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Plastic waste management in refugee camps: A case study from the Somali Region in Ethiopia

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Renewable Energy

Acknowledgements

This master’s thesis is written to finalize my master’s degree in Renewable Energy, under the MINA faculty at The Norwegian University of Life Sciences. My four years studying this has given me a valuable insight into all the different sources of renewable energy, the best ways to utilize these and how to recognize and consider both positive and negative aspects of implementing them into the energy system. Waste management is not per definition a renewable resource but is a very important resource to acknowledge in the transition into a more sustainable world. My motivation to write this master’s thesis is a belief in good waste management being important in all industries, and especially when working with renewable energy. If recycling secondary materials, the use of primary resources decreases. As a result the energy demand to process these primary resources is reduced, contributing to one very important measure, energy efficiency. I also wanted to write my thesis about something meaningful, such as providing better solutions for refugees.

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Abstract

Sustainable waste management is something that has only been studied and developed in a few refugee camps in the world. This thesis, and the project it has been written through, aims to improve the waste management system in some refugee camps by creating value both financially and economically for refugees. The thesis aims to answer the research question "*What are the impacts of implementing plastic recycling in refugee camps, primarily focusing on environmental and financial impacts, and what system can be recommended for the camps in the Somali region in Ethiopia based on these considerations?*"

This question has been explored through material flow analysis, financial analysis and a Life Cycle Assessment of the recycling system planned through Engineers Without Borders' fieldwork during the summer of 2018. Plastic waste amount estimates could be provided for PET and HDPE. The 433 000 inhabitants in the whole area, including refugees, villagers and city inhabitants, probably produce about 89 tons of HDPE and 7 tons of PET per month. HDPE is today being recycled in Addis Ababa, while PET is being dumped in open landfills and burned. The exact products chosen to analyse in this study were flower pots and rooftiles. The environmental analysis proved that production based on PET and production of flower pots are the two most feasible choices when evaluating greenhouse gas-emissions. Production of rooftiles from HDPE will most likely contribute to a net increase of greenhouse gases in the atmosphere. Within the other impact categories, the results pointed in different directions, and so did not point out a clear conclusion. The results from the main financial analysis revealed a negative annual result, by several millions of Ethiopian birr, if producing only rooftiles, but a positive annual result if producing only flower pots. However, there is a restriction of 5000 flower pots sold for the price assumed in the analysis. The analysis also showed that production using HDPE was more financially viable than using PET.

When combining these results, and considering other aspects such as possibilities of making PET closer in financial viability to HDPE, in addition to the positive consequences for the refugees by reducing the amount of PET being burned close to the camps and the remaining debris, the conclusion of the thesis is that introducing systematic recycling of only PET, moulded into flower pots, would be the best solution for these camps.

Sammendrag

Det har foreløpig ikke blitt etablert eller forsket på bærekraftige avfallssystemer i flyktningleirer i noen særlig grad. Denne masteroppgaven og prosjektet den har blitt skrevet gjennom bidrar til at dette feltet blir mer opplyst gjennom å analysere og vurdere økonomiske og samfunnsøkonomiske konsekvenser av å resirkulere plast i flyktningleirer. Forskningsspørsmålet som har blitt besvart gjennom oppgaven er *«Hvilke innvirkninger har plastresirkulering i flyktningleirer generelt og spesielt med fokus på miljøet og økonomisk lønnsomhet, samt hvilket system kan bli anbefalt for flyktningleirene i Somaliregonen i Etiopia med hensyn til dette?»*

Dette spørsmålet har blitt utforsket gjennom materialstrøm-, kost-nytte- og livsløpsanalyse av dagens system og resirkuleringssystemet som ble planlagt av Ingeniører Uten Grenser etter feltarbeid sommeren 2018. Estimater for mengden av HDPE og PET i omløp i områdene ble anslått til henholdsvis 89 og 7 ton for de 433 000 innbyggerne som bor i både flyktningleirene og vertsbyene. I dag blir HDPE-plasten resirkulert i Addis Abeba, mens PET blir brent på ukontrollerte deponier nær bebyggelse. Produktene basert på den resirkulerte plasten som er brukt i analysen er blomsterpotter og takplater. Livsløpsanalysen viste at produksjon av blomsterpotter og produksjon med PET er de to beste valgene med hensyn til klimagassutslipp. Produksjon av takplater fra HDPE vil på den annen side sannsynligvis føre til en økning av klimagassutslipp fra systemet som helhet. Andre påvirkningskategorier ga varierende svar for hva som ville være den beste løsningen. Resultatene fra den bedriftsøkonomiske analysen viste at systemet med forutsetningene i grunnscenariet ville føre til et årlig tap på flere millioner Etiopiske birr ved produksjon av kun takplater, men en gevinst ved produksjon av kun blomsterpotter. En høy gevinst ved produksjon av kun blomsterpotter er dog ikke realistisk, da UNHCR kun kan kjøpe 5000 blomsterpotter i året til den gitte prisen. Analysen viste også at produksjon med HDPE var mer lønnsomt enn PET med antakelsene gitt i hovedanalysen.

Konklusjonen er at ved å sammenstille de nevnte resultatene i tillegg til å vurdere aspekter som kan gjøre PET nær like lønnsomt som HDPE, samt å inkludere de positive konsekvensene resirkulering av PET vil ha på lokalsamfunnet gjennom reduserte utslipp fra forbrenning og mindre plast i lokalmiljøet, vil opprettelse av et resirkuleringssystem kun for PET være det mest lønnsomme. Produksjonen bør i første omgang være av blomsterpotter, men også andre produkter med samme økonomiske og miljømessige substitusjonsverdi bør vurderes.

Abbreviations and definitions

(RoW) – Rest-of-the-World, geographical area used in SimaPro process cards, including average travel distance of materials within that area.

(GLO) – Global, geographical area used in SimaPro process cards, including average travel distance of materials within that area.

ARRA – Agency for Refugees and Returnees Affairs, Ethiopia. The UNHCR counterpart when it comes to operation of refugee camps.

Donkey cart – Donkey pulling a cart, transportation vehicle used for short distances

Ecoinvent – Database used in SimaPro modelling

ETB – Ethiopian birr

EU ETS – European Union Emission Trading Scheme

EWB report - The report written by UNHCR and Engineers Without Borders after fieldwork in the summer of 2018

kgkm – Transportation of 1 kg for 1 km. Used in Life Cycle Assessments to allocate emissions from transport to the goods.

HDPE – High Density Polyethylene

Implementing partner – A humanitarian organization contracted by UNHCR (or others with operation responsibilities) to be responsible for one field of operation in a certain time period

IRC – International Rescue Committee, one of the Implementing Partners in the area

LCA - Life Cycle Assessment

MSWM – Municipal Solid Waste Management

NRC – Norwegian Refugee Council, one of the implementing partners in the area.

PAH – Polycyclic aromatic hydrocarbons

PET – Polyethylene terephthalate

UN – United Nations

UNHCR – United Nations High Commissioner for Refugees (The UN Refugee Agency)

USD – Unites States dollar

WASH – Water Sanitation and Hygiene (UNHCR, 2018n)

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1 Introduction

1.1 Plastic use in the world today

Plastic is a lightweight material which is easy to form and keeps its shape over a long period of time, and has therefore become an important material in the modern society, as many products are made of this material (PlasticsEurope, 2018b). In many cases, use of plastic products is therefore the best option both financially and environmentally, if managed correctly after use (Franklin Associates, 2014). However, this is not always the case.

The last couple years, plastic pollution in the environment and in the oceans has become a problem emphasized heavily in the media. This attention has contributed to extensive research on the subject, both about possible impacts of plastic in the environment and how to prevent plastic from ending up there. Machines that collect plastic from the ocean have been developed, and people collect plastic waste on beaches. This plastic waste has long been regarded as waste that cannot be utilized for anything other than energy production, but more and more initiatives aim to actually utilize this resource. In Norway, for example, there is a project called “Håpets katedral” (Eng.: Hope’s Cathedral), which aims to both show that the plastic picked from the beaches can be utilized in products, and to be a symbol of the fact that when people are working together, nature and oceans can be preserved (Den Norske Kirke, 2018). Recycled plastic will be utilized as a medium for plastic murals on the church ceiling. Even though this attention and the initiatives are very good, it is important not to forget to tackle this problem by its roots and to initiate projects and develop infrastructure to minimize plastic litter in the environment, and the oceans.

Plastic has been produced since the beginning of the 20th century and has become a staple material in the last fifty years. At the beginning of 2016 more than 5.8 billion tons of virgin plastic had been produced, and almost 80% of that plastic had already ended up in nature or in landfills, while additional 0.35 billion tons were produced in 2017 (Geyer et al., 2017; PlasticsEurope, 2018b). Based on numbers in the article by Geyer et al. (2017), 9% of the total produced plastic has been recycled, which has probably given a reduction of about 500 million tons of virgin plastic from fossil resources.

Landfilling is in many places the common way to deal with waste. If landfilled, the plastic do not decompose (Cherubini et al., 2009), and do not contribute to greenhouse gases in the atmosphere, but will in the long run contribute to chemicals in leachate water, because of additives in the plastics (Teuten et al., 2009). Some of the additives, such as plasticisers have an impact on animals reproduction (Oehlmann et al., 2009). Also, the plastic will slowly divide into increasingly smaller pieces over time (Hopewell et al., 2009). Over 260 species have been found to either ingest or get otherwise damaged by plastic debris, and it can lead to less nutritional intake and injuries for wild animals (Thompson et al., 2009). This is an important reason to seek out alternatives to landfilling.

To reduce the amount of plastic ending up in nature or landfills, the best solution will be to decrease the use of plastic where feasible, while the second best solution is to reuse the plastic and third best is to recycle it (Council Directive, 1975). These measures will of course have the largest impact in countries and societies with low recycling rates and high plastic use and can as a whole have a considerate impact on virgin plastic production in a global perspective.

1.2 Refugees and need for plastic waste prevention

There is good reason to believe that refugees, both within and outside refugee camps, in general have access to poor waste management. Often, this entails open dumps, meaning uncontrolled landfills (ISWA, 2012), using open burning, “where smoke and other emissions are released directly into the air without passing through a chimney or stack” (Guendehou et al., 2006). According to the United Nations (UN) Global Trends report, there are 68.5 million forcibly displaced people in the world (UNHCR, 2018g). 25.4 million out of these are refugees. The UN has two agencies for refugees, called United Nations High Commissioner for Refugees United Nations High Commissioner for Refugees (UNHCR) and The United Nations Relief and Works Agency for Palestine Refugees (UNRWA). UNRWA is responsible for Palestinian refugees, while the rest is under UNHCR’s mandate. More than 85% of the refugees in the world are according to the UN hosted by developing countries, 6.3 million alone in Sub-Saharan Africa (Nations; UNHCR, 2018g; UNRWA, 2018). (UNHCR, 2018g). It is likely that more than 30% of the refugees in the world live in refugee camps ((UNHCR, 2017, p. 192).

The literature states how many regions in development countries and especially countries classified as least developed countries by the UN (2018) dispose of their waste in open landfills

(Bundhoo, 2018; Hoornweg & Bhada-Tata, 2012). Bundhoo (2018) found recycling rates in cities and countries in the least developed countries varying between 5% and 15%, while LDCs' total recycling rate is 26%. Thus, there is a large potential for an increase of this recycling rate, by targeting refugee camps. In addition to this, Sub-Saharan Africa, East Asia and the Pacific is claimed to have the highest portion of plastic in the municipal solid waste in the world, with a 13% ratio of all the waste (Hoornweg & Bhada-Tata, 2012). On the other hand, IPCC estimated that only 5.5% of the total waste was plastic in eastern Africa in 2006 (Pipatti et al., 2006). This shows that the proportion of plastic waste in the area has either risen very quickly, or there are big uncertainties in the numbers.

The facts presented in this chapter show that there are many refugees in the world living in camps using open landfills for waste. If waste prevention could be achieved through for example recycling, this would contribute to less waste in their local environments, and it could give opportunities for jobs and the feeling of a new start in a new country. As principles in a circular economy, using the same materials several times has proven to be desirable in many other communities and situations, it can surely be feasible in refugee camps as well, if implemented correctly.

1.3 The UN waste to value project, in the world and in Ethiopia

UNHCR has found prevention of waste and recycling of waste to be an important measure to emphasize in the operation of refugee camps. During the spring of 2018, the UN and Engineers Without Borders Norway started a cooperation for an initiative to create value out of waste for refugees living in camps. The initiative would include 5 different countries as a start. These 5 projects are to be evaluated after the project period to see if similar projects would be feasible in other camps as well, even in other parts of the world. The aim of the initiative is to assess plastic waste amounts in the refugee camps and find good reuse and/or recycling solutions which contribute to a positive environmental impact and an income generation for the refugees. This thesis is a part of this initiative, specifically in the project concerning 8 refugee camps in Ethiopia. All these camps are localized within two different operations called the Melkadida and Jijiga camps. In February 2019 the Norwegian Retailer's Environment Fund (Handelens Miljøfond) donated approximately 7 M Ethiopian birr to this recycling project, and as such the results of the thesis can contribute to making evidence-based choices during the implementation of the project.

One article or one project can never change the whole world's use of plastics, but by addressing the problems project by project and location by location, it can result in substantial improvements over time. This master's thesis is aiming to give input to a project in a society with the bare minimum of organizational infrastructure in place to invest in systems to reduce plastic waste, without the need of the introduction of any country regulations, as would probably be necessary to reduce this problem in a global context. Instead, by looking at refugee camps, examples can be set and other refugee camps and similar societies can be inspired, if the project proves to have positive effects. Refugees must often stay in refugee camps for several years (Salehin et al., 2011). As they are often placed in big camps, it would be reasonable that waste is managed properly, to hinder health risks for the inhabitants, and to create a safe home for these people, as well as creating jobs for them.

1.4 Current state of refugees and waste management in Ethiopia

This case study encompasses all the refugee camps in the Somali region in Ethiopia. Ethiopia is especially interesting in this matter, as it was the country in the world hosting ninth most refugees globally in 2017, with a refugee population of almost 900.000 by the end of the year. (UNHCR, 2018g) Ethiopia adjusted its laws in January 2019 to give refugees more rights, such as opening bank accounts and getting work permits (UNHCR, 2019). According to UNHCR this makes Ethiopian politics regarding refugees the most progressive in Africa, which will probably make the integration of waste management systems with a local workforce easier. This can set a good example for other countries considering a similar strategy.

Ethiopia is also forward-thinking regarding waste management. In 2007, the government of Ethiopia made a proclamation about solid waste management, to " […] enhance at all levels capacities to prevent the possible adverse impacts while creating economically and socially beneficial assets out of solid waste." (SWM Proclamation Ethiopia, 2007). The directive aims to limit regional transportation of waste unless it will be recycled or disposed of in an environmentally friendly way. It also states that a new directive will prohibit plastic bags which are not marked as biodegradable or non-biodegradable, and it prohibits production and import of non-biodegradable plastic bags thinner than 0.03 millimetres. Each household also has a responsibility to segregate recyclables and bring it to collection sites, and the urban administration staff has a responsibility to do environmental impact assessments when modifying or opening new disposal sites. Still, according to Lohri et al. (2014), the proclamation is not "actively enforced", but still, one would believe that initiatives that aim to follow these regulations are beneficial and sought after all the same. According to Regassa et al. (2011) the recycling rate in Addis Ababa, the Ethiopian capital, was about 5% in 2003. There are industries there which buy recyclables from other cities in Ethiopia (Lohri et al., 2014).

1.5 Relevant principles and goals

The waste hierarchy with a priority to reduce waste and to reuse waste before recycling it, is an important measure to take into account when making a waste management system as sustainable as possible (Laurent et al., 2014). The principles of the waste hierarchy was stated in Article 3 in the European Union Directive on Waste in 1975 (Council Directive, 1975), and the use of the term waste hierarchy and a clear order of priority to follow when working with sustainable waste systems was done in the revised directive from 2008 called "Directive on waste and repealing certain Directives" (2008). Therein, Article 4 states that:

> The following waste hierarchy shall apply as a priority order in waste prevention and waste management legislation and policy:
>
> (a) prevention,
> (b) preparing for re-use,
> (c) recycling,
> (d) other recovery, e.g. energy recovery; and
> (e) disposal

This hierarchy shall apply as long as Life Cycle Assessments do not prove otherwise. This is important, as it is found in plastic waste LCA study reviews that, with too much contamination in the plastics and too low quality on the end product, the next steps in the waste hierarchy can prove to be preferable in a life cycle perspective (Lazarevic et al., 2010). Even though Ethiopia is not subject to this directive, the overall principles are still important.

In 2015, the United Nations determined 17 goals called the "Sustainable Development Goals" to promote sustainable development on all levels in the economy and the world (Nations, n.d.). A recycling project in refugee camps fulfils many of the goals, as can be seen in the pyramid in Figure 1.

Figure 1: Illustration of the Sustainable Development Goals possibly impacted by plastic waste management, Photo: Anna Østby

2 Goal of study, research questions and limitations

2.1 Goal of the study

The goal of this study is to provide valuable information to the waste to value-project in Ethiopia initiated by UNHCR, and to other similar initiatives in refugee camps and other remote areas. This analysis will use data collected through the project in Ethiopia, and some of the results received from the project, and will evaluate these, considering both financial and environmental feasibility. The analysis will explore which measures are most important and will strive to suggest good solutions where financial and environmental measures, as well as social factors, interact harmoniously instead of being of conflicting interests.

2.2 Research question

The main research question of the thesis is:

What are the impacts of implementing plastic recycling in refugee camps, primarily focusing on environmental and financial impacts and what system can be recommended for the camps in the Somali region in Ethiopia based on these considerations?

This question will be investigated through a case study of refugee camps in Ethiopia. To resolve the question, 3 research questions will provide answers shedding light upon the main research question:

1. What quantities and types of plastic is passing through or ending up in the refugee camp areas?
2. What are the environmental impacts of such a project?
3. Will the project be financially viable using means such as loans, external funding and/or other schemes, and how will these choices impact the results?

2.3 Preconditions and limitations of the analysis

Figure 2 shows the scope of the whole analysis, and system borders for the Life Cycle Assessment and financial analysis.

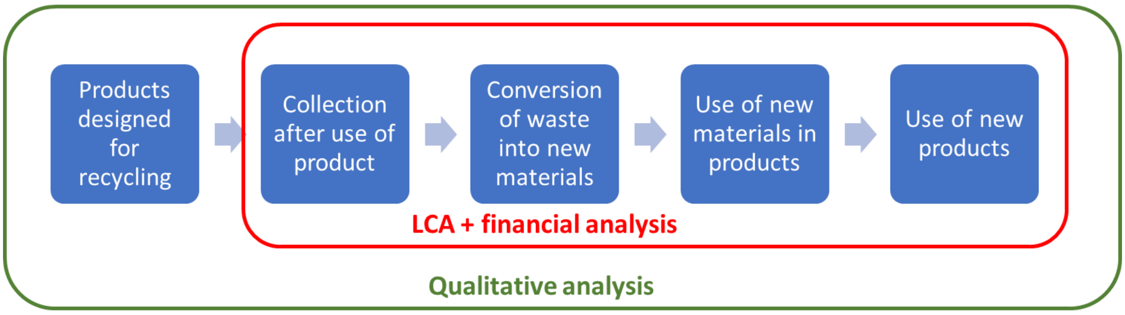

Figure 2: Flowchart showing important stages in a recycling system and system borders of this analysis, based on the principles of implementing recycling from Ragossnig and Schneider (2017)

The preconditions for the analysis are as listed below:

- With the recycling pyramid in mind, prevention of the use of plastic and the reuse of plastic are prioritized higher than recycling. So, outside the scope of this study it is important to consider these strategies. Still, since they are outside the chosen scope, the focus will henceforth be on the recycling of plastic.
- Only plastic types abundant in large amounts in the camps will be included in the analysis, in order for a large-scale system to be justified. The plastic waste fractions to be analysed are bottles made of PET and jerrycans made of HDPE. Plastic bag amounts have been assessed during field work, but the results are of such a quality that analyses cannot be based on them.
- Host communities and cities near the refugee operations are included, as plastic is generated there too, and their plastic will be as valuable as any other plastic. Jijiga city is excluded from this, as there is a solid waste management business which plan to start with recycling there.
- The baseline for this project is that it should be as technologically simple as possible to implement, so that it can run smoothly without highly specialized staff.
- With regard to the aforementioned point, it is assumed that mechanical recycling will be the best choice in the camp (See reasoning in Appendix C).
- For the financial analysis, project development costs are disregarded, as this is already part of the development, and other parts of the development is happening in parallel with the writing of this thesis. Therefore, this represents sunk costs at the moment when a decision must be made.
- Economic feasibility, which includes costs and benefits for the whole society, will not be analysed as a main factor, but will be commented on in the discussion.

3 Literature review of plastic and waste management, with a special focus on refugee camps

3.1 Scope of the literature review

Troschinetz and Mihelcic (2009) identified 12 factors that can influence the recycling of municipal solid waste in developing countries and the sustainability of the system. These measures are identified both on a national and local level, and several of which are also important for the sustainability of the system in refugee camps. Factors that have been discussed with relevance for refugee camps are:

- waste characterization
- waste collection and segregation
- household education
- household economics
- MSWM administration
- MSWM personnel education
- MSWM plan
- local recycled-material market
- technological and human resources
- land availability

Some of these factors have been studied in refugee camps, but a comprehensive analysis of one single waste management system with regards to many of these factors has not been done much before (Regattieri et al., 2015). Waste characterization and other factors impacting this will be investigated through the literature review, where studies including this has been found. Socio-economic aspects and collection methods have not been assessed deeply in this section, as it will not be analysed as part of the environmental or financial analysis. Further input on the matter can be found in Appendix F.

Several studies emphasize the fact that poor waste management in refugee camps can be a threat to both humans and nature (Garfì et al., 2009; Kinyanjui & Barasa, 2002; Regattieri et al., 2015). Already in 2002, a study pointed out that waste from refugee camps may cause big damages to the local environment around refugee camps, especially since they are often established in environments not yet accustomed to human influence (Kinyanjui & Barasa, 2002). Garfi et al.

stated in 2009 that in addition to impacts on the environment, human health can also be hurt by all the packaging rations coming into refugee camps from humanitarian organizations (Garfì et al., 2009). Regattieri et al (2015) pointed out that while waste can cause problems in refugee camps in regard to environment and health, it may also give opportunities in regard to reuse, recycling or power generation (Regattieri et al., 2015). Hence, this is an important issue, and every contribution to improving waste management systems in refugee camps is valuable.

The database Web of Science has been used to find relevant articles by searching for the keywords “refugee” AND “waste” in the core collection. 83 results were found, where 9 of the papers had titles indicating a relevance to the study. After a thorough investigation of those 9 articles, only four were found to deal with waste management in refugee camps, while the rest had a main focus on latrine waste. The four relevant articles were further used to find other relevant articles. As a conclusion, there seems to be quite few studies on waste management in refugee camps. In the literature review also the use of Life Cycle Assessment in waste management decisions, different methods of assessing comprehensive waste management and the feasibility of recycling the different plastic types will be emphasised. The research found through this literature study is described in the following chapters.

3.2 Waste amounts and management in refugee camps

3.2.1 Plastic waste amounts in refugee camps

To best evaluate a new waste management system in a refugee camp, it is important to know what types of waste fractions and what amounts of waste the system should be able to handle, specifically plastic waste in this instance. If a thorough analysis of the waste cannot be done in the refugee camp in focus, results from other similar camps can indicate what amounts can be expected. Saidan et al. (2017) analysed the waste composition in the Zaatari Refugee camp in Jordan in 2015, finding that 13% of the 0.85 kg solid waste produced per person per day was plastic. Segregation of this and other fractions would be feasible, according to the study (Saidan et al., 2017). When the waste composition was analysed in 2015, it had been three years since the establishment of the camp. This is important because the waste composition might differ according to the ages of the camps. The seasonal variation from March to November did not have a significant influence on the waste fractions, but it was found that other local variations in living conditions probably affect the composition more (Saidan et al., 2017). The waste composition analysis is the most thorough of its kind stated in literature, and this study will therefore be used as a reference for this master's thesis. After this analysis was carried out, a humanitarian organization called Oxfam initiated a recycling project in the same camp, where different materials are being separated in households and picked up by project workers (Oxfam GB, 2017). The refugees' and the host community's knowledge about the local conditions and technical solutions was used to start the project. Materials are sorted and processed, and then sold to recycling facilities. This initiative does however have a highly negative result, as there are many employees, and shredded material is sold cheap (E-mail: Cathrine Eckbo, Mission Engineer, 15.05.19). Cathrine Eckbo's description of the camp compared to the Ethiopian camps is cited in Figure 3. She is an engineer through Engineers Without Borders, Norway, and has been on mission in both areas.

Zaatari is a very different camp compared to the Ethiopian camps. In Zaatari they have a big supermarket where they can buy most foods, and as such most of the waste from the camps is wet organic waste, similar to other cities in developing countries. In the camps in Ethiopia, on the other hand, they do not have as much accessible food, and as such there is not much wet organic waste.

Another difference is that there are much closer ties between the refugees and host communities in the Ethiopian camps than in Zaatari. In Zaatari there are high fences around the camp that separates the Syrian refugees from the local Jordanians. The camp is also far away from the closest city, as opposed to the Ethiopian camps, where all the refugee camps are neighbouring the host communities.

Figure 3: Comparison of the Zaatari Refugee camp and the Ethiopian camps, Citation of Cathrine Eckbo, 15.05.19.

Even though no other waste composition analyses from refugee camps are described in literature, one other relevant estimate has been found in regard to plastic waste in refugee camps. According to Regattieri et al., (2015) the World Health Organisation stated in the article "Communicable disease control in emergencies – a field manual" from 2005 that refugees in camps typically produce 0.08 kg plastic/person/day, while the other waste fractions add up to 1.09 kg/day. These numbers are not found in the original article by the author, so they must be treated with a degree of uncertainty.

3.2.2 Waste amounts and end of life management

As there are few estimates of plastic production in refugee camps, also studies which have assessed total waste generation amounts have been included in this literature review. This is to find a basis for comparing this study's estimates and those of other refugee camps, putting the waste amounts into context.

A comparative article from Palestine in 2007 assessed waste management in seven Palestinian districts, and therethrough also touches upon two refugee camps. In these camps, the households' solid waste was picked up from all households by a collection service. The analyses are based on interviews with individuals working with municipal solid waste management in the different areas, in addition to observations of the waste and the management. Monthly waste generation in the two camps were 0.40 kg/person/month and 0.64 kg/person/month. The amounts for the villages and cities were slightly higher and much higher with averages of 0.65 and 1.51 kg/person/month respectively. One of the refugee camps produced only 20% of one of the cities. The differences are proposed partly due to using some of the waste as animal feed in the districts. In one of the camps, all the waste was discarded in "open random dumps outside the boundaries of the residential area with waste burning", and in the other camp half of the waste was treated this way, while the rest was put in "semi-covered dumping outside the boundaries of the residential area". There were no recycling or reuse programs in the camps or other districts. In general, more people (per thousand inhabitants) were working with municipal waste management in the refugee camps than in the villages, even though the same job was done. The proposed reason for this is to give more people work through "emergency employment programs". At the same time there were fewer vehicles in use for waste management in the refugee camps. (Al-Khatib et al., 2007)

Another research paper applied multi-criteria decision analysis to propose a good solid waste management system in Saharawi refugee camps in Algeria. In one of the camps, they estimated an amount of 0.15 kg solid waste/person/day, where 90% of it was packaging materials. At the time when the article was written, the waste in the camp was picked up from households by two trucks, disposed 3 km outside the camp, and burned. The four solutions evaluated had variations of using trucks and/or tippers, and dumping the waste in an open area and burned, or in a landfill. One of the conclusions was that open landfill without burning was better than with burning, as it had a lower negative environmental impact and fewer health risks. (Garfì et al., 2009)

The trend seen in these articles, with open waste dumping with or without burning close to camps, is according to Regattieri et al. (2015) the standard way of waste management in refugee camps. Recycling is however highlighted as good practice, although this practice has not been described in any of the camps reviewed in the literature. It is possible that refugee camps which have not been studied recycle more, but it is unlikely. One paper about a solid waste crisis in an area called Sur in southern Lebanon in 2012 indicates that after the crisis the camps in the area were allowed to transport their waste to a new recycling plant (Stel & van der Molen, 2015).

3.2.1 Recycling in camps

The approach of reuse and recycling of plastic in refugee camps is not ground-breaking, as this was emphasized in a research article already in 2002. A plastic recycling initiative in the Daadab refugee camp was evaluated by Kinyanjui and Barasa (2002), and they emphasized that both for the environment and for the income of the refugees, refugee camps should start recycling and reusing plastic as soon as they have been set up. During a 15 months period from 2000 to 2001, 80 tons of plastic bags and sheets were cleared from the environment and woven into mats sold to CARE Kenya, who were in charge of the project. CARE Kenya was the implementing partner for waste and sanitation, and a regulatory change in Kenya had just made recycling and reuse of waste into a part of waste sanitation in Kenya, giving an extra incentive to implement this as part of the waste management system (Kinyanjui & Barasa, 2002). In the same camp, a new initiative was started in the end of 2016 where members of the refugee camp and host community collect plastic waste, and processes it before selling shredded plastic to recycling facilities (International Committee of the Red Cross, 2018). The initiative aimed to reduce plastic litter in the local environment and improve local health condition, and during the first one and a half year, 8 tons of plastic have been processed.

As the literature study has not discovered abounding amounts of relevant papers covering recycling projects, newspaper articles and information from aid organization have been used to create a picture of the state of the waste management systems of today. When using the terms “recycling”, “refugee”, “camp” and “plastic” in different configurations in common search engines, several articles describing relevant initiatives have been found. Most initiatives deal with women in refugee camps crafting new products of plastic or men collecting and selling plastic (International Committee of the Red Cross, 2018; McKinsey, 2003; UNHCR Lebanon, 2015), but it is hard to find any information about recycling in any refugee camps using machines. There have been projects where plastic has been woven into different products

(McKinsey, 2003), sorting and selling it to recycling companies (UNHCR Lebanon, 2015), or even shredding before selling (International Committee of the Red Cross, 2018), but none where the products are recycled and made into new products, using machines within the camps.

Some initiatives have also aimed at construction of houses within refugee camps. This has both been done by using filled PET-bottles and by recycling bottles into plastic bricks (Fraser, 2017; Messenger, 2017). By actually doing the reuse or recycling inside the camps, the knowledge and awareness about recycling for people living in and around the camps increase, in addition to granting an income to the refugees working with the recycling in the camps. When knowledge like this spread, it can also reach camps far away from recycling plants, so that they also get an initiative and opportunity to recycle.

3.3 LCA in waste management decisions

Life Cycle Assessment (LCA) is a decision-making tool that evaluates environmental- and resource impacts of a system, such as potential impact through greenhouse gas emissions, eutrophication, acidification etc., often compared to another system using the same input materials (Ekvall et al., 2007; Finnveden et al., 2009; Hauschild & Barlaz, 2010). Life Cycle Assessment has since the 90s been used to analyse simple and more sophisticated waste management systems (Goedkoop et al., 2013; McDougall et al., 2001, p. 104). A standard Life Cycle Assessment evaluates the potential impacts from cradle to grave of a product, while Life Cycle Assessment for waste management systems only evaluates the impact of the waste management from the point where a material is considered waste (Hadzic et al., 2018). Different ways to manage the waste, such as end disposal or production of new products with a new life cycle, are possibilities in this evaluation (Cleary, 2009; Hadzic et al., 2018). The energy and materials used in the waste management should be allocated to the waste management, while also the substitution of virgin products can be allocated to the material if made into a product no more considered as waste (Hadzic et al., 2018).

It has been emphasised that today there is a broad understanding that mechanical recycling has positive impacts on the environment, and as such the importance of Life Cycle Assessments is rather to establish the exact benefit, and finding the optimal system (Laurent et al., 2014; Michaud et al., 2010; Ripa et al., 2017). To accomplish this, local data should be used in the analysis (Ripa et al., 2017). LCA reviews have found that local variations such as waste amounts, source of energy and material loss during recycling are the most important factors as to why results from different LCA studies vary (Laurent et al., 2014). All processes omitted from Life Cycle Assessments shall in accordance to ISO 140444 be stated and explained (ISO, 2006). A comparative analysis of municipal waste management systems reviewed with LCA by Clearly (2009) emphasized that even though several studies omit transportation from the analysis, another study had found that transportation had more impact on the analysis than factory and machine infrastructure. Important contributions to the methodical approach to use LCA in waste management systems have been given by among others Clift et al. (2000), Finnveden et al. (1999) and Finnveden et al. (1995), and it has thereby been methodically standardized.

A Life Cycle Assessment of a waste management system may include the full value chain of producers and importers of plastic to optimize the extent and types of plastic being used, and increase recycling rates (Milios et al., 2018). More on this, packaging optimization and feedback loops can be found in Appendix D.

3.4 Applicability of development of solid waste management systems in developing countries

In development of municipal solid waste management systems in developing countries, it has been emphasised that multi-criteria decision analyses are appropriate tools to ensure a sustainable development (Aghajani Mir et al., 2016; Ferronato et al., 2019). Ferronato et al. (2019) evaluated several systems in La Paz, a big city in Bolivia, using five different factors; Environmental protection, economic feasibility, social inclusion, technological suitability and management requirements. The latter mainly addressed the implementation time of a system. The financial sustainability was identified as the biggest barrier against this development. Among other things, they found that investment costs are often a barrier for implementation of new waste management systems in developing countries, but also that recycling of for example plastic improved the financial state of the systems.

A study about waste management in Bahir Dar in Ethiopia, revealed some other interesting facts on the matter of implementing a recycling system in this country (Lohri et al., 2014). A cost-revenue analysis revealed that the main income for the waste collection company was collection fees paid by households and companies and that transportation was a critical factor in this system. The maintenance costs of the trucks were more than 1200 USD/year. As in many other developing countries, informal collection of recyclables and sales of this to Addis Ababa had been observed in Bahir Dar. Several studies have concluded that inclusion of the informal sector into the formal sector could increase the financial, economic and technologic feasibilities (Ferronato et al., 2019; Kamran et al., 2015).

3.5 Plastic types and their usefulness in sustainable waste management

Plastic can be produced out of a number of different materials, with different characteristics in regard to decomposition. In principle, one can say that plastic can be made either of biomaterials or fossil materials, and either of these types may be either biodegradable or not (Rujnić-Sokele & Pilipović, 2017). Even though plastics are biodegradable they do, however, need a specific environment to actually decompose (Rujnić-Sokele & Pilipović, 2017). There is also a difference whether plastics are thermosets or thermoplastics. Thermosets cannot be heated without degrading at the same time, and can therefore not be mechanically recycled, while different thermoplastics can be melted and remoulded into different products (Rebeiz & Craft, 1995).

Physical properties of original plastic products, additives used in the plastic and the washing regime used in recycling are all important to the expected behaviour and applicability of the products (Santana & Gondim, 2009). A more thorough review of this can be found in Appendix E. Some main conclusions that can be drawn are that plastic products made through simple recycling without too many resources drawn to washing, and where personnel do not have experience with plastics and additives, should not be used for food or drinks. Also, by applying antioxidants to the plastic during recycling, the degradation process of the plastic will be slowed down, and the products will last longer. When recycling plastic, it is important to sort out all plastic that has started the degradation process, as this would lower the quality of the new products (Jamtvedt, 2018).

4 Data gathering and methodology

4.1 Methodology

4.1.1 General methodology

Different methodologies have been chosen to resolve the different research questions in this study. Strategies for data collection include semi-structured and open interviews, as well as collection of general data from existing literature and publicly available information such as fact sheets made by UNHCR. A semi-structured interview is a flexible type of interview, where topics and/or specific questions are determined before the interview, but the interviewer asks the questions in whichever order comes naturally, and can add or skip questions (Kallio et al., 2016). The estimates collected through semi-structured interviews have been used in bottom-up material flow analyses. In addition, simple methodologies have been used to scale up the collected data into an estimate for all the camps, and to find the best plastic management solution in the camps. To evaluate the environmental and financial impacts, a Life Cycle Assessment and a cost-benefit analysis has been conducted, respectively.

Local data has been collected through two weeks of field work in and around the 8 camps in the end of July 2018. The field work was conducted in order to collect necessary data as a basis for the recommendation of a specific recycling system and products. Meetings and conversations have been compiled in a summary, and the recommendations have been presented in the report "UNHCR and IUG Plastic Recycling and Reuse in Melkadida and Jijiga Refugee camps" (Eckbo et al., 2018). This report will hereafter be referred to as "the EWB report (Eckbo et al., 2018)", as Engineers Without Borders organized the study.

4.1.2 Data collection and material flow estimation

As there is no international consensus on the method of solid waste characterization, there is a variety of methods used to assess household waste composition (Dahlén & Lagerkvist, 2008; Edjabou et al., 2015). Some methods are standardized, while others are used in one or a few studies (Dahlén & Lagerkvist, 2008). Many methods have been developed to keep track of the waste production within a specific country. While most methods physically sample the waste produced within a certain timeframe from a certain portion of the whole assessed population, some methods are based on product flow and Life Cycle Assessments to predict and estimate the waste that will be produced (Dahlén & Lagerkvist, 2008). Gay et al. (1993) proposed the latter as a cost-efficiency measure in waste composition analysis after having reviewed the commonly used methods. The method they proposed based the material analysis on sales documentation using conversion factors from sales to waste. The US government described the use of such a method in 1999 (Franklin and Associates, 1999), where production of different goods and products, as well as imports and exports, were used to estimate the quantities of waste flows.

Material flow analyses, using physical methods, mainly include sampling of waste collected in municipal solid waste trucks, but differ as to what categories the waste is sorted into (Dahlén & Lagerkvist, 2008). Physical analysis of the whole waste stream has also been used in analyses aiming to find plastic quantities and types (Thanh et al., 2011). In this case, the plastic fraction can be assessed more thoroughly than in the standard analysis methods (Thanh et al., 2011). Mbande (2003) suggested that interviews are also an appropriate approach to collecting estimated waste quantities in developing countries where municipal solid waste is not collected to the same degree.

A widely used standardized method for assessing solid waste composition is to base it on ASTM D5231-92 and do a manual assessment of the waste produced at the household and commercial levels, or in landfills (Abdalqader & Hamad, 2012; Abdulredha et al., 2017; Saidan et al., 2017). It is based on doing physical measurements of a statistical representative share of the waste flow (ASTM D5231 – 92, 2016). This method has been utilized in a waste composition analysis in refugee camps before (Saidan et al., 2017). Figure 4 illustrates the observed flow of plastic waste in the refugee areas in question in this study, with arrows showing the biggest fractions of single plastic products. This flow is important to regard when evaluating if and how this methodology would work in the camps.

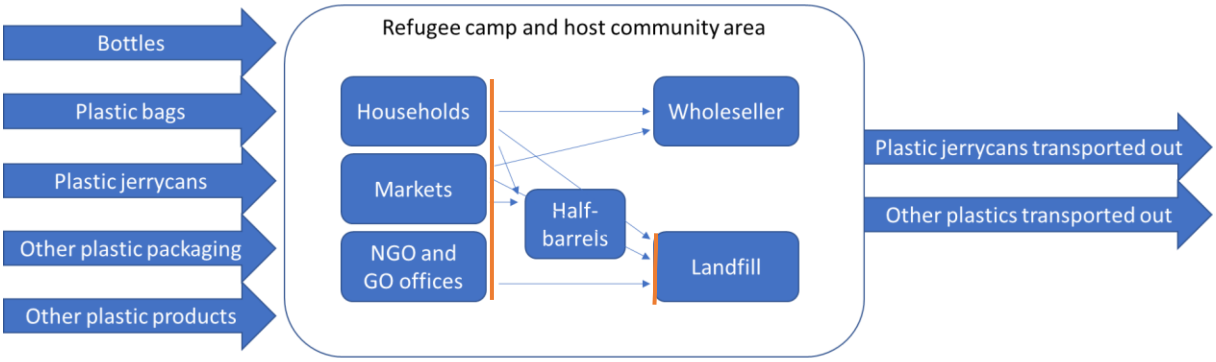

Figure 4: Observed plastic waste flows in the Melkadida area

In the Melkadida operation, waste can be thrown away in shared half-barrels, or may be transported directly to the landfills. The system in the Jijiga operation is in general similar, but there are no half barrels available for waste collection. Therefore, everything is brought directly to the landfills by the refugees and host community inhabitants. If using the ASTM method, one could choose to collect the waste at one of the two orange borders in Figure 4 for most waste fractions. This would be difficult to use, and also it would be difficult to include the HDPE jerrycans in the analysis, as they are currently being sold to Addis Ababa by private persons, and as such do not end up in the landfills. Also, in order to be certain that all waste is accounted for in a waste audit done from households, one should not collect from half-barrels, but from the households themselves, as some waste is brought to the landfills by private persons. The same should be done at markets and company offices.

Instead of using statistical representativeness, as for example in the ASTM method, there are also other methods to know with some certainty that a selection is adequately representative. One of these is to establish the waste amounts of a high share of the total population analysed, as the probability that sizable amounts from all groups in the total population are represented is thus high. This method has for example been used in a report about food wastage in the agricultural sector in Norway, written for the Ministry of Agriculture and Food in Norway. In this analysis, there is a requirement for at least 70% of each branch to be sampled in order for the estimate to be good enough. (Hanssen & Stensgår, 2018)

The method to collect data in this study has been a mix of methods presented above. In general, the field work was planned by the UNHCR staff in charge of the project, and there was little room for adjustments and additional activities, due to the limited time in the area. The data collection method used in this analysis is tailored specifically for the plastic waste situation in these exact refugee camps. Plastic bags, jerrycans and drinking bottles are the main plastic products in use, so the method was constructed to account for these three products in an effective way. This is probably an adequate way to find the relevant plastic waste, as simple mechanical recycling is best suited for homogenous fractions (Al-Salem et al., 2009). The method included investigating these main types of plastic waste, either when flowing into the camps, or when flowing out. As jerrycans flow into the area from different sources, such as aid organizations and private sales, but leave the camp in a single stream, this flow was analysed when exiting the camps. The camps and areas used as samples were chosen roughly at random by UNHCR staff. The flow of plastic bottles and plastic bags were determined when entering the camps through sole suppliers, as these flows mainly go directly to landfills after use, or even disappear into nature through littering. Using this methodology, one assumes that for all the plastic entering the camp at one point in time, the same amount also exits the camp at every conceivable point in time.

For the jerrycans, semi-structured interviews were conducted with private persons living in the refugee camps, host communities and Dollo Ado city, who collect plastics (mostly jerrycans) from households and sell it to trucks travelling back to Addis after having brought goods into the area. In this thesis, these individuals will be referred to as waste traders. Waste traders in the camps and host communities were asked many or all of the questions in Appendix A. When suitable, other questions in regard to plastic and plastic waste were also asked. The method to find the waste traders and to find the number of waste traders in the selected camps was through conversations with ARRA staff and refugees responsible for the camps. Also, when one waste trader was found, they could often name others.

When the material flow analysis is based on waste amount estimates collected through interviews, it is important to take into account how the collected data was registered in the first place. The method used by the waste traders to estimate the plastic flow through their shop, was probably based on weighing of the plastic and the income from selling. All waste traders seemed to have their own wages, and most often also paid for the plastic when collecting it. To do this they probably weighted the plastic coming in, in addition to knowing what the jerrycans of different sizes weigh. The waste traders get paid per kilo plastic delivered to the trucks when selling (stated by all waste traders during interviews). Therefore, they also know which quantity they sell, or at least which quantity the truck drivers claim to buy.

The influx of plastic bottles and plastic bags into the refugee camps and host communities were quantified through establishing contact with “sole distributors” having the sole right to supply the products to the area and distributing it to others. These sole distributors were asked about the quantities and sizes of water bottles and plastic bags they took in per month. These analyses are also sample analyses, where one sole distributor is the main distributor to one whole camp. As there were only sole distributors of plastic bottles and plastic bags in the Jijiga camps, while it was an open market for these products in the Melkadida camps, only estimates from the Jijiga camps were collected. Regarding the quality of the data collected, the sole suppliers of drinking bottles and plastic bags probably have to order these drinks themselves, and therefore should have a good overview of the quantities of bottles coming in and out. They also have the responsibility to distribute the bottles and need to know total amounts for this.

There are different possibilities in regard to methods to scale the data collected. One of the possibilities is to scale up weighted averages based on the population sizes of their respective communities. This method assumes that all areas investigated in sum are representative for the whole area. It can be used both including all estimates, or excluding the outliers, if assumed that the set of data has some abnormalities. Another possibility when aiming at finding plastic waste amounts in populations where it is expected that different communities have different economical living conditions, is by assuming that estimates within different area categories are representative for that area. As the whole area analysed include both cities, host communities and refugee camps where inhabitants get food and living supplies form World Food Program and other aid organizations, the latter method will be used in this analysis for jerrycans, as estimates have been collected for all different main areas. For bottles, where estimates have only been found in one single area, the first method mentioned above will be used.

In general, it is important to do waste composition analyses when there is no special reason for the waste streams to be different from a normal week (Dahlén & Lagerkvist, 2008; Syversen et al., 2015), and the month of July is not recognized as a special month in this matter. It is also considered important that samples include at least one week of waste (Dahlén & Lagerkvist, 2008). In Zaatari refugee camp in 2015 it was found that there was no significant seasonal variation of the waste streams, and this speaks to the fact that there is probably also no such issue with this in refugee camps in Ethiopia. Based on data collected, and assumptions in regard to loss during collection and processing in the different scenario, material flows through the different scenario will be found and presented in flowcharts in line with conventional methods (Finnveden & Moberg, 2005; Markic et al., 2019; Moriguchi & Hashimoto, 2015).

4.1.3 Methodology to assess environmental impact

General methodology

A Life Cycle Assessment (LCA) has been conducted in order to gain answers which are useful in determining the best plastic waste management system, both towards the local and global environment. The methodology will follow requirements specified in ISO 14040 and ISO 14044, and required and clarifying measures are defined in this chapter.

Goal

The goal of the Life Cycle Assessment is to evaluate the potential impact of implementing recycling of HDPE and PET into rooftiles and/or flower pots in the camps. To determine the potential consequences of this change, both the original and the new system have been analysed (Finnveden et al., 2009). The only intended application of the study is evaluating the potential extra revenue the project could create through the EU Emission Trading Scheme (EU ETS). The intended audience of the study is the project developer UNHCR and Engineers Without Borders, to be able to make the most environmentally friendly choices during the planning process of the project, but at the same time keeping aspects such as finance and local quality of life in mind. The analysis can in principle also be used to show future potential sponsors of the project and other similar projects the potential environmental impact of such a project. The reasons for carrying out the study is to get an overall evaluation of the project. Global warming potential is the main impact category used in the analysis, but also other impact categories being affected by emissions from the processes will be presented.

Scope

As this study aims to identify the impact of a change from one waste management system to another, it has been recommended that the functional unit is defined as the waste input to the system, in order to find the optimal waste management (Cherubini et al., 2009). In the choice of a functional unit, the fact that the reference systems are very different for the two plastic waste flows has been carefully considered, with the goal of being able to compare the two waste flows numerically. As the reference systems are so different, recycling one of the plastic types might give a positive environmental impact, while the other might not, and they are therefore analysed separately. To gain comparable results which are meaningful for the project, the functional unit is chosen to be "*management of 1 kg of one plastic type".*

The reference flows that are parts of the functional unit are kgkm transport by donkey cart and kgkm transport by truck, as well as kWh of energy. Infrastructure and fuel will be included in these reference flows. Other resources such as water, washing detergents and additives like antioxidants, will be needed in the production, but are disregarded in the analysis, as they probably affect the system to a very small extent. Where needed, a cut-off of 5% will be used in the analysis.

As the recycling system is to be evaluated in comparison to the original system with open dumping and burning of the PET without energy utilization and recycling of HDPE in Addis Ababa, a system boundary towards this system needs to be made, both geographically and in time. For the boundaries of this system to be consistent with the functional unit and the goal of the study, the analysis starts at the point where the plastic is perceived as waste by the end-user. The analysis can therefore be categorized as a gate-to-cradle analysis (Blengini et al., 2012). Hence, transportation, sorting, washing and recycling from this point onwards will be included in all scenarios, in addition to the impact of the product substitution (see Figure 5). At the point of substitution, the plastic has been recycled and has gone into an existing market for a product and has, according to Article 6 of the Waste Framework Directive (2008), passed the stage of being waste. Emissions from different processes used in the analysis are based on general data, as specific data is not available. The time frame of the emitted substances is set as 100 years in the analysis.

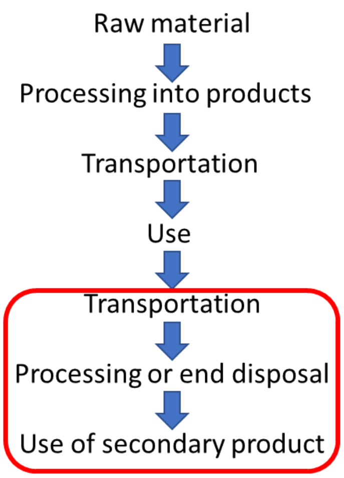

Figure 5: System boundaries

Scenarios

To answer the research questions, two scenarios have been analysed, where the first scenario is to continue in the same way as today and the second is to implement a recycling system using all PET or HDPE available. The background system setup has been based mainly on results from the EWB report (Eckbo et al., 2018). The two plastic types have been evaluated based on production of specific new products needed in the refugee camp areas; Rooftiles and flower pots.

Modelling

The software SimaPro has been used to model the system and calculate the impacts. The database and system model “ecoinvent 3, allocation, cut off by classification – unit” has been used. The model called “cut-off by classification” includes choices in the modelling such as not allocating burdens from a product’s life cycle to future life cycles using the same material. As a result, materials that are no longer in use for their original purpose can be recycled without bearing any burdens from the previous life cycle of the material (Ecoinvent, n.d.). The allocation of emissions and other impacts from construction and operation of the recycling factory will be done through physical allocation.

The chosen impact assessment method is *ReCiPe Midpoint (H) V1.02.* ReCiPe is an internationally recognized tool to classify all the emissions identified through the Life Cycle Assessment into different impact categories, such as global warming potential (through greenhouse gas emissions), or terrestrial acidification (Huijbregts et al., 2017). When using the midpoint method, the results will be based on impact categories, but the possible harmful end-effects will not be quantified. The midpoint analysis is a good tool to show the possible impacts, seeing as the consensus is that it gives less uncertainties than the endpoint method (Bare et al., 2012; Hauschild & Huijbregts, 2015). The (H) stands for *hierarchist* and is one of three perspectives that can be chosen in the impact assessment. The three perspectives have different views on how much nature can adjust to emissions and other human effects, as well as differing time perspectives. The hierarchist represents the middle ground of these methods and reflects common policies, and for example includes a time perspective of 100 years (Goedkoop et al., 2013; Hauschild & Huijbregts, 2015).

In all simple comparison analyses, greenhouse gas emissions have been used as a comparison basis, as the analysis focuses on this. To the greatest extent possible, infrastructure is included. Also, where possible, all process cards used in the analysis include the process in a global perspective. As a result of this, also average transportation by materials in a global perspective is included in the analysis.

4.1.4 Methodology for material and cost benefit analysis

A model has been constructed using Microsoft Excel, in order to establish the financial outcome of the recycling project. This model takes into account all investment costs, operational costs and operational income, such as the price of the plastics and the finished products, the cost to collect or buy plastic and the value creation for the employees. The background system and scenarios correspond to the Life Cycle Assessment. The financial analysis has only been used to consider the feasibility of the establishment of a recycling cooperative, as other costs and benefits of the whole value chain or the economic value would be very uncertain.

The model is used for different scenarios to find the optimal solution, and for a sensitivity analysis. The financial value used to compare the results from the analysis is the annual result, as funding of the investment cost makes traditional measures such as net present value and internal rate on return on the investment less relevant.

4.2 Study objects and collected data description

4.2.1 Introduction to data and data collection

Local data from the refugee camp areas in question and other data the study is based on are presented in this chapter. Most of the data has been collected through interviews and observations during a two weeks period in the field by the author and two other engineers working on the project, and some is retrieved from the EWB report, and from UNHCR fact sheets. Some of the results from the field work stated in the EWB report will be used in the model, such as where the recycling plants should be located. The estimation of investment costs has been based on the estimated values from the from the EWB report (Eckbo et al., 2018). For the environmental analysis, additional data is collected from the ecoinvent database and IPCC guidelines.

The interviews were, as previously stated, semi-structured interviews and unstructured interviews. The languages spoken in the area differs mostly between Amharic and Somali, while some also speak English as a second language. There was no designated interpreter during the field work, but the UNHCR environmental officer who participated in every meeting worked as an interpreter between Amharic and English, and interpreters between Somali and English were brought when needed in the refugee camps.

4.2.2 Camp demographics and description of camps and the areas

In July 2018 UNHCR reported that almost 929 000 refugees live in Ethiopia, of which more than 750 000 are settled in refugee camps (UNHCR, 2018a). The Melkadida and the Jijiga refugee camp areas are two out of six refugee camp areas in Ethiopia (UNHCR, 2018a). In total, 37 000 refugees are living in three different refugee camps within the Jijiga area, and 219 000 refugees are living in five different camps in Melkadida area (UNHCR, 2018a). This adds up to more than 1/3 of all refugees living in camps in Ethiopia. These two camp areas together represent all the camps within the Somali Region in Ethiopia, and host Somali refugees (UNHCR, 2018a; UNHCR, 2018m). The refugee population within each camp can be seen in Figure 6 below, and geographic localization can be seen in Figure 7. In the Melkadida area 65% of the refugees are under 18 years old (UNHCR, 2018a), and in Jijiga refugee camps 56% are below 18 (UNHCR, 2018c; UNHCR, 2018d; UNHCR, 2018j). A long-term goal is that the refugees will become self-reliant and earn money and buy the food and equipment they need, instead of getting everything for free (ARRA chief, Muhammed, Melkadida 19.07.18, Demissew Eshete, Environmental Manager UNHCR 07.18, George Wood, Head of Sub-Office UNHCR, 23.07.18, UNHCR, 2018a). The first camp was established in the Jijiga area in 1991, and the rest of the camps were established between 2007 and 2011, but new refugees are still coming to the area because of draught and violence in Somalia (UNHCR, 2018a, p. 5).

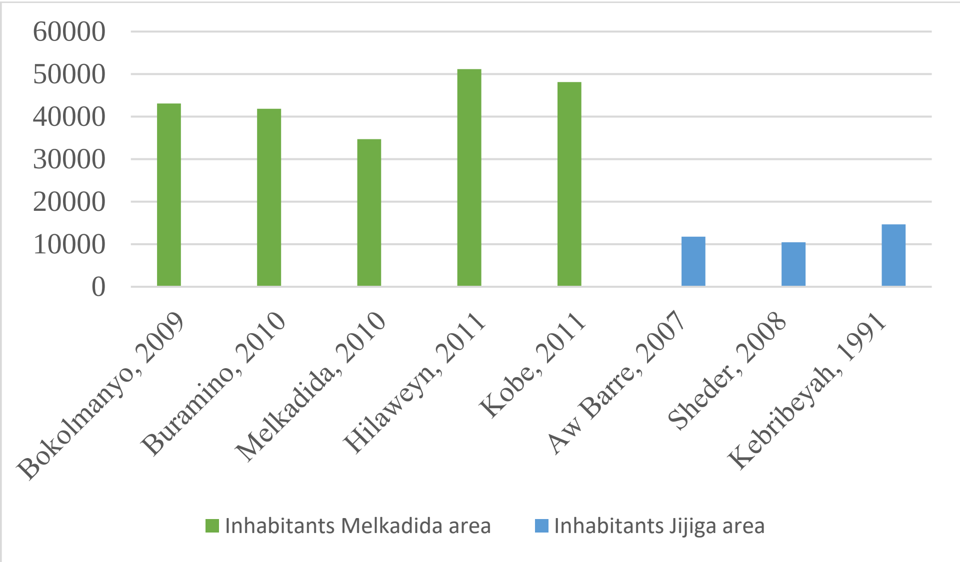

Figure 6: Size of camps and year of camp establishment

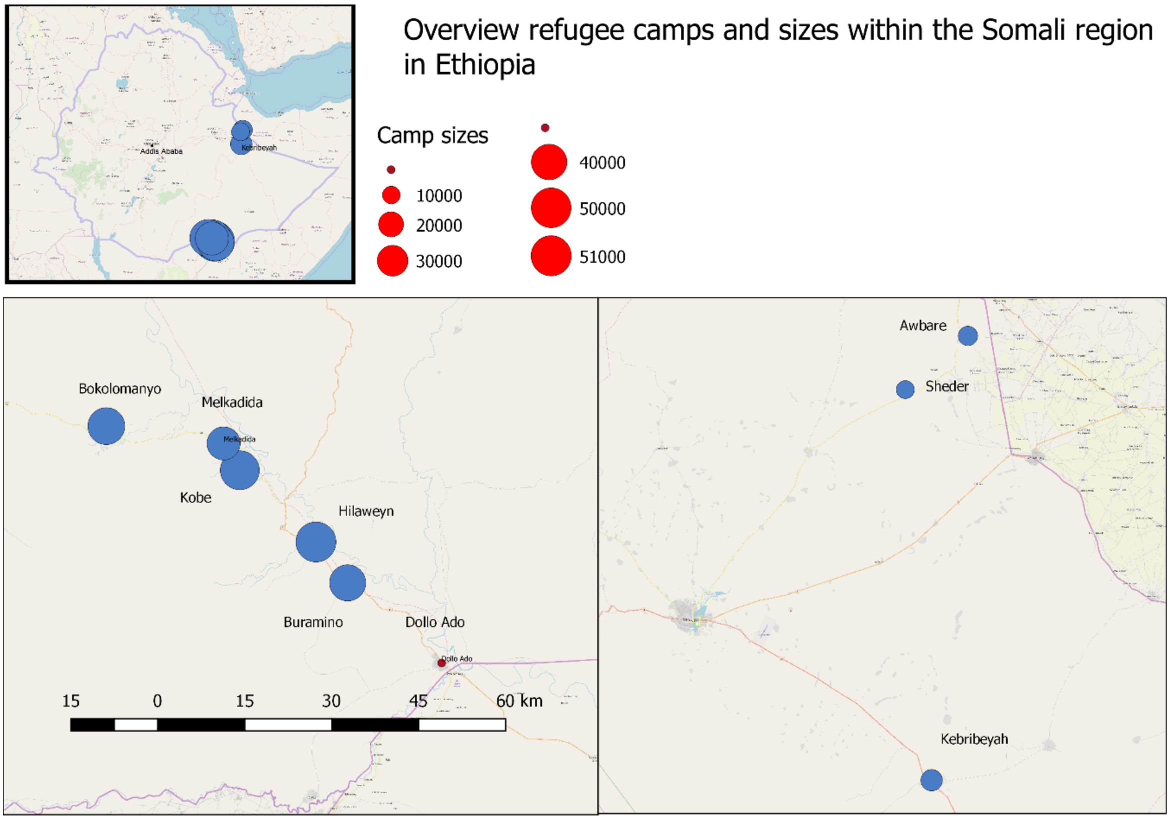

Figure 7: Sizes and geographic placement of Refugee camps. Modelled in QGIS (OpenStreetMap contributors, 2019)

In both refugee regions, there is one big city, and other smaller communities where refugees do not live, but where plastic is also passing through. In the Melkadida area, the city is called Dollo Ado and lies directly on the border Somalian border. Plastic from the whole region around the camps would be possible to collect from, although it is not necessary (Eckbo et al., 2018). In the Jijiga area the big city is, as the name implies, Jijiga city. The refugee camps are spread around this city. Figure 8 shows a map of the Somali region and the populations in the camps and cities. Jijiga city already has one company planning to work with recycling (Faysal Ibrahim Abdi, General Manager, City Wide Waste Management & Recycling Company, 24.07.18), and this project should therefore not interrupt the private market from developing there (Eckbo et al., 2018).

Every refugee camp is paired with one or more host communities, with varying sizes. UNHRC Ethiopia also has a mandate to care for these communities, as it would be unfair to only provide assistance to their neighbours (UNHCR, 2018e). Therefore, this project should include both refugees and host communities, both regarding collection and working opportunities (Demissew Eshete, Environmental Manager UNHCR, 07.18, Diana, Energy Manager UNHCR, 23.07.18).

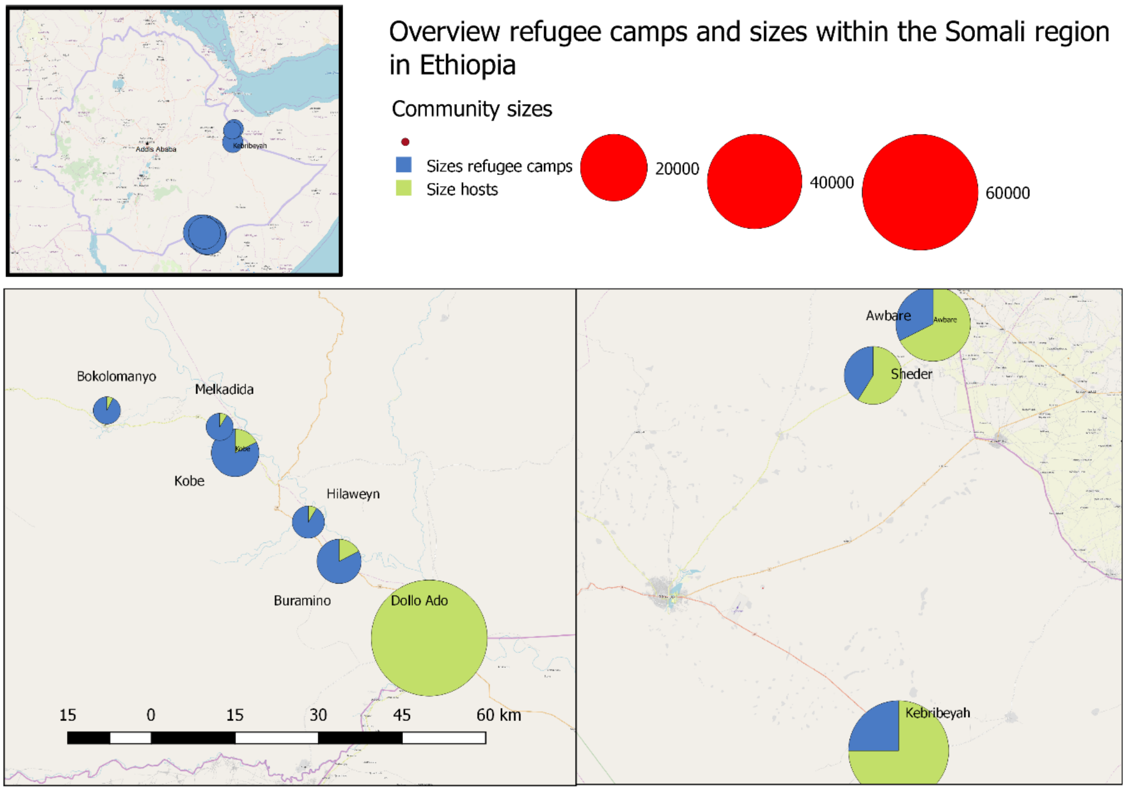

Figure 8: Inhabitants in refugee camps and host communities and Dollo Ado. Modelled in QGIS (OpenStreetMap contributors, 2019)

4.2.3 Relevant stakeholders

UNHCR is responsible for the operation in the 8 refugee camps in question. In refugee camps, there are in general many different parties in charge of different aspects of administration and operation (Regattieri et al., 2015), and in the Jijiga and the Melkadida area these are organized by UNHCR. Together with UNHCR, also the governmental refugee branch, called ARRA, shares the responsibility of camp management (UNHCR, 2018i). Figure 9 shows the different collaborators observed during the field visit, which are the most important decision makers in regard to waste management, being UNHCR, ARRA and the implementing WASH partner. The orange colour represents the organizations with decision-making authority over others in the system or over the system itself.

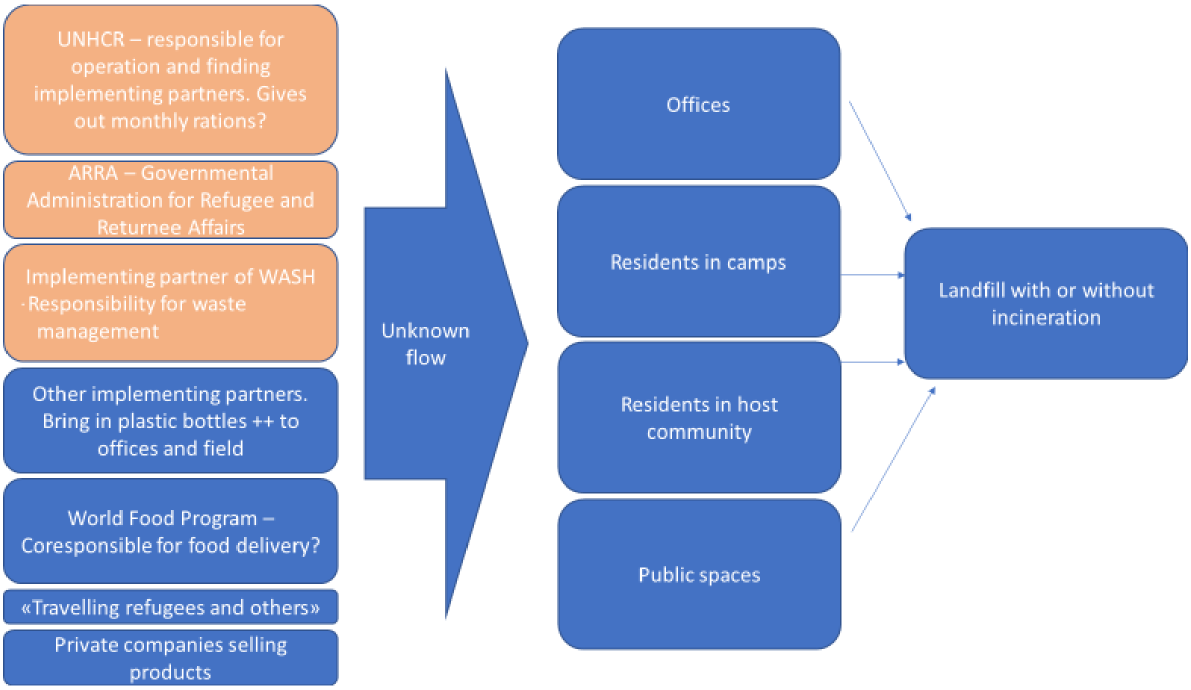

Figure 9: Illustration of involved parties in plastic waste production

WASH is a program for Water, Sanitation and Hygiene that is meant to be implemented in all UNHCR camps (UNHCR, 2018n). It is often done through an implementing partner; Another humanitarian organization with the necessary capacity and knowledge to take the responsibility. Reuse and recycling of waste is one of the technologies listed as low-cost and appropriate for the transition into more efficient activities in operation guideline documents (UNHCR, 2018n). The guidelines also mention that recycling and reuse should be feasible in refugee camps older than 2 years, and are therefore suitable to consider in refugee camps. IRC is the WASH implementing partner in all five camps in Melkadida, and are therefore responsible for the solid waste management today (IRC Camp Manager Melkadida, 19.07.18). LWF and ARRA are responsible for the WASH-program in Awbare (Ato Esayas Yora, Awbare camp coordinator, ARRA, 26.07.18). Also, other organizations can be of interest for the project, considering the whole value chain. Appendix I shows an overview of relevant implementing partners.

4.2.4 Current waste management

Today, the waste management in the camps is simple. The waste management in the Melkadida camps consist of collection of solid waste from half-barrels placed every 50 meters around the camps, transported with donkey-carts to open dumping just outside the camps (IRC Camp Manager Melkadida, 19.07.18, UNHCR, 2018e). Most of the dumpsites consist of pits (See

Figure 10), while others are established on flat land. Over time more and more pits are being built, taking over larger and larger areas, and in some camps there are even problems finding space for new areas for landfills (Aneley Fentie, ARRA Camp Coordinator Sheder, 26.07.18, Eckbo et al., 2018). Amounts and sizes of the pits are further specified in Appendix J. The Bur-Amino camp within the Melkadida area has already been studied in a research article about good camp design, and "lack of waste management solutions" has been listed as one of the challenges (Jahre et al., 2018). In the Jijiga area, there are also pits like in Melkadida area, but there is no organized waste collection (UNHCR, 2018e). The refugees bring their waste to the dumpsites themselves, and burn the waste in the pits (Ato Esayas Yora, ARRA Camp coordinator, Awbare, 26.07.18). When filled with ash and materials, the pits are buried (Ato Esayas Yora, ARRA Camp coordinator, Awbare, 26.07.18).

Figure 10: Illustration of a typical waste pit, Photo: Anna Østby

The half-barrels do not have lids, and the landfills are not covered or enclosed. Therefore, plastics and other waste is blown away both while in the half-barrels, during transport in donkey-carts and from the dumpsites. One can see this in Figure 10 around the dumpsite, and in Figure 11. To reduce the problem of waste blown away, IRC has encouraged the communities to discard the waste in plastic bags, but this is not yet common practice. To remedy this, there is a weekly community project in the Melkadida camps where inhabitants are invited to pick up plastic litter. Local staff estimates a participation of 50-100 individuals each time. (IRC Camp Manager Melkadida, 19.07.18)

Figure 11: Plastic in the environment far from a landfill in the Melkadida area, Photo: Anna Østby

To earn money, some refugees and citizens of the host communities collect plastic jerrycans and some other plastic items to sell to waste trucks. This is not a part of the organized waste management system in the camps, but it reduces the solid waste amounts going to landfills, and provides an income for the waste traders. The cans are normally sold to drivers of 12 feet trucks bringing supply into the camps, who would probably drive an empty truck back if not taking some plastic (Demissew Eshete, Environmental manager UNHCR, 19.07.18).

In addition to this, it is important to know what previous recycling initiatives have been implemented in the refugee camps, both because it gives an indication as to whether people are familiar with the importance of waste reduction, and whether there is anyone knowledgeable on the subject that can help drive the project forward. The relevant initiatives discovered during field work, and other projects or initiatives with a possible positive influence on the project are described in Appendix K.

4.2.5 Plastic waste amounts

Three types of plastics were examined during the field work. These were jerrycans, PET-bottles and plastic bags. Other plastic items such as packaging materials were seen at dumpsites, but the source of this waste was not found and amounts not assessed. During the field work, 8 plastic jerrycan waste traders, one wife of a jerrycan waste trader and one friend of a waste trader were interviewed about prices and amounts of the jerrycans they buy and sell. Additionally, some other traders' gardens were identified and inspected, providing visual confirmation for the estimates collected through interviews. The host and refugee societies in the Jijiga area were not easy to distinguish from each other, and they are therefore treated as a whole. Also three sole suppliers of bottles and two sole suppliers of plastic bags were interviewed in the Jijiga area.

The description of the collected information from these interviews, as well as assumptions done to get all these estimates in the same unit can be found in Appendix L. Assumptions regarding inhabitants in the different communities can be found in Appendix M. The values collected and estimated from these interviews are presented in Table 1.

Table 1: Information collected about waste collection amounts from all waste traders

Sample	**Area**	**Assumed number of waste traders in area**	**Collection (kg/month)**	**Other sales information**
Refugee camp waste trader 1	Bokolmanyo	2	1500	Sells every 2. Month
Host community waste trader 1	Bokolmanyo	3	1650	Sells every 2. Month
City waste trader 1	Dollo Ado	9 of same size		Sells every 2. Month
City waste trader 2	Dollo Ado	1 of same size	5000	Sells every month
Host community waste trader 2	Hilaweyn	Not known	2500	Sells every 2. Month
Mixed community 1	Kebribeyah	3	1500	Sells every 2. month
Mixed community 2	Awbare	2		Sells every third month
Mixed community 3	Sheder	1		Sells once a year

When dividing these estimates into different area categories, one can see that the amount of plastic accounted for is relatively large in most areas (Table 2). 53% of the inhabitants in the whole area were accounted for either by their personal waste trader, or the estimate of other waste traders in the same community. Considering that not all waste traders in all the camps and cities were interviewed, the coverage is 24% (Table 3). One can also see in Table 2 that at least 10% of every area category has been accounted for, while two of the categories are wholly accounted for. Thus, it is plausible that an average representative of the whole population has been found. It also seems likely that almost the whole flow of jerrycans go through the waste traders, as no jerrycans were observed on the dumpsites during the fieldwork. On the other hand, the estimated amounts of plastic sold can contain some small fraction of other plastic waste, such as destroyed chairs or tables. This was observed to a very small degree.

*Table 2: Portion of jerrycan plastic waste accounted for in different area categories, **including interviewees'** estimates about other waste traders in the same area*

Refugee camps in Melkadida refugee camps	19.7%
Host communities in Melkadida area	11.4%
Dollo Ado City	100%
Jijiga camps and host communities	100%
In total	53%

Table 3: Portion of jerrycan plastic waste accounted for in different area categories, ***excluding interviewees'*** estimates about other waste traders in the same area, calculated as weighted average

Refugee camps in Melkadida refugee camps	10%
Host communities in Melkadida area	4%
Dollo Ado City	27%
Jijiga camps and host communities	52%
In total	24%

An estimate of jerrycans distributed from UNHCR can be made with general distribution numbers for the camps. In the Melkadida area they distribute half of the total cooking oil in plastic and half in tin cans. Every month they distribute 5 L jerrycans of cooking oil to 2000 households. They supply approximately 0.9 kg cooking oil per individual each month (Aneley Fentie, ARRA Camp Coordinator Sheder, 26.07.18) . Vegetable oil has an approximate density of 0.9 kg/L (Noureddini et al., 1992). Observations and interview responses from fieldwork showed that a 5 L jerrycan weighs approximately 150 grams (Observation 21.07.18) or 200 grams (Waste trader, Bokolmanyo, 19.07.18). By basing a jerrycan waste estimate on this, it can be used as a benchmark to what is the probable minimum available plastic from jerrycans in the area.

In regard to PET-bottles, most of the observed bottles were water-bottles. According to the three refugee camp leaders in the Bokolmanyo refugee camps, "people are mainly drinking water from the taps that are placed around in the camp, but when there is training in the camp, people get water in bottles." *(*Refugees chosen as leaders for the community, Bokolmanyo refugee camp, 19.07.18). They estimated that there are 2-3 vehicles per day loaded with bottles and emphasized that also the staff of ARRA and other institutions drink bottled water. In addition to this, water bottles were observed for sale in markets and in shops. In the three Jijiga camps, there is always one sole distributor of water. Everyone else in the camp and host community need to get an approval from this distributor to distribute or sell water themselves (Chairman of water distribution association, Kebribeyah, 25.07.18). The distributors gave estimates for the amounts of plastic bottles they sold each month. The foundation for the assumptions made in regard to the weight of different plastic bottle sizes, can be found in Appendix N. The assumed weight, when assuming a linear proportionality, are 10g, 20.7g and 31.3g for 0.5 L, 1 L and 1.5 L bottles respectively. Based on this, the stated amounts of bottles distributed by these waste traders and the corresponding weight are shown in Table 4.

Table 4: Information collected about drinking bottle sales amounts from all sole suppliers

	Kebribeyah	**Sheder**	**Awbare**
0.5 L bottles (pieces/month)	-	6 000	9 600
1 L bottles (pieces/month)	48 000	8 400	6 000
1.5 L bottles (pieces/month)	-	-	19 200

The fraction of the total population which has been accounted for is 28%, as long as the sole suppliers are indeed the only source of bottles in the area, and no one violates this rule. Even though a bigger part of the total population is accounted for than for the jerrycans, the representativity of the samples are not as good as for jerrycans, as all three samples are from communities in Jijiga.

Also for bottles, a benchmark estimate can be found as a production numbers from a water-bottle factory in Dollo Ado were collected during the fieldwork. The factory produces 72 000 1 L-bottles a month, which corresponds to 1488 kg, given that a bottle weights 20.7 g. These are distributed to the whole area surrounding the Melkadida camps, but this can only be seen as a minimum estimate for this area, as also many other bottle brands are sold there. (Manager, Water Bottle Factory, Dollo Ado 20.07.18)

Two estimates for plastic bags were obtained from two different sole suppliers in the Jijiga area. They stated that "[I] sell out 10 cartons of plastic bags with different sizes, and each carton contains 100 packets, per week, which means 30 cartons per month*"* (Plastic bag waste trader, Kebribeyah, 28.07.18) for Kebribeyah and *"*There are 50 x 100 pieces of plastic bags in a box with small plastic bags […] and they distribute 23.500 boxes every month" (Plastic bag waste trader, Sheder, 28. 07.18) for Sheder. The sampled population accounts for 17% of the population in the area, but within only one of the area categories. The sole supplier in Kebribeyah states that he sells more than 500 times as many boxes of plastic bags as the sole supplier in Sheder, even though the refugee population in the two places are quite similar at 14 500 and 10 500 respectively. There was probably a misunderstanding, either with 23.500 bags being sold every month in Sheder (roughly 5 boxes), or maybe 40 boxes are sold every month in Kebribeyah. The information collected was quite unclear, meaning that the quality and statistical significance of the data is relatively low, and therefore plastic bags will not be included in the analysis.

4.2.6 Scenario data – for financial and environmental analysis

The main questions in the environmental and financial analysis are how a change from today's waste management system to a recycling system impacts the environment and whether implementing such a project will be financially feasible. The scenarios in the analysis will differ between the two different plastic materials (HDPE and PET) being analysed in this thesis, and between two possible products than can be produced from this plastic. The plastic products chosen to use in the analysis are a flower pots (Figure 12) and rooftiles (Figure 13). UNHCR has stated that they can be the dedicated buyer of rooftiles and up to 5000 flower pots each year (Demissew Eshete, Environmental manager UNHCR, 07.18). Examples of these products have been modelled in an application called SolidWorks, with help from a mechanical engineering student from Engineers Without Borders at NMBU, and the resulting volumes compiled through the modelling have been used in the analysis. The compilation of data and information from the camp visit, that resulted in these two products and the tests of the products can be found from 0 to Appendix T. The masses and substitution effect of each of the products are summarized in Table 5. As HDPE and PET have different mass densities, the amounts needed to produce the same product differ.

Figure 12: Design flower pot. Modelled in SolidWorks

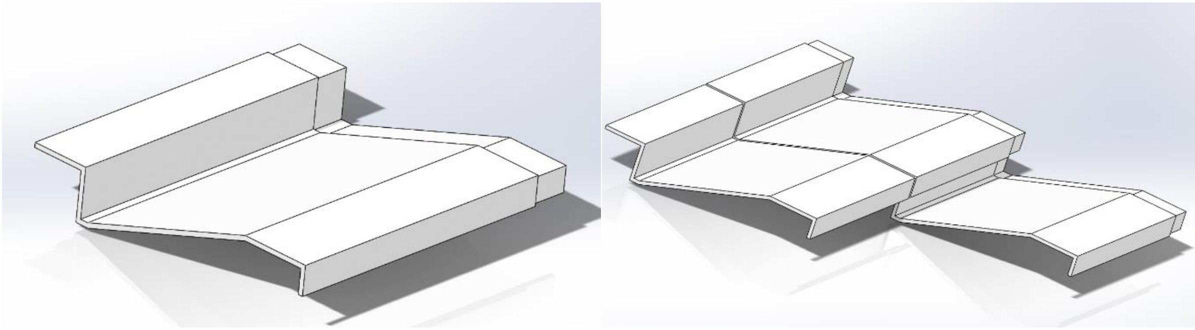

Figure 13: Design rooftiles. Modelled in SolidWorks

Table 5: Product information

	Rooftile		**Pot**	
	HDPE	**PET**	**HDPE**	**PET**
Mass (kg)	1.91	2.85	1.93	2.88
Measures of products	33 cm width (excluded part covered by other rooftile) 25 cm high (excluded part covered by other rooftile) 0.4 cm thick		30 cm width in bottom 40 cm width in top 40 cm high 0.4 cm thick	
Substitution	24 tiles in one 1 x 2 m corrugated rooftile.		One to one flower pot	
Assumed price	600 ETB / 1 x 2 m roof		200 ETB/pot	

The environmental officer with responsibility for the 8 camps in the Somali region proposes that an implementing partner helps during the start-up process, while a local cooperative is formed with the goal of self-reliance (Eckbo et al., 2018, p. 42). A proposed setup of collection places, shredders and factories, including distances, are shown in Table 6. In the Melkadida area, factories are to be set up by the Melkadida refugee camp and in Dollo Ado (Eckbo et al., 2018, p. 42-43). The rest of the camps will have collection and supply-cooperatives which shred and wash the plastic before delivering to the factories. In the report it was proposed that all these collection places also melt and mould some products in an oven, but as a simplification in this analysis, all recycling processes are done at the factories. Bokolmanyo and Kobe send their plastic waste to Melkadida, and Hilaweyn and Buramino send to Dollo Ado (Demissew Eshete, Environmental manager UNHCR, 30.07.18). In the Jijiga area, Sheder will have a big factory, while Kebribeyah has a smaller one, and Awbare has a shredder to process the waste before delivering to Sheder (Demissew Eshete, Environmental manager UNHCR, 30.07.18). A proposition is to buy two trucks for the recycling cooperatives in Melkadida. It is assumed that only one truck will be needed in the Jijiga area.

The report did not specify whether the waste collection should be done by the cooperatives, or if the persons having the roles of waste traders today can continue their business and sell to the cooperatives instead of selling to trucks. For this analysis it is assumed that as little adjustments as possible is the way to go, at least in the beginning, and that by letting the waste traders continue their work, that will be an efficient way of collection, with the cooperative having a stable buying price on the plastic.

Table 6: Location of factories and collection centres, and distances between them

Factories and collection centres	Distance to factory
Factory: Melkadida	-
Collection centre: Bokolmanyo	27 km to Melkadida
Collection centre: Kobe	8 km to Melkadida
Factory: Dollo Ado	-
Collection centre: Hilaweyn	34 km to Dollo Ado
Collection Centre: Buramino	26 km to Dollo Ado
Factory: Kebribeyah	-
Factory: Sheder	-
Collection centre: Awbare	15 km to Awbare

The collection cooperatives will need a building with washing and shredding facilities, while the factories in addition will have equipment for plastic recycling. In this analysis it is assumed that one machine type is sufficient, and this machine is chosen to be an injection moulding machine. There will probably be a loss of plastic during the manufacturing process, assumptions on the amount can be seen in Table 7. The substitution rates used in the analysis are shown in Table 8.

Table 7: Assumed plastic waste losses through the process

Loss during collection	2%
Loss during sorting	5%
Loss during shredding and washing	2%
Loss during transportation to factories	5%
Loss during moulding/recycling processing	2%

Table 8:Substitution rates in end-of-waste scenarios. Data is based on weight of materials and products from Table 5

	1 kg HDPE	1 kg PET	Explanation
Substituted Roof (in kg steel)	0.21	0.14	Assuming that a corrugated rooftile sheet weights 4.7 kg/m^2 (Clotan Steel). 12 plastic tiles will take up the same space.
Substituted Flower pot (in kg PE plastic?)	0.8	0.54	If assuming a conventional pot has 20% less plastic than the recycled HDPE pots.
Substituted Virgin plastic (in kg virgin HDPE granulates)	0.80	Not important for analysis	As factories in Germany (which are specialized in plastic recycling) has about 85% substitution degree, it is probably a bit lower in Ethiopia (Syversen et al., 2018).

The resulting material flows are shown in the following figures (Figure 14, Figure 15, Figure 16 and Figure 17), with the content of each arrow representing the net plastic flow going to the next process. The downward facing arrows represent losses in each stage., and the red border represents the system boundary. In total, six cases will be investigated: the reference cases for PET and HDPE, and the production of rooftiles and flower pots from each of them.

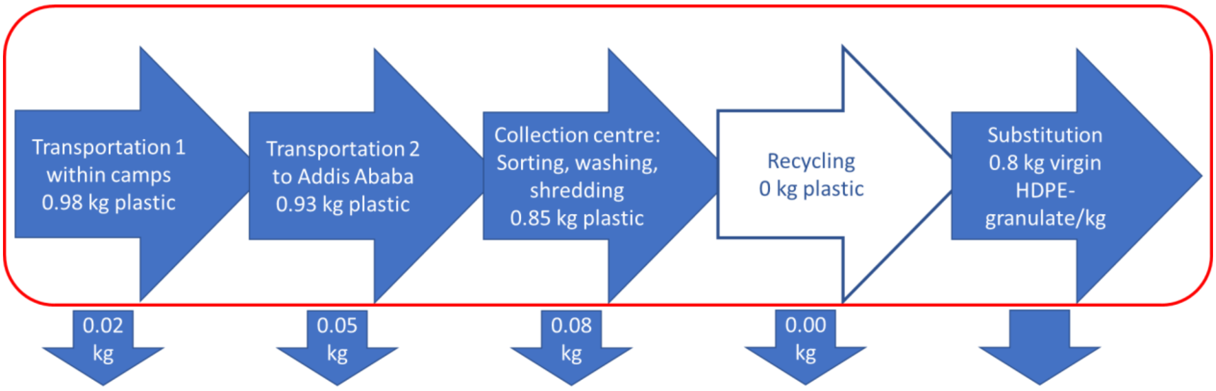

Figure 14: Reference scenario HDPE. HDPE is transported to Addis Ababa substituting virgin HDPE

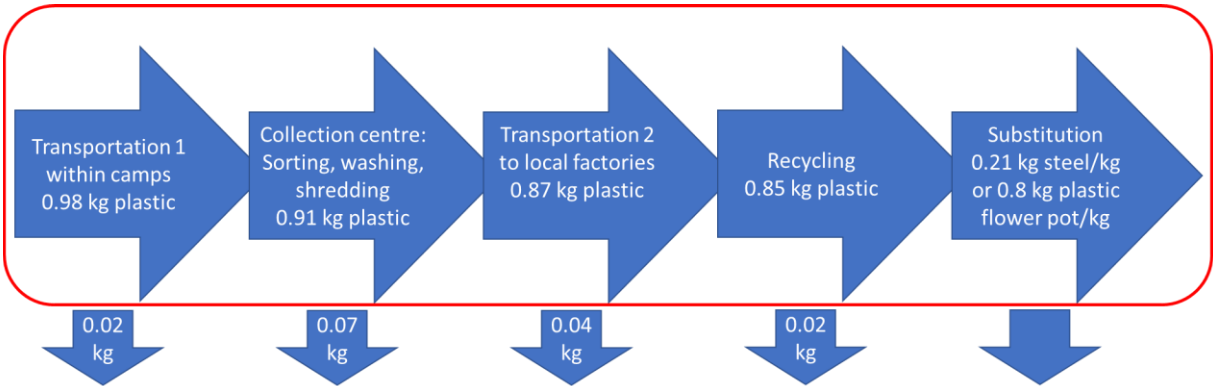

Figure 15: Material flow and reference flows for scenarios with recycling of HDPE

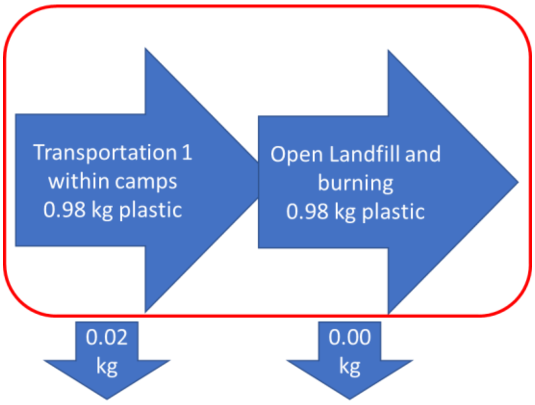

Figure 16: Pet reference scenario with only transportation 1 and open burning

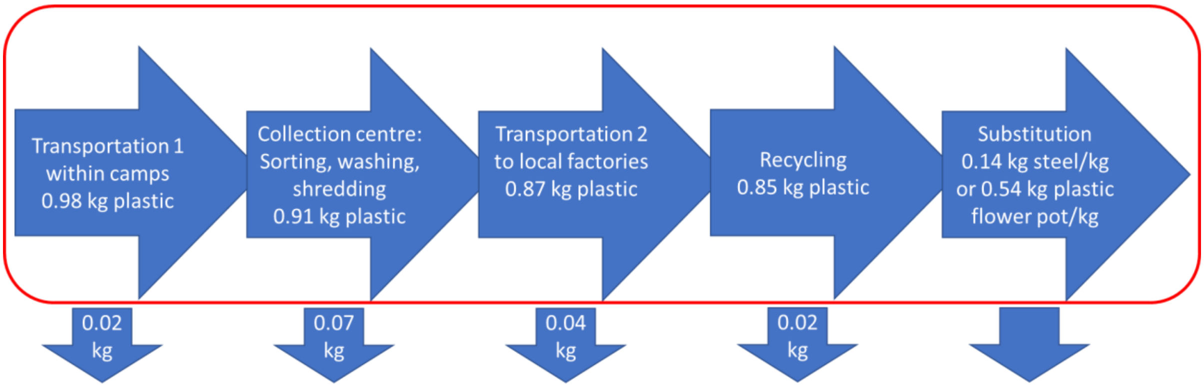

Figure 17: Material flow and reference flows for scenarios with recycling of PET

For the Life Cycle Assessment it is assumed that transportation process 1, by donkey cart, is unimportant for the end results, as the donkeys and carts both are used for several other things over their lifetime, and do probably not have a significantly high environmental impact. The transportation distance is also short, and this process is therefore not included in the analysis. The average distance, 2.7 km, is calculated as the distance from households spread equally across the camps to a collection point, weighted for the inhabitants in different camps. This step is also similar in all scenarios, and therefore will not influence on the results. For the transportation distance 2, with lorry, the mean distance for each kg plastic (weighted after total plastic amount in each area) has been used. In the reference scenario this distance was 888 kgkm from the Melkadida area to Addis Ababa. For transportation between collection centres and factories in the Melkadida area, the mean is 26.8 kgkm. In all processes, the gross plastic amount going into the process is assumed constant throughout the whole process, even though a loss does occur.

4.2.7 LCA data

In general, process cards from ecoinvent have been used in the analysis, but in the case of emissions from open burning, no relevant process card was found. This was then constructed using data from IPCC. Chapter 5 the IPCC Guidelines for National Greenhouse Gas Inventories (Guendehou et al., 2006) outlines methods to estimate CO_2, NH_4 and N_2O emissions from country waste management, and parts of this methodology and the emission factors have been used in this analysis. When finding the emissions of non-organic CO_2, it is recommended to use the carbon content in the dry matter of the different waste fractions to find the amount of CO_2 that will be produced during incineration, as well as the oxidation factor (Guendehou et al., 2006). In chapter 2, Pipatti et al. (2006) suggest a dry mass ratio of the wet mass of 100% for plastics, and a carbon content in the dry mass of 67-85%, but with a proposed default value of 75%. 100% of this is fossil carbon. Guendehou et al. (2006, p.5.18) suggests 58% as a default value for “oxidation factor in % of carbon input” in open burning. Based on these assumptions, an emission factor of 0.435 kg per kg incinerated plastic has been used in the analysis. Emissions of heavy metals, which may have environmental impacts, and PAHs (Polycyclic aromatic hydrocarbons) with possible human health and cardiologic effect, have been taken from Valavanidis et al. (2008) (Presented in Appendix O).

All other processes have been modelled using process-cards from ecoinvent. Where the choice of process, for example for transportation has not been an obvious one, a comparative analysis has been conducted with all relevant process cards, to establish the difference in greenhouse gas emissions and to be able to choose a process with an average emission factor of all the different choices. In these cases, where the process impacts more than 5%, sensitivity of the choice has been assessed by using the probable highest impact and lowest impact that can be obtained by choosing other process cards. All processes used are presented in Table 9.

Table 9: Process cards from ecoinvent used in the analysis

Process cards used in analysis	Used for	Reason for choice and use
Transport, freight, lorry 7.5-16 metric ton, EURO4 (GLO)| market for | Cut-off, U	Long distance transport.	Mean of most likely lorry sizes, see 0.
Transport, freight, lorry 16-32 metric ton, EURO4 (GLO)| market for | Cut-off, U	Long distance transport.	Sensitivity, less impact from transport, see 0.
Transport, freight, lorry 3.5-7.5 metric ton, EURO4 (GLO)| market for | Cut-off, U	Long distance transport.	Sensitivity, more impact from transport, see 0.
Steel, low-alloyed, hot rolled (RoW)| production | Cut-off, U	As corrugated roof.	Steel is closest to corrugated iron roof found in ecoinvent. Median of most likely steel, see 0.
Steel, low-alloyed (RoW)| steel production, electric, low-alloyed | Cut-off, U	As corrugated roof.	Sensitivity, less impact from steel, see 0.
Steel removed by turning, average, conventional (GLO)| market for | Cut-off, U	As corrugated roof.	Sensitivity, more impact from steel, see 0.
Metal working, average for steel product manufacturing (Vergara & Tchobanoglous)| market for | Cut-off, U	Used for conversion from pure steel to a steel roof.	Only metal working process card found in the database.
Polyethylene, high density, granulate (GLO)| market for | Cut-off, U	Used in original flower pots and Jerrycans substitute in reference scenario.	Median of three different plastic granulates, see 0.
Polyethylene, high density, granulate, recycled (RoW)| market for polyethylene, high density, granulate, recycled | Cut-off, U	See above.	Sensitivity, less impact from plastic, see 0.
Polyethylene, low density, granulate (GLO)| market for | Cut-off, U	See above.	Sensitivity, more impact from plastic, see 0.
Injection moulding (GLO)| market for | Cut-off, U	Used in making of original flower pots.	Only injection moulding process.
Packaging box factory (Vergara & Tchobanoglous)| market for | Cut-off, U	1.43E-9 used in sensitivity.	Used in most plastic processing processes in the database.
Plastic processing factory (Vergara & Tchobanoglous)| market for | Cut-off, U	Infrastructure factory: 1.43E-9 used in main analysis, 0.44E-6 in sensitivity.	Is a factory for plastic processing.
Electricity, low voltage (RoW)| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted | Cut-off, U	Energy supply in main analysis.	The median of 17 photovoltaics tested for, see 0.
Diesel, burned in diesel-electric generating set, 18.5kW (Vergara & Tchobanoglous) diesel, burned in diesel-electric generating set, 18.5kW | Cut-off, U	To demonstrate the impact of using diesel generator in recycling in the sensitivity analysis.	For diesel generators only one were found being smaller than 100 kW, and this will be used in the analysis.

In Appendix V, a review of the energy need from the report can be found. As a summary, the total energy consumption in the collection step (including washing and shredding) is 8 520 kWh/month, the recycling step (oven and extruder) uses 10 420 kWh/month, and lighting uses 720 kWh/month. Given a total recycled amount of 38 000 kg/month as stated in the EWB report (Eckbo et al., 2018), if allocating the electricity for lighting equally into collection and recycling, this results in an electricity demand of 0.2337 kWh/kg for washing and shredding and 0.2837 kWh/kg for recycling. These estimates will be used in this analysis. It has also been concluded in the report that with the given assumptions, solar panels will be financially favourable over diesel generators after just a couple of years, and as no other assumptions are collected for this analysis, only solar panels will be considered in the financial analysis. It is assumed that there will be enough space for solar panel installation.

The system will in reality need many other resources, such as water, antioxidants and washing detergents such as caustic soda. The availability of the resources are described further in Appendix H.

4.2.8 Financial data

The recycling system will contain investment costs from the buildings, machines and an electricity producing module, and variable costs from labour, acquisition of the plastic, transport and processing etc. The income will be generated from sales of the products, and any other potential sources. All costs used from the EWB report (Eckbo et al., 2018), stated in USD, have been converted to Ethiopian birr (ETB) with an exchange rate of 27.5 ETB/USD, as this is the exchange rate used in the report. All estimates from the report from August 2018 are considered rough estimates, and are assumed to be unchanged from the summer 2018 to spring 2019. In the financial base case scenario, the recycling cooperative will get funding for the investment costs, but will have to run day-to-day by themselves without relying on aid. The cases that will be investigated financially, in addition to the base case, are as follows:

1. The cooperative only gets 30% of the investment funded and have to finance 70% through debt.
2. The cooperative gets an extra operational income through compensation schemes and European Emission Trading Schemes.

The investment cost estimates are collected from the EWB report, and a linear cost increase per kg plastic available per month is assumed. Investment costs relative to the amount of the plastic amount are shown in Table 10 and other investment costs are shown in Table 11. The operational costs are summarised in Table 12, while the assumptions for the financing option are presented in Table 13. Operational incomes are shown in Table 14.

Table 10: Relative investment costs collected from the EWB report (Eckbo et al., 2018)

	Total investment (ETB)	Plastic amount (kg/month)	Relative investment (ETB/(kg/month))
Solar panels	9 515 000	38 000	250
Washing and shredding	907 500		24
Recycling	646 250		17

Table 11:Other investment costs

	Price (ETB)	Source
Collection point building	250 000	
Collection and recycling building	500 000	
Tipper truck	1 100 000	Estimate from EWB report (Eckbo et al., 2018)
Land	0	ARRA Chief, Muhammed, in the Melkadida camp
Moulds	1% of recycling machines	
Other costs	3% of other investments	

Table 12:Operational costs and income

	Cost	Explanation
Plastic acquisition price, main analysis	22 ETB/kg	In the analysis it is assumed that the collection will still happen through the waste traders who collect and sell jerrycans today. See review, Appendix U.
Other contract workers	1200 ETB/month	See explanation in Appendix U.
Need of employees	0.545 employees / ton plastic each month	See explanation in Appendix U.
Transportation in camps	0 ETB	Assumes that donkeys eat grass etc., and that carts do not need maintenance
Transportation between camps	1.26 ETB/kgkm	See explanation in Appendix U.
Maintenance costs	0.01% of investment costs/month	
Other resources	0.01% of investment costs/month	
Tax	0 ETB	Assumed that project will not need to pay tax.

Table 13: Financing assumptions

	Assumption	**Explanation**
Loan percentage	70%	
Interest	8%	Assumed that interests and yearly payment is paid once each year. Interests are payed on the remaining loan at the end of last year
Payment period	10 years	

Table 14:Operational income assumptions

	Assumption	**Explanation**
Income rooftiles	25 ETB/tile	1/12 of what UNHCR would pay 300 ETB for (Eckbo et al., 2018)
Income pots	200 ETB/tile	Same price as now paid for pots (Demissew Eshete, 08.18)
EU ETS	650 ETB/kg reduced emission	See below
Compensation scheme	1 ETB/kg plastic into camps	See below

An article from 2018 investigates the possibility for a refugee camp to obtain a higher operation income through the European Emission Trading (EU ETS) system by giving Zaatari refugee camp a higher albedo (Manni et al., 2018). This has been a possibility under the EU Emission Trading Scheme phase 3, which will end after 2020 (European Union, n.d.). A certificate bought from such a project accounts for the same amount of avoided reduction for the company or country buying the certificate (European Commission, 2015). A similar scheme will probably be carried forward into the next phase (European Union). In this analysis, one of the scenarios will include an income based on the avoided emissions and the prices of emission certificates. According to Business Insider, the prices of these certificates have varied a lot in previous years, but has increased from 5 euros to more than 20 euros per certificate from June 2017 to the beginning of 2019 (Markets Insider, 2019) The base price used in this analysis is therefore 20 euros (650 ETB), given an exchange rate of 32.5 ETB in one Euro.

The project can in principle also be partly financed by compensating schemes including organizations importing plastic into the area. In order for UNHCR, which is the project’s main benefactor, to have the mandate to initiate this, it is likely that only aid organizations working as implementing partners for UNHCR can be included in this scheme. Compensation schemes can contribute to a reduced influx of plastic, and make packaging and products more sustainable. No analysis has been conducted in order to analyse which price is most efficient in reducing plastic amounts to a more sustainable level. As such, the price is set to 1 ETB/kg plastic packaging being introduced to the area and 0.5 ETB/kg plastic items being imported into the area, based on pure speculation. The amount of plastic being imported into the areas by aid organisations is unknown, but one assumes that the amount of plastic packaging corresponds to the amounts of jerrycans and bottles, while the weight of plastic items corresponds to half of the jerrycans and bottles weight. The thesis will investigate how much must be contributed to the project for it to survive in the long term, and different ways to obtain these contributions will be discussed.

5 Results

5.1 What quantities and types of plastic is passing through or ending up in the refugee camp areas?

5.1.1 Main results

Data from chapter 4.2.5 has been used to scale up the amount of the relevant types of plastic at different localities, to that of the whole population, using the four area categories presented in Table 2 for jerrycans, and with weighted averages for bottles. This gave an estimated total plastic waste amount of 0.22 kg/person/month, divided into 89 tons HDPE/month and 7 tons PET/month from the 433 000 inhabitants in the area. As the results will be compared to corresponding values from other refugee camps, it is also relevant to find estimates only or mainly based on data from refugee camps. In the Melkadida area, the estimate for the refugee population is 0.07 kg/person/month of only jerrycans. In the Jijiga area, the plastic amount has been found through a combination of plastic from host community inhabitants and inhabitants of refugee camps, resulting in estimates of 0.06 kg/person/month from jerrycans and 0.02 kg/person/month from bottles. Using a weighted average to merge these two areas, including all refugees and also some inhabitants from the host communities, this results in a production of 0.08 kg/person/month. A benchmark estimate for the minimum bottle-amount each month in the Melkadida area can be based on the water bottle factory production in Jijiga. If assuming that all bottles from this factory are sold within the refugee camps and host communities in the Melkadida area, in addition to Dollo Ado, this corresponds to 0.005 kg bottles/person/month. By doing the same with the oil distributed to refugees in plastic jerrycans in the Melkadida area, a minimum estimate of jerrycan plastic 0.015 kg jerrycans/person/month is found. Figure 15 displays the plastic amount estimates per person in the different area categories.

Table 15: Results plastic production in all areas, interviewed waste traders in parentheses

	Estimated HDPE plastic production/person/month	**Estimated PET plastic production/person/month**	**Population**
Refugee camps in Melkadida refugee camps	0.07 (1)		219 000
Host communities in Melkadida area	1.38 (2)		31 000
Dollo Ado City	0.38 (2)		60 000
Jijiga camps and host communities	0.06 (3)	0.02 (3)	122 000
In total	0.20		432 000

5.1.2 Sensitivity analysis

A simple sensitivity analysis has been conducted to examine whether the choices made have had a significant impact on the results, and to find the maximum and minimum estimates of plastic waste if parameters are different than assumed in the main analysis. The categories that have been tested for in the sensitivity analysis are those assumed to contain the most uncertain parameters due to the data collection and scaling method. These are described in Appendix L and Appendix M. The categories, sources of uncertainty and sensitivity parameters for the sensitivity analysis of the amount of HDPE plastic are shown in Table 16. The uncertainties described do not concern all data, as only the data given with a degree of uncertainty or values which are purely estimates are tested for.

Table 16: Sensitivity analysis categories and parameters

Sensitivity category	Reason for uncertainty	Parameter change in sensitivity analysis
Population size	In Dollo Ado (DA) and the host community in Sheder (S) and Bokolmanyo (B), the population sizes are especially uncertain, and will be tested for. Based on statements for DA and B.	DA: 25 00 - 60 000 inh. S: 10 000 – 30 000 inh. B: 1 800 – 5 400 inh.
Average size of lorry	Where no exact weight has been stated by waste traders, an average lorry size has been used in the base case. The probable size range of these lorries will be tested for.	Lorry size: 3 – 5 tons in each load
Stated plastic amount ranges	In Dollo Ado (DA) and Bokolmanyo (B) monthly plastic amounts were stated as a range. The average was used in the base case. The extremes will be tested for.	DA traders: 1600 – 2400 kg/month B traders: 1500 – 1800 kg/month
Size of other waste traders	For some waste traders in Awbare (A) and Bokolmanyo (B) their size has been established through estimating the same size of other traders in the same community.	Relative size of other waste traders in A and B host communities: Half the size and twice the size of the interviewees.
Scaling method	Amounts based on area category scaling will be tested for scaling based on scaling using weighted average with and without excluding the outliers.	Weighted average of each estimate & weighted average excluded outliers.

For the PET estimate, a different sensitivity analysis has been conducted, since the prevalent uncertainties differ. These are described in Table 17.

Table 17: Parameters and cases for sensitivity analysis

Sensitivity category	Reason for uncertainty	Parameter change in sensitivity analysis
Population size	As in Table 16	As in Table 16
Bottle weights	Specific data on the weight of bottles of different sizes was not collected during field work. The weight estimate used and a probable range has been described in Appendix N. Weight has been adjusted more up than down from the reference scenario. Most bottles were 1L bottles.	0.5 L bottles: 9 g – 15 g 1 L bottles: 21 g – 38 g 1.5 L bottles 31 g – 61g

Results from both sensitivity analyses are shown in Table 18. The cases correspond to the descriptions in Table 16 and Table 17. Table 18 displays the results, where contributions to a higher or lower estimate are written in blue or red, respectively.

Table 18: Results simple sensitivity analysis plastic waste amounts

Cases	HDPE (tons/month)	PET (tons/month)
Base case	89	7
Population size - higher	74	6
Population size - lower	132	8
Average size of lorry – smaller	88	
Average size of lorry - bigger	90	
Stated plastic amount ranges - lower	82	
Stated plastic amount ranges - higher	98	
Size of other waste traders - higher	119	
Size of other waste traders - lower	74	
Scaling method – weighted average	73	
Scaling method - weighted average excl. outliers	72	
Bottle weights - lower		7
Bottle weights - higher		13

A lower population size has the largest diminishing effect on the results for both plastic types. The highest increasing effect results from using a different scaling method for HDPE and higher population size for PET. The results tend to be relatively larger in the increasing direction than in the decreasing direction. The results show that the highest uncertainty is obtained through assuming a higher bottle weight and a lower population size in the communities where size was uncertain. This resulted in an increase in the estimated amount of plastic by 50%. To establish the overall highest and lowest probable plastic waste production estimates, the different cases have been combined depending on the impact they had on the results. Cases which caused an increased waste estimate (highlighted in blue in Table 18) are collected in a scenario called "Highest probable plastic waste production" and cases which caused a diminished estimate (highlighted in red in Table 18) are collected in the scenario "Lowest probable plastic waste production from both HDPE and PET. The resulting ranges are summarised in Table 19, and give a plastic production range in the area of 70 – 224 tons/month.

Table 19: Plastic waste production range

	Base estimate waste production	**Lowest probable waste production**	**Highest probable waste production**
HDPE (tons/month)	89	64	210
PET (tons/month)	7	6	14

5.2 What are the environmental impacts of a recycling system?

5.2.1 Main analysis

The greenhouse gas emissions from the six main scenarios are presented in Figure 18. The sum of processing and transportation processes do not vary much between the scenarios including recycling. Product substitution is the process creating the largest differences between the scenarios. The substitution of flower pots reduces the net greenhouse gas emissions more than the substitution of rooftiles. The substitution effect of plastic pots with HDPE plastic is even higher than with PET plastic, as PET has a higher mass density, but has been made using the same mould in this analysis.

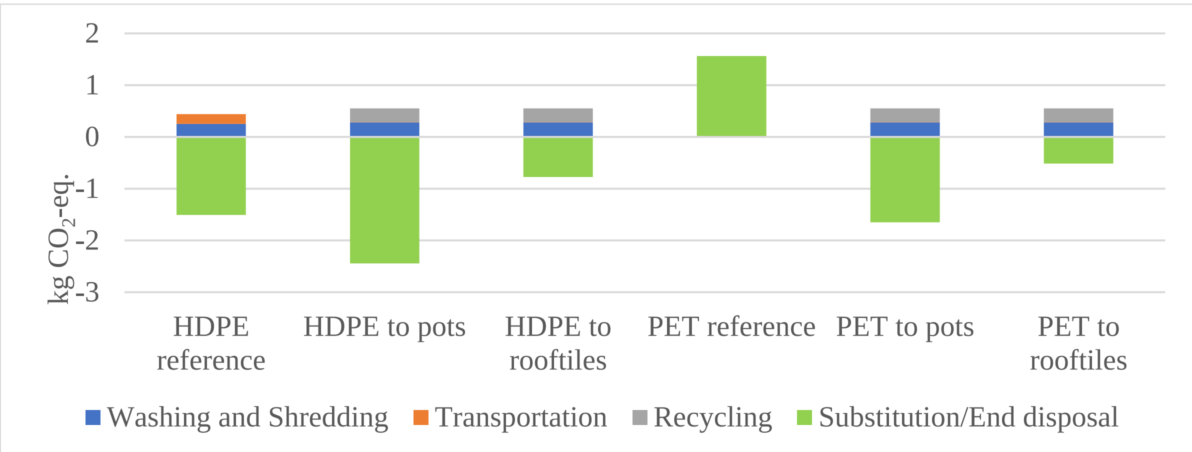

Figure 18: Gross benefit by processes on all scenario

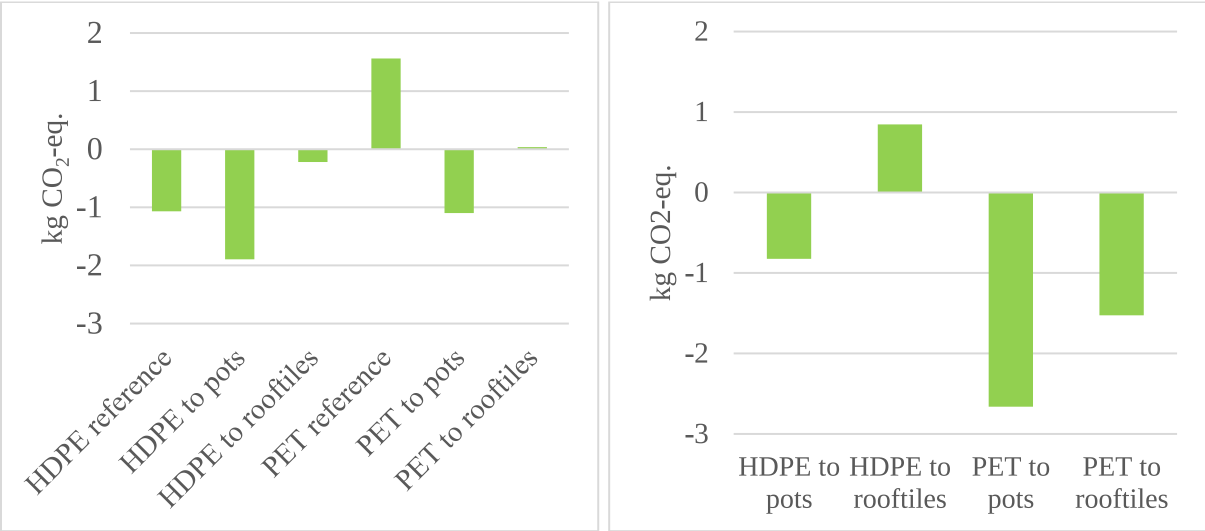

Figure 19: Left: Net benefit from all scenarios
Right: Net change from reference for each recycling scenario in the Melkadida area.

The chart on the left of Figure 19 sums up the emissions form all processes for each scenario, and the chart on the right of Figure 19 sums up the net benefit of implementing each of the four recycling-scenarios. It illustrates that recycling of PET has a higher impact on the total greenhouse gas emissions as the reference scenario of PET has a positive emission factor of about 1.5 kg CO_2-equivalents, while the HDPE reference scenario has an impact of -1 kg CO_2-equivalents. Making rooftiles out of HDPE in the camps is the only recycling alternative that causes an increase in emissions, compared to today's waste management. The net changes from the reference is shown for the Jijiga area in Figure 20, but as only transportation distances differ between the Jijiga to the Melkadida area, there are is not a substantial difference in the results.

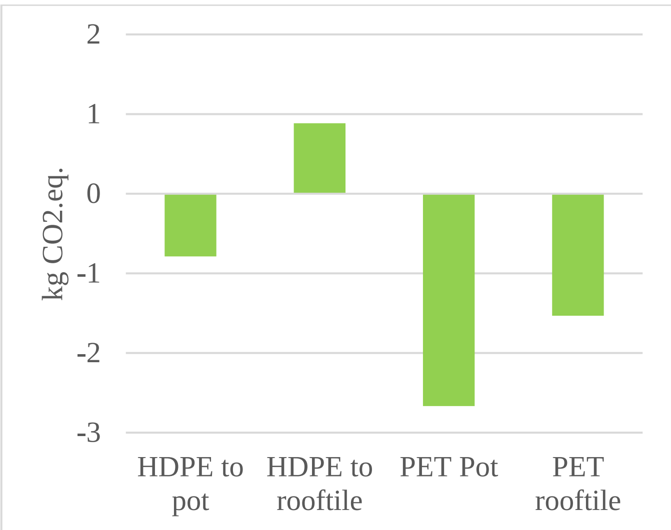

Figure 20: Net change for each recycling scenario from the reference scenario, Jijiga area

The net benefit on all emission impact categories available from the simulations in SimaPro are shown in Figure 21 for PET and Figure 22 for HDPE. All emissions are normalized to the highest emission from one impact category for both PET and HDPE. It is evident that recycling in general is unfavourable when emphasizing impact categories measuring toxicity and ecotoxicity, and that products made out of PET in general have the highest emissions out of the two plastic types, and recycling into pots has the highest emissions of the two possible products. For the other impact categories, the results are more varying. Nevertheless, a pattern can be seen that production of pots is not beneficial for ozone formation, ozone depletion, ionizing radiation and fine particulate matter formation.

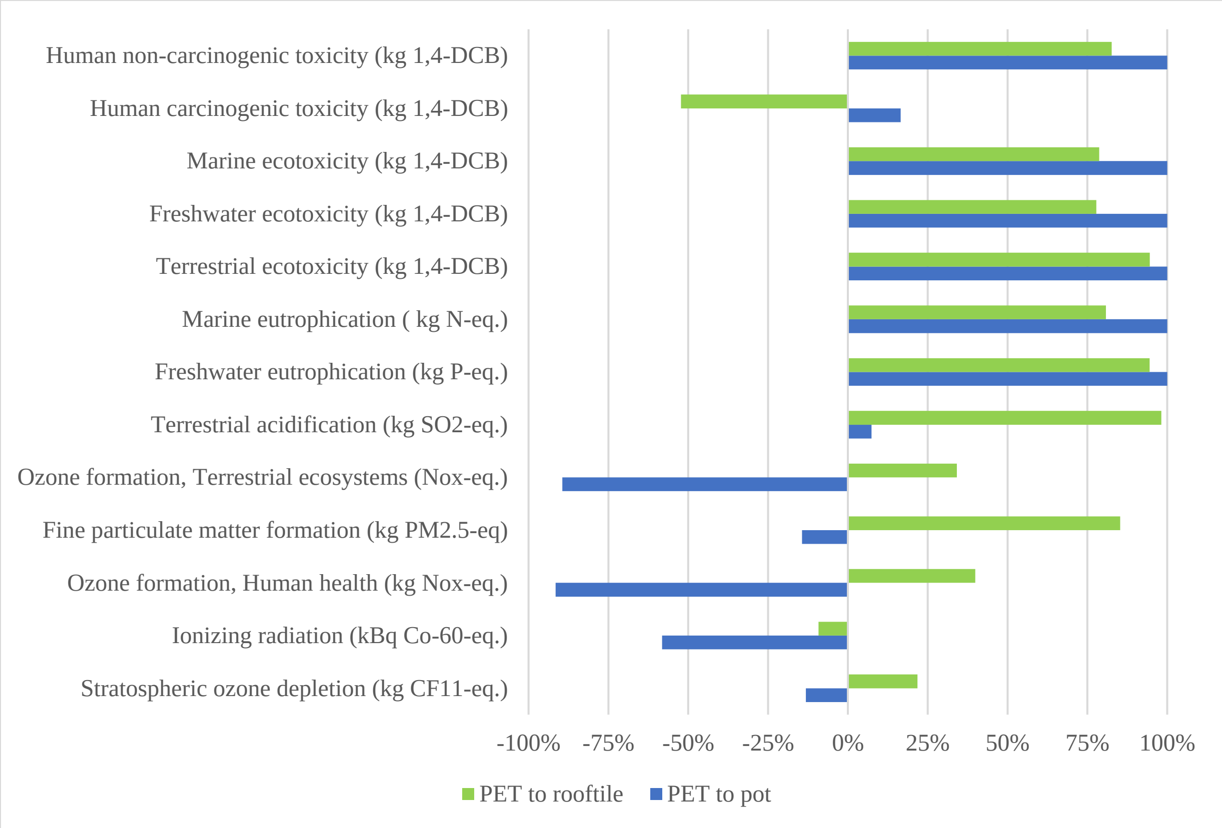

Figure 21: Net benefit from PET recycling on other impact categories

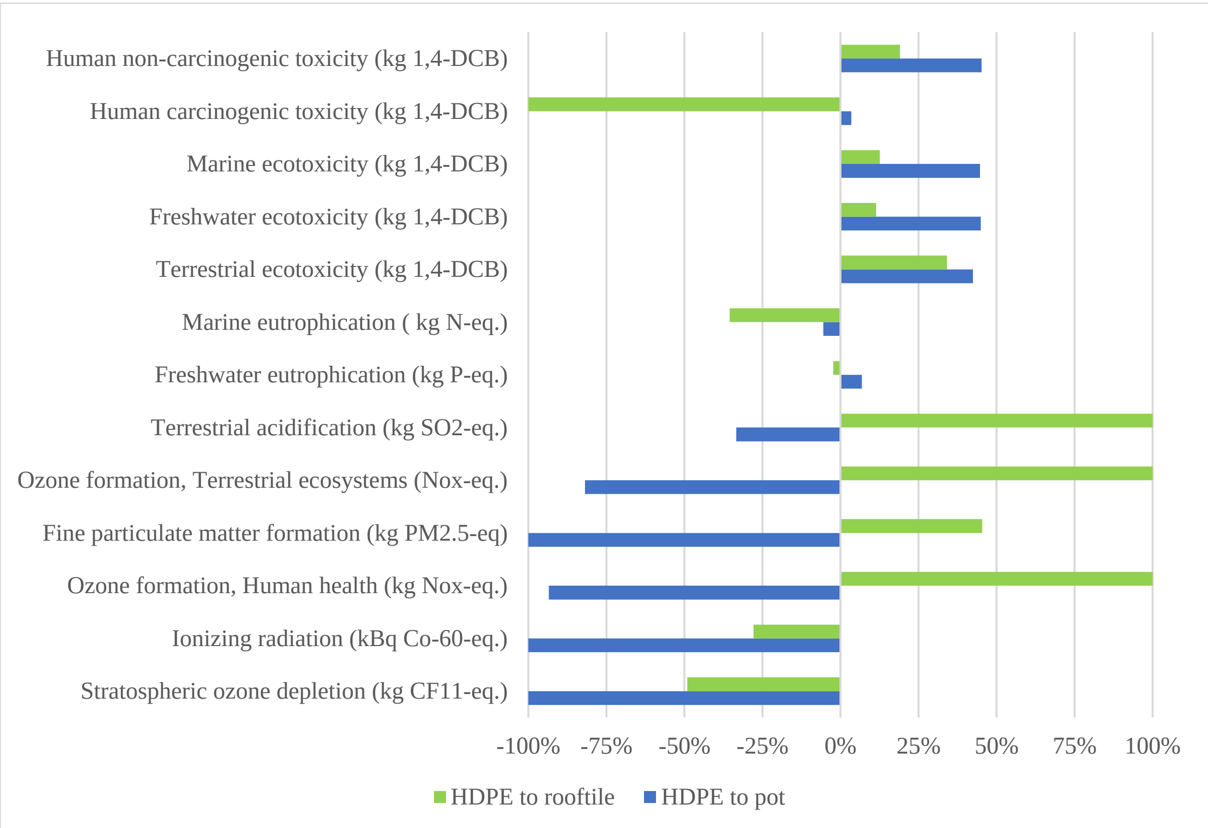

Figure 22: Net benefit from HDPE recycling on other impact categories

5.2.2 Sensitivity analysis

A sensitivity analysis has been conducted to establish what impact uncertainties have on the results. Only processes with more than 5% of the emissions in a certain scenario have been tested for. For example, sensitivity in regard to transportation has only been tested for in the HDPE reference scenario, as it does not have a significant impact on the emissions in the other scenarios. All sensitivity parameters and the descriptions of these are summarized in Table 20.

Table 20: Sensitivity analysis parameters. For a more detailed explanation, see Table 9

Parameter	**Change**	**Explanation**	**Impacting**
Emissions from open burning	1: +30% 2: -30%	A higher or lower oxidation rate, or emissions of other greenhouse gases can contribute to a different amount of emissions in kg CO_2-eq.	PET reference
Different transportation vehicle	1: 0.52E-3 CO_2-eq./kgkm 2: 0.17E-3 CO_2-eq./kgkm	Emissions from bigger and smaller lorries in Euro-class 4.	HDPE reference
Electricity from diesel generator	Same electricity amount, but from diesel generator.	In the case that the electricity for processing and recycling will not be produced with photovoltaics, but diesel generator instead.	HDPE reference HDPE to pot HDPE to rooftile PET to pot PET to rooftile
Different ratio virgin HDPE substitution	80% HDPE granulate/kg and 0.6 kWh/kg HDPE to recycling.	Pré Consultants suggest using HDPE granulate and 0.6 kWh electricity, medium voltage (RoW) market for substitution when recycling. Assumed 80% subst. rate.	HDPE reference
Different subst. ratio plastic to pot	1: 0.35/kg HDPE 0.21/kg PET 2: 0.85/kg HDPE 0.54/kg PET	Assuming more and less plastic in original pot. 1: Smaller orig. pot – assumes that the orig. pot weights 0.7 kg (Schütz, n.d.). 2: Bigger conventional pot. Assuming an 80% subst. rate for HDPE. Correspondingly lower for PET (54%).	HDPE to pot PET to pot
Different plastic type in original pot	1: 2.3 kg CO_2-eq./kg 2: 0.9 kg CO_2-eq./kg	1: Substitution of HDPE (GLO) 2: Substitution of rHDPE (RoW)	HDPE to pot PET to pot
Different factory infrastructure	1: 1.43E-9 of packaging box factory 2: 0.44E-6 of Plastic Processing Factory	1: Used in most plastic processing processes in the database. Used same allocation as these processes. 2: Only factory for plastic processing in database. Physical allocation.	HDPE reference HDPE to pot HDPE to rooftile PET to rooftile PET to pot
Different steel substituted	1: 0.87 kg CO_2-eq./kg steel 2: 3.98 kg CO_2-eq./kg steel	(RoW) steel and hot-rolled steel has been tested for in the substitution, as it is uncertain how corrugated iron roofs are produced.	HDPE to rooftile PET to rooftile
Different substitution ratio plastic to iron roof	1: -30% 2: + 30%	A change of 30% from the original subst. rate of 0.21kg steel/kg HDPE and 0.14 kg steel/kg PET as the rooftiles may have to be shaped differently.	HDPE to rooftile PET to rooftile

The results from the sensitivity analysis are divided into four different charts. They are primarily divided into changes in reference scenarios (Figure 23), changes in the pot recycling scenarios (Figure 24) and rooftiles recycling scenarios (Figure 25). The exception is for the sensitivity parameter “Different factory infrastructure”, as some of these results differ too much from the other results to be displayed in the same chart, ruining the illustrative value. These results are summarized in Table 21.

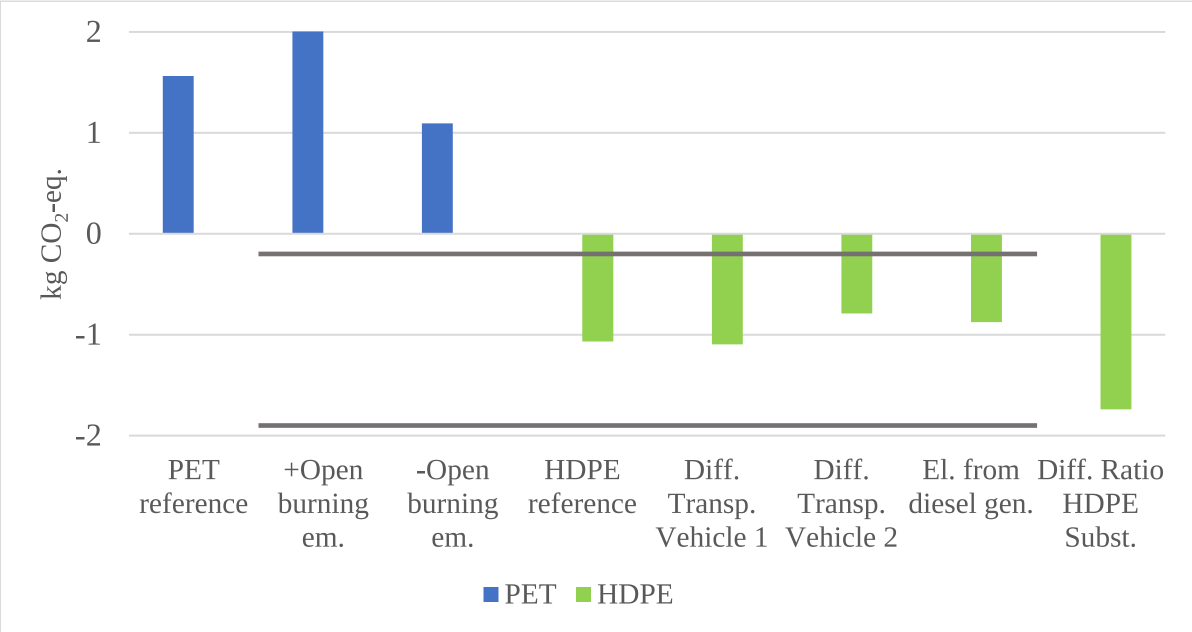

Figure 23: Sensitivity analysis results for reference scenarios

For the PET reference scenario, which is only impacted by emissions from open burning, a change in emission factor per kilo burned PET will impact the result linearly. No changes in the PET reference scenario make recycling of PET detrimental. For the HDPE reference system, the main scenarios of making HDPE into rooftiles and pots are lined up in the chart at -0.2 and -1.9 kg CO_2-eq. respectively. As the main reference scenario of HDPE lies in the middle of these two values, and no change in the reference system shown in this graph crosses any of the values of producing rooftiles or pots, the results shown in Figure 19 do not change. It is still environmentally profitable to produce pots, but not rooftiles, even with all the sensitivities checked for. The change of substitution method is the parameter affecting the result most, but this is also the less relevant uncertainty, as infrastructure in processing of jerrycans to granulates is disregarded.

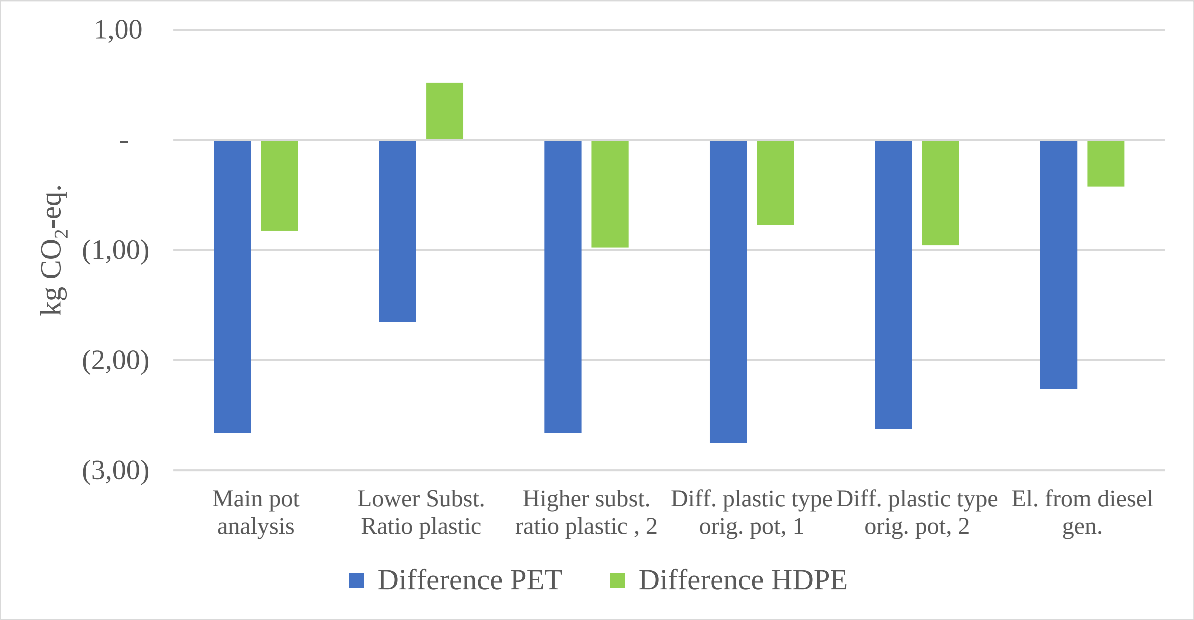

Figure 24: Results sensitivity analysis, changes in plastic pot recycling scenarios, subtracted from the main reference scenario

Most of the uncertainties in the pot recycling scenarios do not have a significant impact on the results. Only the use of a diesel generator in the recycling and an assumption that the original flower pot used today only weighs 0.7 kg has a significant negative impact on the results. When using the lower substitution ratio for HDPE, recycling of the plastic into pots is not a better solution than the reference scenario.

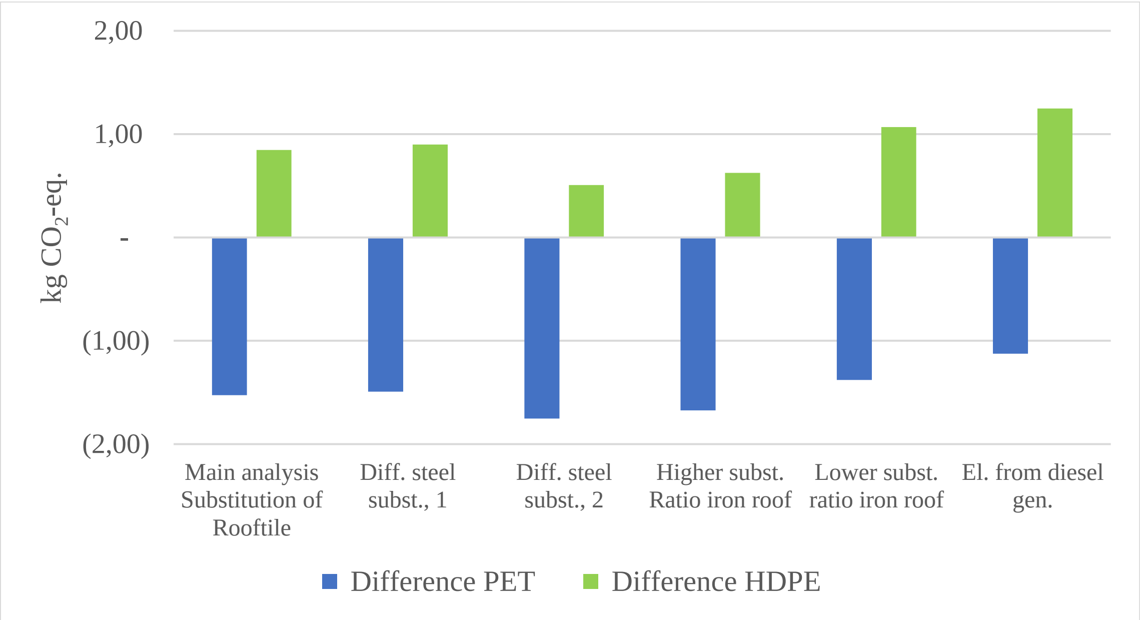

Figure 25: Results sensitivity analysis, changes in rooftiles recycling scenarios, subtracted from main reference scenario

The results for recycling of plastic into rooftiles seem similar to recycling that of into pots. The uncertainties do not have a significant impact on the result, and none of the results displayed in this graph invalidate the main result, which is to recycle PET, but not HDPE, into rooftiles. The highest impact results from the substitution of steel with a higher greenhouse gas emission per produced amount, and a higher substitution ratio of steel.

Table 21: Results sensitivity analysis, different factory infrastructure allocation

		PET		HDPE	
	Unit	**Lowe em.**	**Higher em.**	**Lowe em.**	**Higher em.**
Reference scenario, with higher factory emissions	kg CO2-eq.	1.56	1.56	-1.31	75.15
Rooftile scenario, net emissions	kg CO2-eq.	-0.45	155.94	-0.71	155.68
Flower pot scenario, net emissions	kg CO2-eq.	-1.59	154.81	-2.38	154.01
Rooftile subtracted from reference scenario	kg CO2-eq.	- 2.02	154.38	0.60	80.53
Flower pot subtracted from reference scenario	kg CO2-eq.	-3.15	153.24	-1.08	78.86

The change of factory infrastructure into having a lower impact by using the same assumptions as the other plastic processes in ecoinvent does not result in a substantial deviation from the main results, and does not change the conclusion that all scenarios except for HDPE into rooftiles are environmentally profitable. A change, however, of the infrastructure to the physical allocation described in the process card of Plastic Processing Factory, creates a much larger impact. This change affects all scenarios except for the PET reference scenario, where no plastic is processed. It also affects the HDPE reference scenario half as much as the recycling scenarios, as the substitution is assumed after washing and shredding, but before the main recycling. As a result of this, given that the allocation of Plastic Processing Factory is correct for this given location, one can see that plastic recycling is highly impacting the environment negatively, both when the alternatives are open burning and recycling of the plastic in Addis Ababa.

In general, the sensitivity results show the analysis is robust to probable changes in parameters, except for in the uncertainty regarding plastic recycling factory infrastructure. The change assumed is big, as the different choices available in the ecoinvent database are vastly different.

5.3 Is the project financially viable using means such as loans, external funding and/or other schemes, and how will these choices impact the results?

5.3.1 Main analysis

In the financial analysis, it has been thought to be beneficial to analyse the two refugee areas separately, as there are bigger waste amounts in the Melkadida area, and there are some differences in lorry purchases and transportation distances between the two areas. To avoid inaccurate conclusions, the Melkadida area will be analysed through the main analysis. Some results from the Jijiga area will also be presented, in order to establish the difference in financial feasibility for the project between the two areas.

The main questions in the financial analysis are, as in the environmental analysis, what the differences between the two plastic types are, and which of the products is most feasible in production, both in regard to operational costs and income. These results are presented in Table 22 for the Melkadida area. All results are presented as the annual result (= revenue or loss), as a funded investment can be seen as no investment, and the yearly balance therefore is more interesting.

Table 22: Results in total and per kg from the financial analysis, in the Melkadida area

	Total result – tiles	**Total result - pots**	**Total amount of plastic**	**Result/kg – tiles (Total result/plastic amount)**	**Result/kg – pots (Total result/plastic amount)**
Unit	*ETB/year*	*ETB/year*	*Tons/year*	*ETB/kg*	*ETB/kg*
HDPE	-22 100 000	53 800 000	82	-270	656
PET	-1 850 000	1 380 000	5	-370	276

The only differences between the Melkadida and Jijiga areas impacting the financial analysis are the amount of lorries needed by the factories, transportation distance between camps and amount of plastic produced. Table 23 shows the corresponding results for the Jijiga area.

Table 23: Results in total and per kg from the financial analysis in the Jijiga area

	Total result – tiles	**Total result - pots**	**Total amount of plastic**	**Result/kg – tiles (Total result/plastic amount)**	**Result/kg – pots (Total result/plastic amount)**
Unit	*ETB/year*	*ETB/year*	*Tons/year*	*ETB/kg*	*ETB/kg*
HDPE	-1 080 000	5 950 000	7.5	-144	793
PET	-456 000	815 000	2.0	-228	408

The two main results are that it is more profitable to make pots than rooftiles, and it is more profitable to recycle HDPE than PET. The reason for these results are that the pots have a higher selling price than rooftiles per weight unit, and because more mass of PET is needed to make products of the same size as it has a higher mass density than HDPE. It is also important to emphasize that the results for production of plastic does not include the sales limitation of 5000 pots a year. It is therefore not possible to use all the plastic to produce these. Both waste fractions will be included in the further analysis, with a production of 5000 flower pots each year and rooftiles from the remaining plastic. The result with these assumptions is an annual loss of -23.0 M Ethiopian birr, and will be the reference to which the following results should be compared to. The cost and revenue components of this scenario is shown in Table 24.

Table 24: Costs and revenues in base scenario

Investment costs	**Cost (M Ethiopian birr)**
Collection point buildings	1.5
Factory buildings	5.0
Washer and shredder	2.0
Recycling machines	1.4
Moulds	0.014
Land	0.00
Solar Panels	21.0
Lorry	2.2
Donkey with cart	0.00
Operational costs	**Annual cost (M ETB)**
PET costs	1.0
HDPE costs	13.2
Employees	0.7
Diesel for transport	20.3
Maintenance	39.9
Other resources	39.9
Revenues	**Annual revenue (M ETB)**
Rooftile sale	11.3
Flower pot sale	1.0

Different financial schemes and how they may impact the results has also been investigated, given that such a scheme is possible to implement in the area. The results from this analysis are presented in Table 25. The two schemes that impact the results positively are to sell emission certificates through the EU ETS system and to implement a compensation scheme on plastic in the area or camps. For the EU ETS system the emission reductions used are the scenarios where HDPE is made into pots, or something else with similar impact, and where PET is made into rooftiles or something else with similar impact. In case that the project cannot get 100% funding, also a case where 70% is financed through loaning is investigated. For the scenario with loaning, also the size of investment is of interest. The total investment for the Melkadida camp area is 33 METB.

Table 25: Results different financial scenarios

Different financing scenarios	Result
EU Emission Trading Scheme	-22.5 METB
Compensating scheme	-21.5 METB
Loan/Funding (70/30)	-27.2 to -25.6 METB during 10 payback years

It is evident that a scheme where refugees need to finance the investment through loans and pay back the loan will not be sustainable, as they will not have enough money to pay back the loan, as long as the results are negative. Not even a push by financing schemes like EU ETS and/or compensation schemes will make a big enough difference to make the result positive. They do, however, contribute with 0.5 and 1.5 METB each and can contribute to making such a project viable, if the margins for being financially viable were smaller.

5.3.2 Sensitivity analysis

The sensitivity analysis will investigate whether the negative result is easily impacted by changes in parameters with the highest uncertainties into the maximum and minimum of their probable ranges. For parameters without observed probable ranges, a standard range of ±30% is assumed. 5 different parameters have been tested for. They are described in Table 26. The results from the sensitivity analysis are displayed in Figure 26.

Table 26: Parameters for sensitivity analysis financial analysis

Parameter	Interval	Description
Employed collectors	Same salary as other workers – 1200 ETB/month	Employ waste collectors instead of buying waste from waste traders. In this case also donkey-carts needs to be bought for the collectors. Explanation in Appendix U.
Employees different salary	251-5 000 ETB contract workers 12 -32 ETB/kg plastic waste traders	A change down to the minimum salary today (251), and up to the salary assumed in EWB report (5000) (Eckbo et al., 2018). The base salary (1200) is the probable minimum salary in a few years. Assumed lower and higher buying prices for waste traders in accordance to range stated from different traders during interviews. See explanation in Appendix U.
Corporation different income	Higher: 250 ETB/pot, 35 ETB/tile Lower: 150 ETB/pot, 15ETB/tile	Original selling price was 200 ETB/pot and 20 ETB/tile, collected from UNHCR staff and EWB report respectively. Tile-price is especially uncertain and has been changed to ±40%.
Different OPEX	±30% OPEX	All expenditures are more or less based on uncertain estimates, and the impact of this is important to know.
Different investment cost	±30%	All investment costs are based on assumptions from the EWB report, and an assumed linear proportionality.

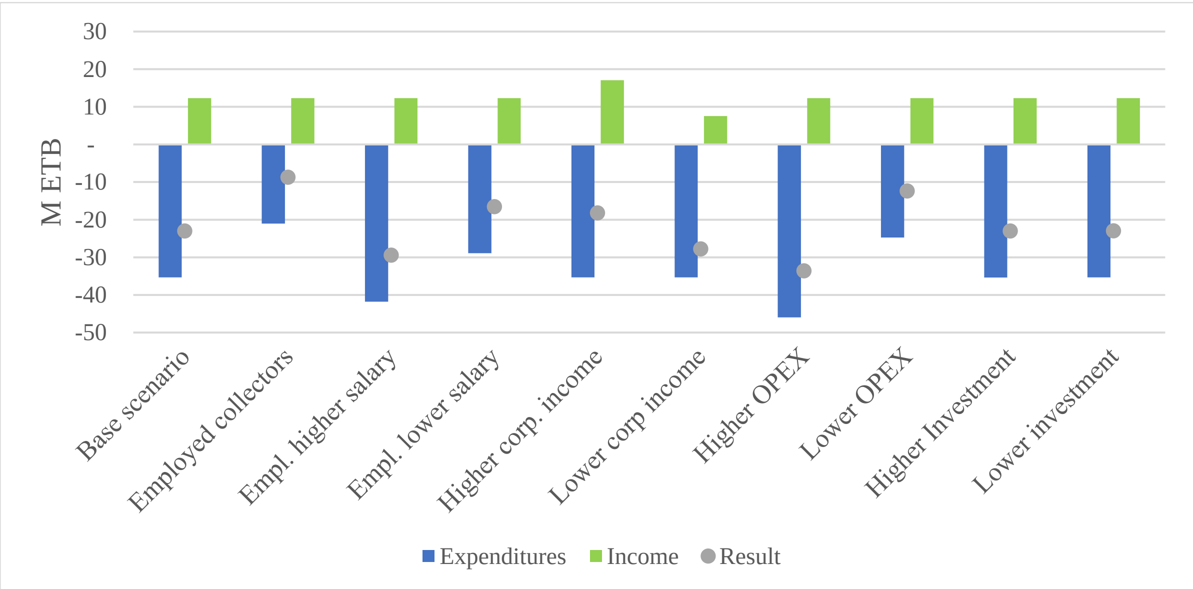

Figure 26: Results sensitivity analysis, with Base scenario displayed to the left as a reference. Melkadida area

The sensitivity analysis shows that none of the sensitivities tested for alone make the project financially viable if both PET and HDPE are to be used in the recycling and the maximum production of flower pots is 5000 per year. The three cases with lower salary for the employees, lower operational expenditures and employed waste collectors all give a significant decrease in costs. The changes in investment costs hardly impact the annual result, as they only affect the maintenance costs. The sensitivity analysis of the Jijiga area showed the same trends, and even had a positive annual result if employing the waste collectors or having a lower OPEX.

For the financial analysis in the Melkadida area, the best and the worst cases have been investigated, to see whether the project can be financially viable with optimization and different estimates. The best case includes both EU ETS and a compensation scheme, as well as employed waste collectors, higher corporate income and a lower OPEX. The worst case still assumes 100% funding, as there is no reason to take up a loan to a project that most probably will have negative results every year. Also, a higher employee salary, lower corporate income and higher operational expenditures are assumed. The results are shown in Table 27.

Table 27: Worst case scenarios and best case scenarios added together

	All negative	**All positive**
Expenditures (METB)	-60	-15
Income (METB)	7	19
Annual result (METB)	-53	4

The results show that even with all positive scenarios added together, the annual result has changed from -23 M Ethiopian birr each year to a marginally positive amount of 4 M Ethiopian birr. This indicates that the project given the assumptions in this analysis is not financially feasible during operation, except for in the cases where the income is at almost the same per kg as the flower pots in this analysis. The project will need to rely on aid for the investments, and probably also some kind of aid during operation, if not significant adjustments can be made. Another result is that HDPE in general gains a higher result per kilo than PET.

6 Discussion

6.1 What quantities and types of plastic is passing through or ending up in the refugee camp areas?

6.1.1 Comparison with other studies

From the analysis described in chapter 4.1.2, the resulting value for the plastic flow (of bottles and jerrycans) in the refugee camp areas is 0.22 kg/person/month. If including only estimates for refugees, the amount is 0.07 kg/person/month for only jerrycans in Bokolmanyo refugee camp or 0.11 kg/person/month including Bokolmanyo refugee camp and Jijiga refugee camps and host communities. In order to discuss the validity of these values, they should be compared to similar values from other studies. In the waste composition analysis conducted in Zaatari Refugee camp the plastic waste amount/person/month was estimated to approximately 0.11 kg in 2015 (Saidan et al., 2017). Hence, the plastic waste production by the refugees might not be too different between the camps in Jordan and Ethiopia, even though the Jordanian refugees have access to more goods (Figure 3).The estimate from World Health Organization, saying that refugees typically produced 0.08 kg plastic/person/month in 2005 is considerably lower than the estimate found both in Zaatari and in the Ethiopian camps (Regattieri et al., 2015). The lower estimate can either be because of a general increase of plastic use since 2005, or because of different conditions in the Ethiopian and Jordanian camps than in a general refugee camp. As the values for only refugee camps in the Melkadida and the Jijiga areas are much closer to the other refugee camp estimates, than the general estimate of the whole area, it seems likely that the results are heavily impacted by the inclusion of host communities into the analysis. This is also in accordance with data collected by Al-Khatib et al. (2007) in Palestine, where the inhabitants in refugee camps produced a slightly lower amount of plastic than other communities close by, and a significantly lower amount than the cities close by.

To know whether these two estimates are indeed typical waste amounts for refugee camps, the total waste amounts in the previously assessed camps should also be compared to these studies. The total waste amount in Zaatari in Jordan was 0.85 kg/person/month, and the typical amount used by WHO in 2005 was 1.17 kg/person/month (See Chapter 3.2.1). Two camps in Palestine produced a total waste amount of 0.64 and 0.40 kg waste/person/month in 2007, while a refugee camp in Algeria produced a waste amount of 0.15 kg/person/month in 2009 (See chapter 0). There are big variations between the share of plastic compared to the whole waste production in the two first studies, and big variations between total amounts for the three last camps. No clear trend can be found through these different amounts, and it seems probable that the waste amounts and plastic waste production in refugee camps are different between camps and depends on different factors. As the Zaatari waste composition analysis is the most recent study, and with a clear description of measuring methodology, this study may be the most representative one for this study. Therefore, to be able to say with a certain degree of probability that there is or is not a difference from these results, different uncertainties in the analysis will be discussed below.

6.1.2 Uncertainties in information collection method

When choosing a method for the information collection for this research question, the choice would have to fall mainly on one of two different approaches: Do physical measurements of the waste during fieldwork or to collect information about waste amount from others. The latter was chosen by UNHCR staff in charge of the fieldwork, due to limited time and resources. The method to collect this information will be discussed in this chapter, and the validity of the waste amount estimation method used by the interviewees to gain the collected information will be discussed in the next chapter.

An advantage of using a bottom-up product material flow analysis, is that one gets results despite time and resources being limited. This has been emphasized by Gay et al. (1993) and Franklin and Associates (1999), and the way this analysis was simplified, with only a few plastic fractions being included, has made it even more time-efficient. But this also results in the disadvantage that the results are more difficult to compare to other studies, as only a few plastic fractions have been assessed. Most other studies, as seen in Chapter 3.2.1, include a total plastic waste estimate. A strength of the form of analysis is the time aspect of the samples. Other studies have emphasized that, in waste characterization analysis, samples should include at least one week of waste. The data collected from waste traders and sole suppliers has been given as an estimate for a monthly amount, and so is probably based on an average of several months. As such, this analysis based on monthly estimates is probably higher in quality than those based on weekly estimates. Additionally, small variations in plastic waste production have probably not influenced the estimated amounts, as these same waste traders and sole suppliers have been in charge of their businesses over a longer period of time, and therefore know the usual average monthly amount rather than stating the amount from only the most recent month.

Another uncertainty is that the water bottle samples only were obtained from one of the refugee camp areas, and their representativity thus suffers. On the other hand, the estimate of kg plastic per inhabitant of 0.02 kg/person/month corresponds decently with the PET base estimate found for Melkadida area based on the one bottle water factory (0.005 kg/person/month).

The initial analysis was a sample analysis and statistical methods were not used to find the best samples to use in scaling. However, the samples found accounted for a big part of the total population. For the jerrycans, almost one fourth of the total population of waste traders, sampled in all different area categories, gave estimates on their collected amounts. The total amount accounted for bottles were 28%, but from only one area category.

6.1.3 Uncertainties in waste amount estimates

The accuracy of answers given in interviews is hard to assess, especially as the foundations for the answers is not known. It is not 100% certain that the interviewees' estimates were based on weighing or sales, even though it seems likely. Therefore, the results in the analysis should be considered the best results attainable given the collected data, but it should be viewed as somewhat uncertain. Since this is an uncertainty which is difficult to quantify, it has not been assessed in the sensitivity analysis, except for quantifiable uncertainties. The analysis could have been made stronger if this had been included. For the data quality and uncertainties, there are several different potential weaknesses and qualities for bottles and jerrycans, as the jerrycan estimates were collected from waste traders and the bottle estimates were collected from sole distributor of drinking bottles, and these businesses are probably run differently. As information was collected from waste traders through semi-structured interviews, some answers differed with regard to units, also creating an uncertainty in the analysis, as answers being interpreted or converted may result in inaccuracies. All cases of interpretation have been assessed through the sensitivity analysis and will be discussed in this chapter. The data quality and uncertainties regarding jerrycan estimates will be assessed first, and the bottle estimated thereafter.

Regarding the data collected on jerrycan waste amounts, the author does not know the exact quality. On the question of how the waste traders knew exactly how much they sell, one of the waste traders answered "The truck drivers can see how much is loaded on their vehicle." (Hilaweyn host community, 21.07.18). It is assumed that the waste traders double check sold plastic amounts by themselves as well. 4 out of 8 waste traders who estimated their amounts informed about how often they sold as well as how much they collected either each day or each month. This indicates that they have a solid foundation to estimate how much they collect and how much they sell, which ultimately give extra credibility to the answers. None looked up the numbers in any kind of financial record, but as this is probably their main vocation, it is likely that they remember these important figures from the tops of their heads. Most waste traders cut the jerrycans into pieces, so that they could make bundles of approximately the same size. This can be one of the tools used to keep track of the quantities, in weight, collected and sold. Also, most interviewees' answers do correspond well with those of others in regard to amount collected per waste trader per month. This could mean that the capacity for one seller is approximately the amount estimated by most sellers, maybe because of factors such as limited time and other resources. Where answers have been unclear in regard to converting all answers to one unit, this has been assessed in the sensitivity analysis. This was applied to three cases where (1) the average size of the lorry used in calculation, when (2) the plastic waste amount sold was estimated as a sales frequency and for (3) the applied plastic amount used for a waste trader when a range of the waste amount collected was stated. The analysis showed that the applied amount of waste used with the range stated has the highest influence on the estimated result, resulting in a 10% change in the results from 89 to 98 and 82 tons. Hence, the uncertainty in waste amount by each collector is not very significant.

For the bottle waste estimate, sole suppliers of bottles in three camps were interviewed and asked questions about their total sales during a month, divided into different bottle sizes. There were not many uncertainties noticed in regard to the data quality, as no answers needed to be interpreted. The trade appeared to work like a traditional business, with dedicated premises and a structured employment process. Therefore, the information collected through these sole suppliers is probably quite accurate and based on specific bottle orders. The highest uncertainty regarding the data used in the bottle waste estimate is through the assumed weight of the bottles, and has been tested for in the sensitivity analysis. This showed that the results are quite sensitive to the choice of bottle weight within the possible range. The PET waste estimate ranged from 7 tons/month to 13 tons/month when testing this in the sensitivity analysis, which indicates that the exact weight of the bottles is important to get an accurate analysis. According to literature, conversion factors should be made in order to convert product flows into waste flows (Gay et al., 1993). The weight of a bottle can be regarded as such a factor, but fails to include all the characteristics a conversion factor should have. The factor does not include losses, which can occur because of destroyed or discarded plastic, which thus adds to the uncertainty assessed in the sensitivity analysis.

6.1.4 Uncertainties in scaling

Area categories have been used in scaling of the collected data from individual estimates to the whole population. Refugees, host communities and city inhabitants have been divided into different groups, also depending on whether they are from the Melkadida or Jijiga area. This method takes into account that there may be differences in living conditions for the refugees, the host communities and the town Dollo Ado, and that this impacts the plastic waste production. As described previously, Al-Khatib et al. (2007) found differences in these three categories in waste generation, and dividing inhabitants into these categories therefore probably strengthens the analysis. Still, the simple division into these categories disregards for example the geographic proximity to cities and other differences between refugee camps that may be within the same area. When testing for different ways to scale in the sensitivity analysis, scaling based on area categories gave the lowest estimate of plastic waste amount for the whole sensitivity analysis, so the choice of scaling method is thus important.

The Bokolmanyo camp, which is the only estimate including only refugees, had 0.07 kg jerrycan waste production per inhabitant per month, which is the exact same amount as the estimated amount of plastic from jerrycans distributed in the Melkadida area. Also, two out of three refugee camps with host communities in the Jijiga area produced approximately 0.07 kg/person/month. In accordance with the fact that refugees should not need to buy any food, it seems probable that the distributed amount corresponds to the jerrycan waste amount, and also upholds the choice to scale based on a lower plastic production in refugee camps.

When having talked to one or several waste traders in specific communities, waste traders' opinions regarding other waste traders estimates in the same community have been used to establish the overall estimate of amount of plastic production in the communities. This was the case in Bokolmanyo and Awbare. There is a possibility that one or more of these estimates are inaccurate, an inaccuracy which might have severe consequences for the scaling. The possible impact this may have, has been tested for in the sensitivity analysis, by assuming that other waste traders in the same community as the interviewees were half the size and twice the size of the interviewees. This showed a possible plastic amount decrease of 17% (from 89 to 74 kg) or increase of 37% (from 89 to 119 kg) respectively. This means that incorrect assumptions impact the results by a relatively small decrease, or a larger increase. Another uncertainty within the scaling is that some of the waste traders may sell to other waste traders, not only to trucks or lorries going directly away from the area, which might cause some amounts of waste to be counted twice. This seemed unlikely from what the team was told during the field work, but it should still not be completely disregarded.

The population size of different towns and villages were collected from several different sources, and these estimates might therefore not correspond well with each other, and especially uncertain estimates have been tested for in the sensitivity analysis. In Sheder host community, a population estimate was not found, and therefore one was made based on population sizes of the neighbouring host communities, and this is therefore also tested for. When changing population sizes, the results decreased by only 17% with an increase in population and increased by 49% with a reduction in population. As many of the population numbers did not come from established sources, the standard error is quite significant.

The scaling method used leads to many uncertainties, mostly because the data foundation was limited. In most cases, there is only one community estimate per area category, and therefore the results from this method is especially sensitive to errors within area categories with many inhabitants. It is not possible to know whether the sampled estimate for the one host community is an outlier for the host communities, or if that is a typical use of jerrycans for their inhabitants. As a result, one should expect the plastic amount estimate to be highly uncertain and prepare for a lower or higher true amount.

When taking all uncertainties into consideration, one cannot conclude that the plastic waste amount in the refugee camps or the area around differ significantly from results from previous studies and plastic production estimates from refugee camps, nor other communities plagued by poverty. The summary in Table 19 illustrates that the base estimates used further in the analysis are very close to the lowest probable plastic waste production estimate, and about half the value of the highest probable plastic waste production estimate. This indicates that the analysis parameters are chosen conservatively, and that the ranges of probable values, according to the sensitivity analysis, are wider in the positive direction than in the negative. This will probably be even more so in the future, as several factors makes it probable that the waste amount will increase. For example as plastic can be recycled several times before the physical properties deteriorate too much, it is likely that the recycled products can and will enter the cycle multiple times (Xiang et al., 2002). This will in the long run contribute to a higher amount of plastic available for recycling . Also, economic growth and population growth can contribute to an even higher amount in the future.

6.2 What are the environmental impacts of such a project?

6.2.1 Results and comparison with other studies

In accordance with other studies, recycling has been found to be the preferred waste management solution when using greenhouse gas emissions as the deciding parameter (Laurent et al., 2014; Michaud et al., 2010; Ripa et al., 2017). In general, the results provided by this analysis has proved to be very sensitive to the reference system used for comparison. Even though more PET has been needed to create the same substitution effect as HDPE because of the mass density, PET has proved to be more favourable to recycle, as the reference system has emissions of 1.6 kg CO_2-eq./kg plastic, while the reference system of HDPE emits 1.1 kg CO_2-eq./kg plastic.

An interesting result, when investigating the relationship between emissions in all impact categories, is that while production of pots in general has higher net benefit when both pots and rooftiles show a net benefit, rooftiles tend to have a net benefit even when pot has a net detriment in other impact categories. This means that a choice will need to be made in regard to which emissions and which impact categories are the most important, and whether a stable low amount of emissions from all impact categories is better than high emissions from some and contribution to lower emissions from others. There is also no clear answer to whether PET or HDPE contributes with the most emissions, as the emissions vary significantly in the different impact categories, between the two types of plastic.

6.2.2 Method

The method used to establish the environmental impact of the proposed new waste management scheme for plastic in the camps, has been to conduct a Life Cycle Assessment. This method is recognized by scientists in the field as a good tool for analysing waste management (Ekvall et al., 2007; Finnveden et al., 2009; Hauschild & Barlaz, 2010). According to relevant literature, the systems have been evaluated from the point where products start being waste and until it reaches the end-of-waste stadium (See Chapter 4.1.3). The methodical choices used as input in SimaPro are in accordance to standardized methods and recommendations for conducting Life Cycle Assessments with similar purposes as this one. The ecoinvent database contained process cards for almost all processes included in the analysis, and using such established process cards strengthens the analysis.

The way of analysing the system has been simplified significantly. For example, no other use of resources in the physical recycling than electricity and plastic is included in the analysis. In reality, also water and additives such as antioxidants will be needed. The inclusion of this would, however, probably not impact the results significantly. Also, the disposal of plastic waste from the process is not modelled. This waste would probably, at least in the local recycling factories in the Melkadida and Jijiga areas, be driven to the landfills and burned together with the other waste fractions. This exclusion has therefore probably made the results from the recycling slightly more environmentally friendly than the real case for PET. For the HDPE plastic fraction, the same would probably happen with waste from the process also in the reference scenario, and the overall result would not be changed.

6.2.3 Choices in regard to data and data quality

The data used in the analysis can be divided into four different categories. Some data are specific data, such as the fact that PET plastic waste is currently being burned, and the distances between the camps. Some data, such as the energy need in shredding, washing and recycling, is collected from the EWB report, and is as such an estimate based on subject matter. A third category is global general data found in the ecoinvent database. The last category is data that does not fit in any of the other categories and has been estimated based on recommendations in IPPC reports, research articles, fact sheets or sellers' information about specific products. The different categories of data have different sources of errors, with different possibilities of testing the sensitivity of probable changes in parameters. The sensitivities which most likely impact the analysis significantly, and those which have not been accounted for in the sensitivity analysis will be discussed below.

Many of the uncertainties in the analysis are derived from general data from ecoinvent that has been applied in the analysis. An example of this is the use of a lorry with medium emissions and the different sizes from the database are applied in the sensitivity analysis. A different load factor on the truck, other than the standard load factor in the ecoinvent process cards, was not tested for. The average load factor of the lorry process card used in this analysis (lorry 7.5-16 metric ton, EURO4) is 3.29 tons. It is not specified for the process whether the average load factor also includes return trips or not. The load factor used in the analysis is probably too low compared to the real load factor in the reference scenario, as the lorries driven to Addis Ababa with waste now bring approximately 5 tons, in addition to the load they brought into the camps. As a result, the emissions allocated to transportation in the reference scenario are probably quite generous. The sensitivity analysis showed that the use of a bigger lorry, with a more probable load factor, impacted the total emissions from the reference scenario by about 20%, and such a change may be right to assume here. Hence, the recycling of HDPE may be slightly more preferable than assumed. Furthermore, the volume of the plastic may be the limiting factor instead of weight on the trucks, but this is not considered relevant as the bigger lorry used probably has enough space for 5 tons of plastic.

Another decision made with regard to use of processes in the ecoinvent database is the modelling of the shredding, washing and recycling processes. It would have been possible to choose for example the injection moulding process also for the recycling, in addition to production of the original flower pots. This was not considered a good solution, as electricity contributes with 63% of the greenhouse gas emissions from this process and additives with 13% (Elduque et al., 2015). In the local analysis, electricity is almost negligible with photovoltaics and there will be used less additives in recycling than production of new plastic. Therefore, it is seen as more adequate to use inspiration from factory infrastructure allocation from the injection moulding process, but still model a unique recycling and washing/shredding impact based on the electricity demand from the EWB report.

The choice of factory and machine infrastructure is, according to the sensitivity analysis, the choice with the biggest uncertainty associated with it. When assuming a higher allocation of the factory to each kilo processed plastic, as well as bigger factory, the original results between -3 and 1 kg CO_2-eq. became a net emission of about 80 and 150 kg CO_2-eq. This is mainly due to a big difference in the processes chosen in the main analysis and sensitivity analysis. Two different process cards and two different allocation sizes have been used in the main and sensitivity analyses as two very different factory allocations were found in process cards and both were tested for. The first allocation found was in a process card called “plastic processing factory” with a physical allocation of emissions on 27 tons plastic/year. The second one was found in a process card called “packaging box factory” with an allocation of 1.32E-9 factories on 1 kg processed plastic, even though the factory produces 14 000 tons/year. In the main analysis a compromise of these two ways have been chosen; 1.32E-9 of the plastic processing factory.

The results from the sensitivity analysis shows that when assuming an allocation of infrastructure as the plastic processing card implies, this process dominates the results, and implies that all recycling at site is not a good solution. It is very unlikely that this estimated value reflects the true value of infrastructure. Firstly, other plastic processes in ecoinvent use a different factory and lower allocation than used even in the base case in this analysis. The other is that a previous review of Life Cycle Assessments emphasized that it has been found previously that infrastructure affects the results of an LCA even less than transportation (Cleary, 2009). In most cases in this analysis, infrastructure was proven to be more important than transportation, and so, it is probably already too heavily emphasized on in the main analysis. In addition, the allocation of factory is also used twice in each of the recycling scenarios, as the washing and shredding is seen as one process, and recycling another. This supports the choice of allocating a smaller fraction to one kilo plastic each of the two times it is processed through the factory.

The emissions being produced through burning of PET is based on general data. The greenhouse gas emissions given in CO_2-equivalents by IPCC are probably good estimates, as they were specifically for open burning. As a 30% change in emissions has been tested for in the sensitivity analysis and burning is the only process included in the modelling of this reference scenario, it also reduced the emissions from PET by 30%. It does however not change the end result of PET recycling being favourable based on greenhouse gas emissions. The emissions of heavy metals and PAHs, however, are more uncertain, as the emissions have been measured during laboratory tests, and not in a pit outside. This was not tested in the sensitivity analysis, as other impact categories were not the main objective of the thesis.

In accordance with principles in ISO 14044 it has been recommended in literature to use as much local data as possible in Life Cycle Assessments, for the results to be site-specific (ISO, 2006; Ripa et al., 2017). As previously discussed, this has not been possible due to the project still being in the planning phase, and not having specific plans, for example for transportation and recycling factory infrastructure. Also, there were limited time to investigate the details of the reference scenarios during fieldwork. There are uncertainties because of this. On the other hand, the three most important local factors emphasized by Laurent et al. (2014) in LCAs of waste management systems were the solid waste amount, loss during processing and the source of electricity. These factors have been more or less assessed with a local perspective. The electricity supply to the recycling facilities is assumed to be from local solar panels, but the use of a diesel generator instead has also been tested for in the sensitivity analyses both in the reference scenario for HDPE and the recycling scenarios. This was the scenario tested for in the sensitivity analysis which changed the estimates most, by 0.4 kg CO_2-eq. for all recycling scenarios and 0.2 kg CO_2-eq. for the HDPE reference scenario. In the recycling in Addis Ababa, an Ethiopian electricity mix was assumed when not testing for diesel. This means that even though it strengthens the analysis that the factors were chosen based on local data, the exact choice of source of electricity has a big influence on the analysis.

The two other factors emphasized by Laurent et al. (2014) have also been more or less local assumptions. The amount of plastic has been assessed in the analysis, but this amount has been disregarded in the choice of factory. A linear physical proportionality has been assumed between emissions from the infrastructure and amount of plastic, without knowing whether a small factory can be built as emission efficiently per kilo plastic processed in it, as a bigger factory. With the previous discussion on factory choice in mind, the infrastructure of factories is probably accounted for well. Also, losses during processing has been included in the analysis, but as pure guesses. A 5% exclusion of plastic has been assumed during sorting, and other losses during other process stages. It has been emphasized in literature that decomposed plastic should be discarded before recycling (Jamtvedt, 2018). This percentage may be too low, as especially the jerrycans are often quite worn before discarded as waste. If there is in reality a different loss, this will mostly impact the results of the PET analysis, as that reference scenario is most different from the recycling scenarios in regard to losses through the process. The inclusion of these local factors is in general good, but more accurate estimates would probably have strengthened the analysis.

General product data has been used in order to decide which substitution effect the recycling will have. Hence, the weight of the actual corrugated iron sheets and flower pots bought by UNHCR currently, that will be substituted, are probably different than the used rates. The effect this has on the analysis has been assessed through the sensitivity analysis by using different substitution rates. This change did not affect the results significantly for rooftiles, but the emissions increased by 0.8 - 1.0 kg CO_2-eq. with a lower substitution rate of the flower pots, and 0.7 kg CO_2-eq. with a different substitution rate of virgin HDPE in the reference scenario. Hence, the substitution rate obtained through the recycling is important for the environmental performance of the system, and it should be optimized through using as little plastic as possible in each product without diminishing the quality. Another uncertainty that has been investigated in the sensitivity analysis is if the original plastic pot is made of a different plastic type or the corrugated iron sheets are made of a different steel type. This proved to not affect the results significantly, except for a steel type which has been more processed, where emissions of CO_2-eq. decreased by 0.2 for PET and 0.4 for HDPE.

When investigating the results from the greenhouse gas emission analysis with the given assumptions, it is evident that production of flower pots in general is more favourable than production of rooftiles. This is probably because one kilo of plastic only substitutes a fraction of a kilo steel, while the substitution rate of the plastic in plastic pots is assumed to be much higher. A factor that strengthens this even more, but that has not been included in the analysis, is that the rooftiles made of recycled plastic will probably not last as long as the corrugated iron roofs. As such, in life cycle perspective the real substitution of steel is even lower than used in the analysis. As the substitution effect of flower pots is so much higher, but there is a limitation on how many flower pots can be produced, this indicates that, given that environmental impact is one of the main reasons to set up a recycling system, other products with a substitution more similar to that of flower pots should be sought after.

Through the environmental analysis, the main focus has been on greenhouse gas emissions. This has also been the case in choice of processes of its kind with medium emissions of greenhouse gases to use in the main analysis. This may have impacted the results of the other effect categories. Nevertheless, they can give an indication on whether these results confirm the results from the greenhouse gas emission analysis or not. In general, the results from different impact categories are contradicting in regard to whether a change from the system today is positive or not.

All the uncertainties in data quality, and choice of simplicity in the method, makes it evident that a marginal effect shown through these analyses should not be considered robust evidence. Many uncertainties and excluded measures in the analysis would probably impact the analysis in a direction of making recycling slightly less environmentally profitable. By adding many of these together, they may have a significant impact on the results. Still, at least the results for PET have such a positive impact on the environment, that all these small changes probably do not change the overall result, except for the case where infrastructure of the factories and machines have a higher allocation and/or impact than modelled.

6.3 Will the project be financially viable using means such as loans, external funding and/or other schemes, and how will these choices impact the results?

6.3.1 Comparison with other studies

The main result of the financial analysis was that the recycling project would not be financially feasible, even with funding of the investment costs. No factors in the sensitivity analysis indicated a positive result on its own. This indicates that the system will need to be optimized in regard to operational costs and income for a recycling business to have the change to be running sustainably. These results are in accordance with studies on solid waste management in Bolivia, where the financial feasibility was emphasized as the most critical factor in a multi-criteria decision analysis (Ferronato et al., 2019). In the same analysis, it was however also emphasized that the investment cost normally is the most important factor when developing waste management systems in developing countries. The investment cost is also in this analysis an important cost factor in the loan scenario, but even without this incorporated in the other scenarios, the costs of the recycling system is higher than the income, due to operational costs.

One of the reasons for the negative result may be that there is no income for the recycling company other than product sales, while other waste management companies also collects a waste management fee from the population (Al-Khatib et al., 2007; Lohri et al., 2014). No such fee is paid in refugee camps. In this analysis, it has not been taken into account that the collection of plastic by this cooperation will reduce the total solid waste amount that will need to be collected. For HDPE, this will not make a difference, as it was already sorted out of the waste stream, but for the PET being discarded in the camps and areas around, this may play a role in the cost of the regular municipal waste collection. One can argue that a transfer of some of the money for the municipal waste collection to the recycling cooperative would be fair.

6.3.2 Method

The cost data used has been obtained from the EWB report and has been adjusted to the specific cases in this analysis. The strategy to process and generate data for the financial analysis was mainly to use cost and income estimates presented in the EWB report. Some estimates have also been obtained from waste trader- and sole supplier interviews and e-mail correspondence with the Environmental manager of UNHCR in the region. This data has been modelled through a financial model, establishing the investment costs, the operational expenditures and the annual income. This is in accordance with the method described in the other waste management study from Ethiopia, described in the literature review (Lohri et al., 2014). A unique aspect in this analysis, compared to standard financial assessments, is that the investment cost only affects the analysis though a maintenance cost which varies based on the original investment.

6.3.3 Choices regarding data and data quality

There are many uncertainties in the financial analysis, and the true annual result of the project is assumed to lie within a broad range. As an example, the investment costs are based on the EWB report written on the project and are considered highly uncertain, as they were based on recycling machine material prices stated by Precious Plastic, an organization which uses used metal and motors (Eckbo et al., 2018). These costs have been assumed linearly proportionate to the amount of plastic processed, which is highly unlikely. It is however not very important for the analysis, as the investment costs are assumed financed through funding. It does impact the assumed annual maintenance costs and other resources and equipment, which are assumed to be 12% annually each of the investment cost, as no similar investment has been found as a basis for comparison. A pure change of investment cost was shown through the sensitivity analysis to not impact the result significantly.

Most analyses conducted in developing countries include waste management as a whole, not only plastic recycling (Al-Khatib et al., 2007; Garfì et al., 2009). When comparing the maintenance costs to costs given for Bahir Dar in Ethiopia, this would suffice for the maintenance cost of about two waste collection vehicles (Lohri et al., 2014). This might indicate that the maintenance cost for the recycling factories in the Melkadida and Jijiga areas are underestimated, but still a maintenance cost of 12% is probably not far off. A large change in the investment costs would impact the analysis in the same way as with changes in operational expenditures, which impacted the results heavily. By assuming a 30% higher and lower operational expenditure, the annual loss of 23 M Ethiopian birr varied with 10 M Ethiopian birr in each direction. This has a huge impact on the final result, and will be discussed further in the paragraphs to come.

The two most important costs in the main financial analysis are purchasing costs of the PET and HDPE plastic to be recycled and transportation costs. These represent 95% of the total costs. These will accordingly be the most important cost factors to optimize. In the sensitivity investigation of employing waste collectors instead of purchasing the waste, the operational expenditures decrease to almost half, by almost 15 M Ethiopian birr. This possibility should therefore be considered seriously. In that case, transportation costs present almost the entire operational expenditures. By doing this, the big cost differences in acquiring the plastic to use in recycling between HDPE and PET will also be evened out, and prioritizing of HDPE due to the financial state of the cooperative will not be as necessary. Consequently, the financial state of the project will be very different. In addition to this measure, other changes in operational costs, such as transportation, may make the project financially feasible.

In accordance with the study on municipal solid waste collection in Bahir Dar in Ethiopia, the transportation costs have the highest impact on the annual costs (Lohri et al., 2014). If this could be optimized, by for example collecting some of the waste from Kobe to Melkadida, which is only 8 km, with donkey cart instead of a lorry fuelled by diesel, that could have decreased the operational costs. Other possible solutions would be to rather invest in two smaller vehicles for each factory, where one is electric, and could have been charged with the excess electricity from the solar panels, when and if the factory is not running with all machines at the same time, or during the sunny season, when the electricity generation is higher than needed. The fact that transportation costs impact the analysis heavily can also be detected through comparing the Jijiga area and the Melkadida area results. The Jijiga area gives rise to a higher profit, and that is probably in part due to lower mean transportation distances for the plastic. Another factor is that a higher percentage of the products there can be rooftiles, as there is a lower total plastic amount. It is important to note that the positive results by producing flower pots can only be obtained either in the one or the other area, or partly in both, as the maximum plastic amount that has been assumed for both places.

The change of operational cost through an increased or decreased salary for the workers in the cooperative in the sensitivity analysis has a certain effect on the results, but is not in any way close to the two costs discussed previously in magnitude. A cost increase or decrease of about 6 M Ethiopian birr was obtained through changes in salary. It is however not a good solution to optimize operational costs through lower salaries, as the salaries assumed in the analysis is the common salary in the area today, and a different salary could make the social status of the work lower than other jobs. Also, as the minimum salary will probably increase to 1200 Ethiopian birr per month, one should not base the financially healthy state of the business on lower salaried than this.

In addition to optimizing the costs, income for the cooperatives is an important measure. Different prices on the products sold proved to change the annual income with about 4 M Ethiopian birr in both the positive and negative direction, depending on whether the price increased or decreased, when assessed in the sensitivity analysis. Another way to gain a higher annual income is through financing schemes such as compensation schemes or ET ETS. The total increase in income from a compensation scheme could be 1.6 M Ethiopian birr, given that the compensation of each kilo plastic brought into the camp is 1 Ethiopian birr. As the amount has not been estimated based on an analysis, but is a pure estimate, this can only be seen as an indication of the probable added income for the cooperatives from such a scheme. Another weakness of this estimate is that it has been calculated based on all the plastic in the area, but in reality, it is probably only organizations bringing plastic into the refugee camps that can be included in such a scheme, as long as there are no countrywide policies regarding this. The social and environmental impacts of such a scheme will be discussed further in the overall discussion below. The uncertainties regarding EU ETS are less than for compensation schemes, as there is a set carbon certificate price at any given moment. The question regarding this is whether it will be possible for the project to be included in the scheme. A positive aspect of compensation schemes, unlike with EU ETS, is that the amount can be collected even though recycling factories are not set up, and the savings from this can eventually be used to pay the investment costs.

As previously mentioned, the whole project will need to look at optimizing measures to make the project financially viable, at least in the operation phase. Also, one should assess whether the estimated amounts are good estimates or should be adjusted. In case the plastic recycling yields a net loss, but this is accepted because there are other positive consequences of the initiative, recycling of plastic material from for example Dollo Ado, and possibly the different host communities, could be excluded from the project as the main recipients of the services from UNHCR are in reality the refugees. In the case where the project will need to take up a loan, or the project receives limited funding, also investment costs should be optimized. A possibility for this is to install solar water heating to heat the water needed for washing. This is both cheaper and less advanced technology. Another possibility is investing in mechanical machines, powered by human force, instead of electricity powered machines. If so, little to no energy production units would need to be bought. Technical and social feasibility would need to be assessed for this option. This would however probably create a demand for more employees, and the operation of the factories would be even more expensive.

6.4 Overall discussion

6.4.1 Quality of sensitivity analysis

The main results and the results from the sensitivity analyses have already been discussed regarding data quality for each research question. A critical review of the way the sensitivity analyses have been conducted is also important to establish whether the results gained from them are trustworthy. For all three research questions, the sensitivity analysis has been based on probable value ranges, assumed based on knowledge gained through data collection. Where a certain range could not be determined from empirical data, an estimated 30% margin of error has been used. This way of conducting a sensitivity analysis also includes the margins of error directly observed during the fieldwork, which is often disregarded in sensitivity analyses. This inclusion gives results representing the real-world values to a higher degree.

For the material flow analysis, the specific method used was to group similar high-uncertainty estimates and test the sensitivity of the results when these values increased to their maximum or reduced to their minimum in a synchronized manner. This method is probably a good way to check the sensitivity in a simple and understandable way, when there are many uncertain parameters, as similar uncertainties are tested for simultaneously. Still, some parameters may have levelled out, if for example an increase in population in one city increases the overall plastic estimate, while in another city, where a waste production estimate has been collected, leads to a total decrease in plastic waste amount in the whole assessed area. The simplicity has therefore led to a possible weakness in the analysis. For the other two sensitivity analyses, most parameters have been tested individually, and this uncertainty is not applicable.

A weakness in all the sensitivity analyses is that general uncertainties, which are not specific to a specific parameter, have not been included in the sensitivity analyses. An example of this is that the bottle waste estimate is in general uncertain because all samples were taken from one area category.

6.4.2 Multiple criteria analysis approach

In previous studies, multiple criteria analysis has been used to assess whether a system for recycling will be feasible. In addition to environmental and financial feasibility, Ferronato et al. (2019) looked into the overall economic feasibility, social aspects, technological feasibility and implementation time. Except for implementation time, as there are at this point no other alternatives for plastic waste management to evaluate in this case, all other aspects should be taken into account in the choice of plastic waste management system. The technical feasibility has been touched upon in this thesis, but it has not been analysed thoroughly. This and social aspects, in addition to discussing the results from the environmental and financial analysis, will be done in this chapter.

An important measure when aiming to obtain good results within several fields are the Sustainable Development Goals developed by the UN. Especially for UNHCR, which is a branch of the UN and should set a good example, striving to support as many goals as possible in all the projects should be a priority. The proposed project in these camps will indeed contribute to important improvements within several goals such as Climate Action (nr. 13) through reducing greenhouse gas emissions, Decent Work and Economic Growth (nr. 8) through creating job opportunities, No Poverty (nr. 1) through job training and salaries, as well as Sustainable Cities and Communities (nr. 11) through reducing waste and utilizing resources more efficiently. Due to less burning of plastics, the God Health and Well-Being (nr. 3) is at least locally being improved, and Life on Land (nr. 15) for mammals will be better with less litter in nature, and due to innovation of simple recycling plants and set-up of factories, the Industry, Innovation and Infrastructure goal (nr. 9) is being improved. On the other hand, the initiative will probably impact negatively on Clean Water and Sanitation (6) as the already limited clean water in the camps will also be used by the collection centres. If UNHCR transfer good values through considering all aspects of an initiative for refugees, this will probably spread to both host communities and communities where the refugees will live later in their lives. Other conflicting matters when using a multiple-criteria approach will be discussed further in this chapter.

One of the most evident results found through the financial analysis is that PET is less financially feasible to recycle than HDPE, due to a higher cost of buying PET from waste traders, and because more PET is needed to make the same products. It has already been discussed and found highly reasonable to employ waste traders in order to obtain a more financially feasible project. Also, designing the products in a way where the durability of PET is utilized, so that less PET is needed to produce the same products, is probably a possibility. For example, according to SolidWorks, a 1 x 1 m rooftile may be durable enough made from PET but not from HDPE, with the same thickness (See Appendix S).

Given that both the aforementioned measures are implemented, there is probably little to no difference in financial feasibility, except for the case where waste collectors take much more time collecting 1 kg PET than HDPE plastic. However, the sensitivity analysis reveals that it is more financially feasible to employ waste collectors than buying plastics through waste traders. This can also have other positive effects than just financial gain for the cooperatives. By employing the waste traders in the recycling cooperatives, they will get a stable income, and not rely on bartering with the truck drivers. To integrate the informal sector into the formal waste sector has been highlighted through literature to also have positive social consequences, such as a decrease in child labour and better working conditions (as described in Appendix G). A negative consequence for the cooperative is a higher uncertainty with regard to collection prices per kg plastic, as one does not know how much time will be spent by each collector to collect a certain amount of plastic. This is however seen as unimportant in comparison to buying with the current price per kg.

Both greenhouse gas emissions and financial results are better in the Jijiga area than in Melkadida, probably mainly because of the lower transportation distances of plastic. This shows that the reduction of transportation costs is important to gain positive financial results without gaining a lower social contribution from the initiative. Hence, the financial state of the recycling factories in the Melkadida area would probably also be better if not collecting plastic from other communities with a lorry. If all assumptions in this analysis are correct, this means that establishing one recycling factory in each community to minimise the need of transportation is the best solution. The linear cost increase per kilo extra plastic being processed in the factories may not be correct, as one often assumes economies of scale. On the other hand, this is not important for the investment in this analysis, as it is assumed funded by a third party. Economies of scale would, on the other hand, be helpful during the operation phase, but with the given assumptions this is not the case. It seems like, as the preconditions for this study included setting up collection buildings in all the communities, dispersing the recycling machines into all these different buildings, instead of having several large factories and needing transportation, would probably decrease the operational costs. Also, investment costs could probably be positively impacted by this, as there would be less need for transportation vehicles.

A matter that should be considered before choosing either plastic waste collection or plastic waste purchasing, is how it will be affected by the existing jerrycan market. If the cooperatives buy the plastic waste, it may contribute to competition, so that truck drivers offer higher prices for the plastic, and the financial state of the cooperatives are even poorer. Also, if the waste traders are employed by the cooperative, other people may start to buy jerrycans from the locals and sell them directly to the truck drivers, creating a competitive state.

Another question is how the collection system should be operated. One solution is segregation at household level and automatic or manual sorting at collection centres. Household segregation and collection from households is probably the most efficient way for plastic collectors to receive the bottles and jerrycans. To obtain this, information campaigns should be run, where the importance of segregation is emphasized. Even more important in this specific area, where it was emphasized that private persons were not the ones buying most water or sodas, but organizations, is to map the activities where bottles are used, and collect the bottles from these places. It is probably easiest to conduct segregation at this stage, as an automatic or manual sorting of mixed waste would require a location to segregate the waste. Today the waste is driven directly to the landfill, and it would require much more resources to make such a sorting place.

There are also other positive economic consequences for the local communities. For example, the solar panels are built in such volumes that an excess of electricity is produced, outside of the rainy seasons. This can be distributed to the local communities, which generally are not connected to electricity. Also, even though the emission categories with possible impacts on human health did not point towards any one solution, this is based on emissions from all processes in the analysis, probably around the world. Despite this, there is most likely a highly positive effect for local emissions and health locally from recycling PET, as toxic emissions from burning will vanish. Also, as about 15% of the plastic will not be oxidized during burning, some of this will probably remain as plastic litter and as charred remains. This can have both a negative impact on the feeling of cleanliness in and around the camps, and more plastic to landfill and open burning means that the landfills will fill up faster and need to be moved to other places earlier. By recycling the PET this problem will decrease substantially.

Yet another positive effect on the local communities is the potential demand for construction workers in the implementing phase, in addition to demand for products such as solar panels and building materials. The Energy Officer at UNHCR Melkadida also recommends buying materials locally, because maintenance will be more time efficient, and therefore is something that should prioritized when possible (Diana, Energy manager Melkadida, 22.07.18). Also, another Ethiopian waste management facility has had problems finding spare parts, and therefore long down times on the trucks have occurred (Lohri et al., 2014)

An important measure in such a project will be whether it can expand and include other waste fractions such as plastic bags, even though this has not been assessed in this analysis. There may also be shifts in waste streams, so flexibility is good in regard to technical equipment. One should probably try to acquire equipment which can also be used for other plastic fractions, to make the project less at risk to changes in waste amounts and/or plastic types.

In case the project is found highly economically feasible, external funding during the operation of the project can be considered. This is however not a good solution, as the project will then end as soon as the funding ends, as has previously happened to other plastic processing projects in refugee camps in the region. Therefore, the aid should be reliable and also motivate to better and more efficient recycling. The products could for example be sold for a certain higher price than the actual value, as this will still encourage the cooperative to perform at the very best.

A question that may come up when discussing projects like this, both aiming to give an environmental benefit but also to develop the local economy and to give refugees jobs, is how many workers can possibly be employed and gain an income from the project. Even though one of the aims of the project is to generate income for the refugees working in the cooperatives, it is important to strive for long term income for the employees, rather than income only during the first year. It is evident from the financial results that the project is not of such financial strength that additional workers can be employed without providing additional value to the cooperative. It is better to let some families have a secure income, than giving many families an income during the first year, but then bankruptcy resulting in an end to that income. Al-Khatib et al. (2007) pointed out that giving a job to more people than needed has been called masked unemployment. This term indicates that that type of work does not add a positive feeling of being employed, and therefore also doesn’t have all the other positive consequences of being employed, other than the income itself.

There are also potential negative impacts from this project, which one must keep in mind. For example, as described in Appendix H, the refugees should have access to at least 20L of clean water per person per day, but in most of the camps in question, this is not fulfilled. Hence, one question is whether it is correct to reduce the refugees’ access to water in order to establish a recycling factory. The need of water has not been assessed in detail, and so the exact impact is not known. The impact of this and other such negative impacts that surely can be found, should be assessed in a full economic analysis including all positive and negative impacts to establish whether there are most positive of negative impacts due to the initiative. Based on the different measures commented on within this chapter, it seems plausible to assume that there are more positives outweighing the negative effects.

6.4.3 Value chain-approach

It has been emphasized in literature that the whole value chain should be regarded in optimization of waste management systems (Milios et al., 2018). This means that the ones deciding what goods that end up in the community and end up as waste should be included in the analysis, as optimisation of amount and type of materials can be determined to be as sustainable as possible.

The compensation scheme that has been assessed in the financial analysis is one of few measures in this analysis that also affects importers of plastic to camps. With a compensation scheme, those responsible for product imports will probably evaluate whether it is still beneficial for them to continue running the business in the current manner, or whether there is some unneeded plastic packaging or products. Maybe they will even shift to products made from other materials, if the compensation scheme price is high enough. This may be a good result, but, as explained in Appendix D, less plastic is not always the best solution. Plastic is a durable material that, when being used in the right setting, has a lower climate impact than alternative materials. Therefore, a general plastic fee may not contribute to the best solution when looking at the environment. This can be solved, either by conducting an analysis on which plastic items should be compensated for and not, or by helping the importers of plastic in the camps with decision-making.

One possible way to do this is through assessing the different ways and reasons why plastic is brought into the camps, in addition to who is responsible for the imports, and to make decision trees for these decisions. An example of such a decision tree can be seen in Figure 27, assuming there will be more recycling capacity in the facilities than the plastic in the area. In addition to the recommendations in this tree, reusable items should also be recommended, and questions should be asked regarding whether another more sustainable material could have done the same job. If feedback-loops from waste management workers to organisations, which bring goods into the region, are established, decision trees like this can be made based on local conditions, and can contribute to better waste management (Appendix E).

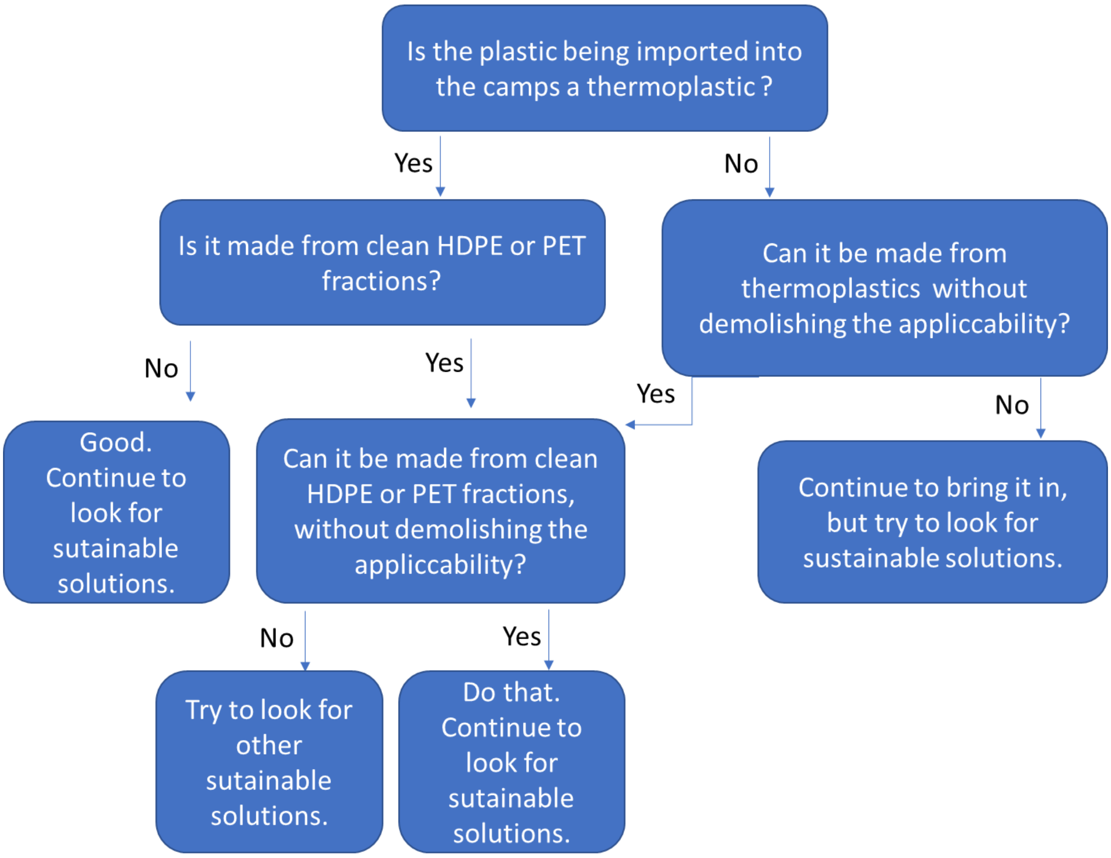

Figure 27: Decision tree for organizations importing plastic

There are also other possible instruments to use, such as restricting the amounts or types of plastic imports to the camps. Also, additives and other materials used in plastic products can be regulated. However, someone needs to be responsible for this and make the decision trees and regulations. In addition to having the resources to do this, one would also need the mandate to do so. UNHCR, in cooperation with ARRA, has the mandate to run the camps, and employ implementing partners. When searching for implementing partners, a possibility is to include criteria benefiting a more sustainable development in the tender. It will take some time to get this implemented in all the new contracts, but it can probably contribute to a big positive change. The criteria should be based on a comprehensive analysis to find the best overall solutions and include the most important matters for the society to develop sustainably, with an integrated waste management approach taking the whole value chain into account and considering ways to minimize the amount of waste (Appendix D). One of the criteria for the WASH implementing partner, could for example be to tax the waste going into landfills. This would motivate for both reducing, reusing and recycling initiatives. The WASH implementing partner already has waste management as area of responsibility and can probably start implementing specific changes very soon. There are however also private businesses running around the camps, which cannot be demanded to make changes. Still, they can be informed about what would be beneficial for the local environment and might adjust where they have possibilities to do so.

6.4.4 Opportunity cost

An important subject to discuss is whether it is correct for UNHCR and other organizations working as implementing partners to use their money on financing a recycling project directly or indirectly. As these organizations have limited resources, one must consider whether it would be correct use of their money, or if the opportunity cost outweighs the benefit. Alternative gains that could have been derived from this money are probably things such as new housing, more food, improved health care or more clean water per person. It will always be difficult to answer questions like this, but in order to discuss it, results from an economic analysis should be used. One would need to look at what effect a specific amount of money would have in the project, and what benefits this has environmentally and socially, compared to the benefit it would have in a different sector. An important aspect to bring into this consideration is the importance of other social impacts such an initiative provides, such as local value creation, development of infrastructure and job opportunities in the camp. Day to day operation and food and clothes are very important contributions, but when camps exist for such long times, the inhabitants should also get the sense of living in a community, not just sitting around waiting to be moved somewhere else. UNHCR also has a big focus on self-reliance, and this project will contribute to this for many workers.

Another question is whether the global or local environment should be the main focus in this analysis. It may not seem fair to take away income from the livelihoods of several refugees to make the greenhouse gas emissions in the world a little lower, if not other local positive impacts justify this choice. Many potential positive impacts have been discovered through this analysis, not only for the workers in the cooperative, but also the local community. For example, as previously discussed, the local emissions will be reduced through recycling of PET. As money is always a limited resource in operations like this, it can be argued that only the plastic fraction with a high environmental and social benefit should be recycled.

It is important to emphasize that questions like the two discussed above are important if the money used in the initiatives would otherwise be used for other contributions for the refugees. There is something completely differently with contributions to the project that would not have been given to the camps if the project had not been initiated. This applies to for example the contributions from the Norwegian Retailer’s Environment Fund, as these funds are designated to projects decreasing plastic in the environment.

7 Conclusion and further work

7.1 Conclusion

The main conclusion that can be drawn from the plastic flow analysis is that the exact amount of plastic waste is not significantly different from other studies of plastic waste in refugee camps. The total plastic waste amount produced in the whole assessed area, from PET and HDPE, is about 96 tons a month, and the study also, in accordance with literature, indicates that there is a difference in amounts of plastic waste between the refugee camps and the surrounding communities and town. The refugees contribute with about 0.09 kg plastic/month, while the other communities contribute with more. The values have a certain margin of error, and establishment of a recycling system should therefore not be based entirely on the assumed plastic quantity, but should be flexible in terms of the exact available amount and types of plastic for recycling.

The environmental analysis based on greenhouse gas emissions proved that production of plant pots made out of recycled PET is the most preferable option, while HDPE to pots is the best choice in regard to financial feasibility. If, however, exploring possible options for optimising the costs in this analysis, and regarding other socio-economic contributions the project may give, the overall best plastic management system is to start recycling the PET into flower pots. The cooperatives should employ waste collectors responsible for collection of jerrycans and plastic bottle waste, and recycling should be prioritized in areas where little to no transport is needed, as these costs are the most important for the annual results. A positive effect of recycling such a small amount of plastic is a positive financial state, caused by a larger fraction of the plastic being used to produce flower pots.

If a higher production is preferred by the project owner, either from the beginning or in the future, other products than rooftiles should be considered. Preferably products which can be sold to UNHCR or other organisations in the area for a higher price per kg plastic, and with a better substitution than for corrugated iron roofs. Other plastic types should also be considered recycled, e.g. plastic bags.

Implementing recommendations from this study can improve waste management in the camps and their surroundings significantly, and the camps can become pioneers and set a good example for other such societies. Some refugee camps have implemented shredding and selling of plastic, but none have to my knowledge implemented full recycling capacity within the camp. Also, as the United Nations Refugee Agency oversees the project, the Sustainable Development Goals developed by the United Nations is an important measure to include in choice of system. The recommended recycling system will to a certain degree contribute towards the goals numbered 2, 8, 9, 11, 13, and 15.

The specific results showing that PET should be recycled into flower pots, are specific results for this exact area, with the reference waste cases as they are today, and the need of products that the organisations in the area have. The finding that products with a stable offset and a set sales price and quantity should be sought after, is important for all recycling facilities.

7.2 Further work in the project

Further work in the project should be based on the results from this study, and as a next step verify the estimates and possibly make corrections. Based on this, optimal geographic localization of the factories and collection centres should be identified, in order to minimize distances driven. Other areas of interest, if analysing with optimization models, are for example the possibility for waste collectors to collect all the plastic from households and other areas in a time efficient manner, also giving results on the quantity of employees needed.

Based on advice from experts on plastic properties and recycling solutions, products should be optimized regarding the use of plastic materials and durability. Additionally, how the recycling machines can be produced with good quality and ease of maintenance should be assessed. Exactly what additives and how much should be added through the recycling to get the best results possible is also of interest.

Economic aspects of the projects should be analysed, especially to establish whether the HDPE should be recycled locally or not. To do this, the whole value chain should be included in the analysis, where both the system as a whole, and each single contributor should be examined on whether they gain a profit or a loss from the establishment of a recycling system. This analysis should also determine the importance of results from the impact categories other than greenhouse gas emissions, and base its results on this as well.

One should also assess more thoroughly how many plastic bags there are in the area, and whether recycling of these may be possible. Plastic bags were more visible in the nature around the camps than bottles, and so would contribute to an even higher reduction of plastic litter. After doing this, and if also assessing other plastic waste types, decision trees regarding which plastic types are the best to recycle can be made. These should be based on all considerations that have been discussed for HDPE and PET, such as future influx and whether the material is being recycled today.

7.3 Further work in the field of research

There are quite few research papers available focusing on waste management in refugee camps. One of the gaps identified in this master thesis is the lack of a comprehensive analysis of management of solid waste from refugee camps. It has been documented that refugee camps in some districts in Palestine get their waste collected and sent to solid waste management facilities, where it is recycled. It would be interesting to know to what extent this is happening, and to what extent the plastic is just driven out of the camps to local landfills or open dumps.

There are also few papers discussing how much resources should be spent on waste management in refugee camps, where the funds are limited. In other areas a waste management fee is paid by the ones getting their waste managed, but that cannot be the case for refugees, as they normally do not have any significant income. The possible positive effects of good waste management systems should be analysed and evaluated further, as through this thesis many positive contributions have been discussed, but not quantified. The effects of doing assessments like this may be valuable both for the world’s refugees and for our planet.

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9 Appendices

Appendix A Questionnaire semi-structured interview waste traders

1) How much plastic do you get or collect each day?

2) How often do you sell the plastic, and how much?

3) How much do you pay for the plastic when collecting?

4) How much money do you get when selling it to the trucks?

5) How many other plastic traders are there in this refugee camp area?

6) Have you considered to also collect PET bottles to sell?

Appendix B Simapro comparing analyses

This appendix shows all processes that have been assessed in a comparative analysis, in order to choose processes to use in the main analysis and sensitivity analysis, and describes the process of choice where necessary.

Appendix B.1 Solar panels

Electricity, low voltage (RoW)| electricity production, photovoltaic, 3kWp facade installation, multi-Si, laminated, integrated | Cut-off, U
Electricity, low voltage (RoW)| electricity production, photovoltaic, 3kWp facade installation, multi-Si, panel, mounted | Cut-off, U
Electricity, low voltage (RoW)| electricity production, photovoltaic, 3kWp facade installation, single-Si, laminated, integrated | Cut-off, U
Electricity, low voltage (RoW)| electricity production, photovoltaic, 3kWp facade installation, single-Si, panel, mounted | Cut-off, U
Electricity, low voltage (RoW)| electricity production, photovoltaic, 3kWp flat-roof installation, multi-Si | Cut-off, U
Electricity, low voltage (RoW)| electricity production, photovoltaic, 3kWp flat-roof installation, single-Si | Cut-off, U
Electricity, low voltage (RoW)| electricity production, photovoltaic, 3kWp slanted-roof installation, a-Si, laminated, integrated | Cut-off, U
Electricity, low voltage (RoW)| electricity production, photovoltaic, 3kWp slanted-roof installation, a-Si, panel, mounted | Cut-off, U
Electricity, low voltage (RoW)| electricity production, photovoltaic, 3kWp slanted-roof installation, CdTe, laminated, integrated | Cut-off, U
Electricity, low voltage (RoW)| electricity production, photovoltaic, 3kWp slanted-roof installation, CIS, panel, mounted | Cut-off, U
Electricity, low voltage (RoW)| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, laminated, integrated | Cut-off, U
Electricity, low voltage (RoW)| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted | Cut-off, U
Electricity, low voltage (RoW)| electricity production, photovoltaic, 3kWp slanted-roof installation, ribbon-Si, laminated, integrated | Cut-off, U
Electricity, low voltage (RoW)| electricity production, photovoltaic, 3kWp slanted-roof installation, ribbon-Si, panel, mounted | Cut-off, U
Electricity, low voltage (RoW)| electricity production, photovoltaic, 3kWp slanted-roof installation, single-Si, laminated, integrated | Cut-off, U
Electricity, low voltage (RoW)| electricity production, photovoltaic, 3kWp slanted-roof installation, single-Si, panel, mounted | Cut-off, U
Electricity, low voltage (RoW)| electricity production, photovoltaic, 570kWp open ground installation, multi-Si | Cut-off, U

All 17 solar panels in (RoW) were chosen. The median of the 17 photovoltaics which will be used in the main analysis is «3kWp slanted-roof installation, multi-Si, panel, mounted» with a total CO_2-emission of 0.02319 kg/MJ.

Appendix B.2 Steel included in analysis

Steel, low-alloyed (RoW)| steel production, converter, low-alloyed | Cut-off, U
Steel, low-alloyed (RoW)| steel production, electric, low-alloyed | Cut-off, U
Steel, low-alloyed, hot rolled (RoW)| production | Cut-off, U
Steel, unalloyed (RoW)| steel production, converter, unalloyed | Cut-off, U
Steel removed by turning, average, conventional (GLO)| market for | Cut-off, U

The medium, highest and lowest emission steel types were used in the analysis.

Appendix B.3 Transport vehicles included in analysis

Transport, freight, lorry >32 metric ton, EURO3 (GLO)| market for | Cut-off, U
Transport, freight, lorry >32 metric ton, EURO4 (GLO)| market for | Cut-off, U
Transport, freight, lorry >32 metric ton, EURO5 (GLO)| market for | Cut-off, U
Transport, freight, lorry >32 metric ton, EURO6 (GLO)| market for | Cut-off, U
Transport, freight, lorry 16-32 metric ton, EURO3 (GLO)| market for | Cut-off, U
Transport, freight, lorry 16-32 metric ton, EURO4 (GLO)| market for | Cut-off, U
Transport, freight, lorry 16-32 metric ton, EURO5 (GLO)| market for | Cut-off, U
Transport, freight, lorry 16-32 metric ton, EURO6 (GLO)| market for | Cut-off, U
Transport, freight, lorry 3.5-7.5 metric ton, EURO3 (GLO)| market for | Cut-off, U
Transport, freight, lorry 3.5-7.5 metric ton, EURO4 (GLO)| market for | Cut-off, U
Transport, freight, lorry 3.5-7.5 metric ton, EURO5 (GLO)| market for | Cut-off, U
Transport, freight, lorry 3.5-7.5 metric ton, EURO6 (GLO)| market for | Cut-off, U
Transport, freight, lorry 7.5-16 metric ton, EURO3 (GLO)| market for | Cut-off, U
Transport, freight, lorry 7.5-16 metric ton, EURO4 (GLO)| market for | Cut-off, U
Transport, freight, lorry 7.5-16 metric ton, EURO5 (GLO)| market for | Cut-off, U
Transport, freight, lorry 7.5-16 metric ton, EURO6 (GLO)| market for | Cut-off, U

For transportation purposes, the solid waste system would not be in agreement with use of Municipal Waste collection lorries, and therefore these have not been considered. All other lorries (GLO) have been compared in a simple analysis. The tested lorries have 4 different sizes and Euroclasses from 3 to 6. The choice of Euroclass has little impact on the emission of CO_2-Equivalents, and hence, the size of lorry is the decisive measure in which lorry to use in the analysis. As there will probably be no lorry of more than 32 metric tons collecting plastic from the refugee camps, the EURO-class 4 has been used for the category 7.5-16 metric tons in the main analysis, and in the sensitivity analysis Euro-class 4 of 3.5-7.5 and 16-32 metric tonnes has been used.

Appendix C Mechanical recycling as the best choice

There are mainly two ways to recycle plastic: Mechanically and chemically. Chemical recycling is an advanced process that normally converts the plastics to fluids or gases in the process of making new products (Mastellone, 1999). Mechanical recycling is less complicated, but also more costly and energy consuming, and the plastic streams need to be relatively clean and pure (Al-Salem et al., 2009). When implementing a recycling system in a refugee camp, it is probably best to look at the simpler solution first. In a review of LCAs conducted in Europe on plastic, it was found that mechanical recycling is better than chemical recycling and incineration, if the plastic is clean and the new product replaces almost the same amount of raw plastic (Lazarevic et al., 2010). Also, in regard to PET bottles, the mechanical method has a lower investment cost, as well as doing less environmental harm (Al-Sabagh et al., 2016). This is likely to also account for other plastic types, and therefore the evaluated method to recycle plastic in this thesis is the mechanical method.

Appendix D Optimization of packaging

When working with waste management one should not forget the overall picture, where less waste is always better than treated waste. Therefore, the term "Integrated waste management systems" has been a part of the literature for a long time and is an important aspect when optimizing waste management systems. The need for optimization of packaging in transportation and operation management is emphasized in a big variety of articles, with focus on aspects such as emissions and cost reductions (Accorsi et al., 2015; Raugei et al., 2019; Regattieri & Santarelli, 2013; Singh et al., 2006). For example, Singh et. al found through a Life Cycle Assessment that using reusable plastic containers instead of paper corrugated trays to transport 10 different fruits and vegetables is better in terms of solid waste generation, energy use and GHG emissions. The more times the plastic can be used, the better (Singh et al., 2006). A further observation done by Ross and Evans (2003) was that making plastic packaging contain more plastic can be positive in regard of a Life Cycle Assessment, if this makes the packaging usable for longer, before being recycled.

As well as for transportation facilities, packaging optimization is also important for the communities at the end-destination of the transportation. The obvious problem with packaging ending up as waste at the end destination of transportation has triggered articles written about reuse and recycling of packaging materials, especially in developing countries (Pacheco et al., 2012; Regattieri et al., 2018). Establishing feedback-loops for the recycling sector to the production sector, so that product and packaging can be utilized for recycling, is expected to increase recycling rates, as for example use of toxic and dangerous additives can be avoided (Ragossnig & Schneider, 2017). Also, Milios et. al (2018) stress that when aiming to recycle more plastic, one should look at the whole value chain in order to find the most sustainable solutions. This can for example mean that products are made using a single plastic fraction and not mixed with other materials or chemicals. Hence, by establishing contact and cooperation between producers, transporters and recycling facilities and focusing on optimization in regard to both environment and economy, the result can be valuable for all parties in the value chain.

Appendix E Additives, washing and degradation of plastics

Additives are used in plastic products for different purposes, such as improving the life expectancy of the product, changing the appearance of the product, or the amount of heat it can be exposed to over time (Gijsman, 2011 p. 375; Hahladakis et al., 2018). There are different groups of additives. Some of the most used additives are the groups plasticizers, antioxidants, heat stabilizers and slip agents (Hahladakis et al., 2018). The plasticizers are mainly used in PVC and PET products, but also PVA and PE, while antioxidants are used a lot in food packaging, such as PP and LDPE, mainly to lower the oxidation and degradation of the plastic material if it is exposed to UV-light. Slip agents are used in LDPE, PP, PS and PVC (Hahladakis et al., 2018). The most important additives in regard to recycling are the additives which impact what products can be made out of the recycled plastic, and what quality the products will have. That means that plastics containing additives which can be harmful by being transmitted into food, may not be recycled into food containers, and additives benefiting the lifetime of the plastic may have to be reintroduced, as the lifetime of the product is over (Gijsman, 2011; PlasticsEurope, 2018a).

The generally most impactful chemical degradation process for polyolefins (which both PET and HDPE are classified as) is called a thermos-oxidative degradation, and is caused by high temperatures and exposure to oxygen together (Gijsman, 2011 p. 375). This process consists of one long induction process where the plastic is stable, but starts to degrade as more and more radicals are created, followed by a more rapid decomposition where the mechanical properties of the plastics deteriorates linearly over time (Gijsman, 2011; Jamtvedt, 2018). The speed of the plastic decomposition process is affected by heat, light and other radiation, and air, water and mechanical stress, and leads to changes in appearance and mechanical properties (Gijsman, 2011). To delay the decomposition process, chemical stabilizers can be added to the plastic in the production process (Gijsman, 2011).

Two important properties for stabilizers are which environmental factors they stabilize against, and how this is done (Gijsman, 2011p. 375). For example, antioxidants can stabilize against UV radiation through different mechanisms, depending on the antioxidant (Gijsman, 2011p. 276). Two different types of antioxidants which protect plastic in different ways are primary and secondary antioxidants. It is recommended to add both types to plastics when recycling them (Jamtvedt, 2018). The reason for the need of additional antioxidants is mainly because the antioxidants that were added during the first processes, have already been broken down during the previous lifetime of the plastic material (Jamtvedt, 2018). According to Welle (2011), there is however no need for antioxidants in recycling of PET bottles.

Some of the additives in plastic can in be classified as PoTs (Potentially Toxic substances) and can be released into different materials such as air or food, and especially during recycling (Hahladakis et al., 2018). Various studies have been conducted on how different substances, such as additives and monomer residues, and their decomposition products, in plastic are transmitted into food and other substances (Hahladakis et al., 2018; Lau & Wong, 2000). A transmission does not necessarily mean that it will harm people, but it might (Hahladakis et al., 2018). There are regulations deciding which stabilizers can be used in products in contact with food (Gijsman, 2011, p. 375). To recycle plastics without thorough knowledge about these substances can result in both environmental and health related hazards, both through the production and use of the recycled products (Hahladakis et al., 2018). In general, it seems like a good rule to be observant in regard to chemicals in plastics both if humans come close to the recycling, and if recycled products will be in contact with food.

A study conducted with virgin HDPE versus recycled HDPE, processed through injection moulding, only found about 3 % reduction in tensile-, compressive and flexural strengths, after having optimized the moulding process using melting temperature between 190 and 210°C (Ng et al., 2011). The resulting mechanical properties are, however, very dependent on the processing parameters such as temperature, injection speed and pressure. Still, several studies emphasize that the lifespan of wood plastic composites made of recycled plastic is in general shorter than the same products made of virgin plastic (Turku et al., 2018). Recycled plastic has also shown a decrease in tensile strength between 2 % - 30% when exposed to weathering conditions such as freeze-thaw and light, while the virgin plastic material used in the same tests were not impacted significantly (Turku et al., 2018).

The washing method of the plastics also impacts the quality of the process and product. Santana and Gondim (2009) presented a study which showed that, compared to liquid detergent or only water, NaOH (Caustic soda) was more efficient in cleaning post-consumer HDPE waste. The melt flow rate increased and the viscosity decreased when washed with NaOH. Caustic soda is a common washing detergent in plastic recycling (Santana & Gondim, 2009). In Switzerland, PET flakes are washed at 200°C before being considered clean enough to be recycled into food packaging (Kägi et al., 2017).

Appendix F Socio-economic considerations

In an article from 2010, over 1000 households were interviewed in the Nabulus district in Palestine to shed light upon waste management in developing countries. The area contained 6.7% or 9.3 % refugees (Al-Khatib et al., 2010). One of the conclusions was that there were different paths regarding whom in the household was responsible for disposing the waste. In the refugee camps, 17.2 % stated that the father had the responsibility. This is in between the results from the village and the city where the answer to the same question were 8.8% and 20.3% respectively. Also, 7.1% stated that the mother had this responsibility, while 46.5% stated that the children were responsible. Regarding the children having the responsibility, the other communities not consisting of refugees stated 41.9% and 39%.

Another study conducted by Al-Khatib et al. (2007) in another Palestinian area including two refugee camps emphasised that inhabitants that collect metal scrap to sell to recycling companies often recruited impoverished children to look for scrap for low wages. Furthermore, Regattieri et al. (2015) states that “the community’s participation and commitment is central to the planning, design and implementation of an effective waste management system” in a refugee camp. When doing this, it is important to consult both with men and women, as they have different responsibilities in regard to the waste handling at home and in the society (Regattieri et al., 2015)

Appendix G Efficient sorting and collection systems for plastic waste

In order to actually get plastics out of the waste flow and into the recycling plant, the fractions need to be sorted at their source, after disposal in waste bins or at the landfill. Different approaches are described in this chapter. The collection system needs to take into account what segregation incentives they give, the efficiency and costs. In general, waste collection can be divided into the two categories informal and formal waste collection (Kamran et al., 2015). Informal waste collection is according to Kamran et al. (2015) the most common way of waste separation for recycling in developing countries and least developed countries (Bundhoo, 2018; Wilson et al., 2009). Informal waste collection can happen through collection at household level, collection from streets, collection of materials during transport to dumpsite, or collection from dumpsite (Wilson et al., 2006). Sorting of recyclables from already mixed waste can impose a health issue for the workers, as the waste is dirty (Wilson et al., 2009). A more organized sector can impact this and the social status the waste pickers have (Wilson et al., 2006). Studies have concluded that by making the informal waste collection formal, working conditions and value from the work for the workers can be improved (Kamran et al., 2015).

It is recognized in many studies that external factors such as information propagation about segregation and proximity to delivery locations are important to increase sorting rates, but there is still no overall agreement whether these or other factors are the most important (Babazadeh et al., 2018; Dhokhikah et al., 2015; Meng et al., 2019). Meng et al. (2019) added willingness to segregate and the personal environmental awareness of the residents to the most important factors for an area in China, while Dhokhikah et al. (2015) found that in the region investigated in Indonesia even more important were factors such as the feeling of not having enough time to segregate and “self-awareness” (Dhokhikah et al., 2015). The similar, but still different results in the studies indicate that local variations in societies also influence what the most important factors are, and knowledge of the population in every project is important.

On the use of collection points, Struk (2017) found that plastic separation was 25 % higher with collection from households instead of the use of collection points, although the difference is not statistically significant (Struk, 2017). Furthermore, the data shows that the average segregation rate grew by 75% when kerbside collection was combined with an incentive program, compared to kerbside collection without an incentive program (Struk, 2017). The incentive program was in most cases a reduction in the waste fee, according to the separated amount the previous year (Struk, 2017). In addition to this, Xu et al. found in 2018 that both economic incentives for households and social incentives, such as information and campaigns, can improve the overall recycling rate, but that in a short perspective, economic incentives worked better than social (Xu et al., 2018). Literature shows that in general, free-riding is lower if the act is visible to others (Bucciol et al., 2019). Regarding waste segregation, it is shown that when sharing an excess waste disposal bin with another household, free-riding is less likely to happen, because the other household always know what has been disposed of (Bucciol et al., 2019). A review of studies on drivers of recycling shows that education on recycling and its benefits is one of the most important factors influencing the private management of solid wastes (Mwanza & Mbohwa, 2017).

Appendix H Availability of resources

The climate in both refugee areas consists mainly of drylands, but close to the Melkadida camps there is a river flowing by all the camps, making a green belt of vegetation around it (Figure 28). The landscape is also quite flat with few trees, so it is quite windy a lot of the time (IRC Camp Manager Melkadida, 19.07.18).

Figure 28: Left picture: Dry land around Melkadida camp
Right picture: Green belt around the Ganale Dorya river, Photos: Anna Østby

UNHCR states that the minimum standard of water supply for refugees is 20 L per day (UNHCR, 2018f). According to the camp fact sheets, all refugees in the Melkadida camps receive 19 L of water per day (UNHCR, 2018b; UNHCR, 2018h; UNHCR, 2018i; UNHCR, 2018k; UNHCR, 2018l). In Buramino, however, a more general fact sheet about the Ethiopian operation states that they get less than 15 L per day (UNHCR, 2018f). In the Jijiga area, the average water received is even less, as Kebribeyah gets less than 15 L (UNHCR, 2018f), Sheder gets 17.4 L (UNHCR, 2018d) and Aware gets 18.5 L each (UNHCR, 2018c).

Appendix I Relevant organisation to the project

In addition to the organisations shown in Figure 9, there are many more organisations in the two camp areas, which deliver and distribute either products of plastic, or products with packaging. These can be included in the project by optimizing the amounts or types of plastic which are brought in. Other organizations, such as education organizations, can be resources for the project, in the way that knowledge about sustainable use of resources, recycling and segregation both in formal and non-formal education is important, and because training of youth in relevant areas is important so that they can be employed through the project. These different organisations with a possible impact on the project are listed below (Table 28), sorted by what they do in which camps.

Table 28: Actors in the camps with different responsibilities possibly relevant for the project (Source: UNHCR camp fact sheets)

Areas of responsibilities	Jijiga area	Melkadida area
Education: Either formal or non-formal	ARRA, DIDAC, OIC-E (Except Kebribeyah)	Jesuit Refugee Service, ARRA, DIDAC
Nutrition	ARRA	ARRA, IMC, MSF-S
Food distribution	ARRA, WFP (Except Kebribeyah)	ARRA, WFP
Logistics and supply		AHADA
Environmental protection	SEE	SEE
Energy		SEE
Livelihoods (skill training and youth program and income generating activities)	DIDAC (Only in Kebribeyah)	WA-PYDO, REST/CPDA
Shelter	ARRA	ARRA, ANE
WASH		IRC
Primary health care or health care	ARRA	ARRA, Humedica (only in Kobe and Melkadida)
CRIs distribution	ARRA	ARRA
Operational partner	WFP (Except Kebribeyah)	
Camp management	ARRA	ARRA
Food supply	WFP	
Supply and distribution of household cooking energy (Ethanol)	GAIA	
Water system	ARRA, UNHCR (In Kebribeyah)	

As many of the organizations have compounds where the staff lives, they are also producing plastic waste here. ARRA, for example, has one office by each camp. In addition to the organisations listed as relevant to the project, there are still other organizations doing other tasks in the camps. In the cases where also these organisations have compounds in the area, that is also an extra source of plastic.

Appendix J Amounts and sizes of waste pits

The Awbare camp was established in 2008, and since the establishment there has been produced 27 pits, whereof 22 are full and 5 are still in use. The pits are 3 m x 4 m x 3 m in size. (Ato Esayas Yora, Camp coordinator, ARRA, Awbare, 26.07.18). In Sheder (uncertain if just in the refugee camp, or in refugee camp and host community) there are 19 pits, where 6 are full and 13 are still in use (Aneley Fentie, ARRA Camp Coordinator Sheder, 26.07.18). As new pits are established, they are located further from the inhabited area because of the space (Eckbo et al., 2018).

Appendix K Previous reuse and recycling initiatives and other positive influences on the project

In Melkadida area, there are already examples of persons and groups who recycle or reuse small amounts of plastics manually (by hand), making for example mats and jewellery (NRC, 19.07.18). In Jijiga, the same trend is recognized, in addition to one bigger recycling project which was initiated by the organization Save the Environment Ethiopia, and funded by the United Nations Development Programme (Save the Environment Ethiopia 24.07.18, Aneley Fentie, ARRA Camp Coordinator Sheder, 26.07.18). The project took place in all three camps in the Jijiga area in 2013-2014, where plastic was collected, shredded, washed and sold. The project ended because the funding stopped.

NRC (Norwegian Refugee Council) organizes vocational skill training for youth, such as metal work training and machine repairing programs lasting between 6 and 12 months (NRC, 19.07.18). This can be beneficial for the project, both because already trained youth can participate in the project, and because the program has the possibility to teach specific subjects useful for the project (NRC, 19.07.18). A subject with focus on the machines in the project and maintenance of these can for example be a good solution (NRC, 19.07.18). In the training facilities they already have some metal working tools which can probably be used in some simple repairs, and possibly in production of basic machines (Observation 21.07.18, Hilwayen).

Appendix L Waste traders plastic amounts

To be able to analyse the total plastic amount in the area, it is important for the numbers to be expressed in the same unit, and to know for which areas one does and does not have estimates, as well as the population in all areas. The areas without any samples are 4 refugee camps and 7 host communities in the Melkadida area. Where plastic amount estimates have been given as an interval, the average has been used. The estimates given as daily estimates have been multiplied by 30 to get monthly collection, and for those two who only estimated how often they sell, an average size of each plastic transportation vehicle has been estimated based on the results in Table 30. Table 29 summarizes the raw data on sales frequency and vehicle size disclosed by all other waste traders.

Table 29: Sales frequency and load sizes

Sales frequency	**Monthly quantity stated (kg)**	**Load weight per single lorry/truck (kg)**
Lorry every second month	1500	3000
truck every month	1650	1650
Truck	-	5000
Double-lorry every second month	5000	5000
Truck every second	2500	5000
Truckload every second	1500	3000

Table 30: Results truck and lorry sizes

	Truck	**Lorry**	**Total**
Average (kg)	3663	4000	3775
Median (kg)	4000	4000	4000
Min (kg)	1650	3000	1650
Max (kg)	5000	5000	5000

One of the waste traders who just specified their amount in pickup frequency instead of weight, called the vehicle ‘truck’, while the other called it ‘lorry’, according to the translator that day. However, the exact choice of words may be a coincidence, as the meaning of the words are very similar. Regardless, 4000 kg load has been chosen as the best way to estimate the load size for the interviewees who did not give an estimate, as 4000 kg is the median for all samples, and the average also is quite close to that. It seems adequate to emphasize the median, as this disregards the outliers on both sides of the spectrum.

Most places, the salesmen pointed out the sizes of other waste traders in the area compared to themselves, which makes scaling within the town or city possible. This was, however, not the case in Bokolmanyo host community, so it is assumed that they were the same size as the interviewed waste trader in Bokolmanyo. The same assumption is made in Awbare, where one of the waste traders were not available when his collection place was visited. This seems plausible, as the collection place looked similar in size to the others in Awbare. As no estimate was given on how many waste traders there were in Hilaweyn refugee camp and/or host community, the estimated amount given by the waste trader in Hilaweyn cannot be used in the estimation of the total quantity of plastic.

The analysis is based on the assumption that every waste trader interviewed sells directly to the recycling factories in Addis Ababa, and that no plastic goes from one of the waste traders interviewed, to another. Based on the interviews it seems unlikely that this is the case, but one waste trader in Kebribeyah drew a chart of the sales system between the villages around Kebribeyah and Jijiga (Figure 29). If one were to talk to waste traders in both Kebribeyah and Jijiga, some of the plastic could be counted twice.

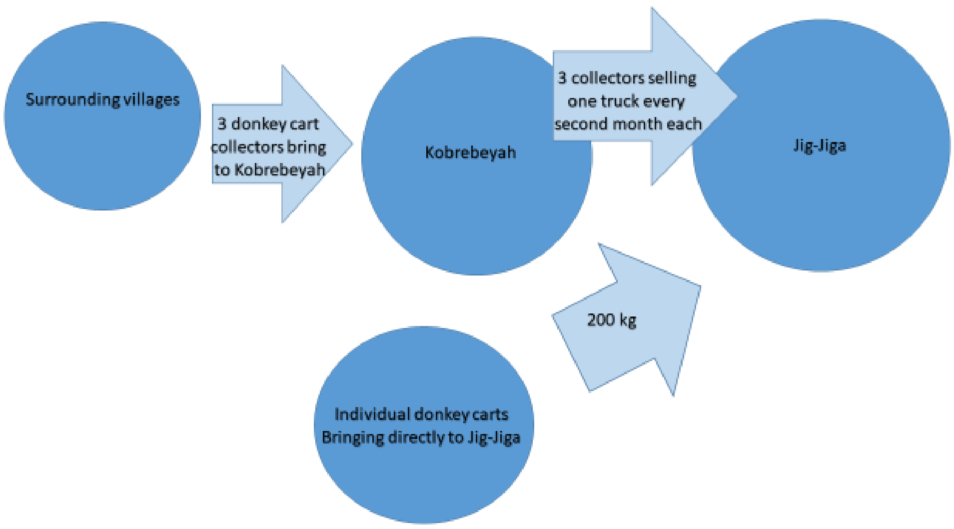


Figure 29: Replication of flow chart drawn by a waste trader, Mezegebe, in Kebribyah in Jijiga area, showing the flow of the plastic in his community

Appendix M Population numbers in all areas

The population numbers of the host communities could not be collected from one source, so different numbers were collected from different sources, to find approximate population numbers for each society. For Sheder no source of data was found, so one assumes that 15000 locals live there. One also assumes that there are equally many citizens in each of the host communities in Bokolmanyo Woreda (in the Melkadida area), as only a total amount is stated the EWB report (Eckbo et al., 2018). Also, given that Dollo Ado City has the only urban population in Dollo Ado and Bokolmanyo Woredas, it contains 35% of 142 000 or 173 000 inhabitants, depending on if government forecasts or Woreda administration estimates are used, respectively (Eckbo et al., 2018). 173.000 has been used as a base, as most other estimates are also collected from local administrations.

Appendix N Water bottle weight

The exact weight of the different plastic bottles in the area has not been measured, and therefore general numbers need to be used in this regard. Gleick and Cooley (2009) established a linear regression of the weight of multiple bottles with varying sizes. The regression shows that bottles weighed 15 (0.5 L), 38 (1 L) and 61 (1.5 L) grams in 2009. The data is 10 years old, but is used as a benchmark, and probably can work as a suboptimal estimate for the bottles, as the bottles in general get thinner and lighter with time. It should be pointed out that no bottle weighing more than 38 grams was used in the development of the regression, so that the estimate for 1.5 L bottles may be inaccurate. RecyclingToday and Platics Industry Association stated that the weight of the average 0.5 L PET bottle had decreased to 9.25 and 9.98 gram respectively by 2014 (Mashek et al., 2017 p. 21; Recycling Today, 2015) The PET resin association stated that while a 0.5 L pet bottle weighs 10 grams, a 2 L bottle weighs 42 grams (PET Resin Association, n.d.). Even though the year of this information is not given, it is assumed that it is around the same year, because the 0.5 L PET weight is similar. All estimates are quite similar, which gives credibility to the sources. As the PET Resin Association is the only source with an estimate both for small and large bottles, these numbers are used to estimate the weight of the bottle sizes between 0.5 and 2 L.

Appendix O Emissions from open burning of PET

Emissions of heavy metals and PAH from open burning of PET are displayed in Table 31 and Table 32.

Table 31: Emissions of heavy metals when burning PET

Heavy metal	Emissions to air (microg/kg PET)	Emissions to soil (microg/kg PET)
Al	1.56	-
Pb	3.22	100.10
Cr	0.64	-
Cd	0.01	-
Zn	2.53	320.32
Ni	0.21	-
Na	-	11 511.50
Ca	333.50	118 368.25
Mg	31.51	6 906.90
Fe	0.78	1 529.03
Si	246.10	107 207.10
P	26.45	13 138.13

Table 32: Emissions of PAH from burning of PET

	Emissions to air (microg/kg PET)	Emissions to soil (microg/kg PET)
Naphtalene	197.8	197.8
Acenaphtylene	184	82.8
Fluoranthene	103.5	103.5
Phenthrene	78.2	78.2
Anthracene	89.7	89.7
Chrysene	50.6	50.6
Benzo(b)fluoranthene	41.4	41.4
Benzo(k)fluranthene	25.3	25.3
Benzo(a)pyrene	64.4	64.4

Appendix P Need of products

During the fieldwork in July 2018, the feasibility to produce different products out of the recycled plastic was investigated. Through discussion with the village leaders, ARRA representatives and UNHCR staff, and by observing markets and visiting family homes, several possible products were found feasible to produce in the Melkadida area from recycled plastic are as follows (Eckbo et al., 2018, Mohammed, ARRA Chief Boklomayo, 19.07.18):

- Wall tiles
- 25 L water tanks
- Chairs and tables
- Rooftiles

- Seedling pots
- Rope
- Wash basins
- Brooms
- Rope
- Woven bags and mats
- Dining plates

In addition to this, there is also a constant need for household and kitchen products such as plates, cups, cooking tools etc., but according to UNHCR staff (Eckbo et al., 2018), Somali culture considers waste as something that will never be clean again, and should not be in contact with food or drinks.

UNHCR states that they can be a dedicated buyer of both plant pots, 25 litre water tanks and rooftiles, to use in construction and operation of the camps (Demissew Eshete, Environmental manager UNHCR, 07.18). Also NRC would be interested in buying plant pots for a plantation under construction, where they will plant trees (NRC, 19.07.18). Wall tiles could be a substitute for iron buckets, which currently are being flattened after use and used to repair walls of the refugee houses (Eckbo et al., 2018), but the willingness to pay for this is not established. The same products were found to probably be in demand in the Jijiga area too, except for plant pots and 25 L water tanks. Four market places were visited to collect information about items sold and their prices, summarized in Table 33. When asking for prices, it was specified that it was for a project, and not because of a purchase, to avoid overpricing.

Table 33: Prices stated by salesmen on selected items at four markets in one refugee camp and towns close to refugee camps (Eckbo et al., 2018)

Item	**Dollo Ado, town**	**Jijiga 1, town**	**Jijiga 2, town**	**Sheder, well established refugee camp area**
Table	330	Not found	Not found	Not found
Small chair	Not found	50	Not found	Not found
Big chair	350	120	270	Not found
Broom	60	Not found	Not found	Not found
Water drum, 50 L	250	Not found	Not found	Not found

The table illustrates how different markets and areas have different prices and different products. The absence of products can be both because of little demand for the product, difficulties in acquisition or some other unknown reason. It is important to emphasize that the markets were not scanned wholly, and products marked as “not found” could have been in the markets without being found during the visit. In general, there seemed to be fewer different products in the Jijiga area than in the Melkadida area. (Observations from fieldwork)

Appendix Q Product specifications

Three of the products stated as needed in the camps need special properties to be suitable, being plastic rooftiles, seedling pots for NRC and UNCHR and water containers. When producing these products, they must fill a certain role or function, which might already be covered by another product, and therefore should have the same qualities. Water containers for handwashing in the latrines and in the households should be as big as possible up to 25 L, but could be shrunk to a minimum of 5 L before they are too small to be of good use (IRC Camp Manager Melkadida, 19.07.18). The water containers should have a lid, and a tap (Demissew Eshete, Environmental Manager UNHCR, 27.07.18). The seedling pots should be about 40 cm x 40 cm and can be designed either with open or closed bottoms. One of the flower pots in current use is shown in Figure 30.

Figure 30: One of flower pots used today by UNHCR in Melkadida compound, Photo: Anna Østby

The roofs on the houses currently built by UNHCR are made of corrugated iron sheets with the dimensions 1 m x 2 m (Demissew Eshete, Environmental manager UNHCR, 27.07.18). One of the main qualities of these roofs, is that they are durable and resilient in harsh conditions. The houses seen in the picture below (Figure 31), are typical houses in the camps in the Jijiga area (Demissew Eshete, Environmental manager UNHCR, 27.08.18). During fieldwork, it was stated that a main component is cloth for insulation; cool in the summer and warm during the winter.

Figure 31: House in the Jijiga area, Photo: Anna Østby

Regarding the quality of products and expected lifespan, it is important to know the expectations and requirements of the buyer of the products. When building, operating and maintaining refugee camps, an important factor is deciding the quality of housing. This has to do with the degree of urgency that exists to build the camp, the expected duration of the refugee situation and the time that the refugees have already spent in the camps. It has been stated in a research paper that Bur-Amino was established in 2011 due to a sudden immigration of refugees from Somalia, and was planned as a temporary settlement, and is in need of an upgrade into the standards of a permanent settlement (Jahre et al., 2018). This is also known by people working in the camps. New houses should be more permanent and durable than previous housing, but do not necessarily need to have the expected lifetime of a regular house (ARRA chief, Muhammed, Melkadida, 19.07.18, Diana, UNHCR energy manager Melkadida, 22.07.18, George Wood, Head of Sub-Office UNHCR, 23.07.18). According to the camp manager in the Melkadida area, building materials are normally considered good if they last for 20 years in the harsh environment there, but with products where spare parts can be produced locally, even 10 years duration is enough (George Wood, Head of Sub-Office UNHCR, 23.07.18). Also, the roofs should be designed in a way that gives all the usual properties of a roof, like keeping water and sand out and insulation.

Appendix R Feasibility of recycling PET bottles and HDPE jerrycans

When deciding on products and design on products it is important to know the plastics' chemical and physical properties. The strength of the plastic products must be high enough for the tensile strength to be comparable to the stress that will be applied to the products. At the same time, thermal conductivity indicates the insulating properties of the products. Plastic properties found in the SolidWorks database are shown in Table 34.

Table 34: Plastic properties, from SolidWorks' database

	PET	HDPE	LDPE
Mass density (kg/m^3)	1420	952	917
Tensile strength (N/mm^2)	57.3	22.1	13.27
Thermal conductivity (W /(mK))	0.261	0.461	0.322

It is also important to make sure that the products can tolerate the environment they will be exposed to through their lifetime. The changes in PET thermally deforming below about 220 °C are very minor, which is important in warm countries like Ethiopia (Lau & Wong, 2000). It is assumed that HDPE also do not deform in the temperatures they will be exposed to. Also, it is important that the recycled products have a lifetime of adequate length. Some producers of outdoor furniture made of 50 % recycled HDPE plastics or more have a warranty of 50 years and 20 years respectively (Perennial Park Products, n.d.; Polywood, n.d.). This indicates that recycled plastic can have a long lifetime, and a conservative assumption is that products can have about 10 years life expectancy.

Appendix S Product results and simulations

Goals that are important when deciding what to recycle the plastic into are to make products which do not harm the users of the products, securing a stable income from selling the products and that the products must function in the same way as the product that is being substituted. As explained in Appendix E and 0 the plastic should not be recycled into items which come into contact with food or drinks, and as such many of the proposed products should not be produced. Additionally, the products should be able to gain a stable offset, and as the prices in the area are not stable, selling to UNHCR with a set price is seen as a good choice Appendix R. When considering these issues, rooftiles and flowerpots are the two most suited products to be produced by the recycling cooperatives based on the data available in this study. Prototypes for these have been made in SolidWorks. This was done in order to create a design that fits the requirements from 0, and to assess the plastic amount needed to make these products.

The dimensions of the flower pot has been modelled to 30 cm in diameter in the bottom, 40 cm on the top and 40 cm high, and with a thickness of 0.4 cm. The rooftiles are modelled in such a way that 24 of them is equal to the size of one corrugated rooftile sheet of 1 m x 2 m. The width of the rooftiles, when excluding the overlapping areas, is 33.3 cm, the height is 25.0 cm, and the thickness is 0.4 cm. Also, a 1 m x 1 m rooftile has been assessed in order to obtain an understanding of the durability of the rooftiles, and the possibilities to make them thinner or bigger. This rooftile has the same thickness, 0.4 cm, as the original rooftiles. Based on the plastic properties from Table 34, the amounts of plastic needed to produce each of these products are shown in Table 35. These plastic amounts are based on the assumption that all the plastic is 100% pure.

Table 35:Plastic masses per products analysed in SolidWorks

	PET mass (kg)	**HDPE mass (kg)**
40 cm flower pot	2.88	1.93
Rooftile	2.85	1.91
Rooftile 1 m x 1 m	18	12

Because of a higher mass density, the products are heavier when made from PET than HDPE, but these products will also be more durable. The modelled products need to be strong enough to do fill their role. A simple way to assess this is to look at the stress (in weight) that can be applied to the products during use and investigate the impact this has on the product and compare it to what the plastic can withstand.

A load simulation for the rooftiles has been carried out. The rooftiles must resist exposure to different weather conditions and loads of sand and possible other loads, such as people stepping on them. The load has been angled at 15 degrees, because the roof will be sloped. The loads are chosen as absolute maximum weight seen as probable for the products to be exposed to. An exception to this is made for the 1 x 1 m rooftile, where 12 times the load applied to the small rooftiles was assessed, even though there will probably not be 12 people standing on one rooftile. The load simulation includes assumptions such as an equally divided load all over the plate, and a complete attachment where the whole side that is connected to a beam is uniformly attached. The applied loads, the “von Mises” stress and ratio of von Mises stress to tensile strength of the plastic products are summarized in Table 36. If the ratio is higher than 1, the load is too heavy for the product design tested for. The tensile strength is taken from Table 34. Simulation reports of the PET rooftile is showed in the end of this appendix to illustrate how the stresses are applied.

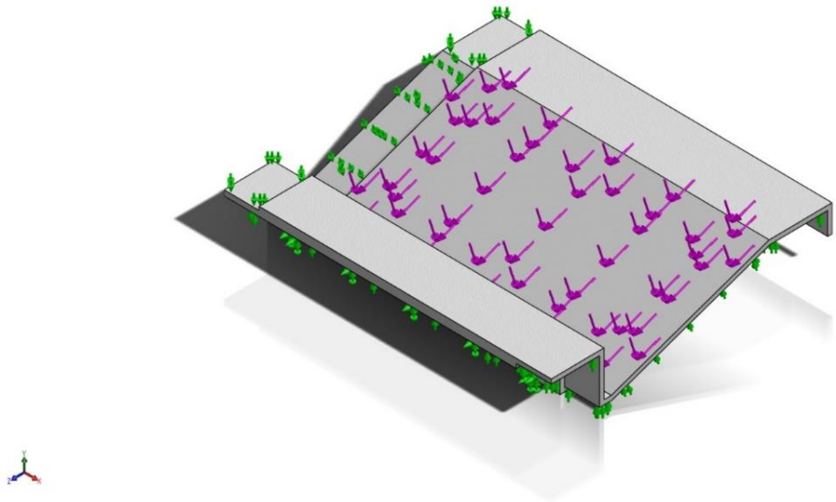
Table 36: Stress results SolidWorks simulation

Product specification	**Applied load**	**Max Von mises stress (N/m^2)**	**Von mises stress-tensile strength ratio (stress/strength)**
HDPE Rooftile standard	80 kg	1 584 000	0.072
HDPE Rooftile 1 m x 1 m – same load	80 kg	2 995 000	0.14
HDPE Rooftile 1 m x 1 m	960	24 530 000	1.1
PET Rooftile 1 m X 1 m	960	24 820 000	0.43

In general, only HDPE has been used as plastic material in the analysis, as PET has a higher tensile strength, and will in general withstand everything that HDPE can. The results show that, except from the 1 m x 1 m rooftiles, the material's strength is much higher than the load applied through the simulations. This indicates that the modelled products are robust enough for the planned usage. As there are uncertainties in the tensile strength of the recycled material, weathering, UV decomposition and other physical measures, the ratio of maximum 0.14 is seen as adequate. The rooftiles will probably be more than strong enough with the assumes sizes. One assumes that if a rooftile can resist a person stepping on it, the flower pots of the same thickness are assumed to resist the soil and plants it will contain.

Load simulation PET rooftile

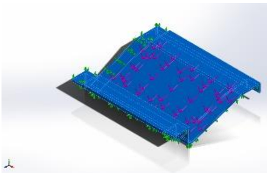
Model Information



Model name: V1_Rooftile

Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude2 	Solid Body	Mass:1.91296 kg Volume:0.00134715 m^3 Density:1420 kg/m^3 Weight:18.747 N	Feb 21 16:48:22 2019

Study Properties

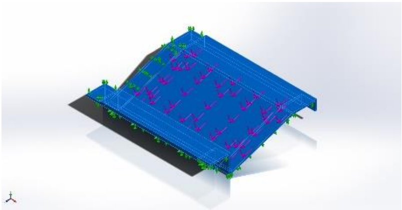
Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin

Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (Z:\Documents\Takplater)

Units

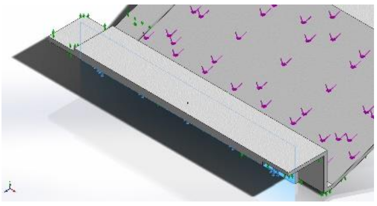
Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

Model Reference	Properties	Components
	Name: **PET** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Tensile strength: **5.73e+07 N/m^2** Compressive strength: **9.29e+07 N/m^2** Elastic modulus: **2.96e+09 N/m^2**	**SolidBody 1(Cut-Extrude2)(V1_Rooftile)**

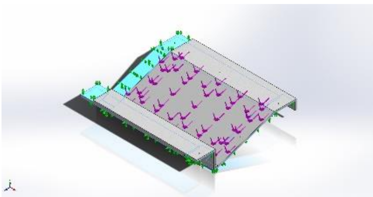
	Poisson's ratio: **0.37** Mass density: **1420 kg/m^3**	
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** **1 face(s)** **Type:** **Fixed Geometry**

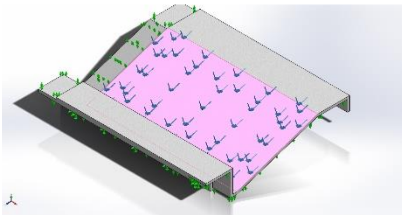
Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	**0.0345418**	**219.972**	**59.399**	**227.851**
Reaction Moment(N.m)	**0**	**0**	**0**	**0**

Fixture name	Fixture Image	Fixture Details
Roller/Slider-1		**Entities:** **10 face(s)** **Type:** **Roller/Slider**

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	**0.00662297**	**576.659**	**-1.33484**	**576.661**
Reaction Moment(N.m)	**0**	**0**	**0**	**0**

Load name	Load Image	Load Details
Force-1		**Reference:** **Face< 1 >** **Type:** **Apply force** **Values:** **---, 203, 758 N**

Resultant Forces

Reaction forces

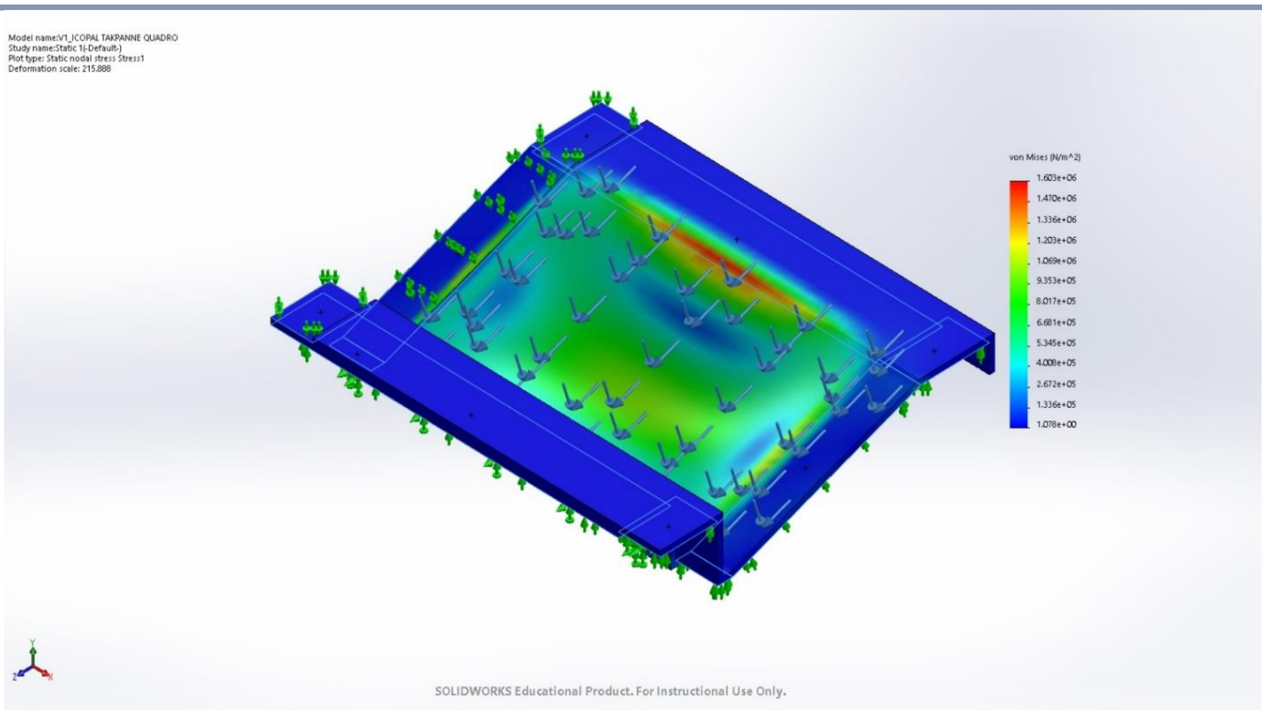
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.0345418	783.339	47.1242	784.755

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

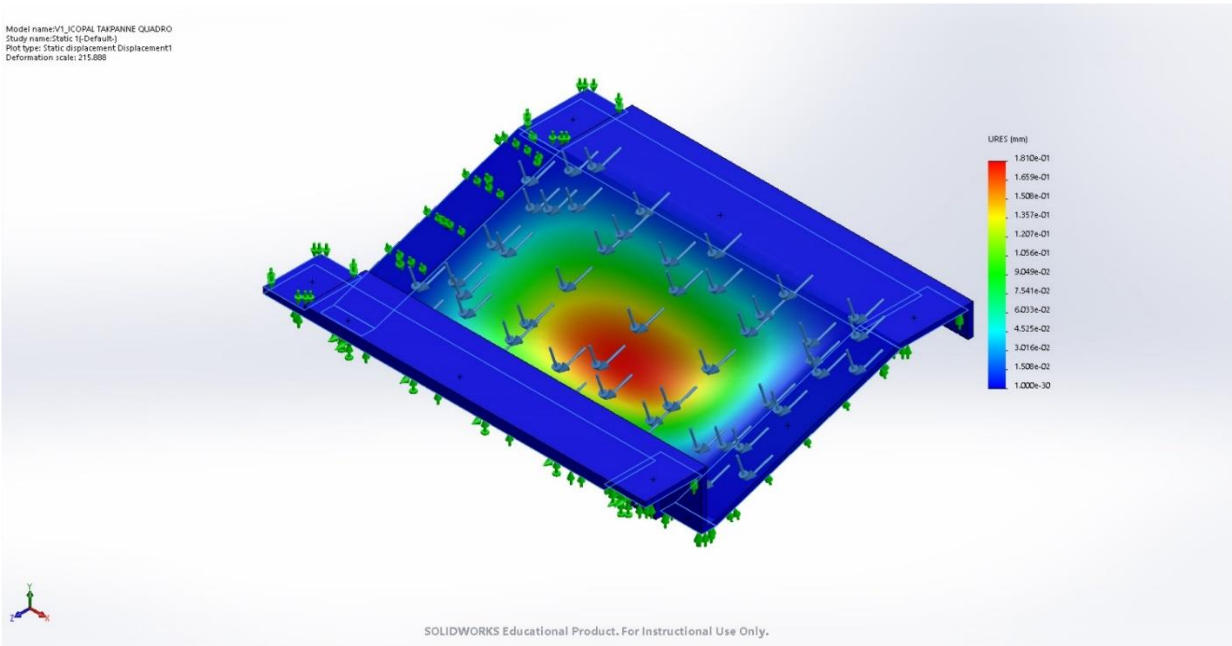
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	1.078e+00 N/m^2 Node: 8320	1.603e+06 N/m^2 Node: 13069



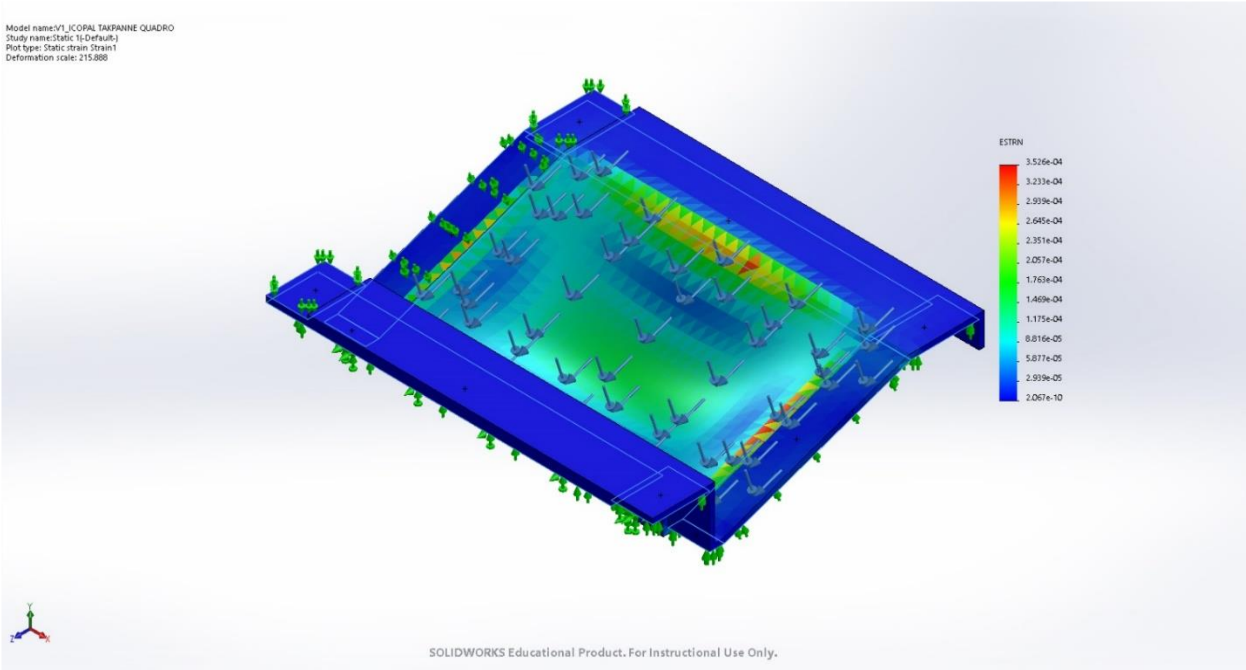
V1_Rooftile-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00 mm Node: 1195	1.810e-01 mm Node: 10957



V1_Rooftile-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	2.067e-10 Element: 2804	3.526e-04 Element: 2654



-Static 1-Strain-Strain1

Appendix T Discussion of product choice

Concerning product choice and representativity for other areas

The choice to have a dedicated buyer of the products before starting the production is regarded a sensible choice, as projects in the refugee camps have a tendency to end when project financing through aid stops (Demissew Eshete, Environmental manager UNHCR, 19.07.18). It is also further underlined as a good idea to have a dedicated buyer at a fixed price for stability, instead of the varying prices of goods at markets. The third consideration that has been decisive in the choice of product, is to not make products that will get in contact with foods or drinks. This choice both considers the possible harms that can occur through additives from the previous plastic emitting into the food, and it respects the Somali culture, where recycled materials should not be in contact with food or drinks. The inhabitants' prejudice can probably be disproven by making high quality products with a clean manufacturing processes, but the fact remains that many have a strong reluctance towards the reuse of waste. The way used to determine which products are best suited to be made out of the recycled plastic was simple but is regarded as good enough for this initial analysis. The exclusion method can probably be used in other areas as well, but the results will probably be very different, because the use of local criteria makes the result less relevant to other areas.

Robustness of physical properties simulation

The physical properties, such as tensile strength and mass density, used in the analysis include assumptions such as 100% pure virgin HDPE or PET material. None of these assumptions are true, as the material used will be recycled plastic, and the washing method will probably not result in a complete cleansing of impurities. Also, the recycling process can cause air bubbles in the finished products. This does not necessary mean that the results are very inaccurate. For example, as explained in Appendix E it has been found through previous studies that the physical properties of recycled plastic are not necessarily very different from virgin plastic. Still, recycled products have a shorter life expectancy, probably because the physical properties change faster through weathering and light exposure (Appendix R). It is not explained in these studies whether antioxidants have been added during recycling to counteract this degradation process. It seems correct to assume that recycled plastic will have a shorter life than virgin plastic, especially when washing is not optimal, but that the products will have a good quality up until this point. The simulations also include other inaccuracies that can lead to uncertainties. The simulations conducted through SolidWorks have only considered one single factor; the 'von Mises stress' the products are exposed to through heavy loads, compared to the tensile strength of the product. This is not the only important physical property, but it does indicate if the product is strong enough for the loads applied. It is important to emphasise that the load is assumed to be equally divided across the whole area of the rooftiles, and within the flower pots. As the margin for most products assessed was very large, these small adjustments will probably not change the end result.

Fulfilment of product requirements

The criteria for products described previously 0, will probably be fulfilled with the modelled products. The properties of HDPE and PET plastic both seem beneficial for these products, but will contribute to different quality in the fulfilment of the requirements, such as insulation and durability. The introduction of a new roof should not make the houses less comfortable, and therefore some insulation should be considered. Insulation with plastic sheets below the roof, with air between the roof and the sheet, will probably be more insulating than just having the plastic tiles as roof. UNHCR distributes sheets that are used for many different purposes, and could also be used for this, as shown in Figure 32.

Figure 32: UNHCR sheet used under roof in ARRA office, Photo: Engineers Without Borders

The PET rooftiles require a higher mass of plastic, but the rooftiles also have a lower thermal conductivity than HDPE rooftiles, and better insulation properties, and therefore can contribute to a more stable indoor climate. The roofs are currently made of corrugated iron, which is a mix of iron and zinc, which have heat conductivities of 75 W/(mK) and 120 W/(mK) respectively (From SolidWorks' database). The conductivity of plastic is less than 1 W/(mK), which is much lower. Still, it may not be better insulation than the roofs used currently, but this has not been assessed, as it would require resource- and time intensive tests, and the alternative of the new build houses is the corrugated iron roofs, and not these self-made roofs.

Appendix U   Operational costs explanation

All the salesmen in the Melkadida area were asked about their acquisition and sales price of the plastic. Their acquisition prices varied substantially, with four of them stating between 8 and 12 ETB/kg, while two stated 16 Ethiopian birr and 4 Ethiopian birr (actual statement was 4 ETB/25 L jerrycan, and this was found to weigh ca 1 kg). The stated selling prices varied mostly between 12 ETB/kg and 32 ETB/kg. One waste trader stated a price of 5 when selling, but it is not certain whether he sold to trucks in big quanta or sold to someone else. This price is disregarded as it differs so much to other prices stated. In Jijiga, only two estimates of acquisition prices were given, and these were 5 and 13 ETB/kg, while their only estimate for the selling price was between 8-10 ETB/kg. In Jijiga such details were in general less accurate, as two out of three interviewees were not the tradesmen themselves, but a friend and a wife. The price used in this analysis is 22 ETB/kg, in order to be an attractive buyer for most tradesmen, while the sensitivity analysis will include 12 and 32 ETB/kg, which is the highest and lowest stated sales prices. The waste traders explained that they did not sell PET as there was little demand, and because the jerrycans are heavier, so it is more efficient to collect these (Waste trader Hilaweyn host community, 21.07.18, Waste trader Dollo Ado, 20.07.18). Therefore, it is assumed one will have to pay more for PET, to make collecting this attractive. This price is set to 25 ETB/kg, and it will be tested at 15 and 35 ETB /kg.

One scenario will also investigate the impact on the financial state of the factories and collection centres if plastic collectors are hired as fulltime employees instead of being payed provisionally. It is assumed that the waste collectors can collect the same weight of plastic each month as the mean of the waste traders interviewed during field visit. 21 waste traders collected 38 450 kg plastic. It is assumed that they have not used their whole capacity, and that collection of plastic bottles with a lower mass per collected item will be possible if employed full time. If workers are to collect the bottles and jerrycans, they will need a donkey cart, which is estimated to cost 1200 USD (Eckbo et al., 2018).

The incentive workers collecting waste through the IRC WASH program earn 700 birr/month (IRC Camp Manager Melkadida, 19.07.18) This analysis uses this price as a basis for all workers in the project. The minimum salary when working on a contract basis is 251 ETB/month today, but there are discussions to increase this to 1200 ETB/month (Mohammed, ARRA Chief Boklomayo, 19.07.18, Demissew Eshete, Environmental Officer UNHCR, 19.07.18). In order for the analysis to be robust in a long term perspective, it will be tested for salaries at 1200 birr/month in the sensitivity analysis, and salaries down to 251 birr/month.

In the EWB report it is assumed that the factories (including collection and shredding) in Melkadida can run with 15 employees, and the collection stations need 6 employees (Eckbo et al., 2018). This gives a total amount of 54 workers to process 27.5 tons of plastic, which results in a need of 0.545 employees per ton plastic processed each month. It is assumed that the same efficiency can be accomplished in the Jijiga area, and so the same ratio is used there. The monthly maintenance costs are assumed to be 0.01 % of the investment cost, and that other resources such as washing detergent, water and plastic gloves for the workers is also 0.01 % of the investment cost each month.

The transportation between camps is assumed to be done using lorries. To get a contingency trough the analysis, the same diesel amount used per kgkm is chosen as in the Life Cycle

Assessment, which is 0.048 kg/kgkm (From SimaPro process card). A kg of diesel is according to the European Union (2005) 0.0835 L, and the cost of diesel in the area is about 22 ETB/L (Demissew Eshete, Environmental manager UNHCR, 19.07.18).

Appendix V Energy

The estimated energy needed in the different locations and their estimated plastic amount from the EWB report (Eckbo et al., 2018) is shown in Table 37. In this report, one assumed that every collection point also had some simple recycling machines to recycle some of the shredded material, but this will not be the case in this analysis, in order for the environmental analysis to be transparent and easily understandable. Therefore, the electricity amounts used are not completely in accordance with the plastic amount being recycled in collection centres and factories in the report. In the scenarios where amount of electricity consumed matters (with a diesel generator), the total electricity amounts from the table used for collection and recycling has been divided by the total waste amount and used.

Table 37: Sum of energy consumption of processing buildings (Eckbo et al., 2018)

Area and type	Unit	Lighting	Shredder and washer	Oven	Extruder
Recycling factory Melkadida area	kWh/month	4 400	46 200	132 000	52 800
Collection points Melkadida area	kWh/month	8 800	92 400	35 200	
Recycling factory Jijiga area	kWh/month	4 400	63 800	39 600	18 150
Collection point Jijiga	kWh/month	2 200	31 900	8 800	

The report written after the fieldwork states that solar panels is the cheapest solution given the assumptions summarized in Table 38. With 17 kW needed capacity at the factories in Jijiga, three alternatives were assessed: 34 kW installed solar, 17 kW installed solar + 8.5 kW diesel generator and 17 kW diesel generator. The first solution proved to be financially superior to the second and third solution after 3.3 years and 1.7 years respectively. The need for diesel in the hybrid solution has been based on a statement from the energy manager of the Melkadida area

(Energy Manager Diana, UNHCR Melkadida, 22.07.18) that there are rainy seasons twice a year, and during those it is constantly cloudy for 2-3 months, and the solar panels then only produce 50% of their capacity. (Eckbo et al., 2018)

Table 38: Assumptions from EWB report in regard to electricity need and costs (Eckbo et al., 2018)

Assumption regarding	Unit	Cost
Cost solar panels	Birr/kW	41 250
Solar panels capacity when cloudy	%	50
Cost 5 kW diesel generator	Birr	151 250
Cost 20 kW diesel generator	Birr	398 750
Cost other diesel generators have been extrapolated between the two prices	Birr	68 750+16 500*(X kW)
Diesel cost	Birr/L	22
Electricity produced from 1 L diesel	kWh/L	3

The same assumptions have been used in this analysis, as the assumptions have been stated by local personnel working with energy and environment, and no better data could be collected. In the financial analysis, only solar panels has been investigated, as the results from the former report were very clear on this being the superior solution. As the solar panels are modelled to supply twice the needed installed capacity at any given time, it is initially irrelevant how much electricity is needed for the recycling, as an excess of electricity is guaranteed.

A possible solution to get a more reliable electricity supply is to have batteries in place, but this also entails certain challenges, for example that the capacity has been found to diminish significantly in a short time if they are discharged to below 50% capacity, and because the warm environment might have a negative effect on such batteries. Additionally, the batteries should be recycled after use, but there are no such facilities in the area, and only three in the whole of Ethiopia. One of them is stationed in Addis. (Energy Manager Diana, UNHCR Melkadida, 22.07.18)

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