assumed constant, although expences such as transport and installation would vary in practice, especially with two extrusion lines from Option A. Table 3 below shows the economic analyses results of the four alternatives. See Chapter 10.3 in the appendix for further details in the NPV analysis of Alternative 4.

Table 3: Scenario 1: Machine costs, resource consumptions, NPV and IRR when combining Option A and B washing and extrusion lines

Scenario 1	Alternative 1:	Alternative 2:	Alternative 3:	Alternative 4:	
	Option A washing and extrusion	**Option B washing, A extrusion**	**Option A washing, B extrusion**	**Option B washing and extrusion**	**Unit**
Total machine cost (incl. VAT)	141 957 794	113 711 090	87 189 375	64 279 358	NOK
Electricity consumption/ton	500	500	650	650	kWh/ton
Fresh water consumption/ton	1	2	1	2	m^3/ton
NPV after tax	**-106 004 843**	**-50 193 907**	**-9 438 616**	**41 821 700**	NOK
IRR after tax	-3,1%	2,2 %	6,4 %	12,9 %	%

Alternative 4, using equipment from Option B for both washing and extrusion, was the only option with positive NPV. Alternative 4 was then the recommended machine supplier combination, and was used to answer the next research questions.

6.2 Research question 2

What is the minimum amount of HPW processed per year to payback the costs over the project's lifetime?

Minimum amount of HPW in the first year was 7,443 tonnes, given same yearly rise in amounts of HPW received. With the yearly increase in received plastic amounts, resulted in 7,432 tonnes received during the last operating year for NPV=0.

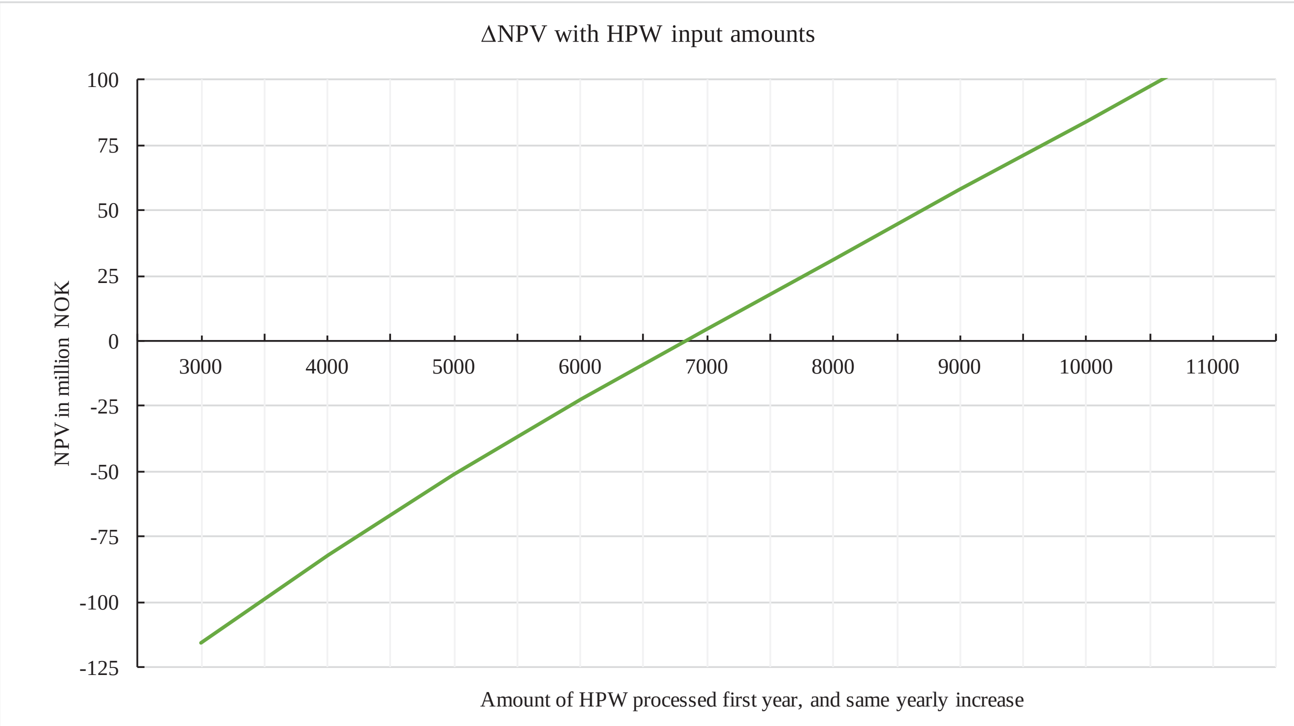

Figure 8: ΔNPV with different amounts of HPW received first operating year

6.3 Research question 3

How sensitive are the results of chosen alternative with regard to economy, and what are the most sensitive factors?

Figure 9 shows how key variables influence the NPV. The intersection has a value of NOK 41,821,700, corresponding to the NPV of Alternative 4. Each slope in Figure 9 specifies how the NPV varies with +/- 25 % change in the given variable, assuming all other factors are constant. The most sensitive variables are recognized by steeper slopes, and have larger effect on the NPV. The most sensitive variables studied in this research were VC and plastic input. Alternative 4 can handle a VC increase of 20 %, or plastic input decrease of 16 %, without resulting in a negative NPV.

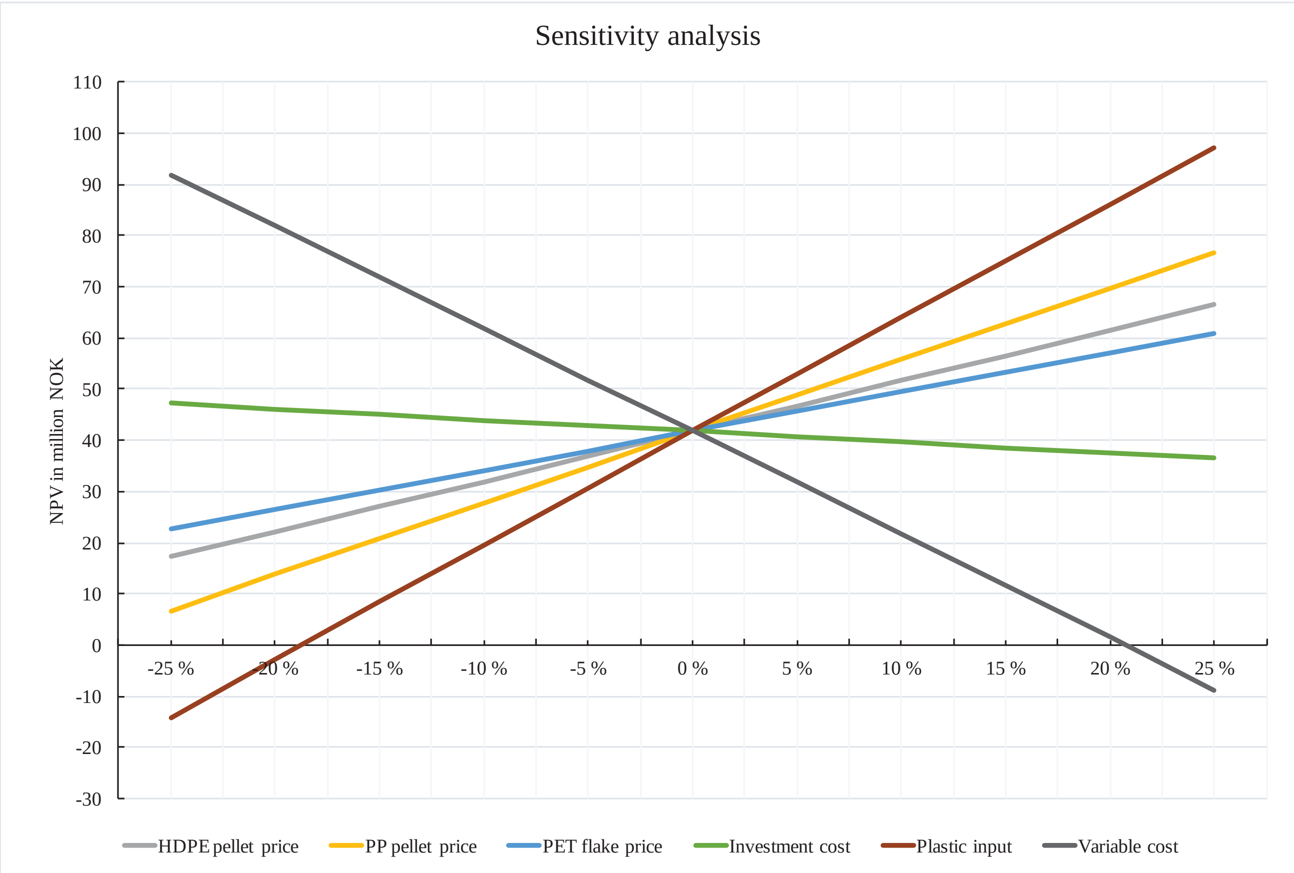

Figure 9: Sensitivity analysis of Option B for washing and extrusion. Effect on NPV of +/- 25 % change in one variable

Life time of facility was also a sensitive factor. The payback period shows how long the facility must operate to payback the investment, and NPV is zero. Figure 10 shows this graphically, where year 0 and 1 was construction period. After operating for 9 years the investment was payed back. From the 10^{th} operating year the NPV>0.

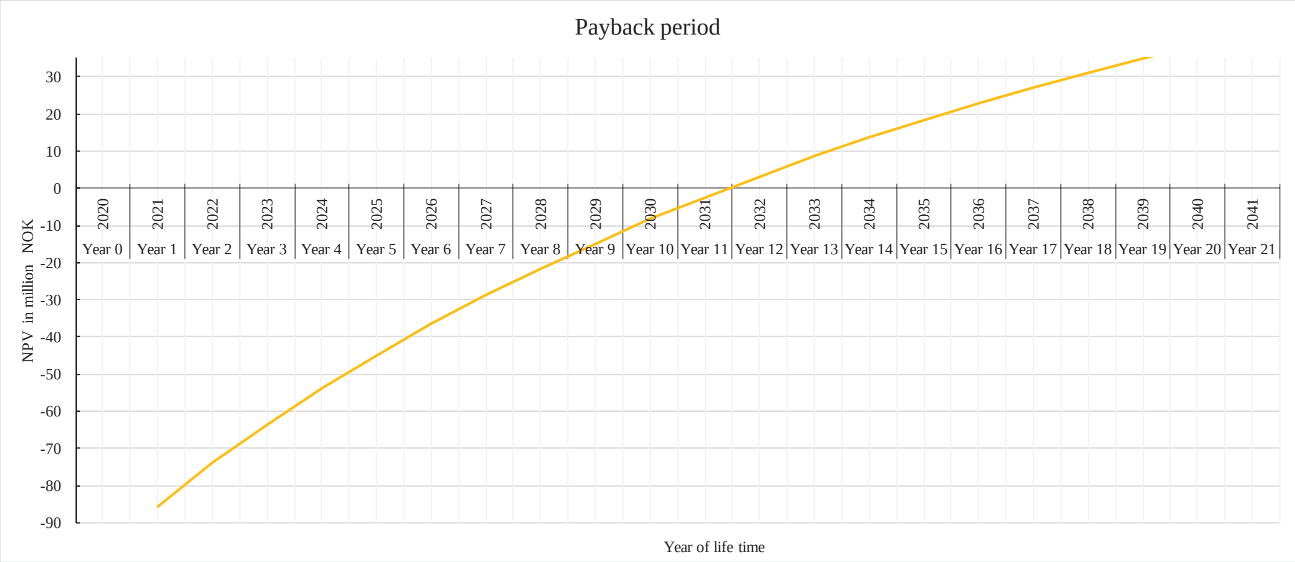

Figure 10: Payback period for Alternative 4

6.4 Research question 4

What is the net potential saving in GHG for a HPW processing plant located in Norway compared to transport and processing in Germany over 20-years life time?

Figure 11 shows emission of tonnes CO_2-eq. during the facility life time with Alternative 4, given country and el-mix. The processes were modelled in SimaPro with domestic and ENTSO-E el-mix. Reprocessing HPW in Norway resulted in net saving of tonnes CO_2-eq., independent of the electricity mix used. Net savings ranged from 15,304 to 72,914 tonnes CO_2-eq. Minimum net reduction equaled emission from transport, where both countries used ENTSO-E el-mix. Largest net reduction occurs when domestic electricity was used in both countries.

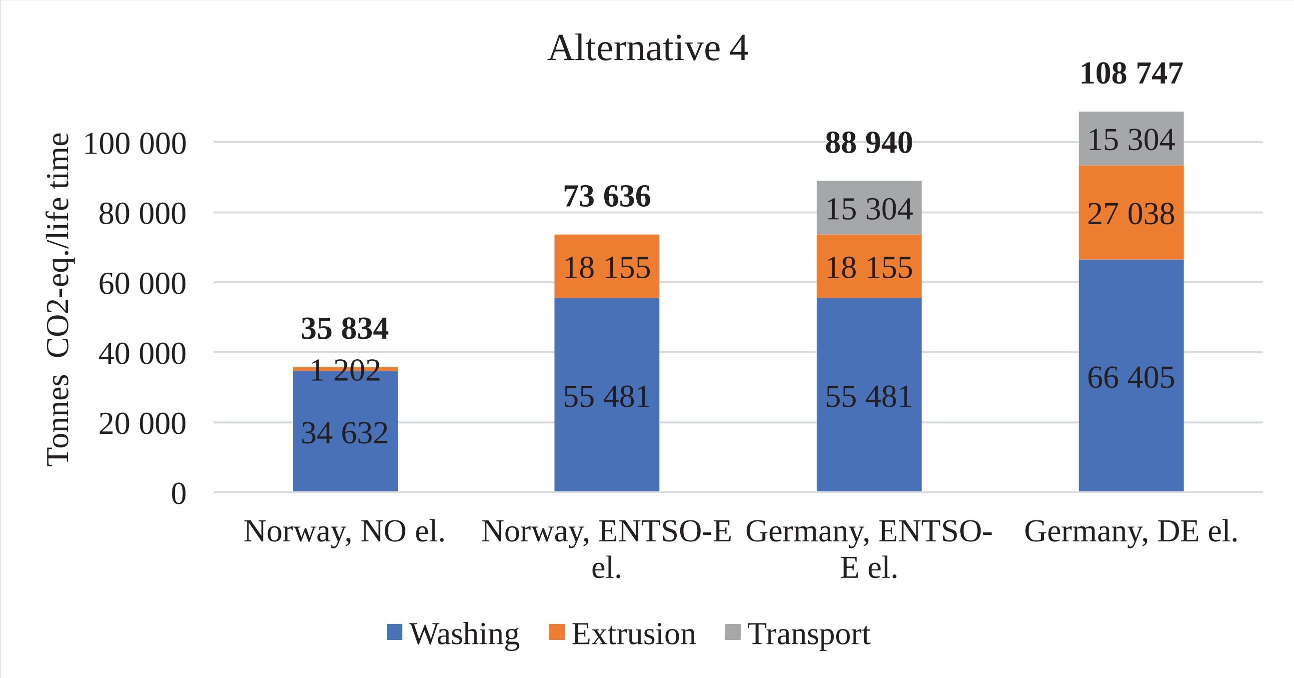

Figure 11: Emission of tonnes CO2-eq. from retreatment processes of HPW during life time, given country and el-mix (SimaPro). Total emissions are presented above the columns.

It was assumed that the machines used equal amount of electricity and resources in Scenario 1 and the Reference Scenario. Yet, the resource consumption can be smaller than used in this analysis.

An analysis of Alternative 1, with Option A equipment, was performed to investigate GWP with different resource consumption. Results are given in Figure 14 in the appendix. If Option A machines were used, and same amounts of resources were consumed in both countries, the net saving of tonnes CO_2-eq. range from 15,304 to 46,544. The reduction in emissions was mainly from reduced GWP from the extrusion line.

Both Alternative 1 and 4 presented reprocessing in Norway as most environmental friendly option in terms of emissions of CO_2-eq. Processing HPW in Norway resulted in a minimum reduction of 15,304 tonnes CO_2-eq emissions due to avoided transport. Reprocessing in Norway with Norwegian el-mix was the best option, constituting of less than 1/3 of total GHG-emissions from worst scenario with reprocessing in Germany with German el-mix, independent of electricity mix used.

7 Discussion

7.1 Economic analyses

Four alternatives were evaluated in the economic analyses. Lack of similar studies to compare with can often reduce the reliability of the results. Yet, much of the data used in the analyses was of high quality, which should prevent loss of credibility.

The main findings were a positive NPV with Alternative 4 of NOK 41,821,700, and negative NPVs of the three remaining alternatives. Equipment used in Alternative 4 was delivered by supplier in Option B for both the washing and extrusion line. Furthermore, the sensitivity analysis results gave valuable insight to the robustness of the project. The economic analyses evaluated two suppliers, and contacting other suppliers could have caused in a different result.

Machine costs are in general not available on supplier's home pages or other open sources, and must be retrieved from contractors through personal communication. Several suppliers replied with machine information, yet this was mostly generic data not detailed enough to use in the analysis. Other suppliers could possibly deliver cheaper systems, resulting in a higher NPV. Nevertheless, cheaper machines often reflect lower quality, causing higher maintenance costs (Rogn 2018; Skjevik 2018).

The cost information for machines in Alternative 4 was from a machine system developer in Norway. Not all necessary project details and time were available for the developer to give an exact offer. Necessary project details include additional information about plastic quality of bales from ØAS, and more detailed operating solutions for the facility. However, the machine system offer was based on most crucial variable; yearly plastic input amounts and the expected impurity level of this. Machine costs were therefore regarded as of high accuracy. Though, other investment costs in this project could be considered less precise.

Expenses related to building of the reprocessing plant is based on IVA's estimates, yet IVA's facility is planned in another area than Øra, and with a higher yearly plastic input. Transport distances of construction material, construction design and size, can differ, resulting in different investment expenses. However, the sensitivity analysis in Figure 9 presents investment costs to be the least sensitive variable among the ones evaluated. This proves an increase or decrease in investment cost will not have significant impact on the NPV. Other unexpected changes connected to investment costs could rather affect the result more significantly.

Years of construction impact the NPV expressively, as the expences increase and income gets delayed. This project assumed a general construction period of two years (Meissner 2017). Nevertheless, many Norwegian projects experience time overrun or extension to complete the construction, leading to a decreased NPV (Zidanea et al. 2015). A detailed analysis of necessary construction time was not conducted in this study, but is crucial in a fulfilled analysis. Another highly sensible factor is yearly plastic input amounts.

Reaching the expected input of plastic amounts the first operating years might be too optimistic. If the process operators do not have experience with the machines, and potential variations in input flows, a learning period with more frequent downtime and reduced production should be expected. Also, complications with supply from ØAS – a newly operating facility – might occur. Both downtime and complications with supply can lead to less plastic reprocessed the first years than planned in the project, which the sensitivity analysis proves affects the NPV significantly. However, the facility is capable of receiving even more than currently projected by increasing number of hours operating. The capacity in especially the extrusion line is not exploited, and IPW with minimal impurities can go directly into the extrusion line (Opt. B supplier 2018). This increases production and sales from the reprocessing plant. Then phases with higher plastic input amounts can compensate for potential periods of lower intake. Another sensible variable, the VC, can be considered rather precise in this analysis.

Many of the variable cost elements retrieved from IVA, were given as expense per unit processed/consumed. These were adjusted to this project given yearly input amounts processed and resources consumed. This implied to factors as transport of offtake, water costs, and electricity costs, resulting in a precise machine operating cost estimate. Future estimations of plastic prices increase uncertainty of the analysis, as these can be difficult to predict.

The plastic prices used in the NPV-analysis was slightly below the five years price average of the plastic types. Yet, historic prices of PP pellets and PET showed a decreasing price trend. This trend was not assumed to continue, as the future plastic prices will likely fluctuate in the future, and regulations can increase the demand. Predictions of future plastic prices could be estimated with even more background research in a fulfilled financial analysis, especially since the plastic price can have even higher effect on the NPV than presented in the sensitivity analysis.

The sensitivity analysis showed that a change in each plastic price affected the NPV, but it did not present the outcome on the NPV if the prices of HDPE, PP and PET increased or decreased at the same time. As discussed, the plastic prices correlate, and changes in the plastic market would likely affect the NPV even more than the sensitivity analysis prescribed. Because of uncertain cost elements and otger factors, there was connected a risk to this project.

The elements of risk are divided into systematic and unsystematic risk. Systematic risk depends on the economy on macro level. Economic booms and recessions will possibly affect the plastic market, where booms result in higher demand, and recessions in decreased demand. Though, a few months time lag before the plastic price change is expected (Skjevik 2018).

Most businesses are affected by systematic risk. However, this project had both input supply of bales, and output of flakes and pellets, in the same plastic market. Price of bales, flakes and pellets would likely correlate in market cyclicals, leading to percent difference between costs and sales could stay almost constant in cyclical upturns and downturns. The five years historic prices of PP and PET presented in Chapter 5.2.1.2-3 express this correlation. This leads to the business' economy being less affected by systematic risk.

Unsystematic risk is on the other hand connected to the specific project. Predictions made for 22 years ahead might change, and other unexpected factors can occur, increasing the risk (Statens Vegvesen 2018). Due to mentioned uncertain cost elements, and level of risk, a relatively high depreciation rate was used in the NPV analysis.

The analysis used a depreciation rate of 10 % before tax, which resulted in a rate of 7.7 % after tax. In a comprehensive financial analysis, the depreciation rate would be determined by the cost coverage rate between investors, private equity and debt. Therefore, looking at fallouts of NPV by different depreciation rates after tax is valuable as the rate could likely be different, and often lower. Figure 12 shows the NPV from high to low when the depreciation rate after tax range from 4 % to 14 %. As Table 3 implies, IRR after tax is 12.9 % in Alternative 4.

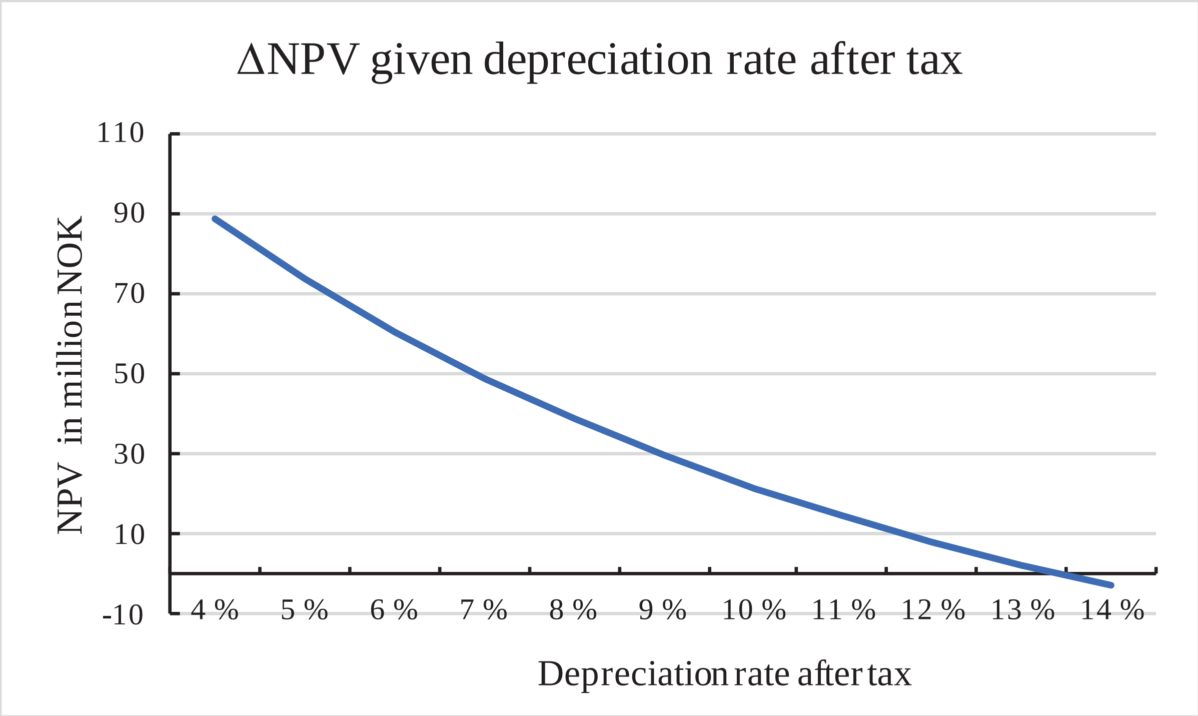

Figure 12: Change in NPV with different depreciation rates after tax

The economic analyses contained costs with different levels of uncertainties. A potential contractor should develop cost analysis specific for site and size of the plant. Other costs were accurate, and can be used in further economic analyses of a plastic reprocessing plant in Norway. Future research should also investigate beneficial interactions with other businesses at Øra.

Location at Øra could lead to several synergies with other actors, lowering costs. Of the VC, charge of electricity is the second largest expence cost factor. Surplus heat from Frevar could be used in the reprocessing plant to a lower this cost. Additionally, return water from Frevar's district heating pipes could be connected with the reprocessing plant to heat water used in the washing line by heat exchangers. Both systems lower VC. As the sensitivity analysis prescribed VC as highly sensitive, a decline in VC can increase NVP significantly. Other benefits due to location are presented in the next chapter.

7.2 Environmental assessment

Results from the environmental analyses show net savings of CO_2-eq. emissions of reprocessing in Norway from 15,304 to 72,914 tonnes. Looking at climate change as the only impact category excludes other negative environmental impacts, such as eutrophication, abiotic depletion, and acidification potential. Including these would give a more comprehensive result, and can be recommended to investigate future research could include these to expand the analysis. Selected assumptions were necessary to conduct the LCA-analyses, yet use of generic data can impact the precision of the results.

Emissions from transport per tkm in the LCA-analyses consisted of generic data retrieved from the Ecoinvent library. Amount of GHG-emissions were based on a process in SimaPro of Euroclass VI diesel lorry, with weight including load of >32 t. Fuel composition and exhaust and non-exhaust emissions were an average of European journeys and load factors. Average load in the process were 15.96 t. Bring loads the Euroclass VI lorries with 25 – 28 t HPW/trip, leading to the GHG-emissions not entirely correct for transport in the Reference Scenario (Asak 2018). However, the transport was adjusted to today's exact distance from Øra to the plants receiving the Norwegian HPW in Germany, which on the other hand increases the data quality of the results.

The weighted distance of 1077 km from Øra to the facilities in Germany resulted in emissions of above 15,300 tonnes CO_2-eq, though this emission was only connected to export. Several plastic producers are located at Øra, demanding reprocessed plastic. Currently there are no actors producing reprocessed plastic in Norway, which means supply must be retrieved from abroad, which can likely be Germany. Including import of reprocessed plastic from same locations in Germany is therefore relevant in consideration of net GHG-emissions between the scenarios. By including import of equal plastic amounts and from same loactions, the net benefit from eliminated transport is doubled, from 15,304 t CO_2-eq. to above 30,600. Transport constitutes then of 25-29 % of total CO_2-emissions in Scenario 1, increased from 14-17 %, depending on el-mix. Furthermore, the import of reprocessed plastic could be transported by lorries registered with lower Euroclass, with higher environmental burden per tkm. The consequence is even higher net benefit of Scenario 1. Kilometres driven with lorry during 20 years operation were substantial.

As mentioned, Bring loads the lorries with 25 – 28 t HPW/trip. A loaded lorry of 28 t per trip results in 4,189 trips with given output of HPW during life time of the facility. Operating at Øra could eliminate over 4,500,000 km driven with loaded lorry. Accounting import of plastic from Germany, the avoided transport distance is above 9 million km. Additonal to GHG-emissions, transport can result in other environmental issues, such as plastic astray.

Transport of plastic can lead to plastic spill along the route. Most spill is often around collection area, but long-distance transport can also discharge plastic materials. Especially spill of small plastic contaminants is difficult to track (M.Karlsson et al. 2018). Furthermore, research link micro plastic pollution to wear and tear of car tires. It is estimated that 5-10 % of plastic in oceans are from wear of car tires, and 3-7 % of particulate matter in air is also due to this (European Commision 2017; Kole et al. 2017). Emission of micro plastics are not included in this research, but the avoidance of transport by reprocessing in Norway would clearly contribute to a higher net environmental benefit due to less plastic astray. Transport with diesel lorries also lead to NO_x-emissions resulting in other disadvantages.

As already mentioned in Chapter 0, use of diesel contributes to negative environmental and health effects due to NO_x-emissions. NO_x is referring to various compounds of nitrogen oxides, mainly nitric oxide (NO) and nitrogen dioxide (NO_2). The gasses are connected to creation of ground-level ozone, particulate matter, acid rain, global warming and formation of toxic products in human body (DieselNet 2018; Queensland Government 2016). However, the transport method and distance might change in the future.

The plastic market is dynamic, and will further develop over the next 20 years. The transport method might change in the future, to a higher Euroclass or to other shipping alternatives, hopefully leading to lower environmental burden. Furthermore, if no reprocessing plant is build in Norway, the transport of Norwegian HPW might change to other plants with longer or shorter travel distances. This can both increase and decrease the GWP. Nevertheless, most emissions in the analyses were connected to the retreatment process of HPW.

Electricity and water consumptions used in the LCA-analyses of Scenario 1 had process specific data retrieved from suppliers. Resource demand during operation in Norway was therefore considered of high accuracy. Precise data also implies to loss amount during washing and extrusion in Norway, as percentage used was retrieved from trial tests where machines from same suppliers were used. The German plants currently processing Norwegian HPW did not respond with information of resource consumption, resulting in the assumption of same energy use in Norway and Germany. However, information from suppliers of Option A and B proves that same processes unnecessarily consume equal resource amount per tonne HPW. Additionally, extrusion trial tests using the combination screw from Option B, exposed an energy consumption of 247 kWh/t for PP, and 353 kWh/t for HDPE. With Alternative 4 equipment processing more PP than HDPE, the energy consumption for extrusion might be lower than used in this study. The German facilities might also release different amounts of CO_2-eq./t, possibly changing net emissions between Norway and Germany. The scenario analysis was performed to demonstrate a potential difference, given in Figure 14 in the appendix.

A calculation setup in SimaPro were run with change in resource consumption to 200 kWh/t in the extrusion line and 1 m^3 fresh water/t during washing, as in Alternative 1 (see Table 3). Results are given in Figure 14 in the appendix. The outcome reveals a GHG-emission reduction from the extrusion process above 40 %, while the washing process had minimal reduction in emission, less than 1 %. The minimal reduction is because of further treatment of losses.

Incineration of mixed plastic waste, constituted of 7.8 % of input - or 78 kg/t processed. 78 kg mixed plastic incinerated was connected to emissions of above 180 kg CO_2-eq (*SimaPro* 2017). Incineration of paper/paperboard contributed 1 % of emissions, not present with 5 % cut-off. Loss composition and amount of plastic waste, paper/paperboard and scrap aluminium can change during the life time of facility, and/or other materials can be present. This can change results in net saving of GHG-emissions in both scenarios.

Moreover, the minimal difference in emissions from the washing process is also due to this research's boundaries. With climate change as impact category, this study did not highlight how change in amount of fresh water could impact environmental benefits/disadvantages of the facility. The cleaning treatment of dirty water would be reduced with declined water use, resulting in less energy consumption connected to this process. Additionally, as use of caustic soda (NaOH) constitutes of 3-4 % of the water amount, using 1 m^3 instead of 2 m^3 reduce this amount significantly, also lowering environmental impact from the washing process. On the other side, using less water per tonne plastic processed could potentially lead to less clean plastic, but this theory is not confirmed by supplier. Nevertheless, the factor affecting the different scenarios most drastically in the LCA-analyses was the el-mix used.

Emissions from use of electricity in Alternative 4 was highly dependent on the chosen electricity mix in the grid. The Norwegian medium voltage electricity mix has clearly lowest emissions per kWh used, with 0.0278 kg CO_2-eq, compared to the ENTSO-E el-mix with 0.4332 kg CO_2-eq, and the German medium voltage mix of 0.6457 kg CO_2-eq. The emissions connected to NO-mix equaled 1/16 of ENTSO-E-mix, and 1/23 of the DE-mix. This data is expressed in table 4 in the appendix.

The electricity mix used in environmental assessments of Norwegian electricity demanding processes, is already a discussed subject (Raadal 2013). With reprocessing in Norway, the Norwegian el-mix can present too low emissions than reality, while ENTSO-E can result in too high emissions. Operator in Norway can also chose to pay an extra fee to guarantee the electricity origin from renewable sources, which correspond to different environmental impacts (NVE 2015). The issue can also be addressed to emissions from German facilities, where the domestic el-mix can give too high emissions than reality, while ENTSO-E el-mix present too low GHG-emissions .

Electricity delivered to the facility will always depend on current suppliers in the grid, decided by connecting electricity market's supply and demand at given time. However, Scenario 1 resulted in net saving of tonnes CO_2-eq compared to the Reference Scenario, independent of el-mix used in the analyses. The retreatment process contributing to highest GHG-emissions is the washing line.

Loss constituting of plastic can go back to ØAS for a second central sorting. As the plastic waste is cleaned, it can likely be more easily sorted into correct fraction by the NIR-scanners. This increase the recycling rate at ØAS and reduce amount of loss to combustion. This is also performed without additional transport by lorry, and lower environmental impacts from the reprocessing plant. Further benefits also arise with location of a reprocessing plant at Øra.

If the reprocessing plant is build next to Frevar – the energy recovery plant located at Øra – transport of losses to incineration is minimized. Transport of losses is not included in the LCA-analysis, but could lead to added shipping in the Reference Scenario. Mentioned in Chapter 1, by location close to Frevar, Frevar's surplus energy can be used to heat water used in the washing process. This can change emissions connected to the process, depending on electricity mix in the electricity grid and GHG-emissions connected to Frevar's energy recovery plant. Still, if the alternative of the surplus energy is no utilization, using this at the plastic reprocessing plant avoids emissions from the electricity consumption. If the plant also pays extra to receive green electricity, it can secure low process related emissions. Additional to environmental benefits by a reprocessing plant in Norway, it serves several social benefits.

As SirkulærPlast prescribes, many businesses treating and using plastic are placed in Østfold. This can develop mutual information sharing and increased transparency regarding quality and specifications of recycled plastics, and improve supplier – customer relations. Building a plastic reprocessing plant at Øra can also ensure plastic product manufacturers a continuous supply of recycled plastic with stable quality, making secondary plastic more available and attractive in the area (Fråne et al. 2015). Also, centralizing waste management in the Østfold-area can be an intencive for other businesses in the waste industry to establish in Østfold. Mentioned benefits by establishing a plastic reprocessing plant at Øra were numerous, leading to the question if more than one facility should be built in Norway.

Scenario 1 processes from 8,400-8,728 tonnes/year of HPW, with possibility to recieve higher amounts. Yet, it is far from capable of receiving all HPW Norway produces each year, as Norway in 2015 delivered 38,357 tonnes HPW to material recycling in 2016 (SSB 2017a). As mentioned, IVAR is currently under construction in Stavanger, planned receiving about 10,700 tonnes HPW (Meissner 2017). Even with operation of both IVAR and the plant at Øra, about 20,000 tonnes Norwegian HPW can not be recieved at Norwegian plastic reprocessing facilities. Establishing additional plastic reprocessing plants other places in Norway is therefore a recommended to investigate. Norway has potential of increasing their plastic expertice, also because future governmental policies can lead to a plastic marked demanding even more recycled plastic.

The EU's ambitions in reduction of GHG-emissions gives an expectation of a tightened CO_2-quota market, and other environmental declarations to reduce emissions (Amundsen et al. 2017). Use of recycled raw material in plastic production instead of virgin raw material from fossil resources can reduce emissions drastically. Dormer et al. (2012) showed by increasing the recycling rate of plastic trays for food packaging from 85 % to 100 %, the carbon footprint of the product was lowered by 24 %. Further, research by Raadal et al. (2016) expressed virgin raw material in PET production was dominating potential of eutrophication, abiotic depletion, and acidification, compared to recycled material. Stricter emission-requirements can therefore lead to higher demand of recycled plastic, in order for businesses to lower product related emissions. This can increase the plastic price, where larger income and reduced risk of the project are expected results of this.

Both analyses conducted in this Master's thesis expressed imapacts of establishing and operating a plastic reprocessing plant at Øra, compared to transport and reprocessing in Germany. Different levels of uncertainty were connected to the data of the two scenarios, as both generic and assumed data, and highly project specific data, were used. Working with this Master's thesis led to additional questions and areas which should be further studied. Expansion of the analyses could include a plastic market analysis, financial budget, solutions related to location, and added environmental effects. Especially three new questions can be addressed for future research:

1. What is potential supply and demand of reprocessed plastic in the Norwegian plastic market?
2. How can the environmental impacts of a plastic reprocessing plant operating at Øra be minimized?
3. What is the socio-economic benefit of a reprocessing plant operating at Øra, compared to transport and reprocessing in Germany?

8 Conclusion and recommendation

Amounts of plastic waste are expected to increase, leading to more plastic astray and potentially increased extraction of virgin raw materials. From 2025 it is estimated a plastic waste generation in urban cities of 22 million tonnes every day, and the consequences are considered a major global environmental problem. Sufficient plastic recycling systems are essential to avoid plastic astray and reduce extraction of restricted virgin raw materials. Plastic astray has negative impact on environments on- and offshore, and production of virgin raw plastic materials also leads to negative effects. The population is still too dependent on plastic to eliminate the use, as well as it serves an important function for many products. Using recycled plastic as raw material instead of fossil resources is an important step towards a sustainable society.

The change to a sustainable society must also take place in Norway. Improvements in the Norwegian plastic value chain is possible, by lowering GHG-emissions where possible. This research demonstrated significant GHG-reduction potentials by reprocessing HPW in Norway instead of current reprocessing in Germany.

The economic analyses presented Alternative 4 with a positive NPV of NOK 41,821,700. The net saving of tonnes CO_2-eq. from the LCA-analysis showed results from 15,304 – 72,914 tonnes during a 20-years life time, depending on el-mix used. With the positive NPV, the exact net environmental benefit of reprocessing HPW at Øra, compared to current reprocessing locations in Germany, will not impact the recommendation from this research.

The recommendation from this study is clear: A reprocessing plant processing HPW at Øra should be installed and operate the next 20 years.

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10 Appendix

10.1 Technology of plastic reprocessing

10.1.1 Washing line

With post-consumer plastic bales as input material, the washing line starts with a debaler breaking up compressed bales of approximately 1 tonne. The bales are placed on a horizontal feed belt into two separately driven rollers breaking up the bales and separating the plastic inside. Gear of the rollers are replaceable, and must be changed regularly due to high abrasion. Utterly pre-size reduction is not necessary for HPW (Opt. B supplier 2018).

A feeding conveyor transport the separated plastic from debaler into a wet shredder. The wet shredder knifes cut the material with simultaneous addition of room tempered water from a closed loop. The knives run under water on low speed to create fine particles and allow impurities to be washed away (Opt. B supplier 2018).

The HPW is following a discharge and dewatering screw, followed by a wash and conveying screw, leading the plastic to a pre-washer and heavy material separation. The pre-washer steps remove mainly metals following the plastic stream, as well as other contaminations (Opt. B supplier 2018).

Further follows a wet granulator with double cross cutters. The grinding process perform washing through friction once water has been added to the cutting chamber. Water protects the material and avoids screen blockage during the cutting process. Washed plastic falls into a dewatering screw, being separated from the dirty water (Opt. B supplier 2018).

To remove labels and other pieces of paper from the HPW, a friction washer is added in the washing line to centrifuge pulped paper pieces. A friction washer is a fast rotating shaft mounted with tilted panels. A mesh screen tunnel surrounds the shaft, and is used for dewatering and filtering small contaminants. Pieces of paper and cardboard are broken into small pieces and exit through the mesh screen. The remaining plastics are then mixed and washed. Water are continuously sprayed at the mesh screen, to prevent potential clogging (ASG Recycling ; Opt. B supplier 2018)

Closer to the end of the washing line is a separation tank. The tank use sink-float technology, which use water, possibly added a medium, to separate materials via densities. The tank is filled with water of $1 g/cm^3$ density. Any article with a density higher than $1 g/cm^3$ will sink to the bottom of the tank, while materials with a density less than 1g/cm^3 will float. This technology is useful in recycling of HDPP and PP, as it has a density around 0.93g/cm^3. Dirt, rocks and metals will sink to the bottom and be collected and removed via a conveyor system (ASG Recycling). The longer the material stays in the water, the more dirt will clear off the plastic, as well as it allows smaller particles to sink to the bottom. The separation tank is usually designed to ensure that turbulences is not disrupting the separation process of plastic and impurities. The second separation step consists of hydrocyclone systems, removing impurities of parts per million (ppm) range (ASG Recycling).

Household plastic with contaminants from food and glue from labels, are not necessarily removed with room temperature water in the wet granulator and friction washer. A hot wash step is carried out to remove the impurities, with water temperature of 60-80 degrees Celsius and use of caustic soda (NaOH) (Opt. B supplier 2018).

After plastic is washed, the material is mechanical dried using centrifugal force. A dewatering machine that uses centrifugal force removes water from the material, usually to about 20-30 %. The shaft can spin at nearly 1000 rotations/minute. Water is pressed out through a mesh screen tunnel, and collected for recycling. All freshwater circulates in a closed loop, where the water is collected, cleaned and then recirculated, to reduce amount significantly. The plastic moves to the next drying equipment, that usually is a thermal dryer (ASG Recycling).

A thermal dryer, where hot air is used to dry the plastic, is specially designed for PE and PET washing lines. Placed after the dewatering machine, the dryer reduce moisture to below 3 %. After dewatering, the plastic material is vacuumed and mixed with hot air in a long set of tubes that winds back and forth. Several thermal heaters may be positioned in a row, to ensure a critical moisture level. This depends on the capacity of the heater (ASG Recycling). Before further reprocessing, the flakes should have a moisture content less than 0.1 % (Worrell & Reuter 2014). The plastic is stored in five silos. PET is sold as flakes, while HDPE and PP goes into the extrusion line.

In a plastic granulator, cutting knives are mounted on an open rotor spun to high speeds by an electric motor. This rotor is encased in a cutting chamber where stationary knives are mounted. As the plastic scrap enters this cutting chamber, the rotating knives come in contact with the stationary knives cutting the plastic into little pieces. A large screen with many holes is placed at the bottom. The plastic will continue to mix and be cut by the knives until it is small enough to fall through this screen. Hence, by adjusting the size of the holes, one can control the size of the cut shreds (ASG Recycling).

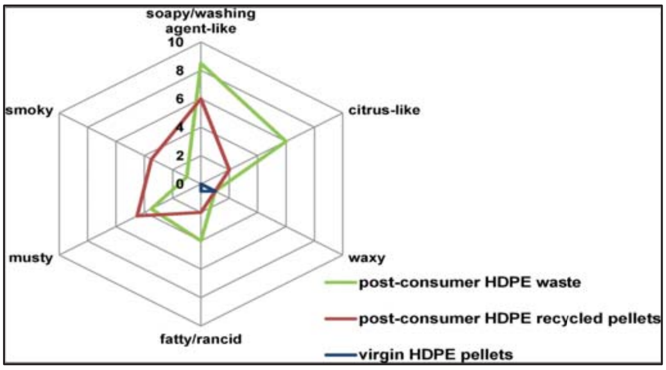
10.1.1 Extrusion

The reprocessing process can be performed by different technologies. The most common ones are agglomeration and extrusion to produce agglomerates and pellets respectively. This research investigated the extrusion process, producing the most commonly used recycled plastic material.

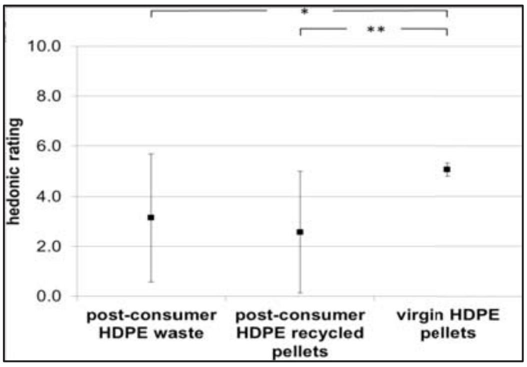
Extrusion is the most applied technique for reprocessing recycled plastic, especially when producing pellets of both virgin and recycled raw material. The material is blended in the hopper, and injected into an extruder. A rotating screw is placed in the extruder, which forces the plastic flakes forward to a barrel of 200-275 Celsius, naturally heated by friction of the plastic. Inside pressure of the barrel allows the plastic to mix and melt gradually while being pushed through the barrel. To remove oil, wax and lubricants is important in this phase, and the melt is therefore exposed to gas. To remove impurities, the molten plastic is pushed through a sieve, and then finally cooled by water and cut into pellets (Worrell & Reuter 2014).

With a single-shaft screw, the extruder can process only one polymer type. Then the reprocessing plant needs an extrusion line per polymer type processed. Some suppliers provide a combination screw, which can adjust the production after polymer processed. Supplier in Option A use a single-shaft screw, while supplier in Option B use a combination screw in their extrusion lines (Opt. A supplier 2018; Opt. B supplier 2018).

Odour is a common obstacle when seeking a high-quality recycled plastic. A recent study by Strangl et al. (2018) compared odorant composition of post-consumer HDPE waste with recycled and virgin HDPE pellets. The study revealed difference in odorant composition between recycled and virgin pellets, shown below in Figure 13.



Odour profile of post-consumer HDPE waste, recycled pellets and virgin pellets (Strangl et al. 2018)



Hedonic rating on a scale from 0 (strong dislike) via 5 (neutral) to 10 (strong like) of the smell of different HDPE (Strangl et al. 2018)

Figure 13: Odour profile and rating of post-consumer HDPE waste and pellets, and virgin HDPE pellets.

HPW typically develops tense odours, caused by contaminants adhering to the surface and migrated odour substances. The latter caused by food, cosmetics and cleaning packaging absorbing odour by the product inside. Thermal desorption when making HDPE pellets seemed to have a low decontamination efficiency of odorants, known as barrier for use of recycled plastic in new plastic products. To avoid this odour barrier, a refresher machine is included in end of extrusion line. As PET will end its process after washing, the polymer will not go through refresher (Opt. B supplier 2018).

10.2 LCA analysis results

Table 4: LCA-analysis results for Scenario 1 and the Rerefence Scenario, with different electricity mixes

Tons processed during life time	171 383							
km/trip	1 077							
tkm during life time	184 579 178							
	Norway, NO el-mi		**Norway, ENTSO-E el-r**		**Germany, ENTSO-E e**		**Germany, DE el-mix**	
Washing (kg CO2-eq/t)	202		324		324		387	
Extrusion (kg CO2-eq/t)	7		106		106		158	
Transport (kg CO2-eq/tkm)					89,3		89,3	
Washing (ton CO2-eq/life time)	34 632	97 %	55 481	75 %	55 481	62 %	66 405	61 %
Extrusion (ton CO2-eq/life time)	1 202	3 %	18 155	25 %	18 155	20 %	27 038	25 %
Transport (ton CO2 eq/life time)					15 304	17 %	15 304	14 %
Sum	35 834	100 %	73 637	100 %	88 941	100 %	108 748	100 %

Table 5: Comparison of the Norwegian (NO), German (DE) and ENTSO-E el-mixes with climate change characterization.

Element	Unit	Electricity, medium voltage| market for | Cut-off, U	Electricity, medium voltage | market for | Cut-off, U	Electricity, medium voltage (***market group for electricity, medium voltage ENTSO-E***)| market group for | Cut-off, U
Total of all compartments	kg CO_2 eq	0,0277	0,6457	0,4332
Remaining substances	kg CO_2 eq	0,0050	0,0172	0,0098
Carbon dioxide, fossil	kg CO_2 eq	0,0215	0,5849	0,3939
Methane, fossil	kg CO_2 eq	0,0012	0,0436	0,0296
Weighted		1	23	16

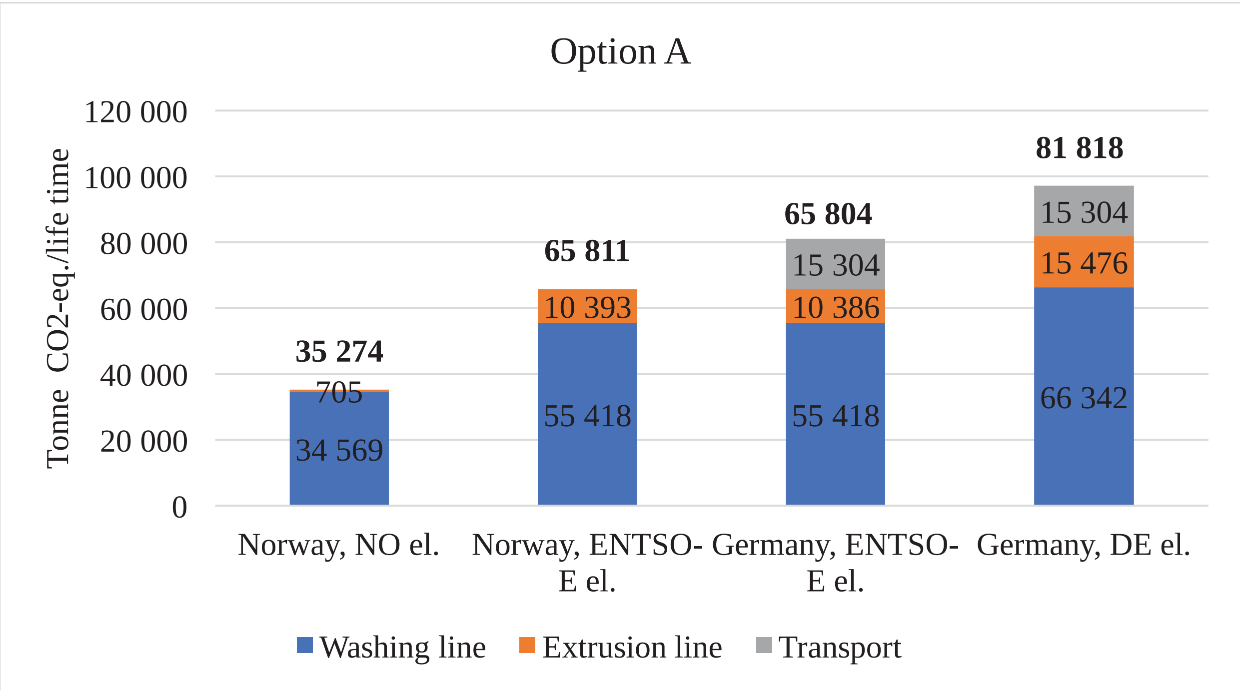


Figure 14: Emission of tonnes CO_2-eq. from retreatment processes of HPW during life time, given country and el-mix (SimaPro). Total emissions are presented above the columns.

10.3 NPV analysis extract (Alternative 4)

	Year 0 2020	Year 1 2021	Year 2 2022	Year 3 2023	Year 21 2041	Sum	Unit	Source
10.3.1 Data used in the NPV-analysis	Construction period		Operating period					
Population (qty)	289 358	292 338	295 122	297 933	345 524		Inhabitans	SSB, Mepex
Total household plastic waste given 6,5kg/inhabitant	1 881	1 900	1 918	1 937	2 246		tonnes	SSB, Frevar
Total household plastic waste given 13kg/inhabitant	3 762	3 800	3 837	3 873	4 492		tonnes	SSB, Frevar
Power price, incl. 2.06% expected price increase (excl. grid rent and consumer fee)	0,24	0,25	0,25	0,26	0,38		NOK/kWh	SSB, NVE
Electricity price (NOK/kWh)	0,99	1,02	1,04	1,07	1,71		NOK/kWh	SSB, NVE
HDPE pellet price	884	902	920	938	1340		€/t	plasticker.eu
PP pellet price	832	849	866	883	1262		€/t	plasticker.eu
PET flake price	364	371	379	386	552		€/t	plasticker.eu
HDPE bales price	248	253	258	263	375		€/t	plasticker.eu
PP bales price	208	212	216	221	315		€/t	plasticker.eu
PET bales price (€/t)	156	159	162	166	237		€/t	plasticker.eu
Water treatment cost	5	5	5	6	8		NOK/m3	2018 (IVA)
Fresh water cost	35	36	37	38	54		NOK/m3	2018 (IVA)
Workforce	676 260	689 785	703 581	717 653	1 024 985		NOK/FTE	IVA

	Year 0	Year 1	Year 2	Year 3	Year 21			
10.3.2 Production	**2020**	**2021**	**2022**	**2023**	**2041**	**Sum**	**Unit**	**Source**
TOTAL INPUT			**8400**	**8418**	**8712**	**171 383**	tonnes	
Household PP			3 192	3 199	3 316	65 125	tonnes	
Household PET			3 444	3 451	3 578	70 267	tonnes	
HDPE loss from washing and extrusion			*415*	*415*	*431*	*8 458*	tonnes	Trial tests
PP loss from washing and extrusion			*1 242*	*1 244*	*1 290*	*25 334*	tonnes	Trial tests
PET loss from washing			*995*	*997*	*1 034*	*20 307*	tonnes	Trial tests
TOTAL OUTPUT			**5 748**	**5 761**	**5 973**	**117 284**	tonnes	
Household HDPE			1 349	1 352	1 402	27 533	tonnes	
Household PP			1 950	1 955	2 026	39 792	tonnes	
Household PET			2 449	2 454	2 544	49 960	tonnes	

10.3.3 Sales

	Year 2	Year 3	Year 21		
	2022	**2023**	**2041**	**Sum**	**Unit**
HDPE pellets	11 298 506	11 549 539	17 101 746	280 422 124	NOK
PP pellets	15 368 666	15 710 130	23 262 457	381 441 035	NOK
PET flakes	8 441 952	8 629 517	12 777 982	209 524 166	NOK
TOTAL SALES	35 109 123	35 889 187	53 142 185	871 387 324	NOK

	Year 0	Year 1	Year 2	Year 3	Year 21			
10.3.4 Investments	**2020**	**2021**	**2022**	**2023**	**2041**	**Sum**	**Unit**	**Source**
Pre-engineering cost and project development	10 404 000							IVA
Transport and installation of all equipment	416 160							IVA
Cost building ground preparations	1 560 600							IVA: 333 NOK/m3
Cost of machinery CF (incl. VAT)		64 279 358					NOK	
Depreciations, 20% of rest value (excl. VAT)			10 284 697	6 582 206	148 218		NOK	
Rest value		64 279 358	41 138 789	34 556 583	2 238 424		NOK	

10.3.5 Variable costs

	Year 0	Year 1	Year 2	Year 3	Year 21			
10.3.5 Variable costs	**2020**	**2021**	**2022**	**2023**	**2041**	**Sum**	**Unit**	**Source**
Bales household PP			691 025	706 378	1 045 955	17 150 817	NOK	plasticker.eu
Bales household PET			559 184	571 609	846 398	13 878 622	NOK	plasticker.eu
Transport offtake			384 596	393 141	582 135	9 545 432	NOK	IVA: 134 NOK/t
Gate fee waste			2 870 116	2 933 885	4 344 291	71 234 565	NOK	IVA: 1000 NOK/t
Rental building (NOK/m^2)			721 614	736 047	1 051 256	17 533 328	NOK	IVA: 333 NOK/m2
Rental warehouse (NOK/m^2)			202 956	207 015	295 669	4 931 298	NOK	IVA: 75 NOK/m2
Leasing machinery to warehouse			135 304	138 010	197 112	3 287 532	NOK	IVA
Electricity cost			3 892 192	4 000 330	6 628 066	102 733 475	NOK	NVE, SSB
Water treatment cost			618 285	632 022	935 854	15 345 468	NOK	IVA
Fresh water cost			90 924	92 944	137 626	2 256 686	NOK	IVA
Personnel costs (operation) with 4 FTE			2 814 324	2 870 610	4 099 938	68 380 662	NOK	Protec S

	Year 0	Year 1	Year 2	Year 3	Year 21			
	2020	**2021**	**2022**	**2023**	**2041**	**Sum**	**Unit**	**Source**
Maintenance (10% of machine cost)			6 957 804	7 096 961	10 136 207	169 056 348	NOK	
Unexpected operating costs (5% of operating expences)			1 118 921	1 166 492	2 475 602	34 247 308	NOK	
TOTAL OPERATING EXPENCES	21 484 260	64 279 358	21 793 118	22 297 042	33 873 957	547 698 525	NOK	

	Year 0	Year 1	Year 2	Year 3	Year 21		
10.3.6 NPV-analysis	**2020**	**2021**	**2022**	**2023**	**2041**	**Sum**	**Unit**
CASH FLOW BEFORE TAX (CF_{bt})	-21 484 260	-64 279 358	13 316 006	13 592 145	19 268 228	323 688 799	NOK
Depreciations (-D)			10 284 697	6 582 206	148 218	49 185 063	NOK
Taxable income (CF_{bt}-TD)	-21 484 260	-64 279 358	3 031 308	7 009 939	19 120 010	274 503 737	NOK
Income tax			697 201	1 612 286	4 397 602	63 135 859	NOK
RESULT AFTER TAX	-21 484 260	-64 279 358	2 334 107	5 397 653	14 722 408	211 367 877	NOK
Depreciations (+D)			10 284 697	6 582 206	148 218	49 185 063	NOK
CASH FLOW AFTER TAX (CF_{at})	-21 484 260	-64 279 358	12 618 805	11 979 859	14 870 626	260 552 940	NOK
CF_{bt} incl depreciation rate (10%)	-21 484 260	-64 279 358	12 105 460	11 233 178	2 864 099	44 091 468	NOK
CFat including depreciation rate (7.7%)	-21 484 260	-64 279 358	11 716 625	10 328 097	3 372 991	**41 821 700**	NOK

10.4 Created processes in SimaPro

<table>
<tr><th></th><th>Amount</th><th>Unit</th></tr>
<tr><td>Input processes from Ecoinvent last edited 09.11.17</td><td></td><td></td></tr>
<tr><td>Washing of plastic (Germany), DE elmix</td><td></td><td></td></tr>
<tr><td>Tap water (RER)| market group for | Cut-off, U</td><td>2000</td><td>kg</td></tr>
<tr><td>Electricity, medium voltage (DE)| market for | Alloc Rec, U</td><td>300</td><td>kWh</td></tr>
<tr><td>Waste plastic, mixture (Europe without Switzerland)| treatment of waste plastic, mixture, municipal incineration | Alloc Rec, U</td><td>0,078</td><td>tonne</td></tr>
<tr><td>Waste paperboard (Europe without Switzerland)| treatment of waste paperboard, municipal incineration | Alloc Rec, U</td><td>0,225</td><td>tonne</td></tr>
<tr><td>Transport, freight, >32 metric ton, EURO6 (RER)| transport, freight, lorry >32 metric ton, EURO6 | Cut-off, U</td><td>1</td><td>tkm</td></tr>
<tr><td>Washing of plastic (Germany), ENTSO-E elmix</td><td></td><td></td></tr>
<tr><td>Tap water (RER)| market group for | Cut-off, U</td><td>2000</td><td>kg</td></tr>
<tr><td>Electricity, medium voltage (ENTSO-E)| market group for | Alloc Rec, U</td><td>300</td><td>kWh</td></tr>
<tr><td>Waste plastic, mixture (Europe without Switzerland)| treatment of waste plastic, mixture, municipal incineration | Alloc Rec, U</td><td>0,078</td><td>tonne</td></tr>
<tr><td>Waste paperboard (Europe without Switzerland)| treatment of waste paperboard, municipal incineration | Alloc Rec, U</td><td>0,225</td><td>tonne</td></tr>
<tr><td>Transport, freight, >32 metric ton, EURO6 (RER)| transport, freight, lorry >32 metric ton, EURO6 | Cut-off, U</td><td>1</td><td>tkm</td></tr>
<tr><td>Extrusion of plastic (Germany), DE elmix</td><td></td><td></td></tr>
<tr><td>Electricity, medium voltage (DE)| market for | Alloc Rec, U</td><td>350</td><td>kWh</td></tr>
<tr><td>Scrap aluminium (Europe without Switzerland)| treatment of scrap aluminium, municipal incineration | Cut-off, U</td><td>0,025</td><td>tonne</td></tr>
<tr><td>Extrusion of plastic (Germany), ENTSO-E elmix</td><td></td><td></td></tr>
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<tr><td>Scrap aluminium (Europe without Switzerland)| treatment of scrap aluminium, municipal incineration | Cut-off, U</td><td>0,025</td><td>tonne</td></tr>
</table>

Washing of plastic (Norway), NO elmix		
Tap water (RER)| market group for | Cut-off, U	2000	
Electricity, medium voltage (NO)| market for | Alloc Rec, U	300	
Waste plastic, mixture (Europe without Switzerland)| treatment of waste plastic, mixture, municipal incineration | Alloc Rec, U	0,078	
Waste paperboard (Europe without Switzerland)| treatment of waste paperboard, municipal incineration | Alloc Rec, U	0,225	
Washing of plastic (Norway), ENTSO-E elmix		
Tap water (RER)| market group for | Cut-off, U	2000	
Electricity, medium voltage (ENTSO-E)| market group for | Alloc Rec, U	300	
Waste plastic, mixture (Europe without Switzerland)| treatment of waste plastic, mixture, municipal incineration | Alloc Rec, U	0,078	
Waste paperboard (Europe without Switzerland)| treatment of waste paperboard, municipal incineration | Alloc Rec, U	0,225	
Extrusion of plastic (Norway), NO elmix		
Electricity, medium voltage (NO)| market for | Alloc Rec, U	350	kWh
Scrap aluminium (Europe without Switzerland)| treatment of scrap aluminium, municipal incineration | Cut-off, U	0,025	tonne
Extrusion of plastic (Norway), ENTSO-E elmix		
Electricity, medium voltage (ENTSO-E)| market group for | Cut-off, U	350	kWh
Scrap aluminium (Europe without Switzerland)| treatment of scrap aluminium, municipal incineration | Cut-off, U	0,025	tonne

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