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Evaluating the impact of system boundaries on decisions that effect CO2 emissions and costs

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Evaluating the impact of system boundaries on decisions that affect CO_2 emissions and costs

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Abstract

In this Master thesis report the impact of system boundaries on decisions that affect carbon dioxide emissions and cost is assessed. A general framework is developed to define the right system boundaries and objective function. This framework is used to assess the impact on emissions and costs of reduction options regarding transport and process decisions at Eastman Chemical Company. In addition, the relationship between inventory and transport decisions is analyzed in terms of emissions, costs and service. Also the emissions resulting from in- and outbound logistics are calculated and assessed on reduction opportunities.

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Management Summary

Companies are paying more and more attention to environmental issues due to a growing pressure of external parties. Most initiatives of companies to cope with these environmental issues have focused on reducing direct emissions. However, to be able to meet the long-term climate goals set by the European Union (20 percent reduction in 2020 compared to 1990 levels) companies must look for other emission reduction options. Previous research at the TU/e has focused on reducing carbon dioxide emissions resulting from transport. A possible downside of focusing solely on transport emissions is that the effect of transport decisions on other processes is neglected. Processes more upstream or downstream can be affected by the transport decisions. This project aims to fill this knowledge gap by assessing the impact of system boundaries of processes and transport on decision making.

Research design

The following central question and sub-questions are defined for this project:

- *What is the impact of system boundaries of transport and processes on decisions that affect carbon dioxide emissions and costs?*
    - *How can the system boundaries be defined? And which impact do different boundaries have on decision making?*
    - *What is the relationship between inventory and transport decisions in terms of carbon dioxide emissions, costs, and service?*
    - *Which transport emission reduction options will reduce the carbon dioxide emissions resulting from outbound logistics, and what will be the impact on costs and service?*

This project was carried out within the Europe, Middle East & Africa (EMEA) region of Eastman CASPI (Coatings, Adhesives, Specialty Polymers and Inks). Only carbon dioxide emissions were taken into account because these emissions have by far the biggest impact on the environment. To narrow the scope of the project even more, the carbon dioxide emissions of 4 selected product groups were calculated and assessed during this project. The carbon dioxide emissions of processes that can be adapted were taken into account and also the carbon dioxide emissions resulting from in- and outbound logistics. TERRA, which is the tool developed during the Carbon Regulated Supply Chain project (van den Akker et al., 2009), was used to calculate the emissions resulting from transport.

Framework

During the project a general framework was developed that describes how companies can define the right system boundaries and objective function to assess the impact of reduction options. Processes and transport that can be adapted must be included in the system boundaries of the assessment. Multiple minimization problems were formulated which can be used in the decision making process of reduction options. Companies can define their goal from an environmental perspective but also from a cost perspective. The framework also showed that companies can directly and indirectly influence their emissions by controllable variables. When external parties are involved a company has to collaborate with these external parties in order to influence the total emissions and/or costs.

Results

The developed framework was used to assess the impact of system boundaries on decisions that affect carbon dioxide emissions and costs. At Eastman there are three different products for which the possibility exists to change the state of the product (for example molten or liquid). In addition, the relationship between inventory and transport decisions is analyzed in terms of emissions, costs and service. Also the emissions resulting from in- and outbound logistics are calculated and assessed on reduction opportunities.

The first case study analyzed a product for which it is possible to sell it in a packed form to the customer or in a molten form. When only transport is taken into account it is better to sell packed material to customers when only the transport emissions and costs were taken into account. However, when system boundaries are wider the results showed that selling molten bulk instead of packed material is beneficial in terms of carbon dioxide emissions. The results also showed that in most cases it is more expensive to sell molten bulk to a customer than packed material due to the high transport costs. The second and third case study analyzed the effect of postponement. For the products of these case studies it was possible to postpone a process to a later point in time. Taking into account only transport emissions in the second case study would again lead to poor decision making; the benefit in transport emissions and costs could not outweigh the emissions and costs from the processes. The results of the third case study showed that postponing a process to a later point in time within the same company did have a positive effect on emissions and costs.

To find an answer on the second sub-question a sensitivity analysis was conducted for the first case study. This sensitivity analysis showed that the average inventories of both Eastman and the customer decrease when transport arrivals are better coordinated. This is only possible when a customer shares his demand information with Eastman. Information sharing can smooth the operations of Eastman and reduce the time spent in storage. For both parties this would have a positive impact on emissions and costs.

The final objective was to give some insight on possible carbon reduction options in transport emissions. First the total carbon emissions of the selected products were calculated with Terra. The outbound logistics data were scanned on possible improvements and two lanes were found on where modal shift could decrease the emissions with 246 tonnes CO_2 in total. For Eastman it is also possible to redesign the network. However, to get better insights data must be collected from the transport movements of a distributor of Eastman.

Recommendations for further research

The project leads to the following recommendations for further research:

- It is recommended to conduct further research on the ocean freight calculations of TERRA. The estimates of carbon dioxide emissions from ocean freight could be improved by reviewing the literature and collecting data from logistic service providers.

- This project only took carbon dioxide emissions into account. It is recommended to conduct further research in which also the impact of the reduction options on other greenhouse gases is assessed.
- Redesigning a supply network can be beneficial in terms of carbon dioxide emissions. This project made a start in analyzing the impact of this reduction option. However it is necessary to analyze the impact of redesign in more detail to get better insights of this reduction option.

Table of contents

1 Introduction

This document is the report of a master thesis project, finalizing the Operations Management and Logistics master program of the Eindhoven University of Technology (TU/e). Previous studies performed at the TU/e only focused on the assessment and reduction of carbon dioxide emissions resulting from transport. In some cases it is necessary to take broader boundaries into account and not only focus on transport. This project studied the impact of system boundaries on decisions that affect carbon dioxide emissions and costs. A framework is developed which can be used to define the right objectives and boundaries when assessing the impact of emission reduction options.

The first section of this chapter gives brief information on the research area Green Supply Chain Management (GSCM) and previous research conducted at the university. A short description of the company where this project was performed, Eastman Chemical Company, is given in section 1.2. Finally, section 1.3 describes the structure of this report.

1.1 General background

1.1.1. Research area

Nowadays companies are experiencing that they cannot ignore environmental issues anymore because they are more and more confronted with global resource exhaustion and increasing environmental deterioration. Green Supply Chain Management (GSCM) is an approach that can be adopted to reduce costs and innovate while maintaining good environmental performance. One of the most complete and suitable is from Srivastava (2007): 'integrating environmental thinking into supply-chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final products to the consumers as well as end-of-life management of the product after its useful life' (Srivastava, 2007, p. 54).

Not only resource exhaustion and environmental deterioration force companies to adopt GSCM practices. Other factors that have driven companies to adopt GSCM are (Sarkis, Zhu, & Lai, 2010):

- Regulations: Governments and other instances are controlling pollution, product material, chemical waste etc. by introducing guidelines, regulations and laws.
- Competitive pressure: competitors may be able to set industry norms and/or legal mandates and therefore they have the ability to drive environmental innovation.
- Economic pressure: companies can increase benefits by reducing costs when they make their supply chain greener.
- Customer awareness: customers exert pressure on organizations to engage in environmental supply chain practices because they become more aware of environmental problems and feel that they are responsible for the community in which they are living.

The most well-known international agreement is the Kyoto Protocol. This protocol is a legally binding commitment of 163 countries to reduce greenhouse gas emissions on average by 5% during the period of 2008 to 2012 (UNFCCC, 1998). To achieve this goal every country has to meet its obligations. The Kyoto Protocol offers them an additional means of meeting their targets by way of three market-based mechanisms (Hepburn, 2007). The first mechanism is emissions trading which is a market-based scheme for environmental improvement and allows a country to buy and sell permits for emissions or credits for reductions in emissions of certain pollutants. The clean development mechanism allows a country to implement an emission-reduction project in developing countries and use the earned certified emission reduction (CER) credits as additional saleable right in their own country. The last mechanism, joint implementation, allows a country to implement an emission-reduction project in other Kyoto-countries and use the earned emission reduction units (ERUs) to meet its Kyoto target.

In Europe the European Union made a unilateral commitment to cut its emissions by at least 20 percent in 2020 compared to 1990 levels. A mechanism that was introduced in 2005 to achieve this goal in European countries is the European Union Emission Trading Scheme (EU-ETS). The EU-ETS is a system that is based on the 'cap and trade' principle, which means that a company is allocated a limit (or cap) on carbon emissions (Emissions Trading System, 2010). If the company exceeds the carbon cap then it can buy the right to emit extra carbon from the trading market and it can sell its surplus if it emits less than its allocation. So the way companies do business is influenced by this kind of regulations.

A method that is gaining popularity in GSCM is life cycle assessment (LCA). LCA is a method which can be used to assess and evaluate the environmental burden of products or services through all phases of its life. All types of impact upon the environment are covered in the term environmental burden, including emissions of greenhouse gases (GHG), different types of land use and extraction of different types of resources. An LCA limited to GHG emissions is often called 'carbon footprinting'. Prime objectives for companies to carry out LCAs are to provide all kinds of stakeholders with information and to understand the interaction between their activities and the environment. According to the ISO 14040 and 14044 standards, a LCA is carried out in four phases: goal definition and scoping, emissions inventory analysis, impact assessment and interpretation. See for instance Rebitzer et al. (2004).

1.1.2. Previous research at TU/e

The European Supply Chain forum started the Carbon Regulated Supply Chain (CRSC) project in 2007 in order to gain knowledge about how future regulations might affect a supply chain. Another aim of this project was to develop a calculation methodology to calculate the amount of carbon dioxide emissions from transport (van den Akker et al. 2009). The project started with an analysis of the different calculation methodologies that were already available; ARTEMIS, EcoTransIT, GHG Protocol, NTM and STREAM. The method that best suited the needs of the CRSC studies was based on the NTM methodology. This method was chosen because it has a high level of detail, it can calculate the emissions at various levels of detail, it offers the possibility of modifying or adding parameters, it is aligned with several European studies and NTM is cooperating with the European Committee for Standardization to set a standard for calculating emissions resulting from transport (van den Akker et al. 2009). During the CRSC project the TERRA (Transport Emission Reporting and Reduction Analysis) tool was developed. This tool is mainly based upon the NTM (2008) methodology. The reason that van den Akker et al. (2009) developed the tool was because the NTM methodology had some shortcomings. The following parameters were added during the CRSC project: cleaning, temperature control and vertical handling.

The tool was used to conduct research which was focused on reducing carbon dioxide emissions. In order to know how companies can reduce its carbon dioxide emissions Boere (2010) made an overview of carbon emission reduction opportunities and chose to analyze payload increase, modal shift and inventory management. For the first two reduction options he designed a maximum payload calculation technique and a modal shift lane identification method. In addition to this, during her project at Philips, Koc (2010) constructed a Markovian model to get more insight on the relationship between inventory replenishment decisions, forecasting accuracy and carbon emissions.

1.2 Company description

In this section Eastman Chemical Company is introduced, including information about its products, organization and their focus on sustainability.

1.2.1. General information about Eastman Chemical Company

Eastman Chemical Company provides chemicals, fibers and plastic materials that their customers use as key ingredients to make products people use every day. The company was founded in 1920 for the purpose of producing chemicals for Eastman Kodak Company's photographic business and became a public company as of December 1993. Nowadays the company employs approximately 10,000 employees around the world to blend technical expertise and innovation to deliver practical solutions for their customer. Eastman is a Fortune 500 company and in 2010 the company had a sales revenue of $5.8 billion (Eastman, 2010). The business where Eastman operates is divided into four different regions: North America (NA); Latin America (LA); Europe, Middle East & Africa (EMEA); Asia Pacific (AP). The company's corporate headquarter and also the largest manufacturing site is located in Kingsport, Tennessee (USA). Eastman owns total sixteen manufacturing sites in nine countries and several sales offices around the globe (see Appendix I).

The products and operations of Eastman are managed and reported in four business organizations:

- Coatings, Adhesives, Specialty Polymers and Inks (CASPI)
- Fibers
- Performance Chemicals and Intermediates (PCI)
- Specialty Plastics

1.2.2. Business organization and products

This project is conducted in the EMEA region of the CASPI business organization of Eastman (see Appendix I for the organization structure). CASPI products are products ranging from household paints to automotive and marine coatings to specialty adhesives. To clarify, Eastman does not make coatings or inks but makes products which are used in coating and ink formulations. The CASPI business serves a variety of diverse markets including building and construction, transportation, packaging, electronics and personal care. For example, the hydrocarbon resins – a popular product group of Eastman CASPI – are used in rubber and plastic modification to fine-tune application properties. One of the goals of the CASPI business is to focus on the development of long-term strategic relationships to achieve preferred supplier status with the customer. In 2010, the CASPI business organization had a sales revenue of $1.6 billion, which is 27 percent of Eastman's total sales.

1.2.3. Sustainability within Eastman

Sustainability has always been part of the Responsible Care® ethics which Eastman has been signed up to for the last 20 years within the chemical sector. Companies who are committed to this initiative agreed to improve health, safety, and environmental performance beyond levels required by law. However, in recent years a broader sustainability view has been adopted within Eastman. This broader view encompasses societal issues – from human rights – to standards of living - to access to natural resources. Customer awareness was the most important driver to adopt the broader sustainability view. Eastman defines sustainability as 'the ability in creating value to all three aspect of the triple bottom line: environmental responsibility and stewardship, social responsibility, company's economic growth' (Eastman, 2010). Between 1998 and 2008, Eastman was able to reduce greenhouse gas emissions from their businesses by 25%, energy use down by 35% and volatile organic compounds (VOCs) emissions by 34%. However Eastman recognizes that their sustainability journey must continue and therefore the company's environmental goals are to further improve energy efficiency by 2.5% and reduce GHG emissions by 2% year-over-year, and to have all new product family launches accompanied with LCA reports within the next few years. For the year 2011 Eastman defined the following mission and vision statements:

- Mission: To leverage sustainability as a source of competitive advantage across Eastman
- Vision: To be recognized as a company committed to sustainability

Until now, within Eastman improvements regarding GHG emissions were mainly focused on scope 1 and 2 (see Figure 1). Scope 3 emissions occur as a result of the activities of the company, the company's demand for goods or services, but are from sources not owned or controlled by the company. This project was focused on all scopes of the GHG protocol. This project was initiated by Eastman because they want to analyze and understand the possible choices that are available to differentiate themselves from competition.

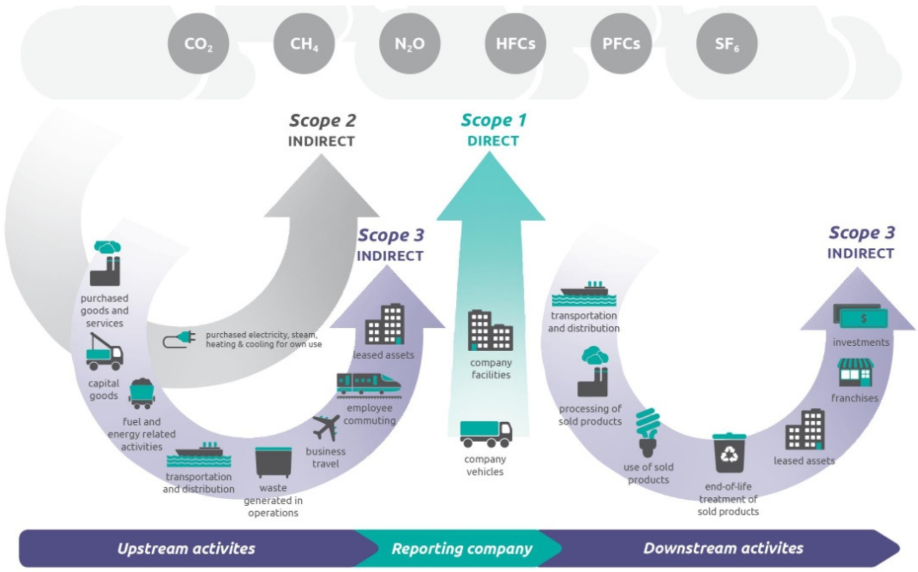

Figure 1 Overview of GHG Protocol scopes and emissions across the value chain (www.ghgprotocol.org)

1.3 Report structure

The next chapter describes the research design: it gives the problems and research questions that are answered in this report. Furthermore it describes the research model which gives an overview which steps were taken during the project. The data used in this project is briefly discussed in chapter 3. In chapter 4 the developed framework which is used to analyze the effect of the three case studies on carbon dioxide emissions and costs is described. Chapter 5 describes the results of three different case studies. An overview of the transport emissions are given in chapter 6. In this chapter also a comparison is made between the transport emissions results of TERRA and of an LCA performed by an external company. Chapter 7 discusses the implementation within Eastman on how they can reduce their carbon dioxide emissions. And in the final chapter, chapter 8, the conclusions and recommendations of this project are described.

2 Research design

This chapter explains the design of this research in detail. First, the problem setting is explained and the problem definition is presented in section 2.1. The research questions that are formulated to find solutions for the stated problem are given in section 2.2. In section 2.3, the methodology used and the way of approaching the problem are explained. The final section gives information about the scope of the project.

2.1 Problem definition

Section 1.1.2 described previous research done at the TU/e. The main focus of this research was to develop a methodology to calculate carbon dioxide emissions from transport. In addition, the impact of various reduction options on total transport emissions was assessed. One of the limitations of previous research is that it solely focused on carbon dioxide emissions from transport. A possible downside of focusing solely on transport emissions is that the effect of transport decisions on other processes is neglected. Processes more upstream or downstream can be affected by the transport decisions. The overall scale emissions of a product is accumulated along the whole supply chain and thus not only by transport. When taking broader boundaries into account it is also possible to see the effect of the interaction among multiple parties within a supply chain on emissions and costs (Benjaafar et al., 2010). Caro et al. (2011) that there are several ways to lower the emissions of operations upstream or downstream. A change in the characteristics of the product (e.g. dimension, form, durability etc.) and information sharing are examples which can decrease emissions. In order to achieve reduction in emissions it is necessary for a company to critically analyze its own processes or to collaborate and try to find reduction options together with other companies.

At Eastman CASPI there are three products for which it is possible make different transport and process decisions because it is possible to change the state of the products, for example molten or solid. The process steps performed at Eastman and the customer depend on the state of the product. Focusing solely on the impact of transport decisions may result in poor decision making. For example, if the molten product requires a truck that keeps the product heated and the solid product requires a regular truck it is better to choose the solid product from a transport emissions perspective. However, in some cases it is better to choose the molten product. This is only possible when emissions from the process steps of the molten product are lower than the solid product and if this positive difference in emissions diminishes the negative effect of the heated transport. It is therefore interesting to analyze the effect of these multiple forms on the carbon dioxide emissions resulting from the processes of 'analyzing company', its customer(s) and from transport. Furthermore, it is also not known what kind of impact the different forms will have on accompanying effects, e.g. effects on cost, service and inventory.

This project aims to fill this knowledge gap and to provide practical insights in this topic. In the next section research questions are identified based upon the problem described in this section.

2.2 Research questions

From the problem description of the previous section the following central questions can be derived:

What is the impact of system boundaries of transport and processes on decisions that affect carbon dioxide emissions and costs?

In order to be able to answer the central questions the following sub-questions are defined:

1. *How can the system boundaries be defined? And which impact do different boundaries have on decision making?*

The problem definition made it clear that Eastman has the possibility to make different process and transport decisions. These decisions depend on the state of the product. Not all processes of the Eastman and their customer will be affected when choosing a different state of a product. The first step is therefore to develop a general framework which can help companies in determining the goal and boundaries of their analysis. After this, the framework can be used to calculate the carbon dioxide emissions and costs of the system boundaries and make a decision about which product state to sell to its customers.

2. *What is the relationship between inventory and transport decisions in terms of carbon dioxide emissions, costs, and service?*

A way to determine the impact of the transport decisions on inventory is to conduct a sensitivity analysis on the results of the previous research question. For this sensitivity analysis also other parameters are identified to which the project decision may be sensitive. This results of the analysis will also show the impact on the result when the values of these parameters are changed.

3. *Which transport emission reduction options will reduce the carbon dioxide emissions resulting from outbound logistics, and what will be the impact on costs and service?*

Eastman is interested in their emissions from transport and how optimized their transport network already is. Several reduction options, together with the applicability are evaluated. The TERRA tool is used to quantify the different reduction options.

2.3 Research approach

In the previous section the research questions are described and in this section the approach that is used to answer these questions is described. The research model of Figure 2 shows which steps were taken during the project. Literature & desk research, preceding projects and interviews with people of Eastman were the first steps taken and resulted in a research proposal. As a second step, data was collected and a framework was developed which can be used in analyzing the effect of reduction options on emissions and costs. The developed framework and the calculation tool TERRA were used to analyze the collected data. The reductions in emission were obtained and the feasibility of these reduction options have been checked. During the plan of action managerial insights were obtained, conclusions were drawn and recommendations were made. The plan of action ended with a master thesis report and a presentation about the findings.

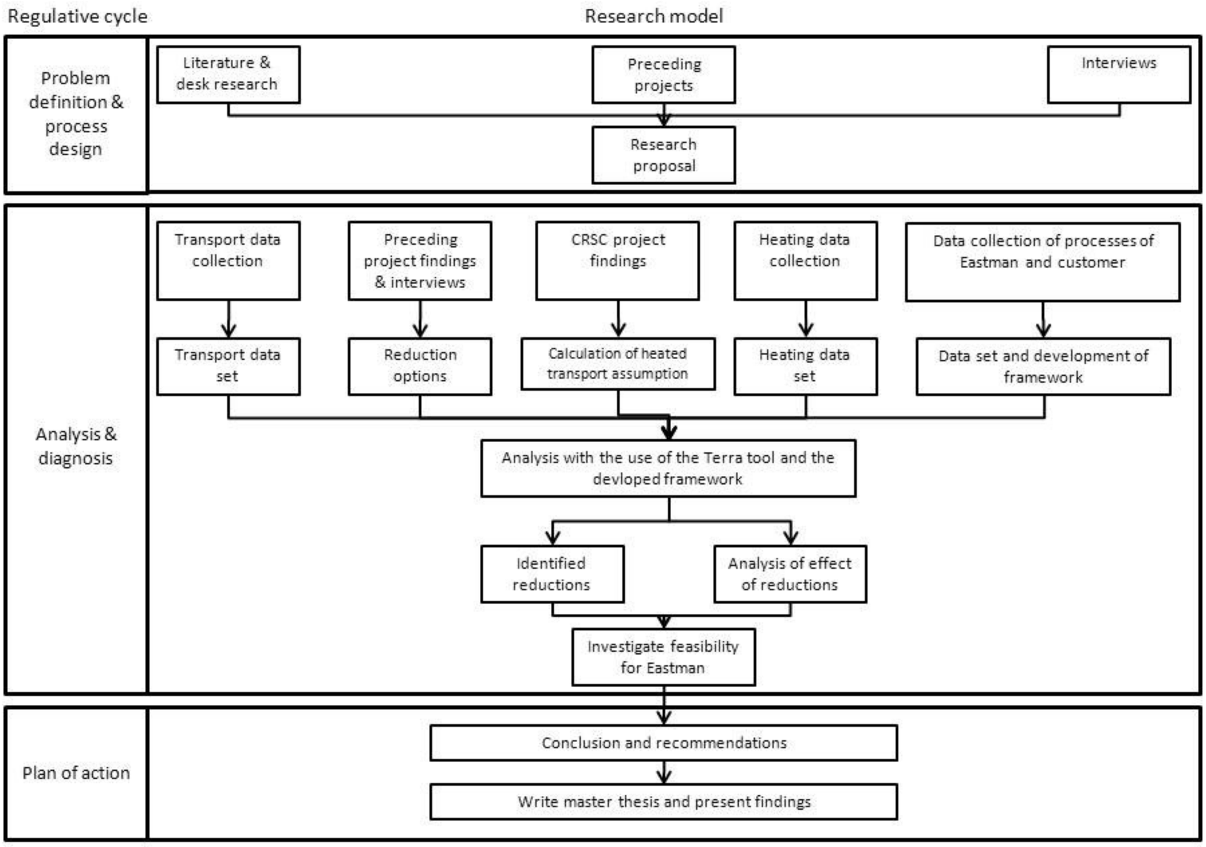

Figure 2 Research model (based Verschuren and Doorewaard (2000) and the regulative cycle of van Aken et al. (2007))

2.4 Research Scope

This section will describe the scope of the project. First the products selected are described. After this, the emissions taken into account are discussed. Finally a selection of the in- and outbound logistics and processes is made.

<u>Products</u>

To narrow the scope of the project, 4 products groups are chosen from 2 different streams (the resins stream and the coatings stream). The two product groups from the resins stream are chosen because there are different states in which the products can be transported. For the two product groups of the coatings stream it is possible to adapt the transport networks. In Appendix II an overview is given of the boundaries of these product groups.

Processes

Process steps of Eastman and of the customer must be considered to analyze the effect of supply chain collaboration. Three reduction options are considered during the project and only processes are taken into account on which these reduction options will have an impact.

Carbon dioxide emissions

There are different kinds of GHG emissions but not all GHGs have the same contribution to global warming. The Global Warming Potential (GWP) is a way to assess the impact on global warming. A GWP is a scale that determines the relative impact of the GHGs on global warming compared to carbon dioxide. Table 1 shows the GWPs of different GHGs.

Table 1 GWP (100 yrs) and comparison of GHGs emissions in transport (extracted from EPA (2009))

GHG	GWP (100 yrs)	GHG in transport	Emission factor (kg/GigaJoule)	(Kg/GigaJoule)*GWP
CO_2 (baseline)	1	CO_2	70.101	1
CH_4	21	CH_4	0.0028	0.07
N_2O	310	N_2O	0.00057	0.698
HFCs	12-11,700			
PFCs	6,500-9,200			
SF_6	23,900			

During transport only CO_2, CH_4 and N_2O emissions are emitted. When looking at fourth column of Table 1 it can be seen that CH_4 and N_2O are emitted in relatively small quantities when compared to CO_2. The fifth column, which represents a ratio of the effect of the GHGs compared to CO_2, shows that the contribution of CH_4 and N_2O in transport is also relatively small. Furthermore, CH_4 and N_2O emissions in transport are already better regulated than CO_2. Because of the aforementioned reasons this study will only take carbon dioxide into account when assessing the impact of transport.

Carbon dioxide emissions will also be taken into account when assessing the impact of supply chain collaboration. Since 2005 Eastman must to adhere the EU-ETS protocol because it operates in a carbon-intensive industry. For Eastman and its customer it is useful to express the selected processes in carbon dioxide emissions because in this way they can see what their loss or gain is in specific situations.

In- and outbound logistics

The supply process to the Europe and the distribution within the EMEA region will be of interest which means that the project will focus on in- and outbound transport. Inbound logistics is chosen because Eastman is interested in the carbon emissions that are calculated with the use of the TERRA tool. In the LCA of the rosin resins family also emission calculations resulting from transport have been done. Eastman wants to know if there are large differences in emissions and when this is the case they also want to know the origin of this difference. The inbound transport consists of a relative small number of lanes. However, for the outbound transport it must be determined which lanes will be investigated. Of all the transport movements only the gate to gate transport is considered. So onsite logistics at the site of Eastman are not considered.

3 Data collection

In order to analyze the effect of different reduction options data of Eastman's transport movements and processes is needed. In addition to this, data must be gathered of processes at the customer. This chapter describes which data was already available, which data needed to be collected externally and for which data assumptions are made.

3.1 Process data

Table 2 gives an overview of the data collection for the analyzed processes. Some data is obtained from the GaBi database. This database contains emission factors of processes, raw materials, waste treatment etc. When the data was not available within Eastman an assumption is made.

Together with an engineer of Eastman the capacities of different engines that used in the processes selected are determined. For some engines it was also necessary to determine the allocation factor because the engines are not solely used by the selected processes. It is difficult to get the exact allocation factor and therefore assumptions were made based on the experience of the engineer.

An assumption is made about energy used to keep the tanks of the customers on temperature. The two customers which already buy molten bulk use hot oil to heat the tanks. The best way to calculate the emissions and costs of the energy use is to assume that these tanks are also heated with steam. Also for customers who currently are buying packed material it is assumed that the tanks are heated with steam. Chapter 5 describes the results of a sensitivity analysis that is performed on the results. The effect of the previous assumption on total emissions and costs is also included in the sensitivity analysis by changing the engine capacities of the tanks.

Table 2 Overview of collected process data

Data	Data source/assumption
Engine capacity	Determined with engineer of Eastman
Electricity price, gas price	Eastman and Eurostat database (2011)
Emission factor electricity	Assumption: IEA statistics (2011)
Heating process customer	Assumption: physical formula
Steam use tanks Eastman	Eastman
Energy use customers	Assumption: are kept on temperature with hot oil but the same approach as for tanks Eastman is used (i.e. steam)
Emission factors packaging material	GaBi database
Bill of materials	Eastman
Reuse big bags	Assumption: a big bag is used twice
Repacking costs	Eastman
Tanklevels 2010	Eastman
Product use customer	Assumption: based on information of Eastman
Kg CO_2 per kg steam	GaBi database
End of life packaging material	GaBi database

3.2 Transport data

Most data collected was already available at Eastman. Data regarding the transport movements of Eastman were obtained from SAP and if not available an employee of Eastman or an external party was contacted. When not available at previous sources the average values defined in NTM methodology were applied. An overview of the transport data is given in Table 3.

Table 3 shows that the International Commercial Terms (INCOTERMS) of a shipment were also available in SAP. An INCOTERM is a trade term which specifies certain obligations within the sales contract. The trade term specifies the (International Chamber of Commerce, 1999):

- Transfer of obligations: where and how the seller must make the goods available to the buyer and how the buyer must take delivery of the goods
- Transfer of risk: when the seller has the right to claim for the contract price even if the goods are lost, damaged or short-delivered
- Division of costs: how the normal costs relating to the export and import of goods should be divided between the seller and the buyer

Responsibilities are thus clearly defined by referring to one of the INCOTERMS and making an agreement on the point of delivery. The data collected for this project stems from the year 2010 and in this year the INCOTERMS 2000 were still applicable. Appendix III gives an overview of the INCOTERMS 2000. The second column gives information about the place until which emissions are calculated. This means that if for instance 'CIF Hamburg' is stated in SAP then emissions are calculated till the port of Hamburg. After this, the customer is picking up the goods. This means that input factors like location, distance, route, modality, load factor etc. for TERRA are not known and therefore emissions are not calculated after this point. Table 8 in Appendix III shows which INCOTERMS were obtained from the data and the percentage of the total volume of each INCOTERM per product group. The last column shows that the emissions of 82.46% of the total volume are calculated until the door of the customer.

An employee of the logistic department helped with making a decision which vessel type to use for ocean freight or water transport. For the other two transport modes (truck and rail) the standard types of TERRA were used. Data of rail transport was only available for shipments in 2011. It is assumed that in 2010 rail transport was used on the same lanes as in 2011.

Table 3 Overview of collected transport data

Data	Data source/assumption
Origin Country, city and area	Downloaded from SAP
Destination Country, city and area	Downloaded from SAP
Incoterms	Downloaded from SAP
Weight of product	Downloaded from SAP
Transshipment country and city	Downloaded from SAP
Transport mode	Downloaded from SAP
Empty returns	Only taken into account when known
Positioning distance	Assumption NTM
Load factor	When available from SAP, otherwise assumption of NTM
Truck type	Assumption: always standard truck semi-trailer
Train type	Assumption: always average train
Vessel type	Employee of Eastman
Distance port to port	http://www.portworld.com/map/
Rail distance	http://dium.bahn-net.de/dium/index.jsp
Temperature control	Employee of Eastman
Cleaning	Employee of Eastman
Road allocation	Determined based on information from SAP
Transport costs	Downloaded from SAP

4 Framework

So far, most initiatives of companies to cope with environmental issues have focused on reducing direct emissions. For example replacing energy inefficient equipment or finding less polluting sources of energy. In addition, previous research at the TU/e focused on reducing carbon dioxide emissions resulting from transport. While there can be value in such efforts, Benjaafar et al. (2010) state that companies ignore a potentially more significant source of emissions; one that is driven by business practices and operational policies. By only focusing on direct emissions and transport emissions companies are ignoring important factors that emerge from the interaction among multiple parties within a supply chain. The overall scale emissions of a product is accumulated along the whole supply chain and thus not only in the operations of one company. When broader boundaries are taken into account it is possible for companies to collaborate and try to identify possible emission reduction options. Caro et al. (2011) developed a framework which can help companies in determining how companies must allocate emissions if they agree to jointly decrease total emissions. This section will introduce a general framework that companies can use to identify the effect of (joint) emission reduction actions on carbon dioxide emissions and costs.

4.1 Optimization problems

The carbon accounting standard of the GHG protocol will be used as a base in this framework (see Figure 1 in 1.2.3). In this standard the following three types of emissions are defined (Bhatia et al., 2011):

- Scope 1: direct GHG emissions, i.e. emissions from sources that are owned or controlled by the company. For example all emissions that result from combustion or chemical process in the company's facilities or facilities controlled by the company.
- Scope 2: electricity indirect emissions, i.e. emissions that result from electricity purchased by the company.
- Scope 3: all other indirect emissions, i.e. emissions that are not included in scope 2 which occur in the value chain of the reporting company, including both upstream and downstream activities.

A term that is often used in literature which represents these emissions is carbon footprint. The total carbon footprint of a product, service or process of a company is as follows:

$$Total\ carbon\ footprint\ (TF) = scope\ 1\ emissions + scope\ 2\ emissions + scope\ 3\ emissions \quad (1)$$

Using the different scope emissions of the GHG protocol implies that the total footprint emanates from multiple components that are possibly carried out at different companies. Within a supply chain there are thus multiple companies that can influence the carbon footprint TF. For example, the scope 3 emissions of Eastman increase when their customer decides to buy molten instead of the solid state due to the increase in transport emissions. This decision will not only affect the scope 3 emissions, also the scope 1 and scope 2 emissions are affected because the molten state requires another process than the solid state. So an external party cannot only influence the scope 3 emissions but also the scope 1 and 2 emissions.

From this example we can see that there are controllable variables that have an influence on the emissions. In this framework the controllable variables are subdivided into internal controllable variables and external controllable variables. Internal controllable variables can only be influenced by the company that is ‘analyzing’ the carbon footprint and external controllable variables can only be influenced by other companies in the supply chain. A company can only exert influence on the external controllable variables when it cooperates with the external party. The reduction efforts that a company exerts associated with each action $n \in N = \{1, \dots, N\}$ are given by $\vec{e} = e_n \forall\, n \in N$ for internal variables and $\vec{a} = a_n \forall\, n \in N$ for external variables. This means that equation (1) will be as follows:

$$Total\ carbon\ footprint\ (TF) = scope\ 1\ emissions(\vec{e}, \vec{a}) + scope\ 2\ emissions\ (\vec{e}, \vec{a}) + scope\ 3\ emissions\ (\vec{e}, \vec{a}) \quad (2)$$

To make a decision on how much effort a company is going to put in the reduction options in order to lower the carbon footprint a company must have an objective (see Table 4). From an environmental perspective the best goal would be to minimize the carbon footprint $TF(\vec{e}, \vec{a})$ subject to a certain budget (options 1 and 2). In option 1 there is a total budget for all reduction options and in option 2 there is a budget for each action taken. However at this moment most companies are not willing to increase costs and lower their profit in order to decrease carbon emissions. Therefore another objective can be to minimize total costs ($TC(\vec{e}, \vec{a})$) subject to a percentage in carbon emissions reduction (option 3). In this option $TF(0{,}0)$ represents the total footprint when no effort is exerted. It is off course possible to define other minimization problems than the ones in Table 4.

Table 4 Overview of minimization problems I

Option	Minimization problem
1	$Minimize\ TF(\vec{e}, \vec{a})$ $s.t.\ TC(\vec{e}, \vec{a}) \leq Total\ budget$
2	$Minimize\ TF(\vec{e}, \vec{a})$ $s.t.\ C(e_n, a_n) \leq Budget(e_n, a_n)$
3	$Minimize\ TC(\vec{e}, \vec{a})$ $s.t.\ TF(\vec{e}, \vec{a}) \leq TF(0{,}0) * percentage$

4.2 System boundaries

A crucial point for a company that is considering putting effort in reduction options is the definition of the boundaries. The problem definition in chapter 2 showed that a boundary definition that is too narrow (e.g. only transport emissions) may result in poor decision making. Taking into account all scope emissions is most of the times unnecessary. For example in a situation where the internal and external controllable variables do not influence the production process of the company it is not necessary to include the emissions and costs of this production process. Processes and transport that can be adapted/changed must be included in the boundaries of the analysis.

The left side of Figure 3 gives a top-down approach which can be used to formulate the objective function when the boundaries are defined. Here internal processes refer to the processes which can directly be influenced by the decision maker. External processes are processes which can only be influenced indirectly by the decision maker, e.g. by cooperating with the external party. The highest level in Figure 3 is represented by the widest boundary possible; the total carbon footprint (TF) model. When only processes of 'analyzing company' and its customer are taken into account then the highest level can be broken down into internal carbon emissions (ICE) and external carbon emissions (ECE). ICE represents all emissions from the product/service of the company and ECE represents all emissions from the product/service of the customer. At level 3 the emissions are even more detailed than at level 2. Here IP represents the internal production emissions. Only emissions from production steps that contribute to the production of a final usable product are included. All emissions that are emitted due to process steps that come after production of the usable product and before transportation are included within IF, for example CO_2 emitted due the packaging process. T represents the transport carbon emissions from outbound logistics of Eastman. The transport emissions can be internal or external depending on the agreement made on terms of delivery (see Appendix III). Emissions that are the results of process steps after transportation and before production are captured in the EF. EP represents the external production emissions and includes all emissions that are emitted due to the production process of the customer. The right side of Figure 3 shows the corresponding costs of the emissions.

Figure 3 shows that not only effort exerted in an internal controllable variable has an impact on internal emissions. Effort exerted in an external controllable variable also changes the internal carbon dioxide emissions. The same holds for the corresponding costs. This stresses the fact that it is important to cooperate with the customer in order to reduce emissions and costs. When a company is only analyzing reduction options for its own processes there is a situation in which external parties do not influence the carbon emissions and/or costs. If this is the case, the emissions and costs only depend on $\vec{e}$.

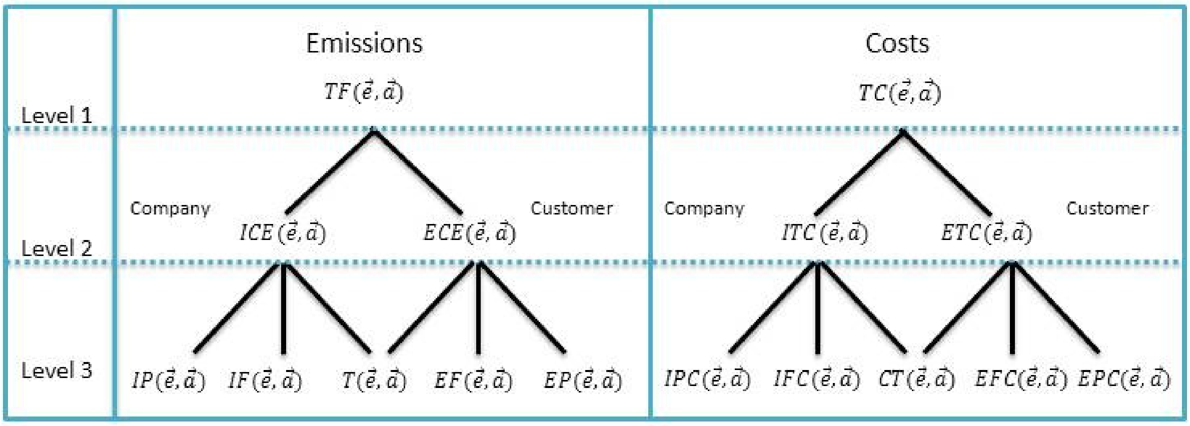

Figure 3 Top down approach of emissions and costs

The integration of the information from Figure 3 and the minimization problems of Table 4 are depicted in Table 5.

Table 5 Overview of minimization problems II

Option	Minimization problem
1	$Minimize\ TF(\vec{e},\vec{a}) = ICE(\vec{e},\vec{a}) + ECE(\vec{e},\vec{a}) = IP(\vec{e},\vec{a}) + IF(\vec{e},\vec{a}) + T(\vec{e},\vec{a}) + EF(\vec{e},\vec{a}) + EP(\vec{e},\vec{a})$ $s.t.\ IPC(\vec{e},\vec{a}) + IFC(\vec{e},\vec{a}) + CT(\vec{e},\vec{a}) + EFC(\vec{e},\vec{a}) + EPC(\vec{e},\vec{a}) \leq Total\ budget$
2	$Minimize\ TF(\vec{e},\vec{a}) = ICE(\vec{e},\vec{a}) + ECE(\vec{e},\vec{a}) = IP(\vec{e},\vec{a}) + IF(\vec{e},\vec{a}) + T(\vec{e},\vec{a}) + EF(\vec{e},\vec{a}) + EP(\vec{e},\vec{a})$ $s.t.\ IPC(e_n,a_n) + IFC(e_n,a_n) + CT(e_n,a_n) + EFC(e_n,a_n) + EPC(e_n,a_n) \leq Budget$
3	$Minimize\ TC(\vec{e},\vec{a}) = ITC(\vec{e},\vec{a}) + ETC(\vec{e},\vec{a}) = IPC(\vec{e},\vec{a}) + IFC(\vec{e},\vec{a}) + CT(\vec{e},\vec{a}) + EFC(\vec{e},\vec{a}) + EPC(\vec{e},\vec{a})$ $s.t.\ P(\vec{e},\vec{a}) + IF(\vec{e},\vec{a}) + T(\vec{e},\vec{a}) + EF(\vec{e},\vec{a}) + EP(\vec{e},\vec{a}) \leq (P(0,0) + IF(0,0) + T(0,0) + EF(0,0) + EP(0,0)) * percentage$

5 Case studies

This chapter describes the analysis of three case studies on which the framework of chapter 4 is applied. The three case studies treat three different products for which it is possible to make different transport decisions. In section 5.2 the first case study will be discussed. This case study analyzed the effect of the influence of packaging material on transport and processes in terms of carbon dioxide emissions and costs. The other two case studies will analyze the effect of postponement of a production steps on transport and processes in terms of carbon dioxide emissions and costs and will be treated in section 5.3.

5.1 Packaging product

In 2009 Eastman started to sell two products of the product group Z in different states; in a solid state (from now on the packed form) and in a molten state (from now on the molten bulk form). Due to these different states it is possible to transport the product with a regular truck or with a heated tank truck. Figure 4 shows the impact of these two states on transport emissions. In this figure the transport emissions when 0% molten is sold represents the situation where the total volume is sold in the packed form. Selling more in the molten bulk form has a negative impact on the transport emissions. This is due to the fact that more fuel is consumed if products are heated during transport. If only the transport emissions were within the boundaries of this case study then it was advised to not sell molten. Figure 5 illustrates that the two forms require two different flows. It is therefore also necessary to analyze the impact of these transport decisions on other processes.

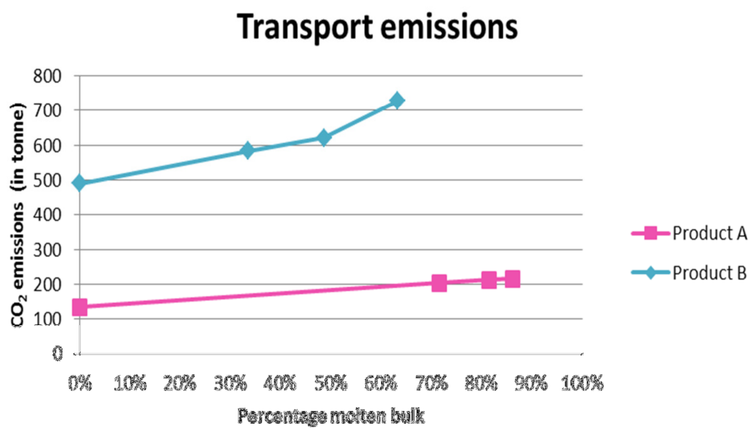

Figure 4 Transport emissions of Product A and B

Process steps before the intermediate tank are still similar for the two forms. After the intermediate tank the process is split into two different processes. When the packed form is sold to a customer the product goes from the intermediate tank to the packout. At the packout the product is first pastillated then filled into bags, stored on pallets and finally the pallets are wrapped into shrink cover. After this the packaged product is loaded onto a regular truck and shipped to the customer. At the customers' site the product must be heated again in order to use it in the remaining processes. If a customer orders molten bulk material the product goes from the intermediate tank to a bulk tank where it is stored. When the tank truck arrives at Eastman the product it is loaded into a heated bulk container and shipped to the customer. At the customers' site the product is loaded into a bulk tank again and can immediately be used in the remaining processes.

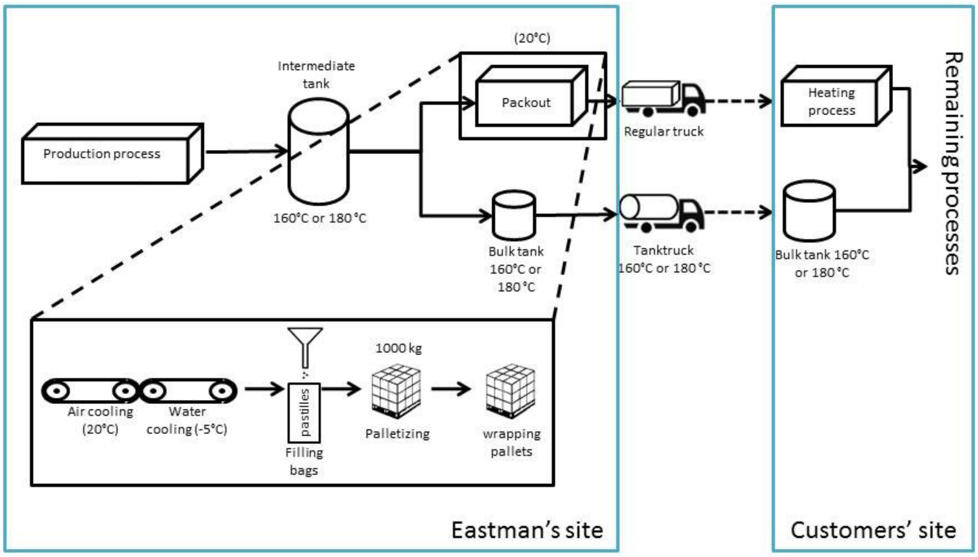

Figure 5 Different flows of product A and B

5.1.1. Model

The previous section described that it is possible to choose two different transport types: a regular truck for the packed form and a heated tank truck for the molten form. For these products it is not possible to only make a decision based on the transport emissions; the processes after production are not similar at Eastman and the storage at the customer is also different. Due to involvement of the customer Eastman has to put effort in both internal and external controllable variables. The internal controllable variable in this situation is the packaging process. A decision must be made whether to make pastilles of the product or to keep it molten. The external controllable variable is storage at the customer. The product can be stored in a warehouse when packed material is sold and must be stored in a bulk tank when molten bulk is sold. Only emissions and costs from the point in time where the processes are different until the point in time where they are similar again must be taken into account. This means that IF, T and EF (see Figure 3 in section 4.2) are within the boundary of this case study. For each action performed there is a specific budget determined, i.e. Eastman is willing to improve emissions as long as the corresponding costs do not exceed the budget. Based on this information the following problem is formulated:

$$minimize\ IF(\vec{e},\vec{a}) + T(\vec{e},\vec{a}) + EF(\vec{e},\vec{a}) \tag{3}$$

$s.t.$

$$IFC(e_n,a_n) + CT(e_n,a_n) + EFC(e_n,a_n) \leq Budget(e_n,a_n) \tag{4}$$

This can be rewritten as:

$$minimize\ IF(\vec{e},\vec{a}) + T(\vec{e},\vec{a}) + EF(\vec{e},\vec{a}) = \sum_{c=0}^{n} ESBT(c) + \sum_{c=0}^{n} EEBT(c) + EPO + EPM + T + EHP \quad (5)$$

$s.t.$

$$PMC + RC + ECPO + \sum_{c=0}^{n} CBT(c) + \sum_{c=0}^{n} I(c) + CT + ECHP + LC \leq Budget(e_n, a_n) \quad (6)$$

Where in equation (5) ESBT(c) represents the CO_2 emissions from steam use of a bulk tank at location c, with c = Eastman=0, customer 1=1 customer 2=2,…, customer n=n. The emissions from electricity use of the bulk tank at location c are EEBT(c). EPO and EPM represent the emissions from the packout and the packaging material. And the emissions from the heating process at the customer are EHP.

In equation (6) the costs regarding the packaging material are PMC. RC represents the repacking costs and ECPO the electricity costs for the packout. The costs for a bulk tank at location c are CBT(c). The inventory holding costs of location c are I(c). ECHP represents the electricity costs of the heating process and LC are the labour costs when bags need to be cut at the customer.

The following is obtained when going into more detail:

$$minimize\ IF(\vec{e},\vec{a}) + T(\vec{e},\vec{a}) + EF(\vec{e},\vec{a}) = \sum_{c=0}^{n} X(c) * ef_s + \sum_{c=0}^{0} \left(\frac{Q_p * V_p(c)}{3600}\right) * ef_E(c) + \sum_{c=0}^{n} \left(\frac{\frac{Q_u * V_m(c)}{l}}{3600}\right) * ef_E(c) + \sum_{c=0}^{n} \frac{P(c)*365*24*60*60}{3600} * ef_E(c) + T_p + \sum_{i=0}^{4} ef_M(i) * U(i) + \sum_{x=0}^{1} \sum_{i=0}^{4} n(x) * ef_D(x,i) * U(i) + T + \sum_{c=1}^{n} \frac{V_p(c)}{Vp(0)} * \left(\frac{Q_h}{3600}\right) * ef_E(c) \quad (7)$$

$s.t.$

$$\sum_{i=0}^{4} p_p(i) * U(i) + \sum_{c=0}^{n} d(c) * \frac{V_p(c)}{20} + p_r * V_b + \sum_{c=0}^{0} \left(\frac{Q_p * V_p(c)}{3600}\right) * p_e(c) + CT + 365 * r * k * y + \sum_{c=1}^{n} \frac{V_p(c)}{b} * p_l + \sum_{c=1}^{n} \frac{V_p(c)}{Vp(0)} * \left(\frac{Q_h}{3600}\right) * p_e(c) + \sum_{c=0}^{n} \frac{X(c)}{\lambda} * z * p_g(c) + \sum_{c=0}^{n} \frac{P(c)*365*24*60*60}{3600} * p_e(c) + \sum_{c=0}^{n} \left(\frac{\frac{Q_u * V_m(c)}{l}}{3600}\right) * p_e(c) + \sum_{c=0}^{n} h * (I_m(\mathrm{c}) + I_p(\mathrm{c})) \leq Budget(e_n, a_n) \quad (8)$$

Where

Objective function

$ef_M(i)$: Emission factor of material i (in kg CO_2/kg), with i = shrink cover=0, pallets=1 and 20kg bags=2, 1000 kg big bag =3, 500 kg big bag =4,

$ef_D(x,i)$: Disposal emission factor of disposal treatment x for material i (in kg CO_2/kg), with x = incineration=0 and landfill=1

$ef_E(c)$: Electricity emission factor at location c (in kg CO_2/kWh), with c = Eastman=0, customer

1=1 customer 2=2,…, customer n=n

ef_s : Emission factor steam (in kg CO_2/kg)

$n(x)$: Percentage of material disposed by disposal treatment x, with x = incineration=0 and landfill=1 and $\sum n(x) = 1$

$P(c)$: Absorbed electric power to stir a tank at location c (in KW), with c = Eastman=0, customer 1=1 customer 2=2,…, customer n=n

Q_h : Required energy for heating process (in kJ/kg) can be calculated with $Q_h = m * c * \Delta t$, where m = total mass of products (in kg), c = specific heat capacity (in kJ/kg/°C)=2.1 kJ/kg/°C and Δt = change in temperature (in °C)

Q_p : Required energy to cool 1 kg down in the packout (in kJ/kg)

$Q_{u/l}$: Required energy to unload/load one kg a tank (kJ/kg)

$U(i)$: Total packaging material used of material i (in kg)

T_p : Transport emissions packaging material (in kg CO_2)

T : Transport emissions from Eastmans outbound logistics (in kg CO_2)

$V_m(c)$: Molten quantity loaded or unloaded at location c (in kg), with c = Eastman=0, customer 1=1 customer 2=2,…, customer n=n

$V_p(c)$: Net quantity of packed products at location c (in kg) with c = Eastman=0, customer 1=1 customer 2=2,…, customer n=n

$X(c)$: Total steam usage of a bulk tank at location c in 2010 (in kJ), with c = Eastman=0, customer 1=1 customer 2=2,…, customer n=n

Cost constraint

b : Productivity of bag cutter (=1375 kg/hr)

$d(c)$: Disposal costs that EMN has to pay per 20kg bag for a customer at location c (in €/20kg bag)

h : Inventory holding costs (in €/kg)

$I_m(c)$: Average inventory molten at location c (in kg)

$I_p(c)$: Average inventory packed at location c (in kg)

k : Ratio which represents how many of the total number of trucks is dedicated for the product under consideration

V_b : Net quantity of big bags sold (in kg)

$p_e(c)$: Electricity price at location c (in €/kWh)

$p_g(c)$: Natural gas price at location c (in €/m^3)

p_l : Labour price of bag cutter (in €/hr)

$p_p(i)$: Packaging price of material i (in €/unit of material)

p_r : Repacking price (in €/kg)

r : Rent of trucks (in €/hr)

y : Number of trucks rented in 2010

CT : Total transport costs of EMN in 2010 of the product under consideration (in €)

z : Conversion factor natural gas per kg steam (=0.0775 m^3/kg)

Objective function

The first part $\sum_{c=0}^{n} X(c) * ef_S$ of the objective function (7) represents the CO_2 emitted by the bulk tanks at Eastman and at the sites of the customer. A method to calculate the total steam usage $X(c)$ for the various tanks is given in Appendix IV. In reality the customers heat their tanks with hot oil. Due to lack of data the emissions and costs of the customers are calculated in the same way as the tanks of Eastman; with steam.

The CO_2 emissions from the packout are calculated by $\sum_{c=0}^{0} \left(\frac{Q_p * V_p(c)}{3600}\right) * ef_E(c)$. An overview of the electricity emission factors per country are given in Appendix V. Together with an engineer of the manufacturing site the required energy to cool down 1 kg of product Q_p is calculated. For each engine in the packout the actual used capacity (in kW) was determined by looking up the capacity (in kW), the efficiency of the engine and the allocation factor.

$\sum_{c=0}^{n} \left(\frac{\frac{Q_u * V_m(c)}{I}}{3600}\right) * ef_E(c)$ represents the part of the CO_2 emissions when a bulk tank is unloaded at Eastman and loaded at the customer. The bulk tanks also use electricity for mixing the product with a stirring device. It is assumed that the stirring device is mixing 24/7 and 365 days a year. The CO_2 emissions that are emitted due to the mixing process can be calculated with $\sum_{c=0}^{n} \frac{P(c)*365*24*60*60}{3600} * ef_E(c)$.

A LCA is conducted for the packaging material because these emissions are not emitted anymore when molten bulk is shipped to a customer. Emission factors until the gate of the packaging material suppliers are sourced from the database of the LCA software tool GaBi. When these emission factors are multiplied with the total packaging material used ($\sum_{i=0}^{4} ef_M(i) * U(i)$) the total CO_2 emissions until the gate of the suppliers are obtained. With TERRA the transport CO_2 emissions T_p are calculated from the gate of the suppliers till Eastman's gate. Also the end-of-life is taken into account within the LCA. It is assumed that the materials will not be recycled and from the database of Eurostat (2011) it is obtained that in Europe on average 34.69% of industrial waste is incinerated and 65.31% will end up in a landfill. $\sum_{x=0}^{1} \sum_{i=0}^{4} n(x) * ef_D(x,i) * U(i)$ represents the end-of-life of the packaging material.

Shipping molten instead of packed material also has an influence on the transport emissions of Eastman. For molten a dedicated tank truck is used that is able to keep products on a high temperature. When packed material is shipped a regular truck is used. The total CO_2 of the shipments (T) are calculated with TERRA. One of the findings of the literature review that was conducted as a preparation for this project was that the assumption for heating in TERRA is baseless. Therefore the assumption is assessed with information of the carrier that currently ships molten bulk for Eastman. An overview of this assessment is given in Appendix VI.

Finally, the emissions that are emitted due to the heating process at the customer can be calculated with $\sum_{c=1}^{n} \frac{V_p(c)}{Vp(0)} * \left(\frac{Q_h}{3600}\right) * ef_E(c)$. Due to lack of data of the heating process at the customer the following formula is used to calculate $Q_h = m * c * \Delta t$.

Cost constraint

The first part $\sum_{i=0}^{4} p_p(i) * U(i)$ of the costs constraint function (8) represents the costs of the packaging material. Eastman must pay disposal costs when packed material is sold to customers in Germany. The costs that a customer has to pay to dispose the packaging material are not included due to lack of data. For customers it is also possible to order big bags of 500 kg or 1000 kg. When this is the case, an external party fills these big bags and Eastman pays a standard price p_r per kg to repack the 20 kg bags into big bags. $\sum_{c=0}^{0} \left(\frac{Q_p * V_p(c)}{3600}\right) * p_e(c)$ represents the costs for the packout at Eastman. Only electricity costs are taken into account because the process is fully automated. For an overview of the electricity costs per country see Appendix V. The costs to transport the product from the manufacturing site to the site of the customer are given by CT. The dedicated tank trucks are rented from a logistic service provider (LSP) and the total rent can be calculated with: $365 * r * k * y$.

Customers who are buying packed material must have an employee who cuts the bags and puts the product into the process. The costs associated with these are $\sum_{c=1}^{n} \frac{V_p(c)}{b} * p_l$ where the assumption is made that the productivity of the bag cutter is 1375 kg per hour and that the labour prices p_l is €20 per hour. When the bags are cut the product is heated up again and the associated electricity costs are represented by $\sum_{c=1}^{n} \frac{V_p(c)}{Vp(0)} * \left(\frac{Q_h}{3600}\right) * p_e(c)$.

The product must be kept on temperature in bulk tanks in the situation where the packaging process is deleted. The product is kept on temperature with steam at Eastman and with hot oil at the customer. For the calculations it is assumed that the tanks at the customers are also heated with steam. The costs associated with the gas use to generate steam is calculated with $\sum_{c=0}^{n} \frac{X(c)}{\lambda} * z * p_g(c)$. For an overview of the gas price per country see Appendix V. In addition to this Eastman and customers have to pay electricity costs for the stirring devices in the tanks ($\sum_{c=0}^{n} \frac{P(c)*365*24*60*60}{3600} * p_e(c)$) and to unload and load the dedicated tank trucks ($\sum_{c=0}^{n} \left(\frac{\frac{Q_u * V_m(c)}{l}}{3600}\right) * p_e(c)$).

The last part of the costs constraint $\sum_{c=0}^{n} h * (I_m(c) + I_p(c))$ represents the inventory holding costs. Inventory holding costs of customers which do not have consignment inventory for the packed material are not taken into account because no data is available on the average inventory. This means that inventory holding costs of customers are only calculated in situations when customers have consignment inventory or inventory in a bulk tank. The expected average inventories are calculated with formula 21 (see Appendix IV) on page 12 of de Kok (2005). For the calculation of the safety stock it is assumed that the demand is normally distributed.

5.1.2. Results

The carbon dioxide emissions from the molten bulk product and the packed product within the boundaries of this project can be subdivided into five categories: ‘waste treatment’, ‘transport’, ‘energy to generate steam’, ‘electricity’ and ‘packaging’.

An overview of the differences in emissions per category can be seen in Table 6. These results only show the emissions when the product was sold to the customer who bought the largest volume in 2010. The last row of Table 6 gives the total impact on emissions. The total CO_2 emissions decreased with 150 tonnes for product A and for product B this is almost 115 tonnes CO_2. In the 0% molten situation no carbon dioxide is emitted in the category 'energy to generate steam'. This is due to the fact that the packout only makes use of electricity.

Table 6 CO2 emissions (in tonne) per category

	Product A			Product B		
Category	0% molten	72% molten	Difference	0% molten	33% molten	Difference
Transport	135.78	203.57	-67.79	492.71	584.46	-91.74
Electricity	180.37	90.75	89.62	311.26	241.69	69.57
Energy to generate steam	-	53.54	-53.54	-	58.49	-58.49
Waste treatment packaging	163.65	45.46	118.19	402.14	268.22	133.92
Packaging production	86.19	22.51	63.68	188.47	126.84	61.63
Total	**565.99**	**415.83**	**150.16**	**1394.61**	**1279.72**	**114.89**

Figure 6 and 7 show the contribution in emissions of each category. It can be seen that the biggest contributor for both products is transport. The rest of the contributors do not have the same order for the two products. For example, waste treatment is a bigger contributor for product B than for product A. This can be explained by the fact that product B has more packed products than product A in the current scenario. For product A we can see an improvement of 26.5% in CO_2 emissions when compared to the scenario where all the products are packed. For product B this improvement is 8.2%. The improvement is mostly caused by the elimination of the packaging material (see also Table 6).

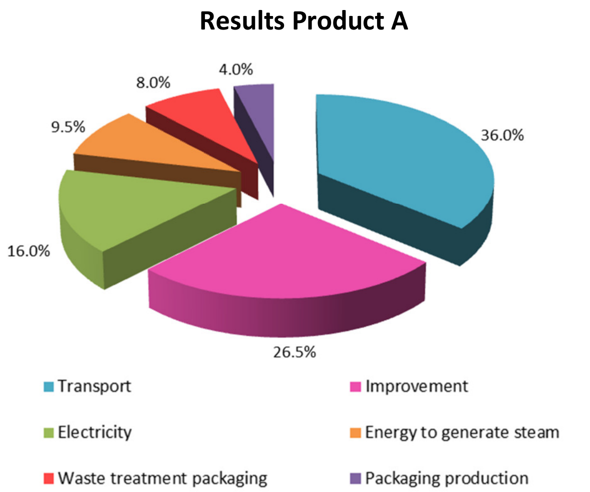

Figure 6 Emissions share per category for product A

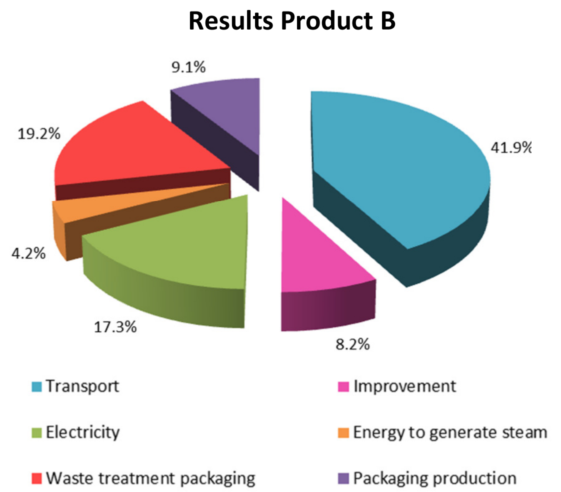

Figure 7 Emissions share per category for product B

Figure 8 and 9 show the results in CO_2 emissions when Eastman will sell molten to more customers. In total there is a decrease of 150 tonnes in CO_2 emissions when Eastman sells product A in molten to their largest customer of this product. The decrease for product B is less than for product A and is equal to

115 tonnes. The number of big bags used is one of the factors that causes this difference. In the situation where all products are packed the largest customer of product A orders big bags and the largest customer of product B orders small bags (=20 kg). When a customer orders big bags the product is first packed into 20 kg bags and then shipped to another location in the Netherlands where the 20 kg bags are repacked into big bags. So when a customer orders molten another step is eliminated in this situation. Both graphs show that there is still a decrease in total CO_2 emissions when more customers are buying the products in molten form. For product A this has a minor effect; selling molten bulk to the second largest customer will decrease emissions with 12.2 tonnes CO_2 and selling it to a third customer will further decrease the emissions with 0.2 tonnes CO_2. This is different for product B; when a second customer buys molten the total CO_2 emissions decrease with 44.2 tonnes and a third customer causes a decrease of 1 tonne.

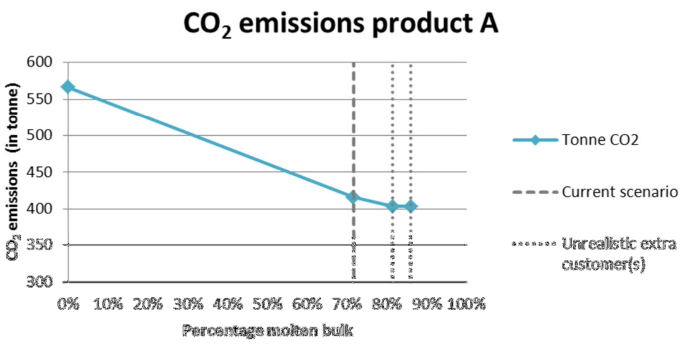

Figure 8 CO_2 emissions product A

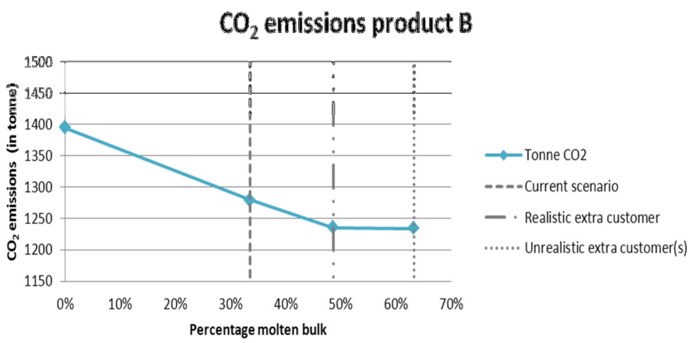

Figure 9 CO_2 emissions product B

It must be noted that for product A it is not realistic to sell more than 72 % of the total volume to their customers in molten bulk. From Appendix VII it can be seen that the total CO_2 emissions and costs of these customers increase when they receive molten bulk. Eastman will have to compensate the customers for this increase in CO_2 emissions in order to convince the customer to order molten bulk. In addition to this, customers that receive molten bulk must have dedicated bulk tanks on their manufacturing site. The investments costs for these bulk tanks are high, which is another disadvantage of selling more molten to additional customers. Adding a second customer for product B can be realistic. The demand of this customer is large enough to consider an investment in a bulk tank. The total CO_2 emissions of this customer will increase when it will use molten bulk and thus the customer must be convinced to order molten bulk instead of packed material. Appendix VII shows that the total costs of this customer decrease. This decrease in costs could be a reason to buy molten bulk instead of packed material. In Appendix VII an overview is given of the advantages of molten bulk compared to packed material. For Eastman a problem will arise when it is considering selling molten bulk to this customer. The current capacity of the bulk tanks can handle a demand of 6,840 tonnes. The total demand of molten bulk will be 7,432.32 tonnes and thus Eastman must investigate whether or not it is beneficial for them to expand the capacity of the bulk tanks in order to fulfill this demand.

Figure 10 and 11 give an overview of the total costs for the different scenarios. For both products it can be seen that if the demand of the largest customers is fulfilled with molten bulk the total cost increase.

The biggest contributor of this cost increase is the transportation. Shipping a full container of molten bulk on a lane is 1.77 times more expensive than shipping a full container of packed material. In addition to this Eastman also pays rent for these tank trucks.

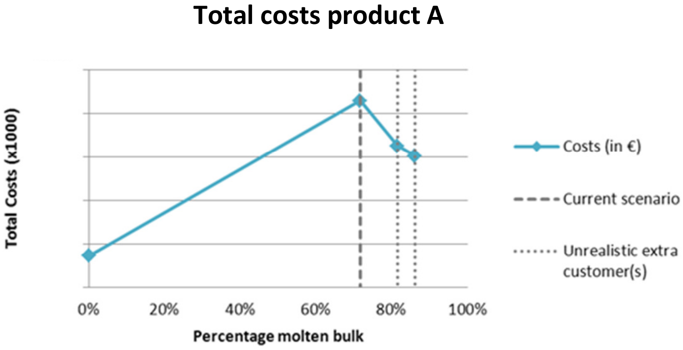

Figure 10 Total costs product A

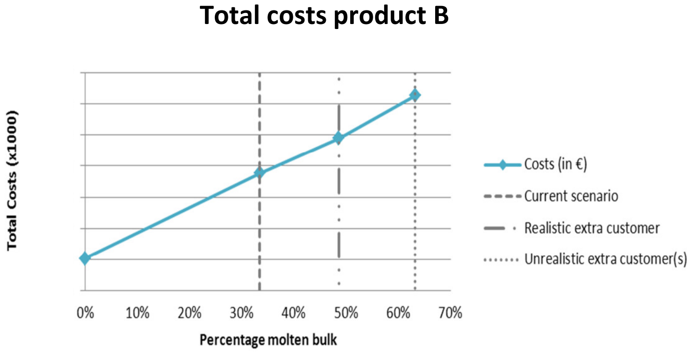

Figure 11 Total costs product B

For product A the total costs decrease when the second and third customers are added to the molten bulk list. The reason that there is a decrease in costs for the second customer is because this customer bought big bags in 2010. Repacking smaller bags into big bags is done by an external party and is very expensive. In addition to this, also transport costs have to be paid to ship the small bags from the manufacturing site in the Netherlands to the external party. In Appendix VII it can be seen that the total costs for this customer increase. This is due to the fact that the costs to keep the product on temperature in a bulk tank are higher than the costs associated with heating the product up again for this customer. Unlike the second customer, the total costs of the third customer decrease when buying molten bulk. For this customer the costs to keep the product on temperature in a bulk tank are lower than the costs associated with heating the product up again. The reason why there is a contradiction is because the customers are located in different countries and the electricity and gas prices are country specific. For Eastman an increase in costs can be seen when molten bulk is sold to this third customer.

The total costs of product B increase when molten is sold to customers. Appendix VII shows that the total costs for the customer decrease; keeping the product on temperature in a bulk tank is cheaper than heating it up again. For Eastman there is an increase in costs due to the high costs that are associated with shipping molten bulk in dedicated trucks.

It is also important to see which impact this change has on the different scopes of the GHG protocol. Figure 12 and 13 give an overview of the three GHG scopes. For both products there is an increase in scope 1 emissions when molten bulk is sold to more customers. The bulk tanks at Eastman are kept on temperature with steam and in the production process of steam natural gas is used. Combustion of natural gas falls within the scope 1 emissions of the GHG protocol (see Figure 1 in Chapter 1). When more customers receive molten bulk, more steam is needed which causes the increase in scope 1 emissions. Scope 1 emissions of Eastman fall under the European Union Emissions Trading Scheme (EU-ETS) due to the fact that Eastman operates in the chemical industry. The EU-ETS system limits companies in the amount of carbon dioxide they are allowed to emit with emissions rights. If companies emit more than they are allowed to, they have to buy more emissions rights and if they emit less than they can sell the remains in emissions rights. The costs when Eastman exceeds the limit allocated by the scheme are not included in costs constraint (4). The total costs of product A could at most increase with €535 when it is assumed that the market price of carbon is €13 and only the increase in scope 1 emissions of the first customer are taken into account. For product B the costs would increase with €565.

The scope 2 emissions (from purchased electricity) are slightly decreasing when more customer buy molten bulk. The emissions from the electricity use of the stirring device per kg product decrease when more bulk is sold and also less electricity is used at the packout.

From the scope 3 emissions it can be seen that there is a large decrease in CO_2 emissions when molten bulk is sold to the largest customer and for the other customers this decrease is minor. As already mentioned earlier the largest contributor of this difference is the packaging material (see Table 6). For product A the difference between 0% and 72% is largely due to the fact that big bags are eliminated when selling 72% of the total volume in molten bulk.

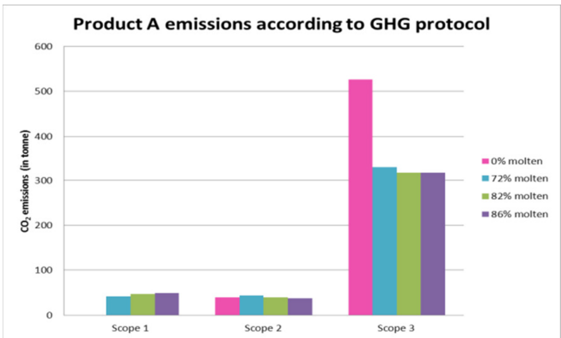

Figure 12 Change in scope emissions product A

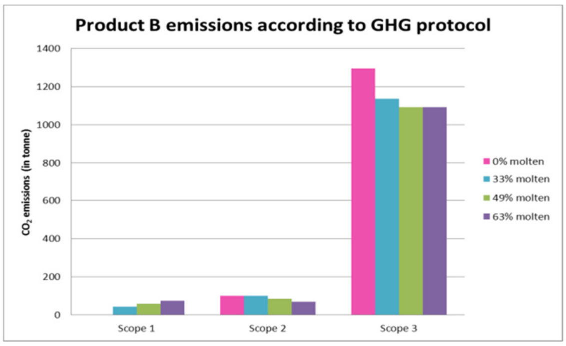

Figure 13 Change in scope emissions product B

5.1.3. Overview Life Cycle Assessment

The previous section discussed the environmental impact in terms of CO_2 emissions and showed that selling molten to the customer is better for the environment than selling packed products. Figure 14 and 15 show which impact the improvements have when a broader perspective is taken into account. Within Eastman LCAs are performed for both products, these LCAs is performed up to and including production of the products and are colored grey in the figures.

For both products it can be seen that the emissions up to and including production are the largest contributors. Although, previous section showed that introducing molten to the market decreased CO_2 emissions with 26.5% for product A and 8.2% for product B the pies above show that this is only 1.9% and 0.6% when a broader perspective is taken into account. It must me noted that these improvements can even be less because the graphs don't represent an LCA from cradle-to-cradle or from cradle-to-grave because the end-of-life of the products A and B are not taken into account.

Due to the large share of the 'upstream' emissions (>92%) it is recommended to analyze whether there are possibilities to reduce emissions in this category. However in Europe, chemical companies are already improving the energy efficiency of their production processes (Cefic: Energy efficiency, 2012). It is therefore important to focus on reduction options like these to further decrease total emissions even though the overall effects seem minor.

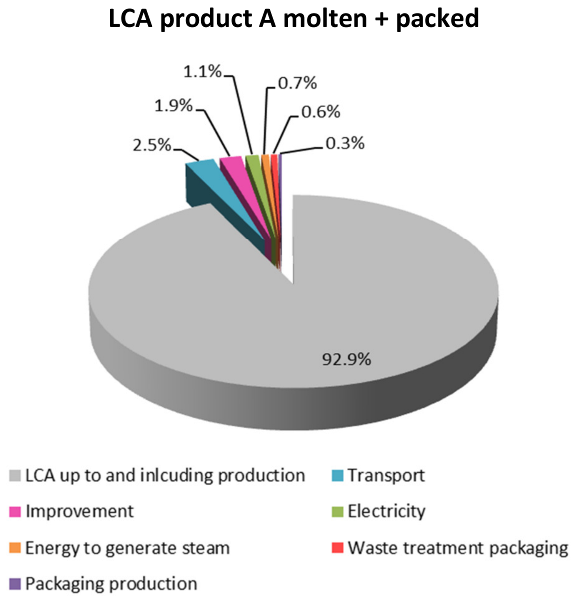

Figure 14 LCA results product A

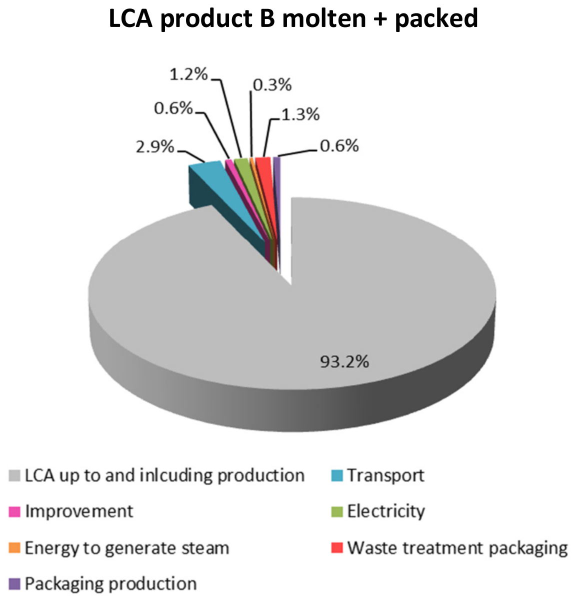

Figure 15 LCA results product B

5.1.4. Sensitivity analysis

During the project a sensitivity analysis was conducted to investigate the consequences of changes in parameter values. Several parameters have been identified that could have an influence on the obtained results. This section describes the results of the sensitivity analysis. An overview of the identified parameters and their impact on emissions and costs are given in Appendix VIII and Appendix IX. Figure 16 and 17 show the impact of five of the identified parameters which will be discussed in the next paragraphs.

The emission factors of the packaging material are sourced from the database of GaBi software. This software system is developed by the University of Stuttgart in cooperation with PE Product Engineering GmbH. The data sets in GaBi are based on input from industry, technical and patent literature. A disadvantage of using data from a database is that it is for instance not known which assumptions are made to calculate the emissions factors. The emission factor of packaging material for which recycled materials are used is different than the emission factor of packaging material for which this is not done. It is therefore interesting to see which impact this parameter has on the results. Lowering the emissions factors with 20 percent results in a total decrease of 4.5 tonnes CO_2 for product A and 25.4 tonnes CO_2 for product B.

A parameter which seems to have a large impact on the emissions is the empty returns with the dedicated tank truck. In the analysis it is assumed that all dedicated tank trucks return empty. When the

LSP or Eastman finds a company (in the same area of its customers) which can also make use of these trucks the total emissions will decrease with 13.03% for product A and with 7.59% for product B. 'Sharing a truck' will probably decrease the costs of transport but it is not known how large this impact will be.

Nowadays, energy companies and governments are investing a lot in the production of clean energy. The electricity emission factor decreases when the production of energy is cleaner. The results of the sensitivity analysis show that the electricity emission factors have a positive correlation with total CO_2 emissions. Section 5.2.4 will analyze the effect when all countries will have clean electricity emission factors.

Changing the time spent in the tanks at Eastman has an effect on both total emissions and on costs. When time spent in the tank decreases the total emissions and total costs decrease. The same results are found when the time spent in the tank of the customer is decreased. The decrease in costs is caused by a decrease in gas use and a lower average inventory. A way to decrease the time spent in the tanks is to collaborate and to share information with each other. When a customer shares his demand information with Eastman this can smooth the operations of Eastman and reduce the average inventory and thus the time spent in the tank. In 2011 Eastman is going to keep the inventory of the tanks at the customers as consignment inventory which means that the inventory costs of Eastman increase. So when looking from an Eastman perspective it is really beneficial to get more demand information of the customer.

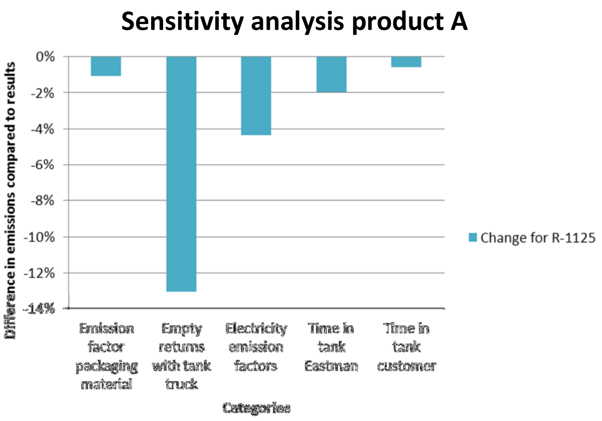

Figure 16 Results sensitivity analysis product A

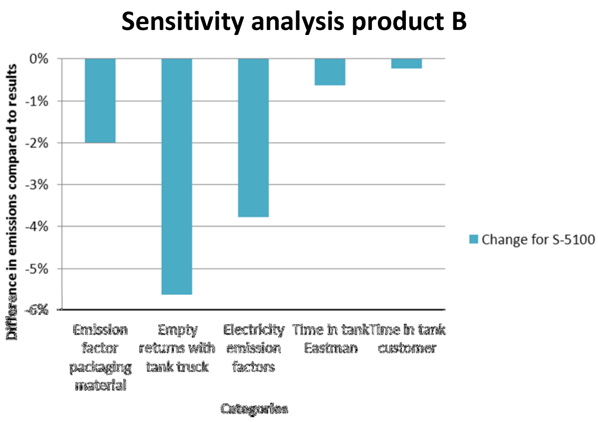

Figure 17 Results sensitivity analysis product B

5.1.5. Results with clean electricity generation

This section will analyze the effect of cleaner electricity generation. Nuclear power and energy from renewable sources (wind, solar etc.) are ways to generate cleaner electricity. In this scenario the electricity data of Norway is used. Electricity generation in Norway is almost entirely from hydroelectric power plants. The electricity emission factor in this country is 0.01 kg CO_2/kWh and the electricity price is €0.0396/kWh (see Appendix V). Currently the molten product is heated with steam at Eastman and with hot oil at the customers. Due to lack of data the emissions and costs of the customers are calculated in the same way as the tanks of Eastman; with steam. In the scenario analyzed in this section all tanks are heated with very clean electricity instead of with steam.

Figures 18 to 21 show the results when Eastman and its customers use clean electricity (see also Appendix X). There is a decrease in CO_2 emissions and costs when only clean energy is used. The decrease in costs is however not as large as the decrease in CO_2 emissions due to the fact that the electricity prices of the customers are not that different than the electricity price of Norway. These results emphasize that clean energy generation can really contribute in the pursuit of environmental goals. For product A the reduction in emission can at most improve with 35.6% and for product B this is 24%. The results also show that the scenarios where customers buy molten bulk are still cleaner than the scenario where customers only buy packed products.

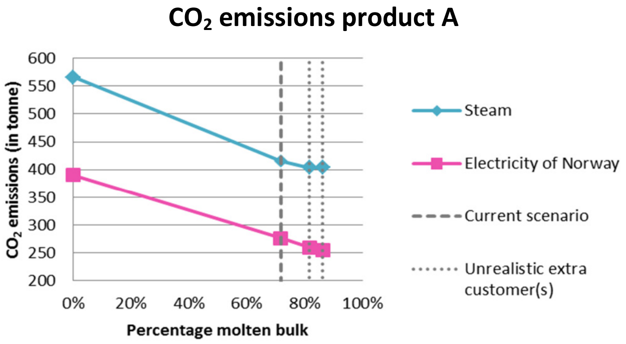

Figure 18 CO_2 emissions product A - clean electricity

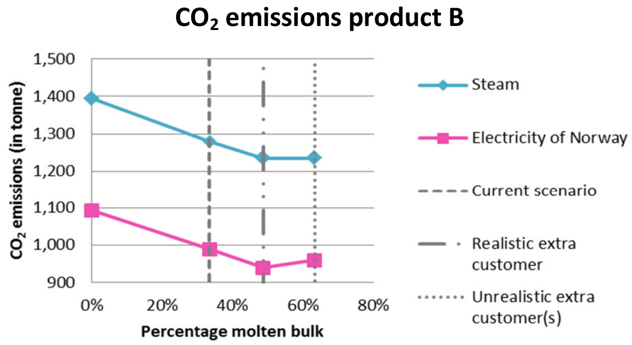

Figure 19 CO_2 emissions product B - clean electricity

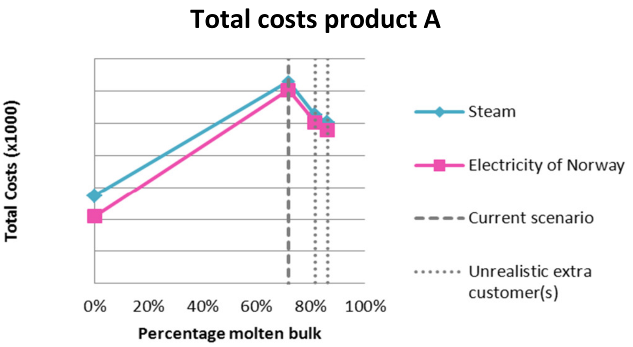

Figure 20 Total costs product A - clean electricity

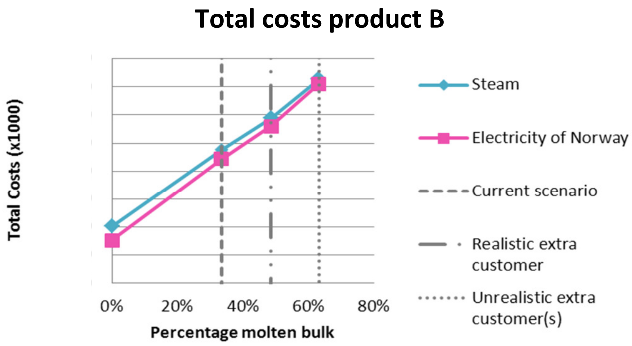

Figure 21 Total costs product B - clean electricity

5.2 Postponement of a process step

The following sections will analyze the effect on CO_2 emissions when a process step is postponed. For the first product there is a possibility to postpone the process step to the customer's site. This case study is done theoretically because the quality of the product will not be the same as when Eastman performs this step at their own site. The second product is produced at a manufacturing site of Eastman in the United States of America and for this product it is possible to postpone a process step to a manufacturing site of Eastman in the Netherlands.

5.2.1. Product C

For this product it is possible to postpone the dispersion process, which is a process in which a resin, water and a kind of soap are mixed under certain circumstances. Currently this is done at the manufacturing site in the Netherlands (see Figure 22). When the dispersion is ready it is stored into a tank. From this point forward it is possible to ship the product in a tank truck or to fill drums or IBCs and ship them in a regular truck. The tank truck is unloaded into a bulk tank and the drums or IBCs are stored in a warehouse until the product is used in the production process of the customer. When the dispersion process is postponed the resin must go to the packout where the product is pastillated, filled into bags, stored on pallets and finally the pallets are wrapped into shrink cover. After this, the product is shipped to the customer with a regular truck and heated to 180°C. When the product is on temperature the dispersion process can start and finally the product can be used in the production process at the customer.

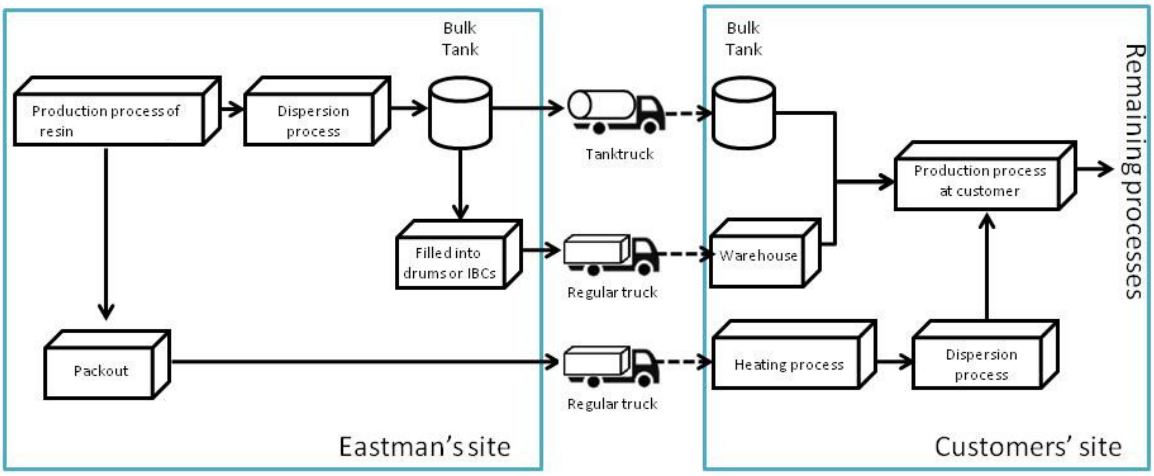

Figure 22 Different flows of product C

5.2.2. Model product C

The transport emissions of this product will decrease when the dispersion process is postponed to the customer because the total volume shipped is lower. Figure 22 shows that not only the transport emissions are affected. It is also necessary to analyze the emissions of the packout and the heating process. For this product Eastman has to put effort in both internal and external controllable variables because the customer is involved. The internal controllable variable in this situation is the dispersion process. Eastman must decide whether to 'postpone' this dispersion process to the site of the customer or to keep it at their own manufacturing site. The external controllable variable is the execution of the dispersion process at the customer. It is not necessary to calculate total carbon footprint of this product (level 1 of Table 4) because the production process of the resin and the production process at the customer is not affected. The minimization problem for this product is as follows:

$$minimize\ IF(\vec{e},\vec{a}) + T(\vec{e},\vec{a}) + EF(\vec{e},\vec{a}) \tag{9}$$

$s.t.$

$$IFC(\vec{e},\vec{a}) + CT(\vec{e},\vec{a}) + EPC(\vec{e},\vec{a}) \leq Total\ budget \quad (10)$$

This problem can be rewritten as:

$$minimize\ IF(\vec{e},\vec{a}) + T(\vec{e},\vec{a}) + EF(\vec{e},\vec{a}) = \sum_{c=0}^{n} EDP(c) + EFD + EPO + EPM + T + EHP \quad (11)$$

$s.t.$

$$\sum_{c=0}^{n} DPC(c) + PMC + ECPO + CT + ECHP + LC \leq Total\ budget \quad (12)$$

In equation (11) EDP represents the emissions from the dispersion process at location c and EFD the emissions from filling drums or IBCs. DPC(c) in equation (12) are the costs for the dispersion process at location c. For other abbreviations see chapter 5.2.1.

5.2.3. Results product C

Around 50 % of the dispersion consists of water which means that when water is added at the customer less product will be transported. The packaging case study showed that the packaging process and the packaging material had a large influence on the total emissions. Therefore the first step for this case study is to analyze whether the gain in transport emissions exceeds the emissions that result from the packaging process and the packaging material. When this is not the case, it is not necessary to further investigate the rest of the emissions. In this short analysis it is assumed that the dispersion process at Eastman and at the customer require the same energy which means that there will be no increase in CO_2 emissions and costs.

The total gain in transport emissions is calculated with TERRA. The demand of large customers who ordered molten bulk is consolidated to a full truck with packed material, i.e. a customer that ordered a full truck molten bulk 14 times a month now ordered a full truck packed material 7 times a month. For customers that received IBCs or drums a lower weight is taken into account but it is assumed the load factor did not change. The gain in transport emissions when the water process step is only postponed to the site of the largest customer is 41.6 tonnes CO_2. When the dispersion process of the total volume of the product is postponed to the sites of all customers the total transport emissions will decrease with 106.3 tonnes (see Figure 23).

The emissions of the packout can be calculated with $\sum_{c=0}^{0}\left(\frac{Q_p * V_p(c)}{3600}\right) * ef_E(c)$. In total 53.3 tonnes CO_2 is emitted when only the volume of the largest customer is packed and 85.2 tonnes CO_2 is emitted when the total volume of 2010 is packed into 20 kg bags. For the packaging material only emissions are taken into account that are caused by packing the product into 20 kg bags (pallets, shrink cover and 20 kg bags): $\sum_{i=0}^{2} EF_M(i) * U(i) + \sum_{x=0}^{1}\sum_{i=0}^{2} n(x) * ef_D(x,i) * U(i)$. The decision is made to not include the IBCs and drums because IBCs are reused and in 2010 only 2 drums were sold. The packaging material causes an increase of 248.3 tonnes CO_2 for the largest customer and 495.31 tonnes CO_2 is emitted when packaging material is used for the total volume. Heating the product again at the customer emits another $\sum_{c=1}^{n} \frac{V_p(c)}{V_p(0)} * \left(\frac{Q_h}{3600}\right) * ef_E(c)$ = 171.3 tonnes of CO_2 for the largest customer and 273.2 tonnes of

CO_2 when the total volume must be heated. An overview of the effect of postponement on total emission is given in Figure 23.

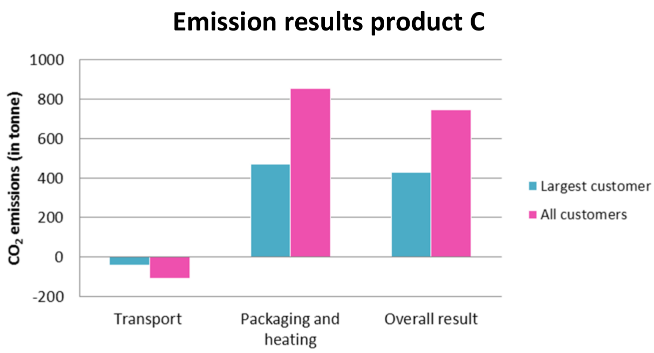

Figure 23 Emission results product C

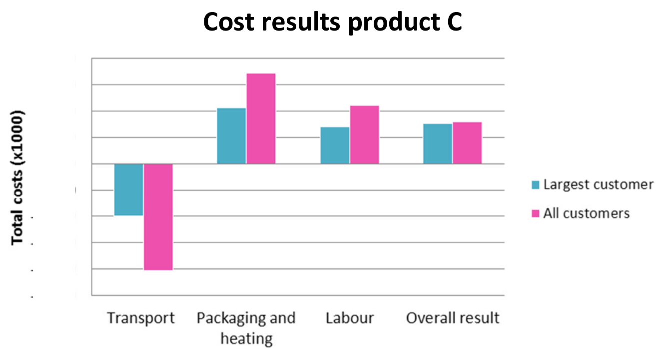

Figure 24 Cost results product C

Figure 24 shows the effect of postponing the dispersion process on costs. The costs included in this analysis are the packaging material costs ($\sum_{i=0}^{4} p_p(i) * U(i)$), the electricity costs of the packout ($\sum_{c=0}^{0}\left(\frac{Q_p * V_p(c)}{3600}\right) * p_e(c)$), the electricity costs of the heating process at the customer ($\sum_{c=1}^{n}\frac{V_p(c)}{Vp(0)} * \left(\frac{Q_h}{3600}\right) * p_e(c)$) and the labour costs of the bag cutter $\sum_{c=1}^{n}\frac{V_p(c)}{b} * p_l$. There is also no benefit in terms of costs when this redution option is exerted at the largest customer and also not when it is exerted at all customers. It must be noted that it is assumed that the cost associated with the electricity/gas use of the dispersion process is the same when performed at Eastman and when performed at the customer. In reality this may not be the case because the dispersion process at Eastman uses for heat released from other processes.

From this short analysis it can be concluded that it is not beneficial in terms of CO_2 emissions and costs to postpone the dispersion process to the customer. The actual result may even be worse because heat is needed at the dispersion process. At the site of Eastman heat of other processes is used and there is a possibility that this is not possible at the sites of the customer. In addition to this, less energy is used when larger volumes of products are dispersed into water at once than when this must be done at multiple customers with smaller volumes.

This second case study again shows that it is important to have the right boundaries. Initially it was thought that this reduction option would only have an effect on transport emissions and transport costs, which would have meant that only $T(\vec{e},\vec{a})$ was analyzed. It was then concluded that this option would decrease total carbon dioxide emissions.

5.2.4. Product D

Product D is a product of which the water content is even more than it is for product C. This product is produced in the United States of America (USA) and shipped to customers in Europe (see Figure 25). Also for this product there is a possibility to postpone the dispersion process to a later point in time. Instead of shipping a product which is already dispersed into water from the USA directly to the customer it is possible to ship a solid product from the USA to the manufacturing site of Eastman in the Netherlands and perform the dispersion process in the Netherlands. After this, the product will be shipped to the customer.

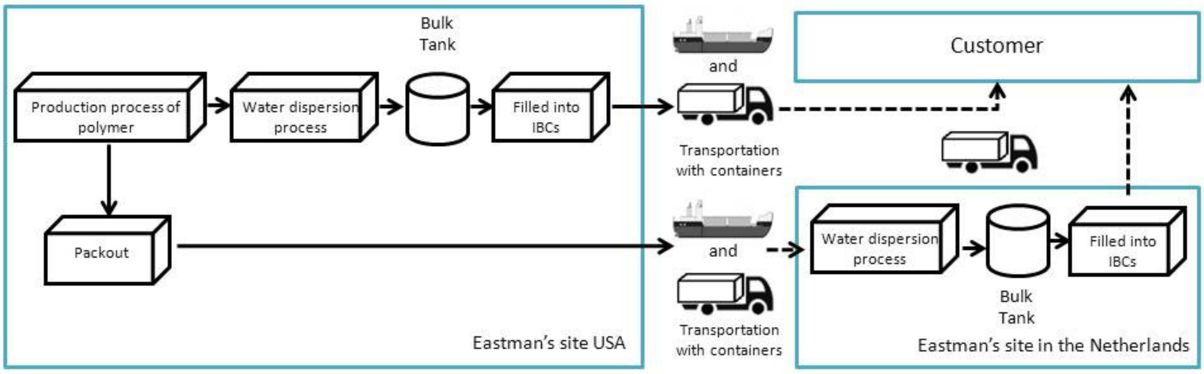

Figure 25 Different flows of product D

5.2.5. Model product D

The previous two case studies analyzed the effect when effort is exerted in external controllable variables. Figure 25 shows that no external parties are involved in this reduction option. For Eastman it is thus only necessary to put effort in internal controllable variables. The shipments costs from the USA to Europe are very high due to the long distance. It is expected that postponement of the dispersion process will have a large impact on the shipment costs. The minimization problem for product D is as follows:

$$minimize\ IFC(\vec{e}) + CT(\vec{e}) \tag{13}$$

$$s.t.$$

$$IF(\vec{e}) + T(\vec{e}) \leq \big(IF(0) + T(0)\big) * percentage \tag{14}$$

This problem can be rewritten as:

$$minimize\ IFC(\vec{e}) + CT(\vec{e}) = \textstyle\sum_{c=0}^{n} DPC(c) + \sum_{c=0}^{n} FI(c) + PMC + ECPO + ECHP + LC + CT \tag{15}$$

$$s.t.$$

$$\textstyle\sum_{c=0}^{n} EDP(c) + \sum_{c=0}^{n} FIC(c) + EPO + EPM + T + EHP \leq \big(IF(0) + T(0)\big) * percentage \tag{16}$$

FI(c) represents the emissions from filling process at location c and FIC(c) the associated costs. From now on it is assumed that the emissions and costs of this filling process are equal when done in the Netherlands or the USA. When it is also assumed that the CO_2 emissions and electricity costs do not increase when dispersion process is done in the Netherlands instead of in the USA equation (15) and (16) can be rewritten as:

$$minimize\ IFC(\vec{e}) + CT(\vec{e}) = \sum_{i=0}^{4} p_p(i) * U(i) + \sum_{c=0}^{0} \left(\frac{Q_p * V_p(c)}{3600}\right) * p_e(c) + \sum_{c=1}^{1} \left(\frac{Q_h}{3600}\right) * p_e(c) + CT + \frac{V_p(c)}{b} * p_l$$

$s.t.$

$$\sum_{c=0}^{0} \left(\frac{Q_p * V_p(c)}{3600}\right) * ef_E(c) + \sum_{i=0}^{2} EF_M(i) * U(i) + \sum_{x=0}^{1} \sum_{i=0}^{2} n(x) * ef_D(x,i) * U(i) + \sum_{c=1}^{1} \left(\frac{Q_h}{3600}\right) * ef_E(c) \leq \big(IF(0) + T(0)\big) * percentage$$

Where c=0 is Eastman USA and c=1 is Eastman Netherlands.

5.2.6. Results product D

The results of postponing the dispersion process from the manufacturing site in the USA to the manufacturing site in the Netherlands are shown in Figure 26 and 27. The left bars represent the emissions and costs when the total volume of 150 tonnes is dispersed in water in the USA and shipped to Europe. The right bars represent the emissions and costs when the dispersion process is performed at the manufacturing site in the Netherlands. There is positive effect on total CO_2 emissions of 4.8 tonnes and the total costs decrease with 78%. So it is beneficial in terms of costs and CO_2 emissions to perform the dispersion process at the manufacturing site in the Netherlands instead of in the USA.

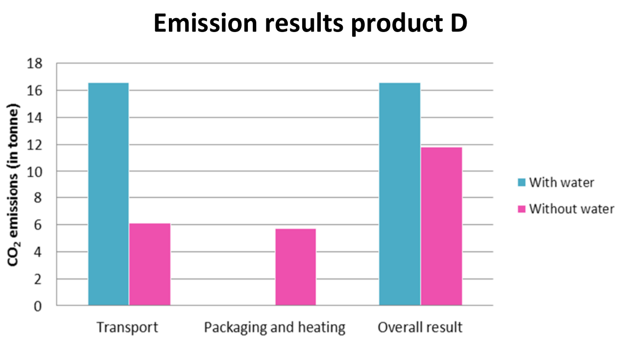

Figure 26 Emission results product D

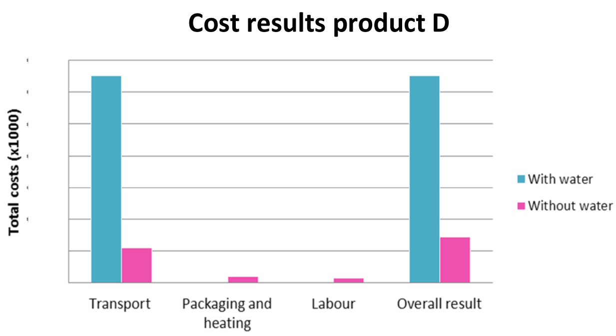

Figure 27 Cost results product D

The calculations for this product are based on a demand forecast of 150 tonnes. The total emissions reduction of 4.8 tonnes seems relatively low. However, the effect on emissions is a decrease of almost 29%. It is therefore recommended to pursue this reduction option because it is expected that the total demand will increase in the future, which will mean that the decrease in emissions will be more noteworthy.

In this analysis it is assumed that the CO_2 emissions and electricity costs do not increase when dispersion process is done in the Netherlands instead of in the USA. The emission factor of the Netherlands is lower than the emissions factor of the USA which would lead to even better results in terms of CO_2 emissions. The opposite effect is expected in terms of costs; the electricity price per kWh of the manufacturing site in the Netherlands is higher than that of the USA.

6 Transport emission reduction options

This chapter will analyze the transport emissions of Eastman. Section 6.1 will give the results of the inbound logistics. In this section also a comparison is made between the transport emissions of TERRA and of an LCA of Eastman. The outbound logistics of Eastman will be discussed in section 6.2

6.1 Inbound logistics

6.1.1. Emission results

Figure 28 shows that in total 3,690.2 tonne CO_2 is emitted to transport the selected raw materials with a total weight of 61,302.2 tonnes from the supplier to the manufacturing site in the Netherlands. The raw materials for the products A, B, C and E are included in this analysis. The transport mode IM Ocean volume/bulk is the largest contributor. The key ingredients to make the products C and E are shipped from ports in China, Brazil, Japan, Finland and the USA which cause the large share of the IM Ocean volume/bulk modality.

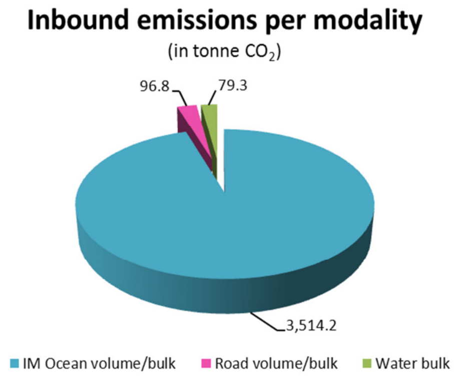

Figure 28 Emissions from inbound logistics

6.1.2. Comparison

Within Eastman LCA is an important approach to examine the environmental impact of their products. This section will compare the LCA and TERRA inbound transport emissions of product E. It must be noted that only operating emissions of transport modes are taken into account because TERRA is not able to give emissions that are caused by maintenance or production of transport modes. According to the LCA 0.213 kg CO_2 is emitted to transport all raw materials that are needed to produce 1 kg of product E. The results of TERRA are 0.116 kg CO_2 per 1 kg product E which is 50.46 percent lower than the results of the LCA.

For the transport emissions of the LCA a standard emission factor per tonnekm (equivalent to one tonne of cargo transported over one kilometer) is taken into account per modality type which means that actual data (i.e. empty returns, loading factors, allocation etc.) is not used. The reason for this is that companies that publish LCA results in the Netherlands are obligated to follow the national standard NEN8006:2004 which is a standard that is governed by the Stichting Milieu Relevante Product Informatie (MRPI). This standard requires the use of literature data from the Ecoinvent database, unless more specific data is collected. The emissions that are calculated with TERRA are based on more specific data and thus could be a reason that there is a large difference between the two results.

The raw material that is used the most for this product is Chinese Gum Rosin. This raw material is shipped from Huangpu port (China) to the port of Antwerp (Belgium) on a containership and this leg is the largest contributor to the total emissions. With the output of TERRA and the Bill of Material (BOM) it is calculated that 0.113 kg CO_2 is emitted by this ocean freight to produce 1 kg of product E. The results of the LCA show that 0.202 kg CO_2 is emitted due to ocean freight. To verify which of these two results is most likely the EcoTransIT tool (http://www.ecotransit.org/ecotransit.en.phtml) is also used to calculate the ocean freight emissions. With the results of this tool it is calculated that 0.115 kg CO_2 is emitted to produce 1 kg of product E. A cause of this difference is the way emissions are calculated.

For the transport emissions of the LCA a standard emission factor per tonnekm of the Ecoinvent database was taken into account. This means that actual data (i.e. empty returns, loading factors, allocation, transport type within modality etc.) is not used within the calculations. With TERRA it is possible to use actual data when available. From the results of TERRA and EcoTransIT it can be concluded that the emission factor per tonnekm used in the LCA is too high.

6.2 Outbound logistics

6.2.1. Emission results

The CASPI business organization has shipped 66,409 tonnes of the selected products to their customers within the EMEA region in 2010. The total carbon dioxide emissions of these shipped products is equal to 6,562.5 tonnes. Shipments which had the incoterm FCA, FCD or EXW are not included in the calculation; i.e. emissons that are the result of customers picking up products are not included. Figure 29 shows the division of the emissions per modality. The emissions of the road and rail legs of intermodal (IM) transport are included within the emissions of each IM modality. The modality IM ocean volume/bulk is the largest contributor to the total emissions. The two largest product groups X and Y are shipped from the United States of America to Europe which cause the large share of the IM ocean volume/bulk modality. Road volume/bulk is the second largest contributor. The emissions of ferry, rail and IM rail are very small due the fact that only a small percentage of the total volume is shipped with these transport modes. For an overview of the emissions per product group and modality see Appendix XI.

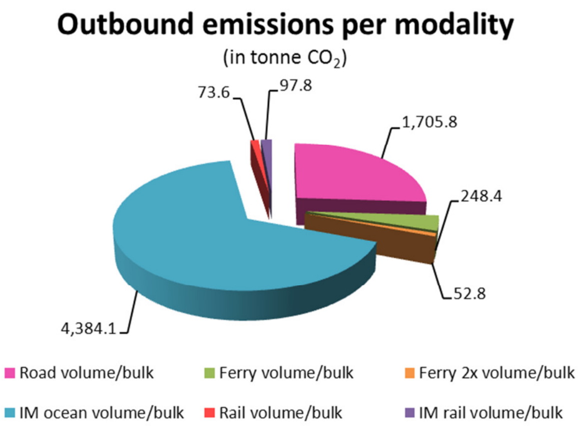

Figure 29 Emissions of Outbound logistics

6.2.2. Improvements

In the previous section an overview is given of the transport emissions of several products of the CASPI Business Unit. Eastman is interested if there are possibilities to reduce their transport emissions and what effect reduction options would have on costs and on service. The calculations of carbon dioxide emission resulting from the transport reduction options are calculated with TERRA.

<u>Modal shift</u>

Shifting to another transport mode provides a reduction option which can lead to significant lower emissions when a transport mode is chosen with a lower carbon intensity than the current transport mode. According to (Chapman, 2007) the most promising transport mode for which it is possible to reduce CO_2 emissions with modal shift is road transport because the carbon intensity of this transport mode is relatively high. Transport modes in order of increasing carbon intensiveness are (in general): water, rail, road and air transport.

From the data collected it is noticed that products of group X filled in drums is shipped by road from the manufacturing site to the port while the molten form is shipped by railcars from the manufacturing site to the port (see Figure 34 in Appendix II). There are two improvements options in terms of CO_2 emissions: ship the drums in boxcars by rail instead of by truck or ship molten by tank car and use a drumming service at the port. Both options would lead to a decrease in transport CO_2 emissions of approximately 120 tonnes.

The first option where drums are shipped in boxcars by rail would not be a feasible solution due to high costs and long lead times. The shipping costs would be 3 to 4 times higher than the current costs and the lead time would increase from four hours to several days.

The second option where molten is shipped by tank cars and drummed at a special service could be a feasible solution. The transport data retrieved from SAP showed that it is cheaper to ship the molten form by railcar than to ship the drummed form by truck. Currently a project group at Eastman is analyzing the impact on costs and lead time of using the drumming service at the port. The results of this project are not presented yet so it is not possible to give the impact on lead time. When Eastman is considering implementing this reduction option it is recommended to analyze the effect on the other processes that are affected by this reduction option. The framework of chapter 4 must be adapted in such a way that it is possible to get better insights.

Also for Europe a lane is manually identified which could lead to lower CO_2 emissions when shifting from road transport to intermodal transport. On average 1.94 full trucks are shipped per week from the manufacturing site in the Netherlands to two customers in Portugal. These two customers are located in the same area near the port of Leixoes. In total a decrease of 148 tonnes CO_2 can be obtained when full containers are transported by truck to the port, then shipped by vessel to the port of Leixoes and transported by truck again to deliver the goods at the doors of the customers. The lead time would approximately be 2 days longer and the total shipping costs decrease with 20%. It is recommended to also analyze the impact of this change on inventory and service.

The previous two improvements were obtained by only screening the data. When Eastman is interested in improving their transport emissions with modal shift it is recommended to use the modal shift method of Boere (2010). The method that Boere developed during his project at Cargill can be used to select lanes with high potential for modal shift by calculating an upper bound in emission savings.

<u>Network optimization</u>
For the two product groups X and Y it is also possible to consider redesigning the current network. Network redesign focuses on adapting the supply chain structure in order to put inventory closer to the customer. It is expected that this reduction option decreases the total transport distances.

Products from group Y are currently shipped from the USA to a port in the Netherlands and then distributed to customers. For products that need to be shipped to for example Turkey this is a roundabout route. It is analyzed what the impact on emissions would be if the product are directly shipped to the right port instead of first going to the port in the Netherlands and then to the customer. See Appendix XII for an overview of which ports are taken into account. When shipping directly the total transport emissions of the Group Y would decrease with 85.3 tonnes CO_2 which is a decrease of 8.7%.

In the current network of group X, drums or bulk is shipped from the manufacturing site to the port by truck or railcar then loaded onto a containership or a tanker and shipped to a port in the Netherlands. When bulk is shipped the products is drummed by an external party in the Netherlands. A large share of the total volume is then picked up at the port by a distributor which then distributes the products to its customers. This distributor is located in eight different countries. For the location in Morocco Eastman makes an exception and ships the drums from a port in the USA directly to the port of Casablanca. Eastman is interested in the effect on the emissions when shipping the products of this distributor closer to the location of the distributor. Multiple options are possible (see Appendix XII) but due to lack of time only option 2 is analyzed. In this option the products are already drummed at the manufacturing site in the USA, shipped by truck to the port and then shipped on a vessel to 4 different ports. For the distributor in Morocco the transport emissions will not change because currently the drummed product is are already shipped directly to the port of Casablanca.

The results of TERRA show that this option has a negative impact on the transport emissions of Eastman. Currently 3,526.7 tonnes CO_2 is emitted and this network redesign increases the emissions with 50.8 tonnes of CO_2. This increase can be explained by the fact that the total distance traveled by Eastman increased with 12.8%. Another factor which can explain the increase is the modal shift. In option 2 drums are transported by truck from the manufacturing site to the port while currently the products of the distributor are shipped as molten with rail cars from the manufacturing site to the port. The fact that molten is shipped with a tanker and drums are shipped by a containership diminishes the result because a containership consumes less fuel per km than a tanker. In addition to this, the load factor in TERRA of a Panama containership is higher than the load factor of a chemical tanker. The transport costs of Eastman for the 'redesigned' network are 2.7 times higher than the current transport costs. The warehousing costs of Eastman will decrease because the responsibility to store the products will shift from Eastman to the distributor. The magnitude of this decrease is not known.

It is expected that this option will have a positive impact on the carbon dioxide emissions of the distributor. However, the routes of the distributor are not known. To get some insight of the total effect on emissions the following formula is used to calculate the expected tour length T^*:

$$T^* \approx \emptyset\, X\, E(\delta(a)^{-0.5}) = \emptyset\sqrt{X}E(f(a)^{-0.5}) = \emptyset\sqrt{XA} \qquad (17)$$

This formula from Daganzo (1999) considers X customers independently scattered in a region according to a spatial customer density $\delta(a)$. If the probability density function $f(a)$ of the customer has coordinates $a = (a1, a2)$ then $\delta(a) = Nf(a) = X/A$, where A is the size of the service region in km^2. The variable $\emptyset$ is an unknown constant. In this case $\emptyset = 0.75$ will be used to calculate the tour length for the distributor because literature shows that this value will give the best representation of reality (Joseph et al. 2007).

For the current situation one tour length is calculated for shipments from the port in the Netherlands to the distributors. Three tour lengths are calculated for the shipments from the ports of Algeciras (ES), Copenhagen (DK) and Felixtowe (UK) to the distributors. The modality type used by the distributors is also not known. The assumption is made that they transport their products by road with the standard truck type of TERRA. The results of the network optimization are shown in Figure 30. The total emissions decrease due to the decrease in the emissions of the distributor. In total it is estimated that the emissions decrease with 322.2 tonnes CO_2 which results in an overall decrease of 7.76%.

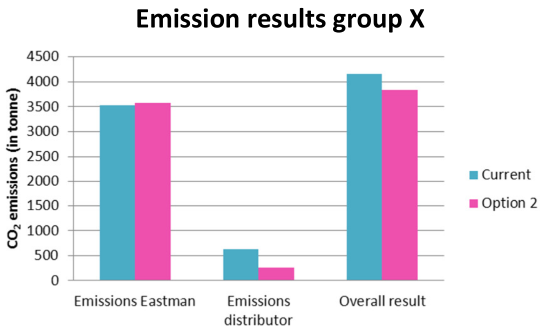

Figure 30 Emission results group X

7 Implementation

Sustainability has become an essential component of Eastman's business. The environmental goals of Eastman are to improve energy efficiency by 2.5%, reduce greenhouse gas (GHG) emissions by 2% year-over-year and to have all new product family launches accompanied with life cycle analysis reports within the next few years. Currently, several projects are running in order to achieve these environmental goals.

This project is performed within the CASPI business unit in the EMEA region. The results of this project could serve as a platform to build a vision for the CASPI business unit and to eventually extend this to other business units. The three case studies showed that the framework developed in Chapter 4 can be easily adapted for different situations. It is thus also possible to translate this to other business units of Eastman. There are however some things that have to be adapted in order to efficiently evaluate the impact of reduction options on emissions and costs.

As already mentioned earlier Eastman set a goal to reduce GHG emissions by 2% year-over-year. This goal holds for the entire company and it is recommended to set a sub-goal for each business unit. In this way business units will not solely evaluate the absolute emissions but can actually take action to decrease their emissions. Project groups can be set up which could investigate the impact of reduction options of their business unit. In some cases it is also necessary to cooperate with external parties to influence transport and processes indirectly. When this is the case, the project team must consist of employees of Eastman and employees of the customer.

When transport emissions are within the boundaries of the analysis it is recommended to use a tool like TERRA. From the LCA comparison it was concluded that the current transport emissions included in the LCA results are too high. Taking into account emissions that are too high could disturb the results which could lead to wrong decisions by the project group. When the decision is made to make use of a transport calculation tool it is recommended to adapt the SAP system in a way that it is easier to obtain all information needed. Currently several transaction codes must be used to obtain the data which makes it harder to indicate whether all data is obtained. Sometimes it was also necessary to run a transaction code for the whole organization because it was not possible to retrieve the information of the business unit in another way. It is advised to develop one transaction code from which all data can be retrieved easily. Better estimations on transport emission can be done when more detailed information is known. Eastman makes use of the service of several LSPs and it is only possible to get more detailed information when the two parties collaborate more. Currently one of the LSPs sends information about intermodal rail transport. It is recommended to also try to obtain this information from other LSPs and load this information into the SAP system.

8 Conclusion & recommendations

This chapter gives the conclusions that can be drawn from this project. It starts with describing the main findings in section 8.1. The chapter ends with limitations of the project and recommendations for further research.

8.1 Main findings

Companies are paying more and more attention to environmental issues due to a growing pressure of external parties. Most initiatives of companies to cope with these environmental issues have focused on reducing direct emissions. However, to be able to meet the long-term climate goals set by the European Union (20 percent reduction in 2020 compared to 1990 levels) companies must look for other emission reduction options. Previous research at the TU/e has focused on reducing CO_2 emissions resulting from transport. A possible downside of focusing solely on transport emissions is that the effect of transport decisions on other processes is neglected. Processes more upstream or downstream can be affected by the transport decisions. During this project the impact of system boundaries of processes and transport on decision making is assessed.

The first objective of the project was to define which processes to include in the system boundaries when assessing reduction options. A general framework was developed which can help companies identifying the effect of (joint) emission reduction actions on carbon emissions and costs. This framework states that processes and transport that can be adapted must be included in the boundaries of the system. Multiple minimization problems were formulated which can be used in the decision making process of reduction options. Companies can define their goal from an environmental perspective but also from a cost perspective. The framework also showed that companies can directly and indirectly influence their emissions. When external parties are involved a company has to collaborate with these external parties in order to influence their total emissions and/or costs.

The framework developed during the project was used to analyze the effect of three possible changes in the current processes of Eastman. The first case study showed that it is better to sell packed material to customers when only the transport emissions and costs were taken into account. However, the results showed that selling molten bulk instead of packed material is beneficial in terms of carbon dioxide emissions when wider boundaries were taken into account. The total emissions decreased with 265 tonnes CO_2 (150 for product A and 115 for product B) when selling molten bulk to the largest customers. The results also showed that in most cases it is more expensive to sell molten bulk to a customer than packed material due to the high transport costs. The second and third case study analyzed the effect of postponement. Taking into account only transport emissions in the second case study would again lead to poor decision making; the benefit in transport emissions and costs could not outweigh the emissions and costs from the packaging process. Another disadvantage of this second study was the quality decrease of the product. The quality of the product is higher when the dispersion process is done at Eastman than when it is done at the customer. The results of the third case study showed that postponing a process to a later point in time within the same company did have a positive effect on emissions and costs. It must be noted that the impact on the emissions were minor but if the same action is undertaken for larger volumes or other products it is expected that the impact would be higher.

The second objective of the project was to analyze the relationship between inventory and transportation decisions in terms of emissions, costs and service. The sensitivity analysis of the first case study showed that the average inventories of both Eastman and the customer decrease when the time spent in the tanks decrease. The time spent in the tanks of the customer can only decrease when the outflow is higher which means that the customer must produce faster or when the inflow is lower which means that the tank arrivals are better coordinated. The time spent in the tanks of Eastman can only decrease when production planning is more aligned with the ordering process of the customer. So when a customer shares his demand information with Eastman this can smooth the operations of Eastman and reduce the time spent in the tanks. For both parties this would have a positive impact on emissions and costs.

The final objective was to give some insight on possible carbon reduction options in transport emissions. First the total carbon emissions of the selected products were calculated with Terra. These results showed that emissions caused by inbound logistics were in total 3,690 tonnes CO_2 and 66,409 tonnes CO_2 for outbound logistics. The outbound logistics data were scanned on possible improvements and two lanes were found on where modal shift could decrease the emissions with 246 tonnes CO_2 in total. For Eastman it is also possible to redesign the network. However, to get better insights data must be collected from the transport movements of a distributor of Eastman. The framework developed during this project could help to identify the impacts of the redesign on emissions and costs.

In general it is found that it is important to focus on the interaction along the whole supply chain or parts of the supply chain. In addition, it is found that it is important to define the right boundaries because the results on emissions and costs can change when a wider or narrower boundary is taken into account.

8.2 Limitations & recommendations for further research

For the first case study, data regarding the customer was collected within Eastman. In addition, the assumption was made that the bulk tanks at the customer's site is kept on temperature with steam. In reality this is done with hot oil and it is not analyzed if the assumption made gives a good representation of the actual emissions. When Eastman is considering offering more products in molten bulk form it is recommended to get more 'real' data from customers.

This project only took carbon dioxide emissions into account. A possible downside of excluding other emissions is that it is unknown which impact the reduction options will have on other emissions. It is interesting to get insight of these effects in future research.

During this project transport emissions are calculated with the use of the TERRA tool. This implies that the results are subject to parameter and assumptions influences and limitations as described in the CRSC report (van den Akker et al. 2009). One of the recommendations of the CRSC report was to conduct more research to get more accurate results of ocean freight. The analysis of this project showed that the majority of Eastman's transport emissions resulted from intermodal ocean freight. It is useful to use Eastman's transportation network to reassess the emission estimates in ocean freight.

For the product groups X and Y there is a possibility to redesign the supply network. For group Y the decision was made to ship directly to port near the customer. A better approach would be to construct a network optimization problem and recalculate the emissions with the solved problem. The results of group X are based on calculated tour lengths which may not represent the actual tour length. For this product it is also recommended to conduct further research in which first the networks are optimized and then analyze the impact on carbon emissions, transport costs and inventory holding costs. More data needs to be gathered from the distributor in order to do this for this product group.

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Appendix I

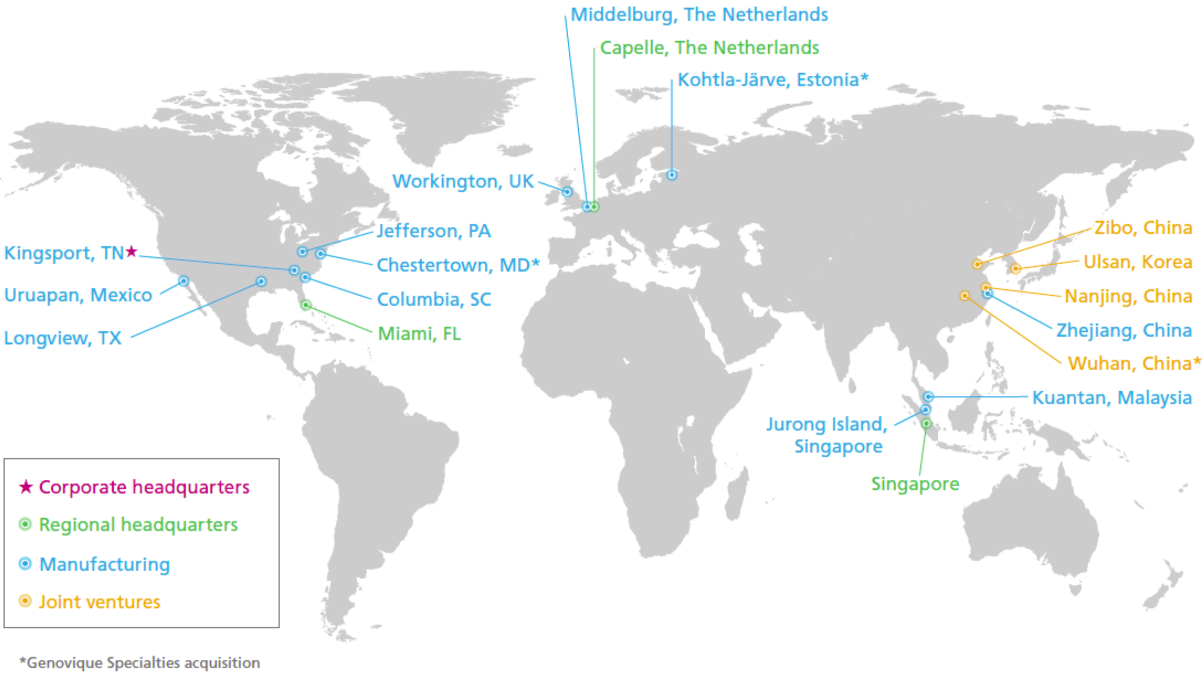

Figure 31 Eastman worldwide

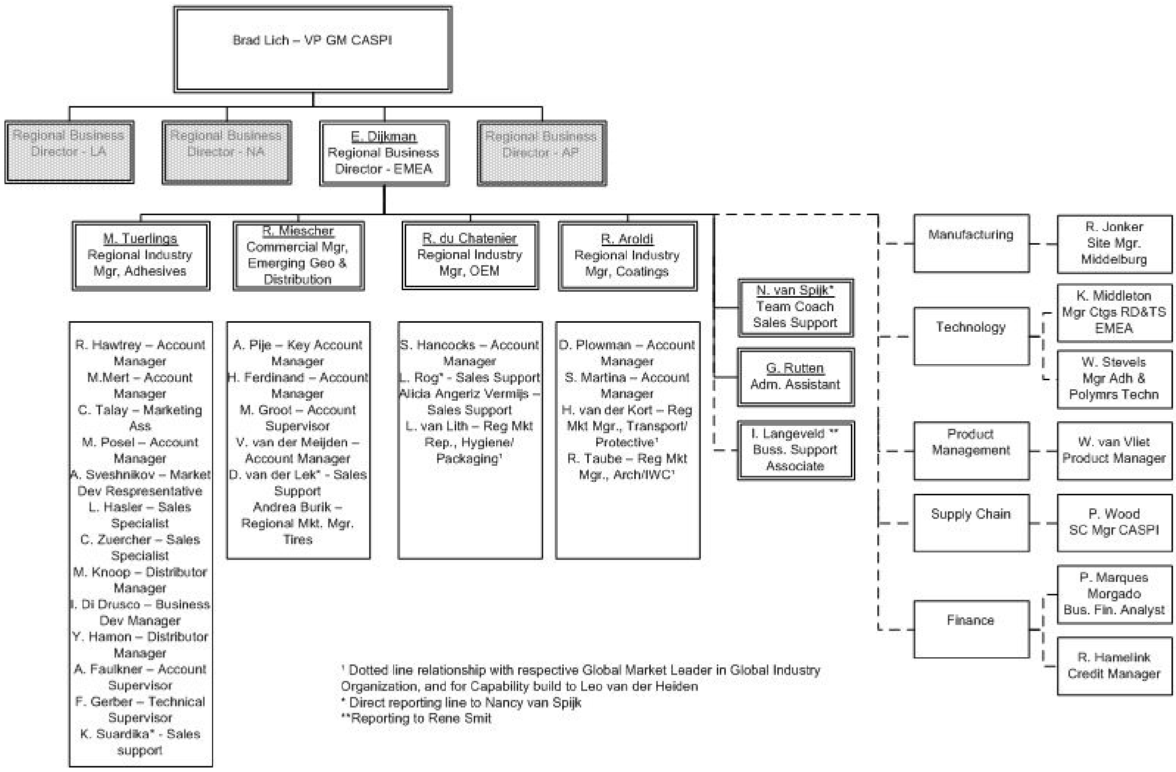

Figure 32 Organization structure CASPI EMEA

Appendix II

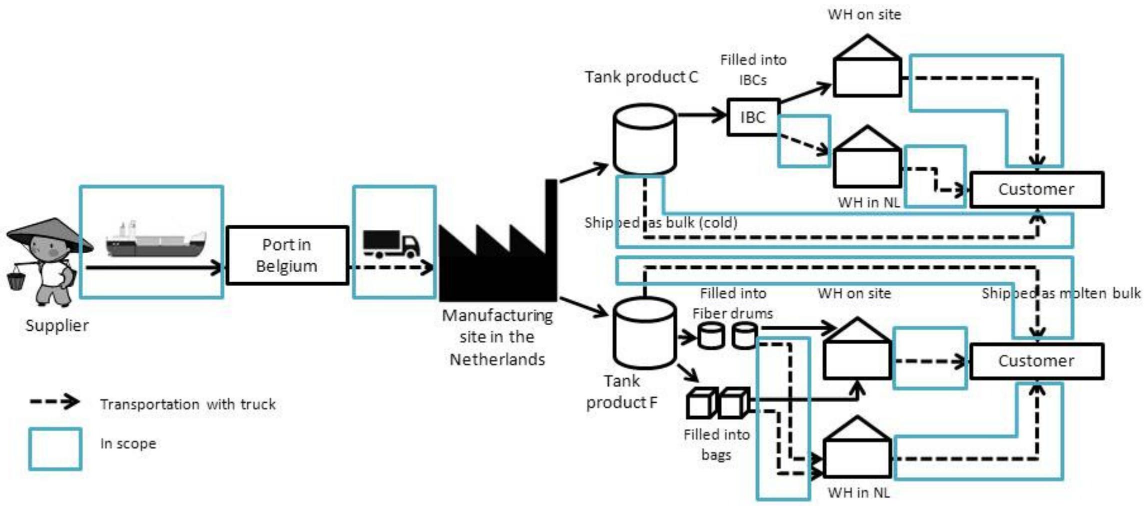

Figure 33 Boundaries for product group W

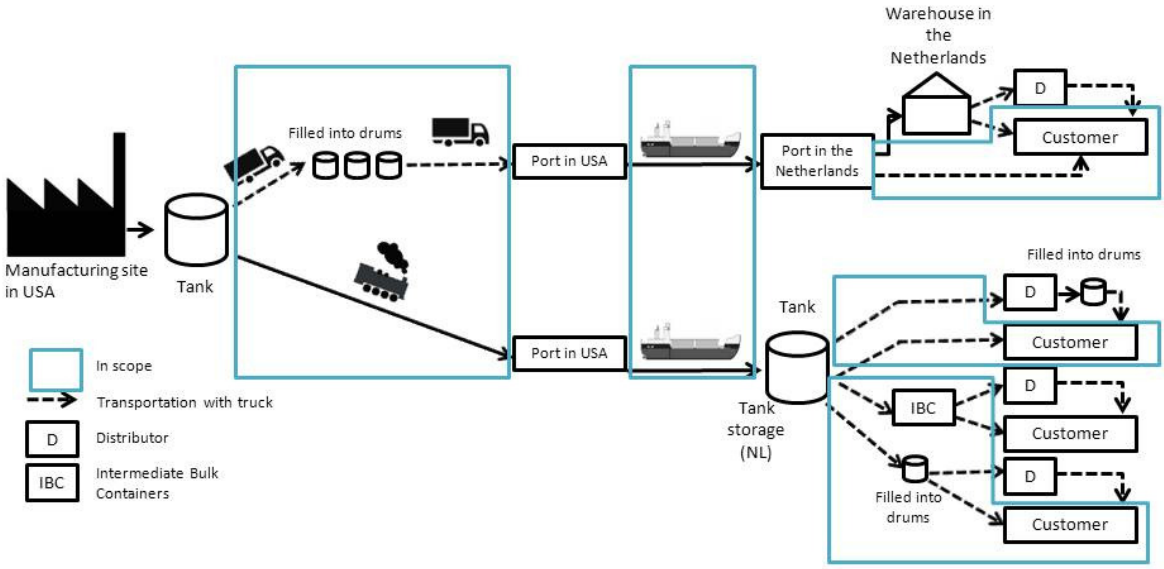

Figure 34 Boundaries for product group X

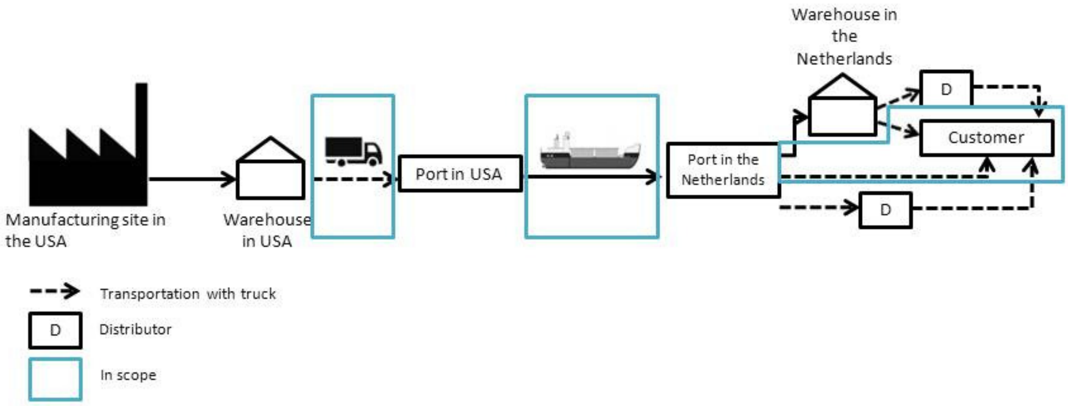

Figure 35 Boundaries for product group Y

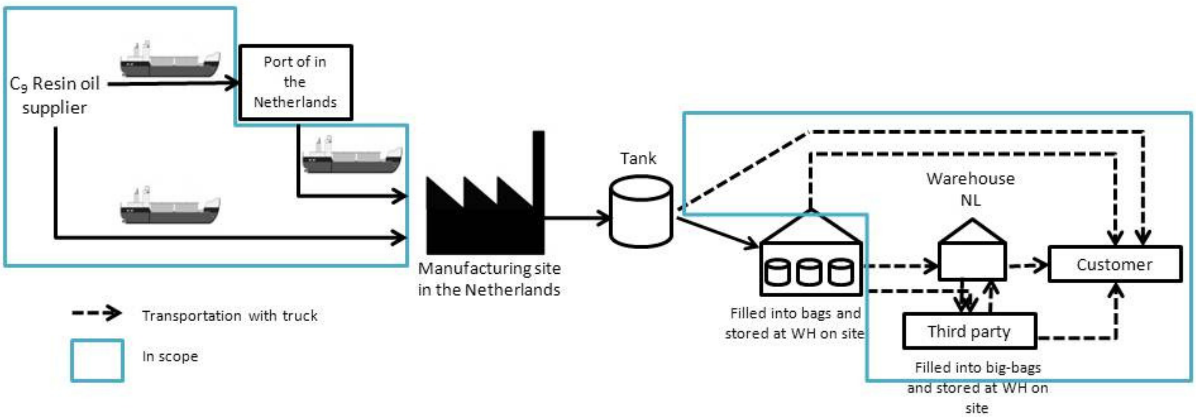

Figure 36 Boundaries for product group Z

Appendix III

Table 7 INCOTERMS 2000 (International Chamber of Commerce, 1999)

Incoterms	Eastman must	Obligations	Risks	Costs
EXW (Ex Works)	Place the goods at the disposal of the buyer at the named place of delivery	Carriage to be arranged by the buyer	Risk transfer from the seller to the buyer when the goods are at the disposal of the buyer	Cost transfer from the seller to the buyer when the goods are at the disposal of the buyer
FCA* (Free Carrier)	Load the goods on the means of transport nominated by the buyer or place the goods at the disposal of the carrier nominated	Carriage to be arranged by the buyer or the seller on the buyer's behalf	Risk transfer from the seller to the buyer when the goods have been delivered to the carrier at the named place	Cost transfer from the seller to the buyer when the goods have been delivered to the carrier at the named place
FAS (Free Alongside Ship)	Place the goods at the disposal of the buyer alongside the ship	Carriage to be arranged by the buyer	Risk transfer from the seller to the buyer when the goods have been placed alongside the ship	Cost transfer from the seller to the buyer when the goods have been placed alongside the ship
FOB (Free On Board)	Deliver the goods on board the ship at the port of shipment	Carriage to be arranged by the buyer	Risk transfer from the seller to the buyer when the goods pass the ship's rail	Cost transfer from the seller to the buyer when the goods pass the ship's rail
CFR (Cost and Freight)	Deliver the goods on board the ship at the port of shipment	Carriage to be arranged by the seller	Risk transfer from the seller to the buyer when the goods pass the ship's rail	Cost transfer at port of destination, buyer paying such costs as are not for the seller's account under the contract of carriage
CIF (Cost, Insurance and Freight)	Deliver the goods on board the ship at the port of shipment	Carriage and insurance to be arranged by the seller	Risk transfer from the seller to the buyer when the goods pass the ship's rail	Cost transfer at port of destination, buyer paying such costs as are not for the seller's account under the contract of carriage
CPT (Carriage Paid To)	Deliver the goods to the carrier	Carriage to be arranged by the seller	Risk transfer from the seller to the buyer when the goods have been delivered to the carrier	Cost transfer at port of destination, buyer paying such costs as are not for the seller's account under the contract of carriage
CIP (Carriage and Insurance Paid to)	Deliver the goods to the carrier	Carriage and insurance to be arranged by the seller	Risk transfer from the seller to the buyer when the goods have been delivered to the carrier	Cost transfer at port of destination, buyer paying such costs as are not for the seller's account under the contract of carriage
DAF (Delivered at Frontier)	Place the goods at the disposal of the buyer on the arriving means of transport at the frontier unloaded	Carriage to be arranged by the seller	Risk transfer from the seller to the buyer when the goods have been delivered at the frontier	Cost transfer from the seller to the buyer when the goods have been delivered at the frontier
DES (Delivered	Place the goods at the disposal of the buyer on	Carriage to be arranged by the seller	Risk transfer from the seller to the buyer when the goods are	Cost transfer from the seller to the buyer when the goods are placed at the disposal of the buyer on board the ship

Ex Ship)	board the ship at the named port of destination		placed at the disposal of the buyer on board the ship	
DEQ (Delivered Ex Quay)	Place the goods at the disposal of the buyer on the quay at the named port of destination	Carriage to be arranged by the seller	Risk transfer from the seller to the buyer when the goods are placed at the disposal of the buyer on the quay	Cost transfer from the seller to the buyer when the goods are placed at the disposal of the buyer on the quay
DDU (Delivered Duty Unpaid)	Carry out the export procedures and deliver the goods at the door of the customer	Carriage to be arranged by the seller	Risk transfer from the seller to the buyer when the goods are placed at the disposal of the buyer	Cost transfer from the seller to the buyer when the goods are placed at the disposal of the buyer
DDP (Delivered Duty Paid)	Carry out the export and import procedures and deliver the goods at the door of the customer	Carriage to be arranged by the seller	Risk transfer from the seller to the buyer when the goods are placed at the disposal of the buyer	Cost transfer from the seller to the buyer when the goods are placed at the disposal of the buyer

Note: EXW, CPT, CIP, DAF, DDU and DDP are commonly used for any mode of transportation. FAS, FOB, CFR, CIF, DES, and DEQ are used for sea and inland waterway.
*FCD (FCA Duty Paid): customer picks up the material from a warehouse and non-EU goods are custom cleared before pick up. When the customer buys the material on FCD, they can handle the material without any customs restrictions within the European Community as if they bought the material from an EU supplier.

Table 8 Share of total volume per INCOTERM

INCOTERMS	Product A and B	Product group Z (excl. product A and B)	Product C	Product group W (excl. product C)	Product group X	Product group Y	All products
EXW	7.40%	10.52%	1.66%	3.65%	0.12%	1.86%	5.17%
FCA	0.12%	1.02%	0.25%	10.90%	12.76%	6.36%	4.21%
FCD	-	0.00%	-	-	16.39%	10.65%	1.45%
FOB	-	0.10%	-	0.90%	3.00%	1.55%	0.48%
CFR	0.70%	2.78%	0.20%	0.66%	3.52%	0.08%	0.86%
CIF	5.86%	0.52%	-	4.54%	19.15%	1.91%	3.17%
CIP	2.63%	-	-	0.02%	9.35%	10.16%	2.08%
DES	-	-	-	0.37%	-	-	0.10%
DDP	83.28%	84.99%	97.81%	78.19%	35.71%	50.29%	79.88%
DDU	-	0.07%	0.06%	0.77%	-	17.13%	2.58%
Total	100%	100%	100%	100%	100%	100%	5.17%

Appendix IV

Steam usage of a bulk tank

$X(c) = \frac{(D(c)*Q_t(c)*V_m(c))}{\lambda}$

$$D(c)\begin{cases} if\ S(c) = 202.5MT\ then\ D(c) = \frac{365}{IT} \\ if\ 81MT \leq S(c) < 202.5MT\ then\ D(c) = \left(\frac{E[I_m(c)]}{\delta}\right) + \left(1 - k(c)\right) * 7 \\ if\ S(c) < 81MT\ then\ D_c = \left(\frac{S(c)}{\delta}\right) + (1 - k(c)) * 7 \end{cases}$$

$where\ IT = \frac{V_m(0)}{I_m(c)},\ E[I_m(c)] = \frac{1}{2}O + s - \mu L = \frac{1}{2}O + ss$ (de Kok, 2005) $and\ \delta = \frac{V_m(c)/12}{\left(\frac{365}{12}\right) * k(c)}$

$D(c)$	: Average number of days of inventory at location c (in days)
δ	: Throughput per day (in kg/day)
$I_m(c)$	: Average inventory molten at location c (in kg)
IT	: Inventory turn - a measure of the number of times the inventory of molten is sold in 2010.
$k(c)$	: Fraction of time that a production line is used, see table below for values
O	: Order quantity (in kg)
$Q_t(0)$	: Required energy to keep one kg in a tank at location c on temperature for one day (in kJ/kg/day)
s	: reorder point s (in kg)
$S(c)$	: Capacity tank at location c (in kg), see table below for values
ss	: Safety stock (in kg)
μL	: Mean demand during lead time (in kg)
λ	: Latent heat of vaporization at a pressure of 30 bar (=1794 kJ/kg)

Table 9 Customers and their properties

	Product A			Product B		
Location (c)	**Country**	$S(c) in\ MT$	$k(c)$	**Country**	$S(c) in\ MT$	$k(c)$
Eastman (0)	The Netherlands	*		The Netherlands	*	
Customer (1)	Germany	*	*	France	*	*
Customer (2)	United Kingdom	*	*	France	*	*
Customer (3)	France	*	*	Italy	*	*
Customer (4)	Italy			Saudi Arabia		
Customer (5)	The Netherlands			France		
Customer (6)	Italy			Sweden		
Customer (7)	Germany			France		
Customer (8)	Germany			The Netherlands		
Customer (9)	The Netherlands			Italy		
Customer (10)	France			Germany		
Customer (11)	France			Turkey		
Customer (12)	France			Germany		
Customer (13)	Germany			Germany		
Customer (14)	Spain			United Kingdom		
Customer (15)	Italy			France		
Customer (16)	Germany			The Netherlands		
Customer (17)	South Africa			Germany		
Customer (18)	Denmark			Italy		
Customer (19)	France					
Customer (20)	United Kingdom					
Customer (21)	United Kingdom					
Customer (22)	Belgium					
Customer (23)	Switzerland					

* Confidential

Appendix V

Table 10 Electricity prices, gas prices and emission factors per country

Country	Electricity prices (€/kWh)[1]	Gas prices (€/GJ)[2]	Gas prices (€/m^3)[3]	Electricity Emission factor (in kg CO_2/kWh)[4]
	2010	2010	2010	2007-2009
Belgium	0.0659	6.475	0.249	0.239
Bulgaria	0.0474	6.810	0.262	
Czech Republic	0.0903	7.857	0.302	0.534
Denmark	0.0787	7.234	0.278	0.311
Germany	0.0686	8.645	0.333	0.447
Estonia	0.0437	7.145	0.275	0.735
Ireland	0.0557	6.380	0.246	0.482
Greece	0.0597			0.739
Spain	0.0641	6.898	0.265	0.337
France	0.0536	7.400	0.285	0.089
Italy	0.0934	7.165	0.276	0.416
Latvia	0.0746	7.562	0.291	
Lithuania		8.345	0.321	
Luxembourg	0.0699	7.220	0.278	0.382
Hungary	0.0809	8.287	0.319	0.326
Netherlands	0.0748[5]	6.732[5]	0.259[5]	0.389
Austria	0.0768			0.183
Poland	0.0722	7.654	0.295	0.379
Portugal	0.0533	7.627	0.293	0.652
Romania	0.0575	3.957	0.152	
Slovenia	0.0660	9.562	0.368	0.337
Slovakia	0.0933	7.954	0.306	
Finland	0.0562	7.965	0.306	0.207
Sweden	0.0649	9.964	0.383	0.041
Switzerland	0.0770			0.04
United Kingdom	0.0777	5.567	0.214	0.48
Norway	0.0396			0.01
Croatia	0.0572	10.198	0.392	
Turkey	0.0699	6.041	0.232	0.484
South Africa	0.048			0.9
Saudi Arabia	0.028			0.74

[1] Annual consumption: 70 000 MWh < Consumption < 150 000 MWh, source: Eurostat (nrg_pc_205)

[2] Annual consumption: 100 000 GJ < Consumption < 1 000 000, source: Eurostat (nrg_pc_203)

[3] Calculated with EU average gross calorific value: 0.03848 GJ/m^3

[4] Source: http://www.iea.org/co2highlights/co2highlights.pdf

[5] For Eastman real values of 2010 are known and are taken into account

Appendix VI

Checking assumption of heating

Currently in TERRA it is assumed that the fuel consumption will increase with 20 percent if the load of the truck is heated during transport: $FC_{LF} = FC_{empty} + \left(\left(FC_{full} * 1.2\right) - FC_{empty}\right) * LF$, where FC_{LF}= Fuel consumption at the specified load factor (liters per kilometre), FC_{empty}= Fuel consumption of the empty vehicle (liters per kilometre), FC_{full}= Fuel consumption of the fully loaded vehicle (liters per kilometre), LF= Specified load factor

The carrier of Eastman that transports the molten bulk uses a diesel generator keep the product on temperature. The carrier did not want share their fuel bills but gave the fuel consumption when the generator is standby (i.e. the generator is running at a speed where it is not delivering power but is running slowly ready for use) and when it is running at highest speed. Also the time that the generator is standby and running at highest speed was provided. Knowing the fuel consumption and the emission factor of diesel (2.640 kg CO_2/liter (NTM Road, 2008)) the emissions can be calculated. In total the CO_2 emissions that are emitted due to heating are 133.31 kg.

To assess the validity of the assumption in TERRA, the emissions of two almost identical shipments are calculated. Both shipments will have the manufacturing site in the Nehterlands as the origin city and the city where the customer is located as the destination city and they will have the same load. The difference of the data is that the first shipment will not have heating as temperature control and the second shipment will have heating as a temperature control. From the table below it can be seen that the difference between the two shipments is 130.25 kg CO_2 which is 2.35 % lower than the emissions earlier obtained with the information of the carrier. On the total CO_2 emission the results of TERRA will be 0.355% lower.

Because the carrier would not share their fuel bills it is not possible to trace the cause of this difference. There is a possibility that the increase of 20 percent in fuel consumption is too low but it is also possible that the estimate of the fuel consumption of the type of modality in TERRA is incorrect. The assumption is TERRA is not changed and thus the calculations are still done with the 20% increase assumption.

Table 11 Results validation

CO_2 emissions 'no heating' (in kg)	CO_2 emissions 'heating' (in kg)	Difference in CO_2 (in kg)
731.09	861.34	130.25

Appendix VII

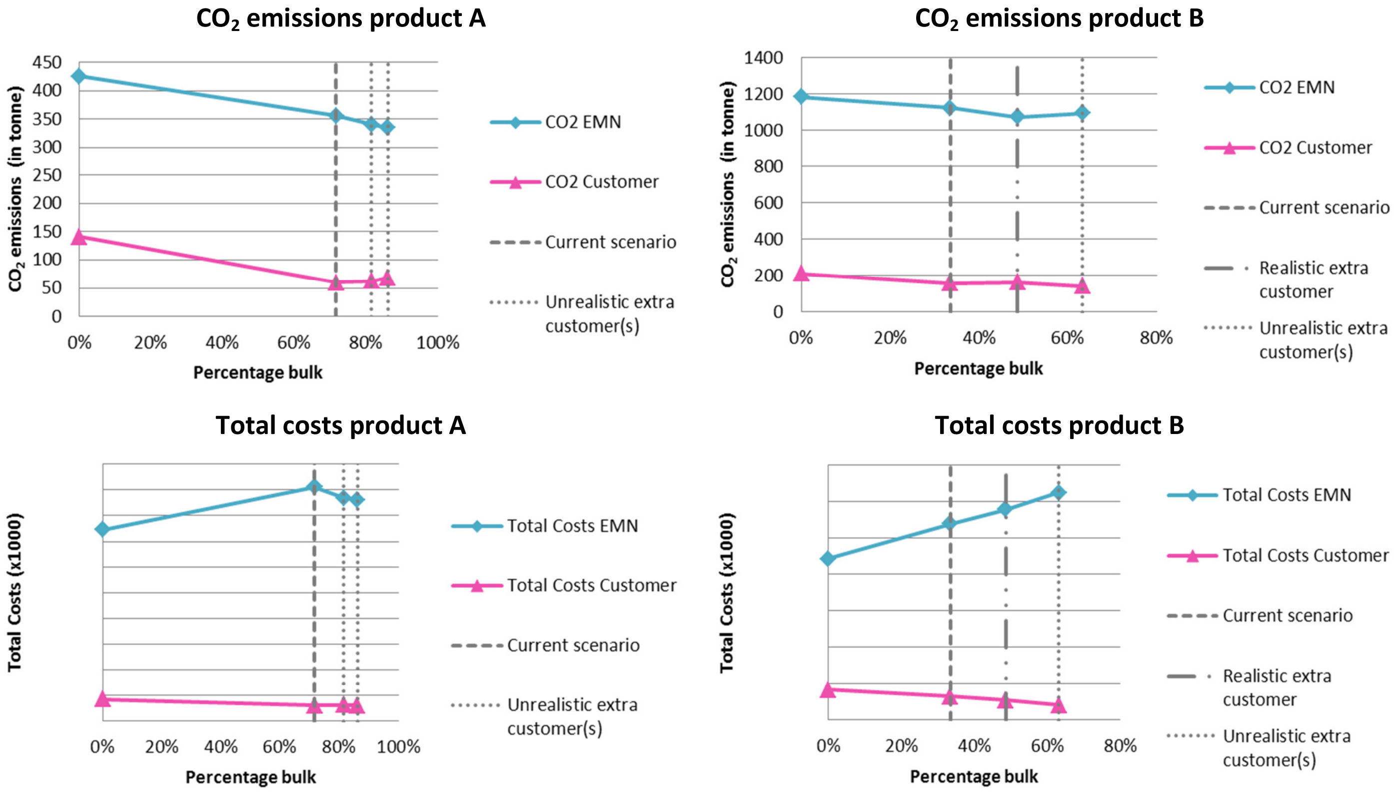

Figure 37 Results Eastman and customers

Advantages molten bulk

- Improved quality
  - No dust (less downtime)
  - No lumping
- Reduced production cycle time
  - Improved capacity
  - Cost reduction per kg
- Labor saving
  - Less pallet handling
  - Less storage handling
- No packaging
  - Less handling
  - No disposal (cost/environment)
  - No storage packaging materials
- Warehousing
  - Less space needed
  - Lower stock = working capital reduction

Appendix VIII

Table 12 Results sensitivity analysis product A I

Current situation (product A: 72% bulk, 28% packed)					
Parameter changed	Change	Total CO_2 emissions (in t)	Change	Total costs (x1000)	Change
Emission factor packaging material	-20%	411.33	-1.08%	-	-
Empty returns with tank truck	0%	361.63	-13.03%	-	-
Percentage of return distance that a normal trucks is empty	40%	426.43	2.55%	-	-
Electricity emission factors	-20%	397.68	-4.36%	-	-
Percentage incineration*	-20%	414.36	-0.35%		-
Time in tank Eastman**	-20%	407.60	-1.98%	****	-1.06%
Time in tank customer***	-20%	413.35	-0.60%	****	-0.37%
Change engine capacities packout	-20%	413.80	-0.54%	****	-0.07%
Change engine capacities tanks	-20%	401.16	-3.53%	****	-0.41%
Change engine capacities customer	-20%	410.89	-1.19%	****	-0.20%
Change # times big bag recycled	3	414.80	-0.25%	****	-0.21%
Electricity price	-20%	-	-	****	-0.64%
Gas price	-20%	-		****	-0.34%
Transport price	-20%	-	-	****	-13.24%
Price packaging material	-20%	-	-	****	-0.72%
Repacking price	-20%	-	-	****	-0.44%
Hourly labour price	-20%	-	-	****	-0.35%
Rent trucks	-20%	-	-	****	-1.82%

* When this parameter is changed the percentage landfill will change in the opposite direction
** Average inventory costs decreased with 20%
*** Average inventory costs decreased with 11%
**** Confidential

Table 13 Results sensitivity analysis product A II

0% bulk, 100% packed					
Parameter changed	Change	Total CO_2 emissions (in t)	Change	Total costs (x1000)	Change
Emission factor packaging material	-20%	548.76	-3.00%	-	-
Empty returns with tank truck	0%	-	-	-	-
Percentage of return distance that a normal trucks is empty	40%	596.99	5.65%	-	-
Electricity emission factors	-20%	529.92	-6.27%	-	-
Percentage incineration*	-20%	560.19	-1.01%		-
Time in tank Eastman	-20%	-	-	-	-
Time in tank customer	-20%	-	-	-	-
Change engine capacities packout	-20%	558.12	-1.39%	****	-0.29%
Change engine capacities tanks	-20%	-	-	-	-
Change engine capacities customer	-20%	-	-	-	-
Change # times big bag recycled	3	558.97	-1.22%	****	-1.68%
Electricity price	-20%	-	-	****	-1.46%
Gas price	-20%			-	-
Transport price	-20%	-	-	****	-8,84%
Price packaging material	-20%	-	-	****	-3.47%
Repacking price	-20%	-	-	****	-3.03%
Hourly labour price	-20%	-	-	****	-0.43%
Rent trucks	-20%	-	-	-	-
* When this parameter is changed the percentage landfill will change in the opposite direction **** Confidential					

Appendix IX

Table 14 Results sensitivity analysis product B I

Current situation (product B: 33% bulk, 67% packed)					
Parameter changed	Change	Total CO_2 emissions (in t)	Change	Total costs (x1000)	Change
Emission factor packaging material	-20%	1,254.36	-1.98%	-	-
Empty returns with tank truck	0%	1,207.83	-5.62%	-	-
Percentage of return distance that a normal trucks is empty	40%	1,376.83	7.59%	-	-
Electricity emission factors	-20%	1,231.39	-3.78%	-	-
Percentage incineration*	-20%	1,271.63	-0.63%		-
Time in tank Eastman**	-20%	1,271.04	-0.68%	****	-0.47%
Time in tank customer***	-20%	1,276.72	-0.24%	****	-0.16%
Change engine capacities packout	-20%	1,266.36	-1.04%	****	-0.16%
Change engine capacities tanks	-20%	1,264.60	-1.18%	****	-0.17%
Change engine capacities customer	-20%	1,276.23	-0.27%	****	-0.07%
Change # times big bag recycled	3	1,277.53	-0.17%	****	-0.18%
Electricity price	-20%	-	-	****	-0.80%
Gas price	-20%			****	-0.14%
Transport price	-20%	-	-	****	-6.07%
Price packaging material	-20%	-	-	****	-1.53%
Repacking price	-20%	-	-	****	-0.38%
Hourly labour price	-20%	-	-	****	-1.25%
Rent trucks	-20%	-	-	****	-0.87%

* When this parameter is changed the percentage landfill will change in the opposite direction
** Average inventory costs decreased with 20%
*** Average inventory costs decreased with 8%
**** Confidential

Table 15 Results sensitivity analysis product B II

0% bulk, 100% packed					
Parameter changed	Change	Total CO_2 emissions (in t)	Change	Total costs (x1000)	Change
Emission factor packaging material	-20%	1,356.92	-2.70%	-	-
Empty returns with tank truck	0%	-	-	-	-
Percentage of return distance that a normal trucks is empty	40%	1,520.42	9.02%	-	-
Electricity emission factors	-20%	1,332.36	-4.46%	-	-
Percentage incineration*	-20%	1,382.64	-0.86%		-
Time in tank Eastman	-20%	-	-	-	-
Time in tank customer	-20%	-	-	-	-
Change engine capacities packout	-20%	1,374.52	-1.44%	****	-0.28%
Change engine capacities tanks	-20%	-	-	-	-
Change engine capacities customer	-20%	-	-	-	-
Change # times big bag recycled	3	1,392.41	-0.16%	****	-0.21%
Electricity price	-20%	-	-	****	-1.22%
Gas price	-20%			-	-
Transport price	-20%	-	-	****	-11.42%
Price packaging material	-20%	-	-	****	-2.61%
Repacking price	-20%	-	-	****	-0.43%
Hourly labour price	-20%	-	-	****	-2.25%
Rent trucks	-20%	-	-	-	-
* When this parameter is changed the percentage landfill will change in the opposite direction **** Confidential					

Appendix X

Table 16 Results clean electricity

0% bulk, 100% packed						
	Steam		Electricity of Switzerland			
	Total CO_2 emissions (in t)	Total costs (x1000)	Total CO_2 emissions (in t)	Change	Total costs (x1000)	Change
Product A	565.99	*	398.94	-31.10%	*	-3.18%
Product B	1,394.62	*	1,093.32	-21.60%	*	-2.39%

Current (product A: 72% bulk, 28% packed; product B: 33% bulk, 67% packed)						
	Steam		Electricity of Switzerland			
	Total CO_2 emissions (in t)	Total costs (x1000)	Total CO_2 emissions (in t)	Change	Total costs (x1000)	Change
Product A	415.83	*	276.25	-33.57%	*	-1.11%
Product B	1,279.73	*	989.87	-22.65%	*	-1.38%

One Extra customer (product A: 82% bulk, 18% packed; product B: 49% bulk, 51% packed)						
	Steam		Electricity of Switzerland			
	Total CO_2 emissions (in t)	Total costs (x1000)	Total CO_2 emissions (in t)	Change	Total costs (x1000)	Change
Product A	403.65	*	260.07	-35.57%	*	-0.98%
Product B	1,235.54	*	939.84	-23.93%	*	-1.14%

Two Extra customers (product A: 86% bulk, 14% packed; product B: 63% bulk, 37% packed)						
	Steam		Electricity of Switzerland			
	Total CO_2 emissions (in t)	Total costs (x1000)	Total CO_2 emissions (in t)	Change	Total costs (x1000)	Change
Product A	403.47	*	254.16	-37.01%	*	-1.01%
Product B	1,234.62	*	960.07	-22.24%	*	-0.64%

* Confidential

Appendix XI

Table 17 Outbound emission results per product group and modality

	Product group X	Product group Y	Product group Z	Product group W (excl. product C)	Product C	Total
Road volume/bulk	95.3	44.8	1,071.6	329.4	164.7	1705.8
Ferry volume/bulk	101.5	13.2	22.2	70.5	41.0	248.4
Ferry 2x volume/bulk	10.7	0	0	42.1	0	52.8
IM ocean volume/bulk	3,224.7	919.5	151.9	86.6	1.4	4,384.1
Rail volume/bulk	71.3	0	0.7	1.6	0	73.6
IM rail volume/bulk	23.2	6.0	55.0	5.1	8.5	97.8
Total	3,526.7	983.5	1,301.4	535.3	215.6	6,562.5

Appendix XII

Table 18 Ports for product group Y

Country	Port
France	Le Havre
Greece	Piraeus
Italy	Genoa
Saudi Arabia	Jeddah
Saudi Arabia	Dammam
Spain	Algeciras
Turkey	Istanbul
United Arab Emirates	Abu Dhabi
United Kingdom	Felixtowe

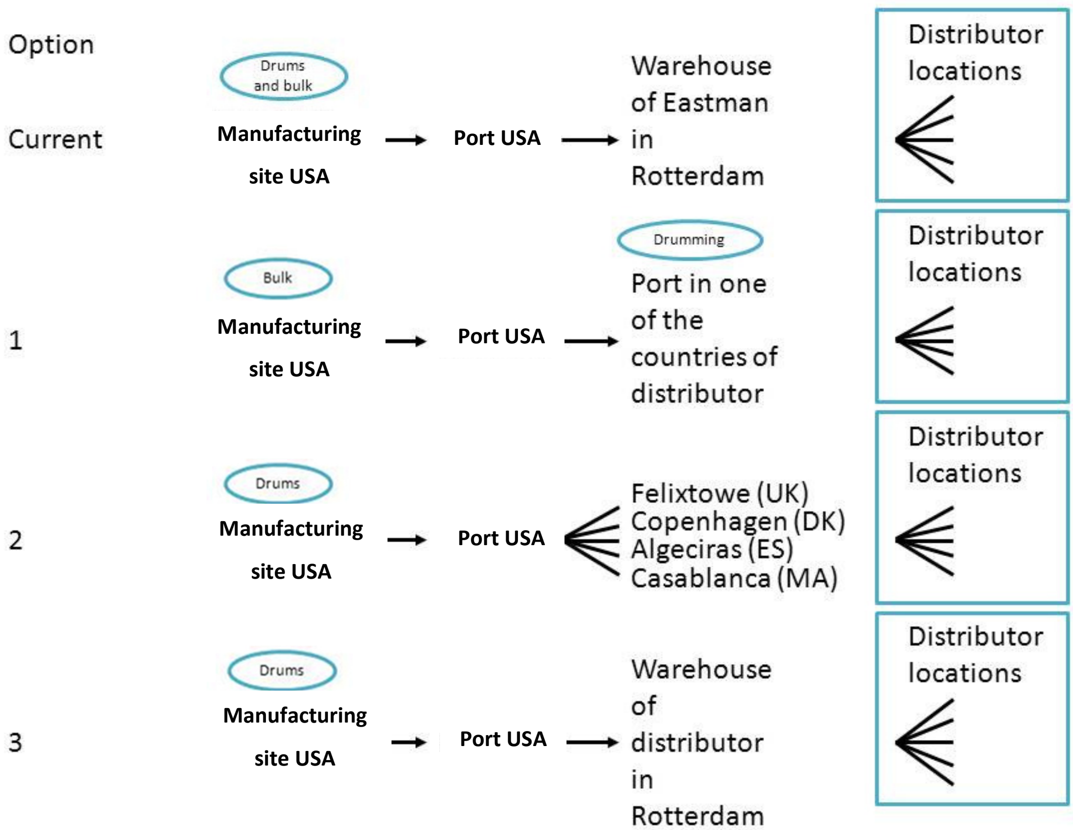

Figure 38 Options for product group X