Agentschap NL
Ministerie van Economische Zaken

Cradle to Cradle: Incorporating closed-loop material chains in the industry

Master thesis

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Executive summary

The focus on sustainability increases in businesses. Awareness amongst organisations, regulation from the governance, the increase in consumption and shortage of raw materials generate an interest within the industry to look into environmental management solutions. Organisations noticed problems during the attempt to recover materials when trying to comply with the C2C concept. Many unexpected bottlenecks are not taken into account when approaching a setup to recover their materials. Theoretical studies for recovery like closed-loop supply chain management and reverse logistics are only described by academia. They do not consider the specific material possibilities in a practical recovery process. There is a need to build a new model to join academia and industry knowledge together to approach material possibilities. A new model that gives insight and can estimate feasibility and possibilities of closed-loop material chains in reality. The research main question is:

"How can the Dutch industry get better practical insight in the feasibility to recover materials with closed-loop material chains?"

This study investigates the possibility to create a tool that can be used by the SMEs to grade the feasibility of a specific closed-loop material chain. This tool exists of two separate functions, 1 – a framework that gives an overview of all relevant aspects for closed-loop material chains, and 2 – a questionnaire to grade the feasibility of that certain closed-loop material chain. It extends current theoretical studies on reverse logistics and closed-loop supply chain management studies. The study will hopefully remove any barriers for the industry to start committing to product recovery with closed-loop material chains, and create a more sustainable industry to the environment.

By reviewing current literature in all imaginable aspects of recovery, and comparing this to existing material chains, provide knowledge to the gaps between theoretical and practical information of recovery. Findings of both the theoretical studies and the practical case studies are incorporated to one new model. The closed-loop material chain framework. This framework creates insight in the relations of issues within recovery in material chains. Derived from this framework is an additional questionnaire to calculate feasibility of the material chain.

The feasibility is calculated in three themes of the material chain, namely strategy, product and retrieving. These themes indicate in which area the most problems occur. Tests of the framework and questionnaire conclude that the tools are a representation of reality, and are useable for new or existing closed-loop material chains of any material, by any user within the chain. All encountered difficulties and successes are described, explained and motivated in this thesis.

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1 Introduction

1.1 Problem introduction

The focus on sustainability increases in businesses. After all the focus on global warming and pollution, we start to realize more and more that people in all industries are responsible for this problem.

This awareness was not always as clear as it currently is. The first awareness for the environment came in the 1950's with the Clean Air Act. In 1972, the real rise of sustainability began to take its form because of the report "Limits of Growth" published by the Club of Rome. Environmental awareness became a real issue to governments, businesses and the public. This resulted in several international conferences which led to international environmental agreements. Studies of the impact of greenhouse gases, the environmental movement and especially the movie "An inconvenient truth" by Al Gore became a turning point for a lot of people. People became aware, and began to realize that we have to consider the environment. This awareness puts many businesses in the position to decide how to be more sustainable. But being a sustainable business means making choices and changes. Decisions have to be made to decide how sustainability is incorporated in the organisation. Modern environmental management prescribes sustainability in manufacturing with the focus on waste prevention or reduction, and responsible care of the earth's natural resources (Kumar and Putnam 2008).

One concept to incorporate sustainability in organisations is Cradle to Grave (C2G). Considering the birth and lifetime of a product (Cradle) until it becomes waste again (Grave). Producers design and create products that pollute less, and produce less waste during production and usage. The writers of the book Cradle to Cradle (C2C): Remaking the Way We Make Things (Braungart and McDonough 2002), introduced a new concept amongst sustainable product developments. Cradle to Cradle, often used with the equation waste = food, where producers design and make products to be not polluting to the world. Creating no waste that is wasted, but materials that can be reused in the same or better quality as before. With this concept, the end of a product's lifetime becomes a birth possibility for nature or a resource for other products. C2C has a distinction in biological cycles where materials are absorbed by nature as a nutrient, or technical cycles where materials are recovered. 'Wasted' waste does not exist anymore in the C2C concept. According to Braungart and McDonough, our definition of recycling is often down-cycling. To downgrade a resource and use it in a product that is of a lesser quality. In their approach they strive to product re-cycling, or even better, up-cycling where products maintain the same or better quality.

Governments all over the globe stimulate these approaches by imposing regulation. This is noticeable in different sectors of the industry. Examples are the WEEE for electronic waste and ELV for end-of-life vehicles in the car industry. These constraints push forward the motivation of organisations to boost competition in providing the best materials and products conform the regulation (Darnall, Jolley and Handfield 2008). Kumar and Putman add that the problem concerning increase in consumption, and the shortage of raw materials is also a motivator for organisations to seek solutions within environmental management.

1.2 Problem definition

Awareness amongst organisations, regulation from the governance, the increase in consumption and shortage of raw materials generate an interest within the industry to look into environmental management solutions. NL Agency, a department of the Dutch Ministry of Economic Affairs that implements government policy for sustainability, innovation, and international business and cooperation, observes problems in organisations that initiate an attempt to recover materials when trying to comply with the C2C concept. They experience problems setting up the process to recover. Many unexpected bottlenecks are not taken into account when approaching a setup to recover materials. Theoretical studies for recovery like closed-loop supply chain management and reverse logistics are often only described by academia. They do not consider the specific material possibilities in the recovery process (Guide Jr, Harrison and Wassenhove 2003). There is a need to build a new model to join academia and industry knowledge together to approach material possibilities, and make it a useable technique in the process of recovery. This new model will be called closed-loop material chain, a slight difference with current terminology, where the focus and perspective of this model is the material itself. This model coordinates the recovery by depending on the characteristics of the material. Because of this feature, the advantage of this new model is the possibility to use it for any material or product recovery.

According to NL Agency, the Dutch government (especially minister Cramer from the department of VROM) wants to stimulate sustainability in the Dutch industries using the C2C concept, but on the other hand is afraid to commit to C2C, as it is an initiative of a commercial party. Valuable momentum is wasted if nothing is done to stimulate the industry. NL Agency is interested in this research because of a solution to guide the recovery of materials in material chains. This research is for NL Agency of value because it helps them achieving one of their objectives, creating a more sustainable industry and society. Because of the intended ideas with C2C from the Dutch government, this research focuses on the crucial recovering aspect within C2C. Since 2007, the Dutch government is initiating the attempt to include waste management into material chain concepts to include recovery within the chain (J. Cramer 2008).

NL Agency points out that current available information is theoretical knowledge that is not practical enough to be used by the small and medium-sized enterprises (SME). It lacks in practical information like, how to estimate feasibility and possibilities of closed-loop material chains in reality. This information is of great value for the SME and makes them aware of the possibilities and problems that can occur when setting up, and using the closed-loop material chain in practice.

In short, the problem is summarized in the main question of this research:

"How can the Dutch industry get better practical insight in the feasibility to recover materials with closed-loop material chains?"

To reach the goal of a better insight in feasibility, this study will investigate the possibility to create a tool that can be used by the SMEs to grade the feasibility of closed-loop material chains. This tool exists of two separate functions, 1 – a framework that gives an overview of all relevant aspects for closed-loop material chains, and 2 – a questionnaire to grade the feasibility of that certain closed-loop material chain.

1.3 Scope, objectives and risks

This research will limit to only one important aspect of C2C, namely the aspect of recovering materials from the technical cycles. All aspects of C2C like the product design, emissions during production, re- and up-cycling methods and all other aspects are not taken into account. The reason for this limitation is because the defined problem narrows the scope down to only product recovery.

The framework and questionnaire is written for the SMEs, but could probably be used by any organisation, for any material because of the generality of the tools.

The case studies done during this research are limited to current existing or pilot material chains in the Netherlands, provided by the professionals at NL Agency. Material chains in general have many aspects to investigate and could be broaden to unlimited possibilities. For this reason, this research limits its scope by defining objectives for the possibilities of the closed-loop material chain framework.

Objective 1: Create a framework to be used by the Dutch SMEs to give an overview of issues in closed-loop material chains in practice.

Objective 2: Create a measurement questionnaire to identify the feasibility of a successful closed-loop material chain.

Objective 3: Let the questionnaire identify bottlenecks in material chains

Objective 4: Give solutions to identified bottlenecks.

This research will not advise organisations in the actual process how to reintroduce the products to the forward logistics. The focus of this research is to create a tool to help organisations estimate the feasibility of recovering products in their situation, not how to reintroduce them in new products.

A risk in this research is the generality that is investigated for the framework and questionnaire. The more general the models are, the higher the risk is that these tools will cover only aspects that are already known. In that case, the purpose of this research will be too obvious and a waste of time. The reason why this research focuses on a general approach to all material chains, and will not divert to one specific chain is because of the impact and new area of investigation it will open up in material chain studies. It is said that material chains are personalized and specific to that material or product it recovers. This research seeks to prove otherwise and create generalization in the approach to closed-loop material chains.

1.4 Contribution

Knowledge about recovery is often complicated because of unknown data. Developments in practice are therefore slow. However, interest is growing in the US and Europe due to profitability and legislation (Guide Jr, Harrison and Wassenhove 2003). There is a growing awareness of the problems and opportunities this industry brings to the environment of the world (Dyckhoff, Lackes and Reese 2004). With these problems and the linkage to environmental management, there is a growing interest in managing product recovery in the form of material chains. New models need to be created by a joint effort of both the industry and academia to create this approach to use in practical cases.

This research will do just that, joining industry and academia together. By conducting a research in sustainability with a focus on Cradle to Cradle, closed-loop supply chains / reverse logistics and practical casus. This research will create a framework and questionnaire that can be used as a tool to have an overview of closed-loop material chain issues and the feasibility of a chain. The framework gives an overview indicating what possible aspects of a closed-loop material chain needs to be considered. The questionnaire grades a material chain in the feasibility of being a successful closed-loop material chain. Using the tools identifies the possibilities of actions and bottlenecks to be solved for creating a successful chain with a higher feasibility prospect.

It extends current theoretical studies on reverse logistics and closed-loop supply chain management studies. Doing so, this study will hopefully remove any barriers for the industry to start committing to product recovery with closed-loop material chains, and create a more sustainable industry to the environment. This research will furthermore contribute to the understanding of combining theoretical aspects with practical issues within the area of product recovery. It presents a study based on recent literature and recent insights and awareness in practice, and redesign the current concepts to a practical approach called closed-loop material chains.

1.5 Thesis structure

This thesis is a qualitative research to find out how organisations can create effective and efficient closed-loop material chains without spoiling recourses after usage of products and materials according to the Cradle to Cradle concept. The thesis is built in 7 main steps; figure 1 shows a graphical overview.

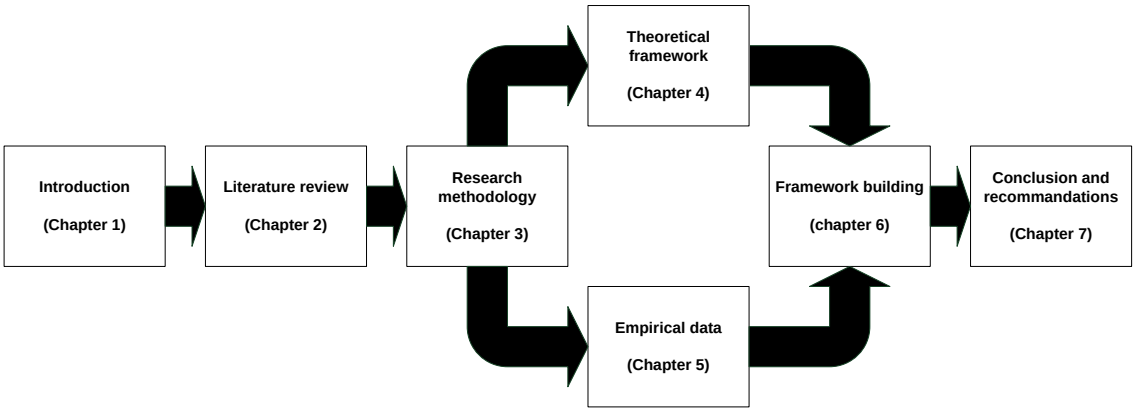

Figure 1: Graphical overview thesis structure

Chapter 1: Introduction, explains the main problem of this research. It gives a short introduction of the context of the problem, scope, objectives, risks and contribution of the investigation.

Chapter 2: Literature review is an abstract of all relevant theoretical information needed to solve the problem defined in chapter 1. It motivates and explains why and how certain subjects are chosen to contribute to the solution of this problem.

Chapter 3: Research methodology discusses the used methodologies to solve the main question. This chapter will also separate the main question in themes and assign them to sub-questions of

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this research. It explains and motivates how and why the chosen approaches are validated on reliability.

Chapter 4: Theoretical framework explains how the outcome of the literature review is used in the following stages of the research. It presents a table of questions derived from the literature review, to be used during the case studies.

Chapter 5: Empirical research describes the findings of the case studies. The theoretical framework is used to structure the method to conduct the case study. In this way, it is possible to compare the findings of the case studies and literature review, and note any possible new findings from practical experiences.

Chapter 6: Framework building. This chapter interprets the findings and joins theoretical and practical experience of recovery. Based upon the findings, all results are used to create the final tools to solve the defined problem. Once these are created, the validation of the tools is done by testing them with current and new material chains. Results are presented in this chapter.

Chapter 7: Conclusions and recommendations present the final conclusion of the overall research. It discusses if the solutions presented, will solve the initial defined problem and how it will be used in the future. This chapter also recapitulates all main findings, lessons learned and possible limitations of the research.

2 Literature review

This chapter gathers all relevant theoretical information needed regarding the problem defined in the previous chapter. To get started, the first task is to identify all relevant information by defining topics that will be investigated in the literature review. Once this is done, the literature review can begin. The review assesses all information concerning the identified topics that contributes to the solution of the main problem. To find out the quality of information, it is important to review the source type and the motivations of the source. Once all relevant information is identified and collected, it will be summarized in this chapter. Afterwards, the interpretation of the findings concludes how all collected theoretical information is used in the next stages of this research.

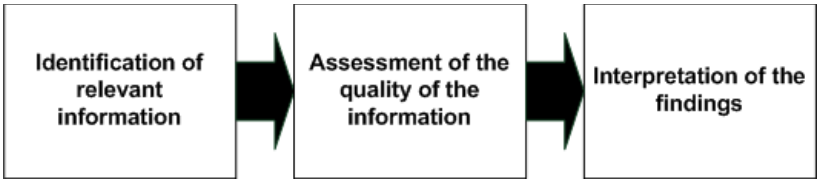

Figure 2: Literature review approach

Brainstorm sessions were done to identify all relevant information, and defining the topics to research during the literature review. The sessions are done with Hanneke op den Brouw, Astrid Hamer and Rommert Dekker. These persons are currently working on subjects that have an affiliation with the defined problem in chapter 1. The subjects that came across during the brainstorm session and will be investigated during this literature review are:

- Identifying stakeholders and finding out their objectives.
- Investigating the Cradle to Cradle concept.
- Set a definition of waste.
- Social responsibilities and motivation of an organisation.
- Investigate legislation and governmental policy.
- Investigate information and communication technology possibilities to complement sustainability.
- Investigating reverse logistics and closed-loop supply chain management theories.
- Investigate risks and opportunities concerning recovery.

These topics are chosen because they represent most, if not all aspects of a closed-loop material chain. The gathered information contributes to the final results of this thesis. All these topics are discussed in the following paragraphs of this chapter, explaining their relevance and contribution to solve the problem.

2.1 Stakeholders and objectives

Stakeholders in this research are all persons, organisations or agencies that are involved or can affect the results of the problem. It is important to identify the stakeholders and be aware of their

objectives. The aim is to find a solution that satisfies all stakeholders. Identifying their objectives and taking these into account result in reliable final conclusions. The following stakeholders are defined in this research:

- Dutch government / NL Agency
- Dutch industry
- Consumers

The overall objective of the Dutch government regarding the environment is to have a cleaner climate. Important aspects that are mentioned by minister Cramer of the department of VROM, are lower energy consumption, stimulate markets of sustainable products and stimulate developments in sustainability with the correct balance of people, planet and profit (Cramer, Ministerie van VROM 2007). NL Agency's objectives are to create a more sustainable industry and society. Sustainability is a term that encapsulates in short, to save the planet by maximizing usage of resources and re-cycling, avoiding pollution and creating a better surrounding for everybody and anything on this planet.

This research focuses on the SME of the Dutch industry. The European Commission defined SME as all enterprises with less than 250 employees with an annual turnover at the highest of € 50 million, or an annual balance sheet total smaller or equal to € 43 million. These enterprises are occupying 99,7% of the total Dutch industry (MKB Servicedesk sd). All enterprises want to maximize their profit. This is their main objective and reason for existing. All companies use different techniques to reach this objective. Possible factors in creating a successful and profitable company are increasing market share, customer satisfaction, company continuity, being innovative, being unique and decrease costs.

Consumers are the users of materials available on the market. They compare product prices to product properties, and assess if these properties meet their expectations.

Defining the objectives of the three key stakeholders places them in a possible context so all stakeholders can benefit from the new models and achieve their objectives.

- The government wants to have a cleaner climate.
- The industry that wants to make profit
- The consumers want to have the lowest possible costs for their product expectations.

The challenge is to create a solution for the main problem and comply with all stakeholders' objectives.

2.2 Cradle to Cradle theory

The objective of the concept Cradle to Cradle (C2C) is production without waste. By reviewing the current method of production, and using clean materials that fit the biological or technical cycles, it is possible to make products that will not produce waste during production and after the product's lifetime. Products will either be biological reused as a nutrient, or technical re- or up- cycled as a resource for a new product.

> *"The purpose of the Cradle to Cradle Design is to restore continuous cycles of biological as well as technical nutrients with long terms positive effects on profitability, the environment and human health." (EPEA Internationale Umweltforschung GmbH 2009)*

An important bottleneck within C2C and other recovering techniques, is to recover used materials from the technical cycle, to reintegrate them in the forward logistics (Guide Jr, Harrison and Wassenhove 2003). Several cases in C2C achieved the possibility to recover products, but full integration with current existing forward material chains is still difficult.

Although this is a problem, the C2C concept reinforces all objectives of the Dutch government, consumer and the Dutch industry. C2C has the potential to create a cleaner climate for the Dutch government by maximizing the use of resources and eliminating waste. C2C upholds for the consumer high quality products. The potential for the Dutch industry is to be innovative, unique and decrease costs by using less new resources, or reuse resources and having less costs to eliminate waste (Braungart and McDonough 2002).

The difference of C2C compared to conventional sustainable product development, is its focus on attempting to eliminate the harmfulness from the product. Conventional sustainable product developments are limited to analyse a product's birth, usage, and disposal, also known as life cycle assessment (LCA) or Cradle to Grave (C2G) analysis. These analyses investigate the environmental impact of the product and try to minimize this damage. According to Braungart and McDonough, these methods are only designed to be less bad. Their saying "Be good, not less bad" embodies exactly what the C2C concept is trying to reach (Braungart and McDonough 2002). Designing sustainable product developments to be good, not less bad. All used raw materials and resources can be reused in other new products once it has been disposed. The big difference in C2C is that all resources are reused or reprocessed to the same or better quality, or that resources are absorbed by nature as a nutrient. The result is to not pollute the environment at all because all resources are reused.

Cradle to Cradle is a cycle. Producers start production of their products. Once consumers bought these products, they eventually need to dispose it after the product's lifetime. Following the C2C concept, this can be done by the means of the biological cycle, where products become a 100% nutrient for nature, or technical cycle, where products are brought back to producers to be re- or up-cycled. In this process, the disposed product is used in a new product of at least the same quality (re-cycled) or a better quality (up-cycled) (Braungart and McDonough 2002). A downfall of C2C is recovery in the technical cycle. If for example the consumer does not send a product back to the producer, and it will cost too much effort and resources to recover the materials, it can become too expensive to retrieve the material. The idea will then not be used in practice.

In short, there are a few criteria according to the C2C concept from Braungart and McDonough.

- Products need to be redesigned to fit the C2C concept.
- The material quality will be preserved during re-cycling.
- Materials will be returned in biological- or technical cycles.
- All materials that will not be absorbed by nature as a nutrient will be returned in the technical cycle.
- Technical cycles will preserve the same quality, or improve the quality of a material when re-cycled.

Unfortunately, the C2C concept knows a few, to almost none scientific studies that assess the possibilities of C2C. The found studies relate to conventional methods to recover materials like reverse logistics and closed-loop supply chain management. In these studies there are some general arguments that also apply to C2C recovery.

- Maximizing resources by re-cycling and redesigning production can decrease costs for virgin materials and will be less of a burden for the earth. (Logistiek 2008).
- Being more sustainable seems to improve the reputation of a company and could increase profit (PriceWaterhouseCoopers 2008) (Koedijk, et al. 2006).
- Many companies need to reorganize to conform to the C2C concept. Current companies are designed for only forward logistics. (Logistiek 2008).

Other arguments about C2C are not representable as scientific studies but do reflect the current role of C2C in practice. The sources are perspectives from C2C proponents, books, documentaries and statements of individuals.

- Cradle to Cradle concept provokes businesses to be aware and do better to preserve or minimize damage to the environment. It brings the opportunity to use current considered waste as a new nutrition for a new product. (Hattum 2006).
- This idea mobilizes people to start to commit to Cradle to Cradle thus sustainability. (Werf 2009).
- Cradle to Cradle will create better conditions for work and living. (Hattum 2006).
- Participating in Cradle to Cradle will help a company meet the regulation of the Dutch government and beyond. In this way the produced products will fit to the standard of sustainable purchases by the Dutch government (Cramer, Ministerie van VROM 2007).
- Production according to the Cradle to Cradle concept can simplify assembly and disassembly of products and decrease costs in this aspect. (Hattum 2006).
- There is little knowledge known about Cradle to Cradle and little information about 'clean' materials. Investigation in these materials cost money. (Hattum 2006).

This summary reflects the manner C2C stands in the community at this point. Unfortunately, few scientific studies have been done on C2C. In the end, C2C enables awareness in some organisations, and provides a stimulation to critically rethink possibilities in redesigning and recovering materials and products.

2.3 Waste definition

The term waste is commonly used with the combination of reuse and re-cycles materials. This section explains what exactly the definition of waste is, and what the relation is with reusing and recovering.

Waste is a term that seems logical and explainable on surface, but when it is brought together with re-cycle or reusable materials it begins to be very confusing. There are different definitions of waste.

> *"Waste shall mean any substance or object in the categories set out in Annex I which the holder discards or intends or is required to discard."* (European Union 1975)
>
> *"Wastes are substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law."* (The Secretariat of the Basel Convention 1989)
>
> *"Waste includes all items that people no longer have any use for, which they either intend to get rid of or have already discarded. Additionally, wastes are such items which people are require to discard, for example by law because of their hazardous properties. Many items can be considered as waste e.g., household rubbish, sewage*

> *sludge, wastes from manufacturing activities, packaging items, discarded cars, old televisions, garden waste, old paint containers etc. Thus all our daily activities can give rise to a large variety of different wastes arising from different sources."* (European Topic Centre on Sustainable Consumption and Production 2010)

Common in all these definitions are that something, a substance, will be disposed or discarded. Motivation for the disposal of the substance could have several reasons. But is it still waste under the conditions when the disposed or discarded substances could be reused in a re-cycle process? Or is it under these circumstances a resource for a new product? This problem also occurs vice-versa. When are substances or materials reusable resources and not categorized as waste. This problem seems not that important, but the difference between the definition waste and reusable resource has an impact in legislation. A substance could be seen as waste for one, but a valuable resource for the other. This definition problem is in practice abused in several manners. Illegally shipping waste to third world countries under the format that it is a reusable material is one of those examples.

Other problems occur in licenses. When materials are marked as waste, organisations are confronted with licenses and legislation in order to reprocess the material. There is a switching point that discarded or disposed substances will become reusable resources. For this reason, the European Union is setting-up the end-of-waste criteria (European Commission 2008). This criteria defines the switching point whether substances are waste or become reusable resources. In practice this will unburden organisations that currently must be waste processing organisations by law to reuse materials.

2.4 Responsibilities and motivations from organisations

As pointed out earlier in this research, the main objective of an enterprise, thus the industry, is to create a maximum profit. Each management aspect will be carefully analyzed to reach this objective. Waste management is not an exception to this. Many companies consider waste as a cost, and waste management as a method to keep costs as low as possible. When thinking outside of the box, waste could then be seen as an opportunity to create a higher profit (Flapper, Nunen and Wassenhove 2005). Reuse and re-cycling are keywords in this idea. Unfortunately, organisations do not realize that it can contribute to their profit (Boulding and Christen 2003). Making waste management profitable is often a commitment with a long trajectory, and will initially require investments to create profit. According to studies, once business continuity is in a 'healthy' state, organisations will only then have other objectives in mind than direct profit maximization.

The term Corporate Social Responsibility (CSR), embraces the responsibility of businesses and proactively promotes businesses to be more sustainable. According to studies done by Carroll, his four stages model shows that the first stage represents the economic responsibilities to be profitable. The second stage represents the legal responsibilities, obeying the law. The third stage represents the ethical responsibilities, this is the obligation to do what is right and avoiding harm to oneself. Finally the fourth stage is the philanthropic responsibility to be a good corporate citizen. To really improve the quality of life and contribute resources to the quality of life. These four stages are schematically shown in Figure 3: The Pyramid of Social Responsibility (Carroll, Business & Society: Ethics and Stakeholder Management 1996).

Figure 3: The Pyramid of Social Responsibility (Carroll, The Pyramid of Corporate Social Responsibility: Toward the Moral Management of Organizational Stakeholders 1991)

Next to this, there is a growing pressure from all types of initiatives to motivate business sustainability. Environmental groups, customer organisations and even their own stakeholders are pressuring to take the environment into account (Flapper, Nunen and Wassenhove 2005).

2.5 Legislation and governmental policy

Product recovery and legislation have a narrow connection with each other. Hence, the reason to take this subject into account when researching closed-loop material chains to recover materials. However, there is much different legislation for different types of materials. This section gives some examples of active legislation, and will shortly explain one of them.

Some examples of legislation that is active in the Netherlands:

- Directive on Waste of Electrical and Electronic Equipment (WEEE).
- Directive on End-of-Life Vehicles (ELV).
- Directive on paper and cardboard packaging.
- Directive on Restriction on Hazardous Substances (RoHS).

All legislation concerns a certain material. For example, the purpose of the legislation WEEE is to reduce or prevent waste from electrical and electronic equipment, and stimulate the reuse and recycling of these materials. It makes producers responsible for the costs to recover their products at the end of usage (Commission of the European Communities 2009).

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Because the scope of this research is to approach the general aspects of closed-loop material chains and material recovery, it will not further investigate different legislation. All these legislation contribute to the effect of creating more sustainable businesses. Previous studies showed that legislation do not always have a positive effect. According to these studies, legislation in the form to be more sustainable creates initial higher costs. These costs could be calculated to the consumer, resulting in higher prices for materials. Conclusions are to take legislation as a gentle push to stimulate sustainability (Guide Jr, Harrison and Wassenhove 2003).

Another possibility to stimulate sustainability in the industry is to set policies. In the Netherlands for example, they aim to have reached certain goals in a period of time. The role of the government is to be an example to other organisations. Policies like buy-in sustainable goods, using green energy, reducing energy usage and emissions are examples of the goals they want to reach (Cramer, Ministerie van VROM 2007).

2.6 Information and communication technology and recovery possibilities

Information and communication technology (ICT) often have a supporting role in complex processes. This section examines how ICT can support the possibilities in recovery and the closed-loop material chain.

A study by Kokkinaki et al. identified that ICT systems for reverse logistics have attempted to address three themes. One is product data, this is data regarding the condition and configuration of the return. The second theme is process facilitation. Process facilitations specifically support operations of reverse logistics. These are like administrative tasks and relate recovery options to returns. The third theme is redistribution to the market. This aspect attempts to consolidate the fragmented market places. A central issue in this theme is how to redistribute the recovered material back to the market (Kokkinaki, et al. 2003). Kokkinaki et al. created the following three dimension figure of current ICT systems in reverse logistics.

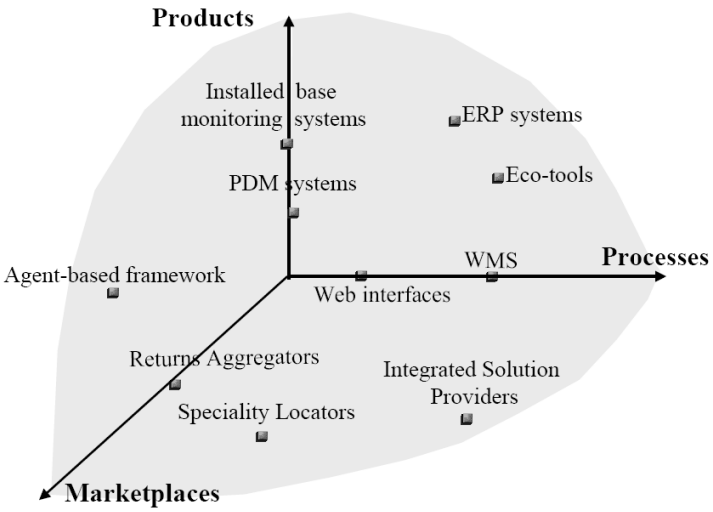

Figure 4: A classification for ICT systems in reverse logistics (Kokkinaki, et al. 2003)

Relating this information to this research, we see that the themes products and processes are important for closed-loop material chains. For this reason, we focus only on these two themes and their belonging ICT systems to advise in the final conclusions how ICT can complement in the solution.

It is important to note that all these systems from the previous figure contain uncertain data. The problem in this research area is that the required data is information about future parameters. This makes the data in these systems uncertain, and the whole recovery option unreliable. Previous studies show that forecasting models that predict return rates and volumes with uncertain information are an issue (Guide Jr. 2000). These uncertainties are marked as significant risks to recover materials in a proper and manageable method (Srivastava and Srivastava 2006). How to mitigate these risks is difficult according to a study by Kokkinaki et al. Investing in ICT systems could be a solution, but will not always provide the wanted outcomes.

Within the field of recovery, the ICT systems move towards a trend like previous developments in information management. Examples are ICT systems like Customer Relationship Management (CRM) and Enterprise Resource Management (ERP). More and more organisations buy these packages to add to their current information management. A new trend is the possibility to install Radio-Frequency Identification (RFID) tags. These tags are small chips, which can be placed in any kind of material. It could contain information about the material. When recovering materials, all properties like quality, production date, and composition are easily read from the chip. This is an example of an investment that mitigates some uncertainty aspects discussed previously.

Other opportunities with RFID are the usage to recover and collect materials. A study by Lee and Chan showed that the RFID technology could be used to develop a sophisticated reverse logistics system. When materials are recovered, the RFID tags are scanned and the computer can decide what the best possible route is for that material to recover.

Lee and Chan demonstrate in their study, the benefits of using a computational intelligence technique and RFID to form an integrated model for optimizing the coverage of product returns. In this way the infrastructure helps to keep track of all sorts of properties like quantity of returned products at each collection point. It will be more easy to determine the transportation possibility from collection points to collection centres. In their results they indicate that the strengths of the system are the ability to get information regarding coverage, and minimizing holding time of recovered material (Lee and Chan 2009).

All these discussed studies show that there are possibilities with ICT to contribute in material recovery. At the end, it is a management decision how to invest in ICT to contribute to the solution of an organisations' recovery. In some studies like the RFID Reverse Logistics System, it will bring enormous possibilities in the whole process of recovery. But is such an investment profitable? This question has to be answered for each recovery in a closed-loop material chain. Next to this, the arguments that confront the fact that the needed information in such complex ICT systems are uncertain and can result in unreliable data, thus unreliable prognoses of the estimation.

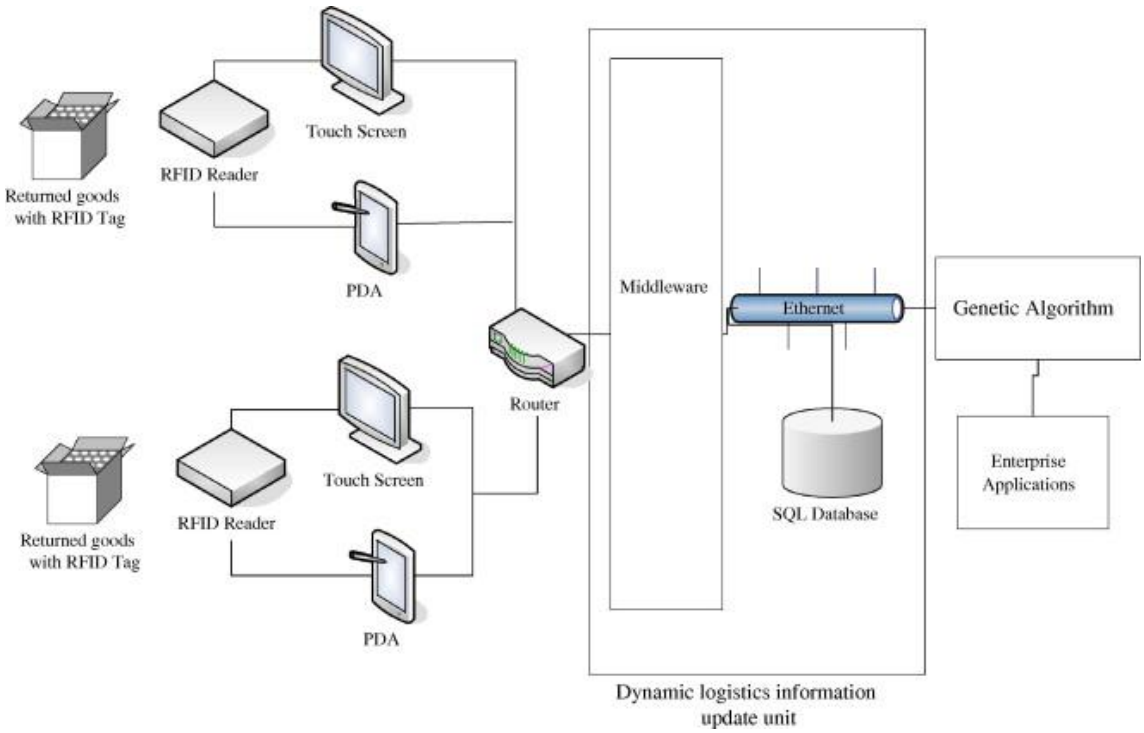

Figure 5: System architecture of RFID-based Reverse Logistics System (Lee and Chan 2009)

2.7 Theories reverse logistics and closed-loop supply chains

To correctly understand what reverse logistics implies, we need to understand what a supply chain is. Supply chains can be divided in activities involving people, technology, transportation, information and resources for a product or service between a producer and customer. A supply chain can be broadened or narrowed down to its own extension. It is at least the flow of materials, information and finances when including the processes between the entities of the supply chain. It can include a necessary collaboration between more than one company or several departments. In the beginning, supply chain management was based upon the forward logistics; meaning all flows within the supply chain from producer to customer. This could mean Business 2 Business (B2B) or Business 2 Consumer (B2C) depending on the focus of the supply chain.

Product recovery, product take back and other policies and legislations became mandated by several nations and companies. This is an important new insight for supply chains previously pointed forward, now also pointed back to the producers. Also known as reverse logistics, reverse implying the backward stream in the supply chain.

Closed-loop supply chains (CLSC) or closed-loop supply chain management (CLSCM) and reverse logistics are terms used closely to each other. Academia have set several definitions for these terms, one of the definitions of reverse logistics is by the European working group on Reverse Logistics (REVLOG).

> *"The process of planning, implementing and controlling backward flows of raw materials, in process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal."* (REVLOG 1998)

CLSCM is described by Guide Jr. and van Wassenhove as follow:

> *"CLSCM is defines as the design , control and operation of a system to maximize value creation over the entire life-cycle of a product with dynamic recovery of value from different types and volumes of returns over time"* (Guide Jr. and van Wassenhove, Closed-loop Supply Chains: An Introduction to the Feature Issue 2006)

There are a lot more terms used closely in this research area. Examples are waste management, green logistics, environmental management etc. These different terms are confusing in the literature and practice (Melissen and Ron 1999). Additional information about all distinctions between these terms can be read in a study by Brito, (Brito, Reverse Logistics - a framework 2002).

A closed-loop supply chain refers to both the forward logistics as well as the reverse logistics of a supply chain. The reason that there is a distinction between the two terms, is because both forward and reverse logistics interact with each other. Material in the chain 'move' in a closed way (Weixin, The principle for closed-loop supply chain design 2003). The following framework shows the schematic view of the closed-loop supply chain, the light colour in the schematic represents the forward logistics, the darker colour represents the reverse logistics.

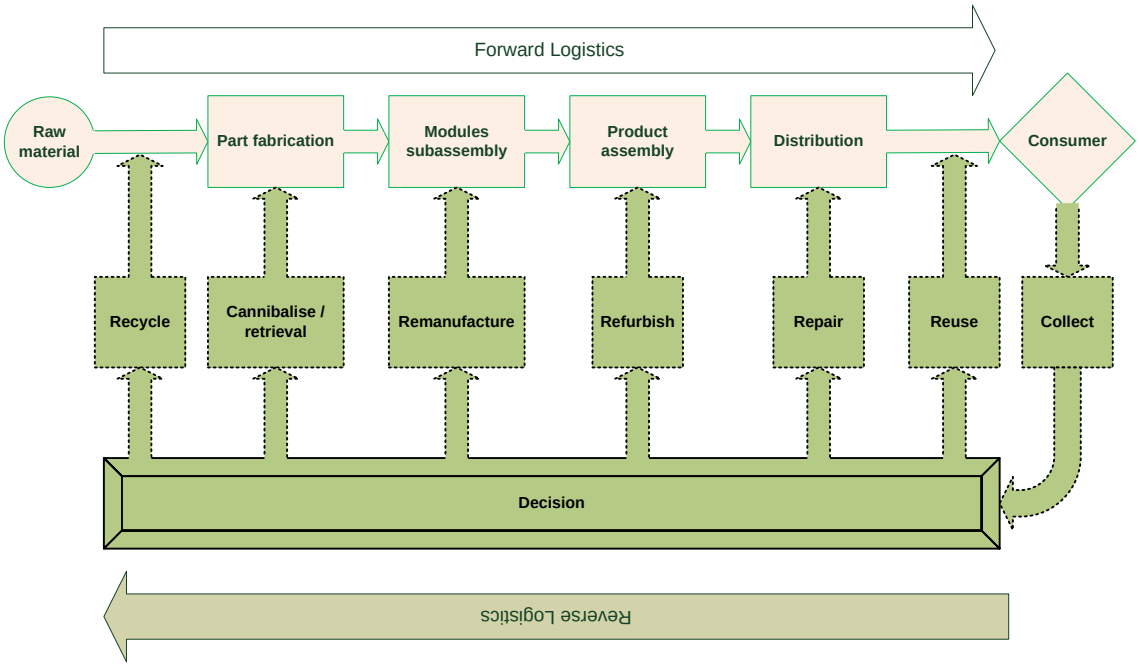

Figure 6: Framework closed-loop supply chain with integrated reverse logistics

In the closed-loop supply chain framework the processes and activities are clearly recognizable. It starts with the supply of raw material from a third party vendor or from an inside department. The flow goes from raw material to part fabrication. In part fabrication the singular parts of an object are made. In the next flow, modules subassembly, the singular parts are assembled to become part of a product. In the following step, the assembled parts are put together to become a product. When the product is finished it will be distributed to the customer. The end of the product lifecycle, is the start of reverse logistics.

The first step of reverse logistics, collection, is one of the most important and complex steps (Lee and Chan 2009). There are several solutions to collect products that will be addressed in the next paragraphs. Once collection is done, a producer must make decisions how the used product can be "closed" back to the supply chain, like intended in closed-loop supply chains. Products are evaluated in the following order, reuse, repair, refurbish, remanufacture, cannibalise and recycle. This order is of great importance, the further you go in the product lifecycle, the more effort it takes to disassemble the product. As shown in the previous figure, the interaction between reverse logistics and forward logistics is intense. Supply to the forward logistics can come on any level, depending on the method that is decided in the reverse logistics. This is typical to closed-loop supply chains.

Now it is known how reverse logistics plays a role in a supply chain, the following step is to understand reverse logistics and its dimensions. Referring to (Brito 2003) there are five dimensions, approached by the questions:

- *Why receiving?*
- *Why returning?*
- *What is being returned?*
- *How are products recovered?*
- *Who is doing the recovery?*
-

2.7.1 Reasons why organisations want their products back

Why receiving? To understand this question it is important to realize that product recovery is done because the producers decide that their products may/can't be disposed with the normal waste. This question is to be answered by the producers. There are several reasons imaginable why organisations are trying to get their products back. Considering the four stages model by Carroll, the motivation for product recovery are the economical benefits (Carroll, Business & Society: Ethics and Stakeholder Management 1996). The second reason is the legal responsibility; the third and fourth imaginable reasons are the ethical and philanthropic responsibility. It is important to notice that initiation of the return is done by the producer. Another reason, which is not mentioned by Carroll, is related to product recovery. This involves products with an issue in safety, health or product errors.

- *Economic benefit.* Product recovery and economical benefits can be realised in many ways, but not in every way. It could be done by direct economical benefits, this means that an organisation can reduce direct costs in recovering their product. Costs can be reduced because the costs in processing waste and old products are lower. Other direct benefits are in line with the direct recovery of materials. In this case it is important to be aware about the costs of raw materials and its shortage, the labour and technological intensity of the materials, and the comparison with the costs of recovery. This is a dependent whether the recovery of products is beneficial or not. Raw material or components are expensive because 1) there is a shortage on the raw material, 2) the production of the material/component is labour and/or technological intensive, or 3) costs of recovery are lower than new material/components because of economies of scale. The Cradle to Cradle concept strengthens this method. Other benefits are indirect economic benefits, these include image building. Product recovery is often related to being sustainable, reputational value of being sustainable improves the reputation and indirectly increases profit in this way (PriceWaterhouseCoopers 2008) (Koedijk, et al. 2006).

- *Legal responsibilities.* In terms of legal responsibilities, an organisation is facing current and future developments in legislations. Many legislations and policies are planned ahead or already mandated involving product recovery. Organisations that already foresee this responsibility can conveniently make use of it and have a head start compared to other organisations. The European Parliament has currently different directives considering product recovery in different branches of products. For example, the End-of-live Vehicles (ELV) Directive for processing cars at the end of their life-cycle. (Fergusson 2007), but also the Waste of Electrical and Electronic Equipment (WEEE) directive. WEEE is currently the fastest growing waste stream in the European Union, producing 8.3 - 9.1 million tonnes in 2005, growing to 12.3 million tonnes of waste by 2020. (Commission of the European Communities 2008). These examples are just a small collection of different sorts of legislation, but show that both government and market are reaching a more sustainable way of working.

- *Philanthropic responsibility*. Also referred as Corporate Social Responsibility (CSR) is probably the less common motivation for organisations to implement product recovery in their supply chain. In Carroll's four stages model it is recognized that product recovery is led by philanthropic responsibility that occurs in the last stage when organisations have all their other goals realized (Carroll, Business & Society: Ethics and Stakeholder Management 1996). Once profit is stable and business continuity is safeguarded, being a good organisation for people and planet becomes a new goal. Brito named this 'corporate citizenship' (Brito 2003), companies that express their respect for the society out of good principle. The firm is 'feeling; socially impelled to act in a certain way (Tichy, McGill and St.Clair 1998).

2.7.2 Reasons why products are brought back

Why returning? In the literature described by Brito, there are three groups differentiated for return reasons. These are manufacturing returns, distribution returns and customer returns (Brito 2003). In this case, for the boundaries of this research, we narrow it down to the distribution returns, that are distribution returns (B2B), and customer returns (C2B). The reason for excluding manufacturing returns is because of the scope of the defined problem. The material chain and problem are viewed from a perspective to seek an answer how to recover products back to the producer, the manufacturing returns include internal flows of recovery within the producer.

Furthermore, we can conclude that there are end-of-use and end-of-life returns in both B2B as C2B. This results in the following options when asks for the return reasons.

- *Business to Business (B2B) returns.* Another business is in this case the customer of a producer. In example, a reseller has an overstock and will return remaining products back to the producer.

- *Consumer to Business (C2B) returns.* This includes the customers that return their product because of warranty, guarantee, reimbursement of other issues concerning product failure.

- *End-of-use returns.* These are products where the lifetime is still ongoing, but the purpose of the product is not relevant anymore.

- *End-of-life returns.* In this case the product has reached the end of its lifetime, the product cannot be used anymore.

2.7.3 Types of product and their characteristics

What is being returned? In both forward as reverse logistics the characteristics and types of a product play an important role. Depending on the answer to the question "What is being returned?", the conditions and methods of the product retrieval are influenced. The following product characteristics are relevant to create an efficient and profitable reverse logistics method.

- *Transportation.* The more compatible the transportation is with common transportation methods, the more efficient the recovery method is. The recovery transportation can often be the same method as it is to transport the products to the customer. The characteristics concerning transportation are as follow:
    - *Size*
    - *Weight*
    - *Shape*

- *Composition.* The composition of a product is the first step to successfully recover products in an efficient way. The simpler the composition is, the simpler the processing of the recovered products is. Gungor and Gupta already stressed this importance between product design and recovery (Gungor and Gupta 1999). The easiness of a products' disassembly and extraction of resources are defined in the design of the product. A good example is the Cradle to Cradle Herman Miller, Inc. Mirra® chair (McDonough Braungart Design Chemistry (MBDC) 2009) where designers specifically designed the chair to quickly disassemble it, and reuse its parts. Summing up, important aspects in a products' composition are:
    - *Homogeneity/heterogeneity*. The homo- heterogeneity of a product is a factor to decide how the product needs to be disassembled and separated its streams of materials. One could imagine the relevance and probability of problems that will occur when several materials are used, and/or hazardous materials are used. The separation of materials and processing the materials has an effect on the economics and time of the whole recovery process.
    - *Disassembly*. The faster and easier a product is disassembled, the more efficient the part will be brought back into the supply chain. An extra advantage is also when the design is made to disassemble quickly and easily, it often is the same when assembling the product. This same advantage occurred in the Herman Miller, Inc. Mirra® chair Cradle to Cradle project (McDonough Braungart Design Chemistry (MBDC) 2009).
    - *Testability*. Testability refers to the possibilities to investigate if the recovered product still has the same quality to be reused. The easier it is to observe if a products' quality is still the same, the easier it is to decide in which forward stream the product needs to re-enter. Having in mind "Figure 6: Framework closed-loop supply chain with integrated reverse logistics" you can see that there are different blocks that represent a level in the supply chain. Testability is important in all these levels within reverse logistics. When products are recovered the testability can decide in which level the product needs to re-enter to the forward logistics.

- *Deterioration.* All products are subject to a deterioration process, the effects of the deterioration have an impact on recovery possibilities. Products deteriorate in different ways, economical and physical deterioration.
    - *Economical deterioration* The answer to this question reveals if the recovered product has an economic value. For example, mobile cellular phones have a rapid economic deterioration. Because functionality becomes obsolete in comparison with newer versions, mobile cellular phones are quickly disposed of. However, the materials and several parts used in the mobile cellular phone do not deteriorate in line with the economical value of it. For this reason, physical deterioration has to be evaluated separately.
    - *Physical deterioration.* Will the physical individual parts of the product deteriorate? Products that exist of several parts could deteriorate equally fast, or not. It is important to evaluate whether the product in total, or in parts still have a value. Hence, a possible low economic value of the recovered product, the products physical value could still be high enough to recycle or reuse it in new parts.

- *Use pattern.* The methods how products are used and bought have an impact on the decision how to recover that certain product. The following aspects have to be taken into account:
    - *Intensity of usage.* The intensity of usage of a product also determines a little about the deterioration like in one of the previous aspects. The only difference is that the variable time is not an important role in the intensity of usage. Imagine a book used by a consumer, when bought, it will be used for one time and stored. The time that the consumer has the book, can be a long time, and deterioration is very slow. However, if the book is used every day, deterioration is faster because of the intensity of usage.
    - *Usage.* An important question with this aspect is if the product is sold and recovered in large scales, or individually sold in small scales. This determines also what possibilities there are to the collection options. One could imagine that if products are used in a large scale, economies of scale could be achieved and offers great possibilities to create a successful material chain.

2.7.4 How to retrieve value out of products

How are products recovered? Recovering products have more aspects than only collecting. When products are recovered, the means are also to evaluate the product. The following recovery tasks are taken into account (Brito 2003):

- *Collection*
- *Inspection / testing*
- *Selection*
- *Sorting*
- *Recovery*

The recovery options are divided into two options, direct recovery and process recovery. Direct recovery is simple, products that are recovered can be used again as a total without any other process that comes in between. Reuse and re-sale are possible options within direct recovery. Reuse implies that products are used again without any purchase in between, in comparison to re-sale, the products are sold again to a new costumer. Examples of re-sale are flea markets.

Process recovery implicates more possible options. Brito summarizes perfectly the recovery options with process recovery; these options are coherent to the schematic of the figure showing the closed-loop supply chain framework with integrated reverse logistics (Brito 2003).

- *Recycle (material level)*
- *Retrieval (at part level)*
- *Remanufacturing (at component level)*
- *Refurbish (at module level)*
- *Repair (at product level)*
- *Reuse (from direct recovery)*

2.7.5 Possible actors and their assignment to recover

Who initiates the recovery? Recovery initiation has three different possibilities.

- *Recovery by producer/manufacturer*
- *Recovery by third party*
- *Recovery by customer*

The first possibility for the material chain is the initiation by the producer self. Recovery can be done direct by the producer, or the producer can appeal to its distributors, retailers or customers to recover their products.

The second possibility to recover products is trough the initiation of third party players. These are recycling specialists, collectors, foundations and dealers. They often collect certain types of products from any producer, and create a large scale of recovered products. Third party players often play a huge role in the recovery, the recovery tasks for example, are often done by these same players. They offer the selected materials from recovery back to interested parties.

The last recovery possibility is initiated by the customer. This is not often seen, but imagines volunteering to recycle you mobile phone or used clothing. Customers still see the functional value in a product and donate the products.

Within these three possible initiators, there are five possible routes when it comes to recovery of products within closed-loop supply chains (Weixin, Atomic models of closed-loop supply chains in e-business environment 2006).

- *Manufacturer – Retailer – Customer – Retailer – Manufacturer*: in this route distribution and recovery is done by the same retailer.
- *Manufacturer – Retailer – Customer – Third-Party – Manufacturer*; in this route distribution is done by a retailer, but recovery is done by a third-party.
- *Manufacturer – Retailer – Customer – Manufacturer*; in this route distribution is done by the retailer but recovery is directly from customer to manufacturer.
- *Manufacturer – Customer – Third-Party – Manufacturer*; in this route distribution is directly from manufacturer to customer, recovery in this case is done by a third-party.
- *Manufacturer – Customer – Manufacturer*; in this route there is only an interaction between manufacturer and customer in distribution as well as recovery.

It is important to note that in practice the recovery of products, do not always return to the same producer that distributed the product. It could easily be, that recovery is already done by another party and keeps it for self use. Important to the closed-loop supply chain is that all resources are

reused again from a reverse logistics into a forward logistics. However, the scope of this research is to focus on products that will recovered by the original manufacturer, and that this manufacturer wants all their products back.

2.8 Risks and opportunities concerning recovery

To create a successful closed-loop material chain, it is important to study the known risks and opportunities to successful recovery. This section covers the found risks and the opportunities that lead to successes.

As already discussed in a previous paragraph covering ICT systems we determined that recovery consists of a lot of uncertain data, making systems and predictions unreliable. Uncertain variables are time, quantity and quality (Guide Jr, Harrison and Wassenhove 2003). Another study by Geyer and Jackson defined three common bottlenecks or risks in closed-loop supply chains:

- Limited access to end-of-life products leaving the use phase
- Limited feasibility of end-of-life products reprocessing
- Limited market demand for the secondary output from reprocessing (Geyer and Jackson 2004)

These risks should be evaluated before any attempt is made to set up a recovery option of a material with a closed-loop material chain. Uncertain data could be mitigated to invest in historical data, collecting all data available about the history of the material. This is also the case to eliminate the problem of limited access to end-of-life products. When historical data is available, it serves as a source for the prognoses. Limited feasibility of end-of-life product reprocessing can only be guaranteed when the used techniques are proven. When the reprocessing technique has not proven to work, it is probable to fail a successful recovery of that material. This is also important for economic prognoses in costs. The last bottleneck or risk, is to invest in demand information of recovered material. The sector who could be interested can be addressed to get an estimation of the demand.

These risks are there to be treated when entering the recovery business. They are only mitigated when actions are undertaken. Besides these risks, recovery brings opportunities and possibilities to add value to an organisation. According to Geyer and Jackson's study there should be searched for a win-win situation in both economical and environmental aspects of a chain. But the study warns for unbalanced equations where the economical aspects will win in respect to the environmental aspect that will lose, or vice-versa (Geyer and Jackson 2004).

Other opportunities are to be ahead of the competition and possible legislation. When organisations already invest in a sustainable approach, they can be ahead of future legislation and the competition, resulting in a possible better market value. Next to this, the pressure from society can put them in the perspective of a considerable organisation that takes responsibility for their activities, and be rewarded in this way by society.

A bottleneck that needs to be discussed is alliances or collaborations. The paragraph "How to retrieve value out of products" focuses only on the internal process and possibilities when products are already collected. But to have a successful retrieval in reverse logistics, it is important to zoom out one level, and review the possibilities how the actual process of collecting is tackled. In practice, it seems that many of the supposed alliances to achieve a successful material chain have failed because of lack of collaboration and perseverance. This is not a surprise. Several studies have

shown that alliances between organisations are risky (Gomes-Casseres 2000). Although alliances are risky, organisations do not discourage this way of business. All imaginable risks that an organisation can encounter are shared with the collaborative partner (Alter and Hage 1993). Another important motivation to join forces is to share costs and to gain knowledge. These advantages come for the price to also share the profit that is gained by the alliance.

There are two varieties in collecting. The simple model is that the producer has all processes in the total supply chain in control, from producing to distribution to recovery. This means that it controls: all supplies, logistics, transportations, collections and other processes. The advantages of a producer that has control over all these processes, are that the producer could align the work and create an efficient and effective closed-loop supply chain. As it is one company, with the same goals and visions, and can collaborate within the cooperation with other departments to achieve these collective goals and visions. Unfortunately, this is very uncommon in the industry.

The more common and sophisticated model is that a company only has one of the roles in the total supply chain of a product. To achieve a successful recovery of products in this scenario, it is a necessity to collaborate and start alliances with other organisations. Alliances in a material chain can be met in different stages and purposes of the material chain. Due to limitations of this research the investigation of alliances are narrowed down towards recovery of products and distribution of raw materials to work towards a Cradle to Cradle solution. All other alliances like transportation partnerships and distribution partnerships, are taken into account. This results in three main varieties in material chain alliances that are discussed in this research:

- Alliance to find a dedicated partner to recover products, to get professional help in recovering products
- Alliance to find a partner to recover a certain kind of waste, to create economies of scale
- Alliance to find a partner to buy-in a raw materials, to work towards a Cradle to Cradle solution

Although there are three different varieties of alliances, to create a successful collaboration, the issues are basically the same. Collaborations are not always successful. It is important to have a qualitative and healthy management to organize and lead an organization towards success (Berendsen, Alders and van Liere 2006). This means that the first reflection is to evaluate if the company's own management is managed in a 'good' way. Setting up an alliance will cost money, time and energy. It is for this reason important to evaluate if the alliance is a good investment. Before an alliance is setup, we need to consider the lifetime of the alliance, the goals we need to reach with the collaboration and the expected results of the alliance before the decision can be made if an alliance is the solution to the problem.

Once decided to setup an alliance, there are several phases to walkthrough to control risks and achieve a successful alliance. There six phases of lifecycles in an alliance (Berendsen, Alders and van Liere 2006).

Phase 1: Awareness.

Recognizing the strategic decision-making to setup an alliance. Questions are analyzed to reflect if an alliance is a strategic possibility. Evaluate lifetime of an alliance, set goals of the alliance and consider expected results of the alliance.

Phase 2: Exploration.

Preparations and selection to consider potential partners to collaborate. Setting up a basis of the alliance by measuring each other's goals and expectations. Central aspects are to explore several potential partners, and communicate ideas with each other.

Phase 3: Commitment.

Agreement with the potential partners. A partner is found on the basis of matching goals and visions of the collaborations in phase 2. In this phase, practical conditions of the agreement are formed. How to divide risks, revenues, knowledge and other issues of the alliance. In this phase the focus is to make the alliance operational.

Phase 4: Expansion.

During the expansion of the alliance the focus is to strengthen the alliance. Activities within the alliance are divided, and protocols are defined. The intense exchange of information, people and resources between the partners creates a narrow band with each other.

Phase 5: Exploitation & continuous improvement.

Continuing, maintaining and improving the alliance. Central issues are how to control processes within the alliance and assess achievements. An important factor is to learn from the alliance, and evaluate how to improve the performance of the alliance.

Phase 6: Dissolution.

This phase is to end the alliance. How to do this in a controlled manner where both parties can secure all gained benefits. For this research, the phase of dissolution is not that important. We will focus in setting up, maintaining and improving the alliance.

2.9 Contribution literature review to the research

Thanks to the brainstorm sessions in the preparing stage of the literature review, it is possible to identify the topics that needed to be explored in the available theoretical studies. Seeking answers to stakeholder and objectives in this problem, C2C, responsibilities, motivations, legislation, policy and ICT possibilities in recovery, gives an overview of the academic perspective about these topics. The gained knowledge by investigating reverse logistics and closed-loop supply chain management gives the possibility to understand the context of the problem.

The C2C basic principle is to redesign products to be good for the environment. Having in mind the objectives of all stakeholders, C2C fits to create a possible better environment by producing according the C2C principles. Allowing in this way, to maximize profit for the industry, creating a better planet for the government and giving the consumers the best quality products.

An important bottleneck identified in C2C that also concerns this research, is recovery of products in the technical cycle. Additional bottlenecks and risks are uncertain information about end-of-life, feasibility of reprocessing, market demand and alliances.

Investigating studies about current methods for recovery, like reverse logistics and closed-loop supply chain management noticed that these studies were focussed on describing the recovery instead of implementing them in practice. For this reason, other additional aspects that are mentioned in the brainstorm sessions were taken into account during the literature review. These additional topics are alliances and risks of recovery. This review adds these topics to the current studies from Brito, that describe the recovery (Brito, Managing Reverse Logistics or Reversing Logistics Management? 2003). Derived from literature review is a theoretical framework to be used for conducting the case studies, this is discussed in chapter 4.

3 Research methodology

This research is conducted during an internship at NL Agency. During this research, there are several aspects that have been approached by different methodologies. The overall research is based on a qualitative research method, exploring the why and how of decision making (Denzin and Lincoln 2005). This research method fits exactly in the type of problem formulated in this research. In the following sections the motivations and contributions of the used approaches like Grounded Theory (GT), case studies, frameworks and questionnaires will be discussed.

This chapter discusses the methodology to approach the general main question defined in chapter one of this research.

"How can the Dutch industry get better practical insight in the feasibility to recover materials with closed-loop material chains?"

The goal is to answer the general question stated above, and find a solution to the defined problem in this research. To do this, we introduce sub-questions that will answer themes within the general main question. These sub-questions structuralise the subjects within the problem, parallel to the methodologies used in this research. In the final stage, all answers contribute to the research conclusions, answering the general question in total. The sub-questions are:

1. What are the overall basic principles of C2C and their stakeholders' objectives?
2. What are the bottlenecks in C2C and recovery?
3. What are the bottlenecks of recovery in practice?
4. What is the gap between current studies and the industry?
5. What is needed to overcome the gap between current studies and the industry?
6. How to give practical insight in the feasibility of closed-loop material chain recovery?

Sub-questions 1 and 2 are already answered thanks to the literature review from the previous chapter. Sub-question 3 will be answered in the chapter "Empirical research" where the case studies are finalized. In the chapter "Framework building", questions 4, 5 and 6 are answered. Leading to the chapter "Conclusion and recommendations" where the general main question will be answered.

3.1 Grounded theory

There are several qualitative research approaches. These approaches are all qualitative research methods, but differ in the manner and field of research to reach the goal. The chosen approach for the setup of this research is "Grounded Theory". The strategy of the grounded theory is to generate a theory / hypothesis from the found relevant information (Martin and Turner 1986). Instead of formulating a hypothesis first, and conducting a research afterwards to test the hypothesis, grounded theory starts the research by collecting data. Data sources for grounded theory are for example quantitative data, interviews, observations and surveys. Aspect like the scope of the investigation, the main question of the research and the goal of the research are first defined. The next stage is to set up a theoretical framework. The theoretical framework helps to conduct and compare case studies and analyze gathered data and conclusions.

3.2 Case study methodology

To complement the Grounded Theory, the Case Study methodology is also applied. The total case study approach is fluently incorporated within all segments of this total research. The following figure shows a graphical overview of the case study approach. The first things to notice are the 3 stages in this approach:

1. Define and Design
2. Prepare, Collect, and Analyze
3. Analyze and Conclude

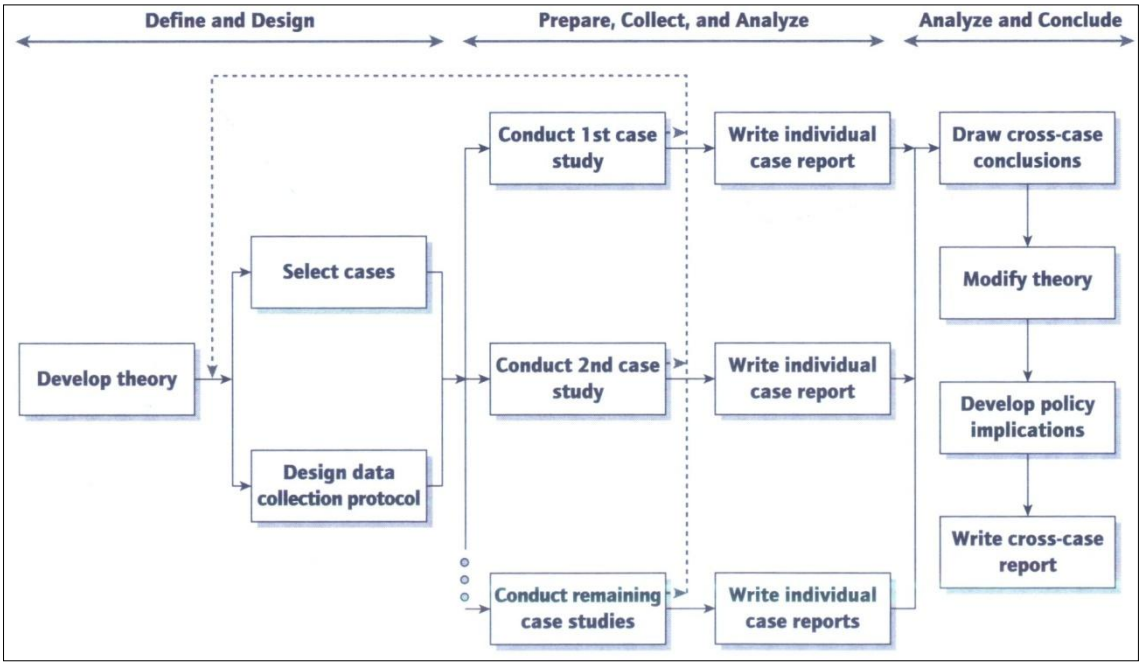

Figure 7: The used Case Study Methodology for this research (Yin 2009)

Develop theory: This is done by using the grounded theory approach. To develop a theory, brainstorm sessions are done in the preliminary stage of the literature review. This provided the topics to be investigated and summarized the central theory used for this research. This can be found in chapter 2: Literature review.

Design data collection protocol: The results of the literature review form a theoretical framework. The selected elements from the literature review form the pillars of the theoretical framework. This theoretical framework is used to collect data from the case studies. In chapter 4: Theoretical framework, the details and usage of the theoretical framework are explained.

Select cases: In this segment, the cases are selected to be used as case studies in this research. The motivation why and which cases are selected, is explained in paragraph 3.3: Case study selection methodology and interview structure.

Conducting case study & write individual reports: Thanks to the theoretical framework that is used as a protocol, the cases can easily be compared. After conducting the case studies, the individual reports with all findings are written. This is described in detail in chapter 5: Empirical research.

Draw cross-case conclusions: An overall conclusion is written based upon all case studies and assessed with the known theory. The case studies could easily be compared with their differences thanks to the theoretical framework. Paragraph 5.5: Case study conclusions discusses this.

Modify theory: Small modifications are made in the theory based on the comparison done between the case studies and known theory. Different aspects of the research findings are added or deleted to the concluding theory. These modifications are described in paragraph 6.1: Findings and interpretation.

Develop policy implications: All results lead to the final end-product and solution of this investigation, a closed-loop material chain framework with an additional questionnaire to measure feasibility of closed-loop material chains. With the known modifications in the theory, new suggestions and approaches are developed by creating the framework and questionnaire. Further reading about the development and testing of these tools can be viewed in chapter 6: Framework building.

Write cross-case report: This stage of the research refers to the final chapter 7: Conclusion and recommendations. In this chapter all results and comparisons from the total research will be recapitalized and a final conclusion and recommendations are made.

3.3 Case study selection methodology and interview structure

There are four case studies conducted to study practical experience. Having in mind the defined problem, namely finding the answer to give the Dutch industry insight in the feasibility of recovery with closed-loop material chains, makes the criteria for the casus simple.

Starting with the criteria Dutch industry. The Dutch industry represents all sorts of materials and products. Therefore it is important to include a range of different material chains in the conducted case studies. The higher the variation is in the cases, the more representable it represents the Dutch industry. Currently there are a few material chains operational or investigated. There are several consultants within NL agency currently working on material chain cases. Each material chain has its own expert on this area. These experts are invited to represent a material chain case. Furthermore, it is explicitly chosen to use material chains where recovery is a success, and where it is not a success. The purpose of this distinction is to identify success factors and bottleneck factors in practice. This makes it simple to select the cases. It has to be representable to the area of research. In this case, a general insight in feasibility of material chain recovery concluded to seek cases that are material chains with different types of material.

The results are that the selected case studies are:

- Asphalt material chain
- Paper and cardboard material chain
- PVC material chain
- Mattress material chain

The interviews conducted with the four cases are semi-structured interviews. Semi-structured interviews makes it possible to derive in-depth information about specific subjects from the interviewee (Wengraf 2004). The theoretical framework is used for the content of the interviews. Using the theoretical framework brings theoretical knowledge to the test with practical experience. In this way, an attempt is made to join theories and practical experience to be useable and available for closed-loop material chain approaches.

3.4 Theoretical framework

The theoretical framework is derived from the literature review that is summarized in the previous chapter. The purpose of the theoretical framework is to create a protocol on which the case studies can be assessed with. The theoretical framework exists of several diagrams and a table of questions coherent to the diagrams. The diagrams are a graphical presentation of all relevant subjects from the literature review. Coherent to these subjects are questions. In an additional table of questions, all subjects are discussed during the case studies. In this way we can structure the case studies and verify gathered information between cases.

3.5 Data analysis

The table of questions from the theoretical framework gives an overview of the subjects that are relevant in practice and what subjects are discussed in the literature. Comparing the literature and cases in this manner, provides the needed information on what current theories can add to practical experience and vice versa. As earlier argued, there is a need to join known theoretical theories with practical experiences.

From the results, it is possible to derive the criteria that is needed to introduce in the new model. Assessing and comparing findings with the table of questions. All added or deleted subjects are taken into account in the final model, the closed-loop material chain framework. By comparing the existing literature about reverse logistics and closed loop supply chains with the case studies in practice of several different material chains; this research indentifies the important issues about the process to create a material chain where the producer's waste can be successfully and cost efficiently retrieved.

3.6 A closed-loop material chain framework concept

The objective of a framework in this research is to create an overall understanding about closed-loop material chains. It structures the subject and shows the relations between each concept within the chain. By comparing it to reverse logistics and closed-loop supply chain theories, it identified the elements and dimensions in the subject and explains their relations between each other. When forming this information in a framework, it allows the user to get more insight about the subject of closed-loop material chains.

The closed-loop material chain framework is designed to be used by companies. It creates an overall understanding, thus more insight to the industry about the issues concerning closed-loop material chains in practice. Many companies identify the possibility to be more sustainable to the environment, but do not know how to tackle this as an organisation. They recognize a complex supply chain and a stream of waste that is a result at the end of the supply chain. Questions arise how to tackle this problem, where to start and how to benefit from it.

The framework will be a guide through this process. It helps identifying important issues within the closed-loop material chains, and gives the user more insight of the possibilities in the chain. This framework allows every organisation in whatever branch to use the framework and discover what issues exist when an attempt is made to create a closed-loop material chain.

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3.7 A closed-loop material chain questionnaire concept

The closed-loop material chain questionnaire is formed from all issues noted in the framework. The framework gives insight and an overview of the closed-loop material chain, the questionnaire grades the feasibility of the closed-loop material chain.

Using all issues from the framework, and forming them in closed-ended questions where the response is dichotomous, it makes it possible to grade each answer. The answers in total will be calculated to a feasibility percentage. Thanks to these questions and the different feasibility grades, it is possible to identify personal bottlenecks in the chain of the user. Because the questions are answered dichotomous, the opposite answer of a negative answer is the advise to mitigate that certain issue. In this way, the questionnaire functions as a tool to calculate feasibility of a closed-loop material chain, and advises immediately on issues that form a bottleneck for the material chain.

To grade feasibility per question, it is important to grade the questions on their relevance and impact. When grading all questions individual, it is possible to distinguish which questions have more impact than others on the feasibility scale. The feasibility scale will be in percentage from 0% to 100%, being the lowest percentage not feasible and the highest percentage very feasible. The gradation of the questions is done by the same experts used for the case studies and additional people from different backgrounds that are considered recovery experts. These additional persons vary from background from high academia, to process recovery engineer. The reason to add other persons is to verify that the gradation is not influenced by earlier discussions. The gradation of question will be done by 7 persons. After the gradation, the questionnaire is finished and tested with new cases found by the same selection methodology criteria as used for the initial cases.

3.8 Reliability and validation

Because of the nature of this research, it is a necessity to conduct this research using several methodologies. Qualitative research investigates the how and why of a certain problem. In this case, this research investigates how to create a closed-loop material chain and give insight in the feasibility of such a chain.

The grounded theory support the function to create a new type of theory. Diving into the subjects reverse logistics and closed-loop supply chains, creating a new concept closed-loop material chains with new insights to analyze chains from the perspective of product or material characteristics. The use of both literature review and case study methodologies only strengthen the research findings.

The chosen method to create a framework, is to give organisations a graphical overview and more insight about material chains. A model that structures certain concepts and gives a graphical overview of the subjects in closed-loop material chains. With the additional questionnaire, it is possible to grade the feasibility of the intended closed-loop material chain. The separate gradation of the impact of answers makes the questionnaire a reliable tool to assess the feasibility of the chain with. Thanks to build in controls, assessments and tests, the reliability of the questionnaire to grade the feasibility is of a high quality.

These controls and assessments are in this research found in several forms. The research is more reliable when the persons involved in the research are independent (Dul and Hak 2008). In this investigation, the researcher and the interviewed experts take an independent role. The interviewed experts are not stakeholders in the material chains they hold as an expertise. They are

independent consultants from the government guiding material chains that are set up by the industry.

Validation is according to Dul and Hal achieved when the results of the research are applicable in other settings and environments then the area conducted in (Dul and Hak 2008). This validation is tested, when the end results of the research are used to give more insight and grade feasibility of other material chains than discussed in this research. Unfortunately, the limitation in time does not offer the validation if the material chain can fully operate based on the advices of the questionnaire and framework.

4 Theoretical framework

As already mentioned earlier, the theoretical framework has been derived from the literature review. The purpose of the theoretical framework is to create a protocol on which case studies can be assessed with. This literature review provides a solid basis to understand the issues and possible problems that occur when material chains are created. By using the found information during the literature review, it was possible to create a theoretical framework existing of graphical overviews in the form of diagrams and a table of questions coherent to the subjects mentioned in the diagrams. They bring all aspects together that occur in material chains. The gathered theories of the literature are essential to the process in setting up a material chain. The current limitation in these diagrams are the practical suggestions that have to be incorporated to be a useful closed-loop material chain framework.

Next to the diagrams, a table of questions has been created with all aspects that are mentioned in the diagrams. This table of questions will be helpful during the case studies to note if handled aspects from the literature review were important in practice or not. In the following stages of this thesis, the results of the case studies and the theoretical framework are compared and interpreted to discuss in final conclusions and solutions.

4.1 Diagrams

The first diagram has the central question why organisations would recover. The three possibilities to recover according to the literature are economic benefit, legal responsibilities or philanthropic reasons. The diagrams contain also a short explanation of the different aspect in this context. Economic benefits can be created by reducing costs and saving money in processes. For example, reducing costs because conventional waste disposal methods are more expensive than offering the material for retrieving options. Direct economic benefit could be created because the recovered material is for example cheaper than the virgin material. An example of an indirect economic benefit can be that an organisation improves its reputation towards the market and indirectly increase profit because of it. The legal responsibilities in the first diagram is divided in two options. Future and current legislation. The difference is that organisations that initiate their recovery under the motivation of future legislation, can create an advantage compared to their competitors. The downfall of it, is that the organisation is the only one in the sector initiating recovery, and possibly cannot get support from other parties. When initiation of recovery is done because of current legislation, it means that the total sector is committed to recover. It is probable that organisations help each other to recover and meet legislation standards. The philanthropic responsibility is when organisations initiate recovery just to be good to the environment. There are no additional benefits than being innovative and creating a better environment for all.

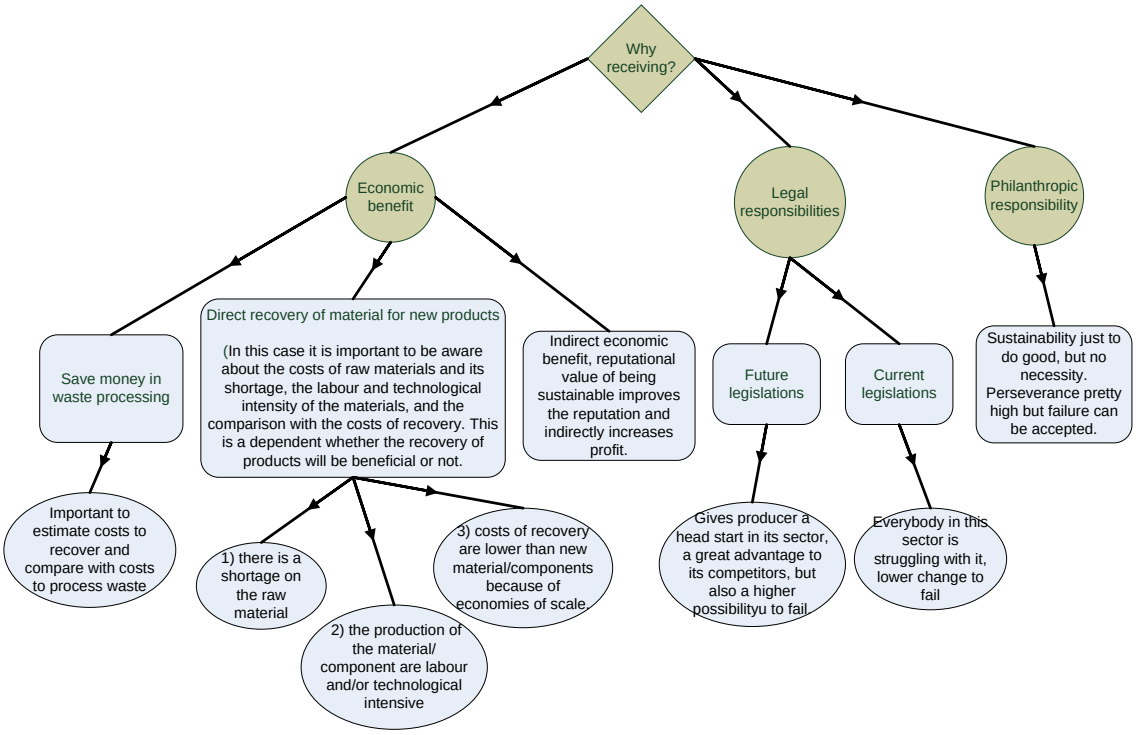

Diagram 1: Why receiving? - Theoretical framework

The second diagram covers the motivation why other parties than the producer would return the material. Four options are discussed in the literature, namely B2B, B2C, end-of-use and end-of-life returns. Identifying the return reasons gives information about the material being recovered. B2B returns can for example imply bulk usage and can create scale advantages. C2B can imply faulty products that cannot be used anymore. Within these return origins, there are two return possibilities, end-of-use and end-of-life returns. The difference is important, end-of-use suggests that the material is still good but not used anymore, end-of-life suggests that the recovered material is passed its lifetime and qualitative not good anymore.

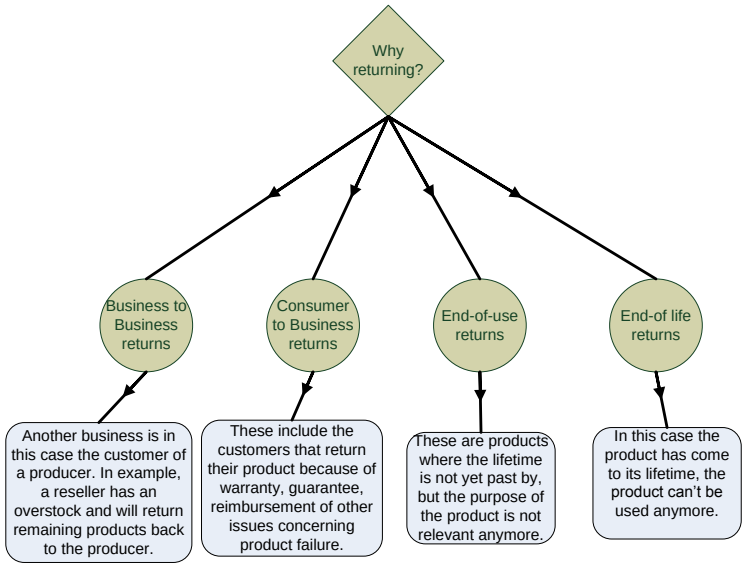

Diagram 2: Why returning? - Theoretical framework

The third diagram gathers in-depth information about product characteristics, what is being returned? There are four main product characteristics indentified, use pattern, deterioration, composition and easiness of transportation. The product characteristics give more information about the product seen from the perspective of recovery. The purpose of analysing these characteristics is to discover if the materials or products grants itself to be recovered.

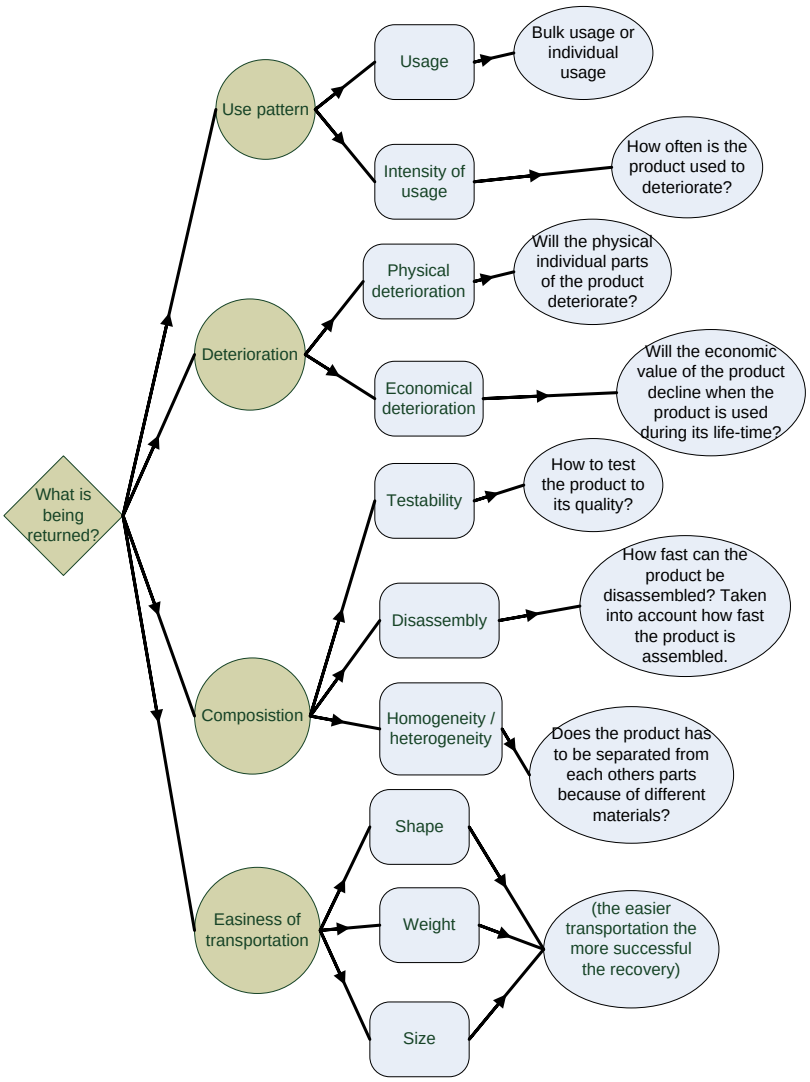

Diagram 3: What is being returned? - Theoretical framework

The fourth diagram tries to distinguish how products are recovered, and what possibilities there are to recover. Recovering products have more aspects than only collecting. The following recovery tasks are taken into account: collection, inspection / testing, selection, sorting and recovery. The recovery option is divided in two options, direct recovery and process recovery. Direct recovery is simple, products that are recovered can be used again as a total without any other process that comes in between. Reuse and re-sale are possible options within direct recovery. Reuse implies that

products are used again without any purchase in between, in comparison to re-sale, the products are sold again to a new costumer. Process recovery has more options. Recycle at material level, retrieval at part level, remanufacturing at component level, refurbish at module level and repair at product level.

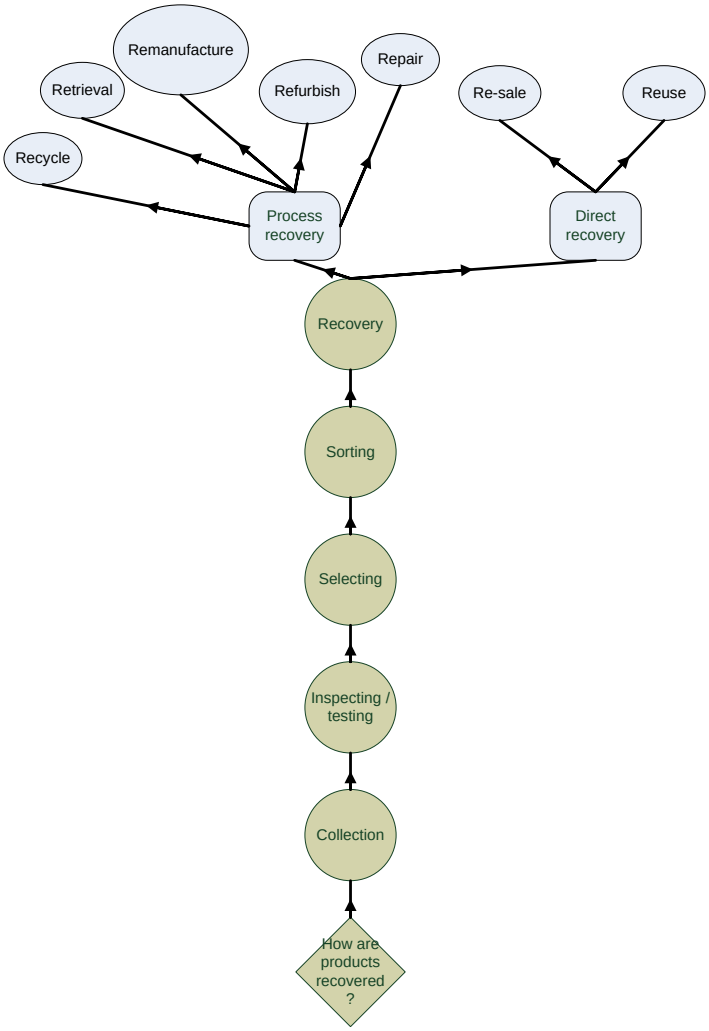

Diagram 4: How are products recovered? - Theoretical framework

The fifth diagram handles all aspects for alliances, and discusses which steps within an alliance is important. *Phase 1: Awareness*. Recognizing the strategic decision-making to setup an alliance. Questions are analyzed to reflect if an alliance is a strategic possibility. Evaluate lifetime of an alliance, set goals of the alliance and consider expected results of the alliance. *Phase 2: Exploration*. Preparations and selection to consider potential partners to collaborate. Setting up a basis of the alliance by measuring each other's goals and expectations. Central aspects are to explore several potential partners, and communicate ideas with each other. *Phase 3: Commitment. Agreement with the potential partners.* A partner is found on the basis of matching goals and visions of the collaborations in phase 2. In this phase, practical conditions of the agreement are formed. How to divide risks, revenues, knowledge and other issues of the alliance. In this phase the focus is to make the alliance operational. *Phase 4: Expansion.* During the expansion of the alliance the focus is to strengthen the alliance. Activities within the alliance are divided, and protocols are defined. The intense exchange of information, people and resources between the partners creates a narrow band

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with each other. *Phase 5: Exploitation & continuous improvement.* Continuing, maintaining and improving the alliance. Central issues are how to control processes within the alliance and assess achievements. An important factor is to learn from the alliance, and evaluate how to improve the performance of the alliance. *Phase 6: Dissolution*. This phase is to end the alliance. How to do this in a controlled manner where both parties can secure all gained benefits. For this research, the phase of dissolution is not that important. We will concentrate in setting up, maintaining and improving the alliance.

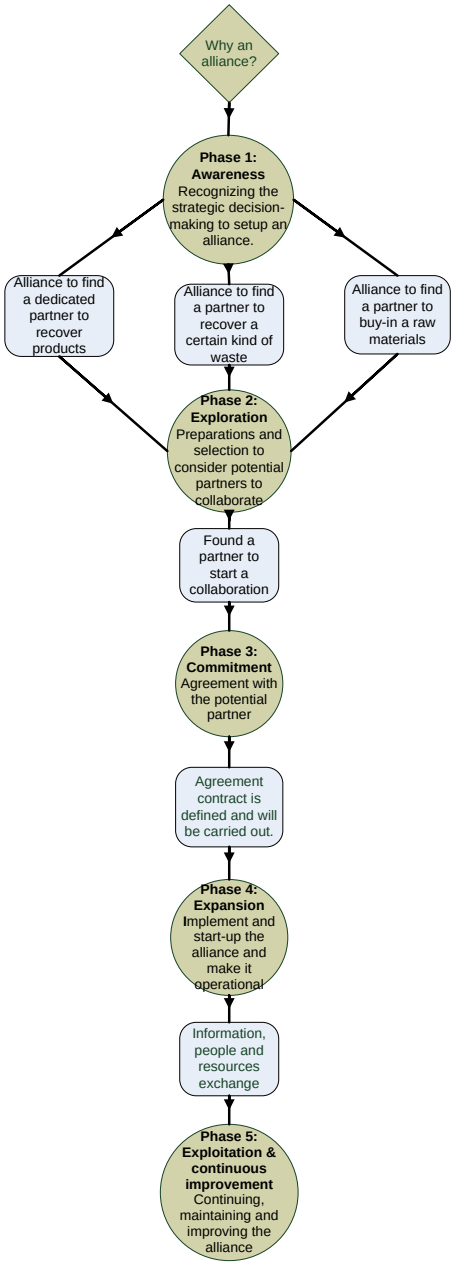

Diagram 5: Why an alliance? - Theoretical framework

The sixth diagram is about the recovery initiation and route. According to the literature, the more links there are, the more problems are expected. The first possibility, and the most important possibility for the material chain is the initiation by the producer. Recovery can be done direct by the producer, or the producer can appeal to its distributors, retailers or customers to recover their products. The second possibility to recover products is trough the initiation of third party players. These are recycling specialists, collectors, foundations and dealers. They often collect certain types of products from any producer, and create a large scale of recovered products. Third party players often play a huge role in the recovery, the recovery tasks for example, are often done by these same players. They offer the selected materials from recovery back to interested parties. The last recovery possibility is initiated by the customer. This is not often seen, but imagine, volunteering to recycle you mobile phone or used clothing. Customers still see the functional value in a product and donate the products.

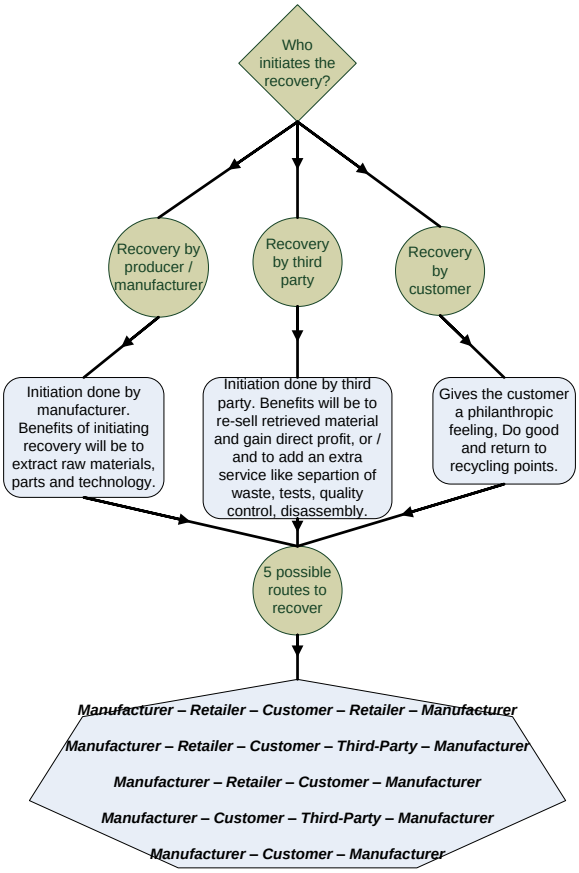

Diagram 6: Who initiates the recovery? - Theoretical framework

The last diagram, number seven is a diagram about risks in recovery. This diagram attempts to find out if the risks in the literature are also occurring in practice. The risks are all occurring because of uncertain data of future recovery. These risks should be evaluated before any attempt is made to set up a recovery option of this material with a closed-loop material chain.

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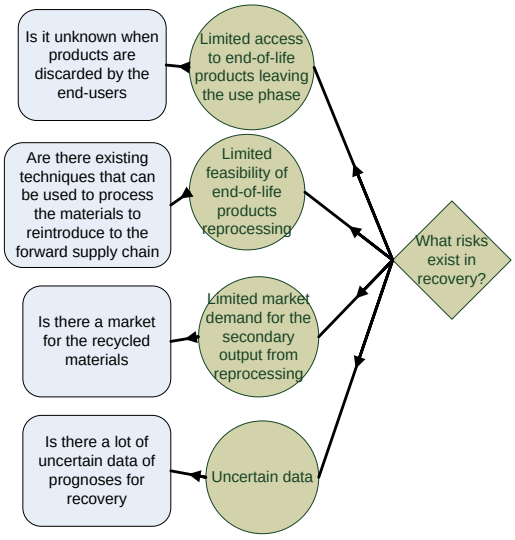

Diagram 7: What risks exist in recovery? Theoretical framework

The purpose of the diagrams are to give the interviewee an overview during the interview of all subjects that will be handled. Each diagram is a topic within recovery that structures the case study interviews.

4.2 Table of questions

The table of questions consist of the subject found in the literature review. The table of questions are an extension of the diagrams. Where the diagrams visualize the relations of the aspects, the table of questions create a logical sequence of questions to be handled during the case studies. Each aspect in the diagrams is a certain question handled in this table. The purpose of the table of questions, is to structure answers given in the case studies, and to simply evaluate and compare results after conducting the case studies. The questions are closed-ended questions with three possibilities, relevant to the chain, relevant to other chains or not relevant at all. Additional comments are noted during the interview.

The purpose of the table of questions is to give the interviewer a logical sequence of questions to be asked. The conducted case studies are in this way comparable because all content of the case studies covers the same topics as the other.

4.3 Contribution of the theoretical framework in this research

The literature review of chapter 2 are the pillars for this theoretical framework. Thanks to the brainstorm sessions in the preliminary stage of the literature review all topics are defined. These topics are investigated and recapitulated in the literature review. High-lighting the elements of the investigated topics and structure them in diagrams and table of questions gives the possibility to provide a graphical overview and logical sequence of questions for the case studies.

This theoretical framework is used during the case studies in chapter 5. It structures and determines the discussed content of each case study. In this way it is easier to compare findings of the cases.

Table 1: Table of questions

Why receiving?	Economic benefit	*Does the chain save costs on waste processing?*
		Will costs be reduced by direct recovery of materials?
		Is there an indirect economic benefit?
	Legal responsibility	*Is there a possible future legislation effecting the chain?*
		Are there current legislation effecting the chain?
	Philanthropic responsibility	*Is the consideration to recover for philanthropic reasons?*
Why returning?	B2B returns	*Are businesses returning the materials in this chain?*
	C2B returns	*Are consumers returning the materials in this chain?*
	End of use returns	*Are products returned because they are not used anymore?*
	End of life returns	*Are products returned because they do not function anymore?*
What is being returned?	Use pattern	*Is the usage in bulk?*
		How often is the product used to deteriorate?
	Deterioration	*Will the material physically deteriorate?*
		Will the economic value of the product decline when used?
	Composition	*Is the product easy to disassemble?*
		Does the product has to be separated because of different materials?
		Does the material has to be tested before reprocessing?
	Easiness of transportation	*Is the shape of the material easy to transport?*
		Is the size of the material easy to transport?
		Is the weight of the material easy to transport?
How are products recovered?	Collection	*Are collection methods relevant for the material chain?*
	Testing	*Is testing relevant to recover in the material chain?*
	Selecting	*Is selecting relevant to recover the material?*
	Sorting	*Is sorting relevant to recover the material?*
	Recovery	*Is the recovery method a direct recovery?*
		Is the recovery method a process recovery?
Why an alliance?	Awareness	*Is the alliance to find a dedicated partner to recover products?*
		Is the alliance to find a partner to recover certain kind of waste?
		Is the alliance to find a partner to buy-in raw materials?
Who initiates the recovery?	Recovery by manufacturer	*Is the material chain initiated by the OEM?*
	Recovery by third party	*Is the material chain initiated by a third party?*
	Recovery by consumer	*Is the material chain initiated by the consumer?*
What risks exist in recovery?	End-of-life moment	*Is it unknown when products are discarded by the end-user?*
	Techniques to reintroduce	*Are there no proven techniques to reprocess the materials?*
	Market demand recovery	*Is there no market for the recycled material?*
	Uncertain data	*Is there a lot of uncertain data of prognoses for recovery?*

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5 Empirical research

The data for the empirical research is provided by interviewing "experts" in the field of waste- / material chains They are consultants at NL Agency. They play a narrow role in the development, progress and setup of several chains to recover material. Every interviewee has a field of expertise in a certain material. Their knowledge is based on practical experience, problems and successes that they encountered to create a closed-loop material chain. An additional advantage of the chosen interviewees is their general knowledge of material chains. They know specific details about their own chain, but also have general knowledge of all other material chains.

This section compares practical experience of these cases to the theoretical framework. By using the results of the theoretical framework, several diagrams that visualized the known theoretical science about recovery are used in combination with the table of questions. This theoretical framework, existing of the diagrams and table of questions is used to structure the interviews and get in-depth information about the research area. During the interview, all additional information provided from practical experience are noted, in this way we will join findings in theory and practice as a whole. After conducting the interviews, we can answer sub-question 3: "What are the bottlenecks of recovery in practice?", that is defined in the chapter "Research methodology".

5.1 Case study: Asphalt material chain

5.1.1 Introduction

Martijn van Groen from NL Agency is an consultant for the asphalt material chain. The goal of this case study is to compare if practical experience in the asphalt material chain are coherent with the theoretical framework. Objectives are to find practical bottlenecks, specific success factors, and to find out if elements are missing or should be added to the diagrams. By conducting this case study we will understand in detail how the asphalt material chain works.

5.1.2 Interview

The asphalt material chain is currently a successful working chain, 100% of all asphalt material is recovered and 40% is recycled according to van Groen. An important advantage is the fact that the producers of asphalt in the Netherlands are also the contractor to place the asphalt on the roads for the customer. Besides this fact, the contractors are also responsible to process and take away any old asphalt from the old roads when replacing it with new asphalt. This means that existing routes in the forward logistics are used to reverse the logistics back to the producer. This is once again simplified because there are only a handful producers in the Netherlands. It is easy to know each other's quality, the only obstacle is that testing is required.

When walking through the theoretic framework, the reason to recover is because of existing legislation for this chain. The literature states that in this case all entities in this sector struggle with the same problems, this results that the chance in failure is smaller. There were no other reasons why the asphalt material chain is receiving back their own products.

Returning asphalt is done on the basis of business to business (B2B). The return reason of asphalt is the end-of-life of the asphalt. In this material sector, old asphalt is often replaced for new asphalt. But according to van Groen the B2B returns does not change the possibilities in recovery. It is an aspect to be aware of, but does not influence the possibilities. The return reason end-of-life and the fact that asphalt is often replaced, results in both an equal flow of demand in new asphalt and supply in old asphalt. This is an important factor, the cycle of a material chain needs to have a constant flow of continuity in supply and demand to reach a successful closed-loop material chain. Given the fact that replacement of asphalt is common, the possibilities to use the same forward logistics transport route to recover old asphalt is often used. This saves transportation costs and provides a constant flow within the cycle.

Asphalt will physically deteriorate but still has a perfect potential to use it recycled in new asphalt. It is a material that is not easily disposed and the quantity used are often in bulk. The supply of new asphalt to a location gives immediately the opportunity to recover the old material. Legislation demands a correct manner of processing old material in this sector. The responsibility lays with the contractor replacing the asphalt, they are responsible to carry out the right processing manner for old asphalt. As already stated above, the contractor is also the producer, thus the same route can be used. The only issue is that recovered asphalt is not necessary of the same composition as the receiving producer. The handful producers of asphalt in the Netherlands, thus several contractors to place the asphalt. It could easily be that a producer takes back asphalt that has its origin from another party. In this case it is important to test the old asphalts composition and determine in what manner it could be used in recycling. Because it is probable that producers get each other's products, testing and recognizing each type of asphalt is important. This goes along with a need to collaborate between producers. Alliances are necessary.

5.1.3 Conclusion asphalt material chain

Concluding, the successful asphalt material chain has current and future legal responsibilities. This is the main motivation for the closed-loop material chain. But other than that, the recycled material is cheap to reuse compared to virgin material. The reasons for returning are only B2B, when asphalt is at its end-of-life or end-of-use. The usage of asphalt is in bulk, providing for economies of scale benefits. As it is a material that physically deteriorate instead of economically, it's still a valuable material. This is because it contains a lot of resources. Because of the different types of asphalt, it is a must to test and sort the asphalt on quality. Luckily it is not difficult to disassemble, and it does not have to be separated from other materials. Because of the tools available when removing asphalt, it is easy to transport in all aspects. The method to recover the product is to test the quality, there is no additional sorting and selecting needed. The alliance is needed to collaborate between producers about the types of material. The initiation of the chain is done by the producers of asphalt. According to the theory, there are four risks that exist in recovery. The asphalt material chain does not have any problems with any possible risks.

There are no found bottlenecks in this case study or any other items not mentioned in the theoretical. Explicit notes were made were possible risks could be are namely in collaboration or alliances, in this material chain the alliances are well worked out. Another important note to bring to the attention are the successes that lead to a working closed-loop material chain.

- Using the same links for reverse logistics as for the forward logistics
- Collaboration between the few producers
- Proven technology to reprocess the material
- Easy transportation
- Legal responsibilities
- Economies of scale

The following table shows an overview of the given answers to the table of questions from the theoretical framework. When a question is relevant for the material chain it will be under the column Relevant questions ✓. When a question is not relevant for that specific material chain, but possible relevant for other material chains, it will be noted in the column Relevant questions for other. If a question is not relevant at all, it will then be placed in the column Not relevant questions ✗.

Relevant question ✓	Relevant question for other	Not relevant question ✗
Will costs be reduced by direct recovery of materials?	*Does the chain save costs on waste processing?*	*Are businesses returning the materials in this chain?*
Is there a possible future legislation effecting the chain?	*Is there an indirect economic benefit?*	*Are consumers returning the materials in this chain?*
Are there current legislation effecting the chain?	*Is the consideration to recover for philanthropic reasons?*	*How often is the product used to deteriorate?*
Are products returned because they are not used anymore?	*Will the economic value of the product decline when used?*	
Are products returned because they do not function anymore?	*Does the product have to be separated because of different materials?*	
Is the usage in bulk?	*Is selecting relevant to recover the material?*	
Will the material physically deteriorate?	*Is the recovery method a direct recovery?*	
Is the product easy to disassemble?	*Is the material chain initiated by a third party?*	
Does the material have to be tested before reprocessing?	*Is the material chain initiated by the consumer?*	
Is the shape of the material easy to transport?	*Is it unknown when products are discarded by the end-user?*	
Is the size of the material easy to transport?	*Is there a lot of uncertain data of prognoses for recovery?*	
Is the weight of the material easy to transport?		
Are collection methods relevant for the material chain?		
Is testing relevant to recover in the material chain?		
Is sorting relevant to recover the material?		
Is the recovery method a process recovery?		
Is the alliance to find a dedicated partner to recover products?		
Is the alliance to find a partner to recover certain kind of waste?		
Is the alliance to find a partner to buy-in raw materials?		
Is the material chain initiated by the OEM?		
Are there no proven techniques to reprocess the materials?		
Is there no market for the recycled material?		

Table 2: Asphalt material chain questions sorting

5.2 Case study: Paper and cardboard material chain

5.2.1 Introduction

Martin van Nieuwenhoven from NL Agency is familiar with the paper & cardboard material chain because of his position to consult from the government to organisations in this sector. The goal of this case study is to compare if practical experience in the paper and cardboard material chain are coherent with the theoretical framework. Objectives are to find practical bottlenecks, specific success factors, and to find out if elements are missing or should be added to the diagrams. By conducting this case study we will understand in detail how the paper and cardboard material chain works.

5.2.2 Interview

It was obvious for van Nieuwenhoven to start naming the problem at hand a material chain instead of a waste chain. Multiple consultants within NL Agency agreed that the term waste chain was not good because of the affiliation with waste. Because this thesis investigation results in a solution for the Dutch industry, the term waste chain will not be used anymore. Throughout this thesis there will be referred to material chains focussing on the reverse logistics.

The paper and cardboard material chain is a successful material chain. The goal was in 2008 to recycle 75% of all paper and cardboard waste; the chain achieved this goal by recycling 80% of all waste in this sector (Papier Recycling Nederland (PRN) 2009). It costs a lot of energy to produce paper in this material chain. A logical step to take in this sector was to analyze the possibility to reduce energy usage in the production of paper and try to be more sustainable. Reducing energy, thus costs, in production is one of the motivations why paper & cardboard are recovered. Another economic benefit is gained by balancing the costs to incinerate or recycle paper. In this case the incineration of paper & cardboard costs more than recycling it. The paper & cardboard producers are together the initiators to receive and recover used paper & cardboard. A covering sector organisation Koninklijke Vereniging van Nederlandse Papier- en kartonfabrieken (VNP) coordinates the paper & cardboard recovery. Next to this sector organisation there are some other foundations like Papier Recycling Nederland (PRN) and Verpakkingen Recycling Nederland (VRN) that contribute in the success of this material chain.

Within the paper & cardboard industry there is a separate packaging sector that has legal responsibilities. Packaging organisations are by legislation forced to `pay packaging taxes. There is a goal set to recover at least 75% of the total packaging industry. This goal is easily achieved in the Netherlands. For the producers of paper & cardboard this legislation is a great advantage. Because the packaging organisations are held responsible for the costs to recover the packages, the producers of paper can easily receive waste streams back for recycling.

There is furthermore no philanthropic motivation with the producers to recycle paper. Their motivation is purely based on economic benefit, opportunity and legislation. The only philanthropic responsibility in this material chain is with the end users. Paper and cardboard have the image to recycle easily. It is a product that is not dirty or difficult to store. An important thing to realize about paper & cardboard is that it has a very short usage time. Paper & cardboard are information carriers, the value of paper is not in the paper itself, but the information it carries. Once the information is transported, the value of the paper or cardboard declines to no value. This is also the case with packaging. These characteristics are important to realise for the material chain. A short life-time, a continuous need of the material, philanthropic feeling with the end-users to return it, not dirty and easily stored and disposed to recycle are all elements that make the successes of the paper & cardboard material chain. The short life-time and continuous need for the material ensures

a good prediction of available waste in the future, in this way producers can estimate the supply of paper & cardboard waste to recycle. The philanthropic feeling at the end-users to recycle paper instead of wasting it, and the characteristics of the material gives end-users a low barrier to participate in recycling to uphold a continuous stream of paper waste back to the producer.

There are obvious economic motivations in the paper & cardboard material chain, but the resource is not unlimited available. Luckily, they are renewable but need space, time and money to renew. Trees are used in several possibilities; one of them is paper production. The advantage in this sector is seen when there is a shortage of trees.

Other return reasons for paper could also be to retrieve old products of an organisation. When old products are gone, the possibility will open up to sell newer versions of a product. Within the paper & cardboard sector this is a very important aspect with magazines. A lot of magazines need to be refreshed, so new products can be sold again. The retrieval of products does not have to be costly, in many cases old paper magazines can be recovered with the same transportation that delivers the new magazines.

In the paper & cardboard industry the recycle methods are proven to work within the business they operate. This is according to van Nieuwenhoven an important aspect. A characteristic of paper is that it can be easily mixed with recycled material. The method to recycle, the costs to recover and the way to reuse it need to be cost efficient to initiate it. This is a key issue to ensure certain feasibility in the material chain. The paper & cardboard industry is responsible to innovate within these methods. It is important that manufactures commit to their activities within the chain and be clear about the conditions that it wants.

In this industry the recovery and selection of paper is done by recyclers. Within this industry it is easy to distinguish the collection by quality of paper. Imagine that administrative companies only have good quality paper, and newspaper companies have a lower quality. On this basis, there is already a small selection in paper recovery. For this reason, the criteria B2B or C2B returns is important in this material chain. In cases that this is not possible, recovery will be done in bulk by collecting it in a central storage at the treatment facilities.

5.2.3 Conclusion paper & cardboard material chain

Concluding, we will compare the successful paper and cardboard material chain the table of questions from the theoretical framework. This chain finds motivations in all categories, economical and legislation by organisations and philanthropic reasons at the end user of the material. Paper and cardboard is being returned by businesses and consumers, only when it is at the end of usage. Thanks to the bulk usage of this material and the high business return rate there is a great economy of scale advantage in this chain. The deterioration of the material is purely economical; the material quality does not deteriorate. The composition of the material is simple, there are no explicit tests of disassemble needed. What could be done is the separation of several materials like the ink on paper and cardboard. However, this is not that often a necessity. The transport possibilities with paper are endless, it is an easy to transport in size, shape and weight. It is also a very easy, clean and small material to save up; this benefits the end users returning the materials. Paper and cardboard is reprocessed to be used as a new resource. The methods to collect, select and sort are important in this chain, but can mostly be done at pick up. In this material chain, they can sort and select by different sources of collection point. For example, schools and organisation often have very good quality paper, industrial construction companies often have cardboard. In this manner, a large aspect of sorting is already done. In this chain, the

alliances needed are partners to recover the material. Further risks are in uncertain data when users going to discard the material. It could be very long, or very short, but because of scale advantages there is a certain supply of discarded paper and cardboard.

Additional found bottlenecks in this case study is the worry about licenses. Any organisation reprocessing a disposed material is a waste treatment facility. This is a great obstacle for organisations trying to commit to material recovery. They do not want to be affiliated with waste, and next to that, protocol of being a waste processing organisation is very costly and forces total organisational change. Other added success factors are that the material is clean, easy to store and transport and the awareness of recovery options at the end users. End users have philanthropic reasons to recycle paper. Also the fact that a proven technology or method to reprocess the material is needed makes it important for recovery. These conclude to the following additional aspects relevant in closed-loop material chains according to van Nieuwenhoven.

- Licenses for waste processing
- Clean product characteristics
- End user philanthropic reasons
- Proven technology to reprocess the material
- Use same connections for the reverse logistics as the forward logistics

Other successes that are also mentioned in the theoretical framework are the following.

- Benefits in all categories, legal, economical and philanthropic
- Economies of scale
- Easy transportation
- Easy sorting and selecting at collection
- Clean material that can be stored end users

The following table shows an overview of the given answers to the table of questions from the theoretical framework. When a question is relevant for the material chain it will be under the column Relevant questions ✓. When a question is not relevant for that specific material chain, but possible relevant for other material chains, it will be noted in the column Relevant questions for other. If a question is not relevant at all, it will then be placed in the column Not relevant questions ✗.

Relevant question ✓	Relevant question for other	Not relevant question ✗
Does the chain save costs on waste processing?	*Is there an indirect economic benefit?*	*How often is the product used to deteriorate?*
Will costs be reduced by direct recovery of materials?	*Are products returned because they are not used anymore?*	
Is there a possible future legislation effecting the chain?	*Will the material physically deteriorate?*	
Are there current legislation effecting the chain?	*Is the product easy to disassemble?*	
Is the consideration to recover for philanthropic reasons?	*Does the product have to be separated because of different materials?*	
Are consumers returning the materials in this chain?	*Does the material have to be tested before reprocessing?*	
Are businesses returning the materials in this chain?	*Is testing relevant to recover in the material chain?*	
Are products returned because they do not function anymore?	*Is the recovery method a direct recovery?*	
Is the usage in bulk?	*Is the alliance to find a dedicated partner to recover products?*	
Will the economic value of the product decline when used?	*Is the alliance to find a partner to buy-in raw materials?*	
Is the shape of the material easy to transport?	*Is the material chain initiated by a third party?*	
Is the size of the material easy to transport?	*Is the material chain initiated by the consumer?*	
Is the weight of the material easy to transport?	*Is there a lot of uncertain data of prognoses for recovery?*	
Are collection methods relevant for the material chain?		
Is selecting relevant to recover the material?		
Is sorting relevant to recover the material?		
Is the recovery method a process recovery?		
Is the alliance to find a partner to recover certain kind of waste?		
Is the material chain initiated by the OEM?		
Is it unknown when products are discarded by the end-user?		
Are there no proven techniques to reprocess the materials?		
Is there no market for the recycled material?		

Table 3: Paper and cardboard material chain questions sorting

5.3 Case study: PVC material chain

5.3.1 Introduction

Klaas van der Sterren from NL Agency is part of the energy covenant and acts in a supporting role within the PVC material chain as a consultant. His expertise is to analyze material chains, and support it as one whole problem. The goal of this case study is to compare if practical experience in the PVC material chain are coherent with the theoretical framework. Objectives are to find practical bottlenecks, specific success factors, and to find out if elements are missing or should be added to the diagrams. By conducting this case study we will understand in detail how the PVC material chain works.

5.3.2 Interview

The first thing to notice is that the PVC material chain in the Netherlands is currently divided in two segments PVC pipe-lines and PVC window frames. These two segments together cover roughly two-third of all PVC material in the Netherlands. The other one-third is often a mixed PVC with different other materials. This segment is not recycled within the material chain.

The PVC material chain is currently not a successful material chain. PVC material has a bad image as a material; this resulted in low demands for the material the past years. The image that PVC carries is to be a polluting material to use. For this reason, the PVC industry is setting up a better production process to decrease emissions and trying to recycle the material with the setup of a material chain. Because the whole PVC industry has the same goal, to change the image and increase the demand for PVC, it started a material chain to improve the possibilities to recycle PVC. "BureauLeiding" is a sector organisation founded by all parties in the PVC material. BureauLeiding is the initiator and coordinator for the PVC material chain. The image of PVC has improved over the years because of 'cleaner' production procedures, but it still does not have an image of a good and clean material to use. This has an effect to the results of the PVC material chain to be unsuccessfully closed-loop.

But this is not the only problem of this material chain. The life-time of PVC is very long. Because of this long life-time it is uncertain what the continuity of supply is in disposed PVC for the upcoming years. With a lifetime of a couple of decades, we are uncertain in the Netherlands how much PVC was used in the past years. These statistics were never measured. To have a successful closed-loop material chain, one of the key factors is to have a continuous supply of the disposed material. This is not the case with PVC, and one of the reasons why it is not working at this time.

Another issue is the choice between incineration of PVC and recycling of PVC. Processing PVC through waste disposal methods like incineration is cheap, considering the costs to recycle it and costs to create raw materials for PVC. These are risk issues that need to be mitigated or at least considered. Raw materials for PVC are derived from aluminium and oil. Prices for these materials fluctuate a lot. These fluctuations are also visible in the price to produce new PVC material. Considering costs, recovering PVC and recycling it is very expensive compared to waste disposal methods. There are currently no legislation or goals to be met for the PVC material. Despite all these problems, the industry takes on the challenge to create a better PVC material. A better image to be more friendly and sustainable, hoping to boost PVC demand.

The material chain for PVC is at this point unstable. The image of PVC needs to improved, and it is trying to do it by creating a material chain closed-loop for recovering and recycling PVC. There is no real pressure from legal responsibilities, but warnings were made that improving emissions and creating a better material from PVC is a necessity, the PVC material will otherwise be prohibited. This is the biggest motivation for the industry to setup a material chain.

PVC is often integrated in buildings that will be demolished. It is difficult to retrieve the PVC products from this. Because of these difficulties it will be more convenient to just demolish and process it through the normal waste disposal. When PVC is returned it will be done by the demolishers. They will extract PVC material and collect and return it to a PVC producer. For the PVC window frames industry, consumers can call their window frame replacers; they take away immediately the old PVC frames and recycle it.

In this material chain, the collection, testing and selecting of different PVC materials is done by the collectors and recyclers. They sell it back to the PVC manufactures that process the recovery and recycle it back to raw material. In terms of PVC material, it is not possible to recycle it to the same

quality as virgin material. Where virgin PVC material is white, the recycled PVC material is always slightly gray.

Another problem in this material chain is the commitment the industry has. They all want to develop a material chain, but are not committed to it. They see that it is a problem, but it is in their eyes not yet critical enough to pull all strings together and get the task done. This results in no intensive alliances between organisations to strengthen each other. In some cases there are fixed partnerships, but only to a low level of commitment.

Although recovery is supported by the whole PVC industry, the initiators are the recyclers. They fall in the structure that the manufacturer sells PVC to retailers, they sell it to the end-users, and via third party recyclers it will be returned back to the manufacturer.

5.3.3 Conclusion PVC material chain

When comparing the theoretical framework to the case, the motivation for the chain is philanthropic and, there is a possible future legal responsibility. PVC is returned in the form of B2B and when the material is at its end of usage. It is used in bulk and will not deteriorate at all. It is a homogeny product so it is not needed to disassemble it. What is needed is to test the material for any hazardous substances still on the material when it was used. Furthermore, the material is easy to transport because of the demolitioners that come to break down, and pick up the material. Once it is collected, it is reprocessed to be used as a raw material. There is still a need to find alliances in a dedicated PVC recovery. At the moment it is done by general demolition organisations. When dedicated partners can be found, the PVC material can be easier separated from the other debris. The initiation of this chain is done by third parties. Unfortunately, the producers do not yet see the need of the closed-loop material chain, as the third parties in the chain do. Luckily, there are already proven techniques that can be used to reuse PVC material, the only bottlenecks that are also mentioned in the theory are the uncertainty of data and time of disposal.

When comparing the findings of this case study with the theoretical framework we can identify that there are certain possible success factors, and a few risks in this chain. Bottlenecks at the moment are:

- There is no current legal responsibility and economical benefit
- Better alliances needed
- Uncertain data for prognoses
- No proven techniques to reintroduce
- Unknown market demand

Possible success factors are:

- Product is homogeny, resulting in no needed disassembly.
- Easy to transport
- Proven technology to reprocess is already there
- Economies of scale

Additional found bottlenecks is the lack of commitment within the material chain; everybody sees the problem but not the urge to really solve it. Next to this, important identified bottlenecks are the issues in costs and prices that fluctuate. These have an impact of the chain, considering the cheap possibility for disposal, or the fluctuating prices for virgin materials for PVC. Of course can this price fluctuation in virgin material be a stimulant, when it stays at a higher price compared to

recovered PVC. Furthermore, the issue of continuity is a big risk in this material chain. There is unreliable data of PVC material to be recovered. This causes uncertainties to the benefits of the VC material chain. Unfortunately, the chain is still not a success despite the potential it has as described earlier. Without the lack of commitment, the chain will never be a success. These conclude in the following added bottlenecks.

- Fluctuations in prices
- Comparison costs recovery to waste disposal methods
- Scarcity
- Commitment
- Continuity

The following table shows an overview of the given answers to the table of questions from the theoretical framework. When a question is relevant for the material chain it will be under the column Relevant questions ✓. When a question is not relevant for that specific material chain, but possible relevant for other material chains, it will be noted in the column Relevant questions for other. If a question is not relevant at all, it will then be placed in the column Not relevant questions ✗.

Relevant question ✓	Relevant question for other	Not relevant question ✗
Will costs be reduced by direct recovery of materials?	*Does the chain save costs on waste processing?*	*Are businesses returning the materials in this chain?*
Is there a possible future legislation effecting the chain?	*Is there an indirect economic benefit?*	*Are consumers returning the materials in this chain?*
Is the consideration to recover for philanthropic reasons?	*Are there current legislation effecting the chain?*	*How often is the product used to deteriorate?*
Are products returned because they are not used anymore?	*Are products returned because they do not function anymore?*	
Is the usage in bulk?	*Will the material physically deteriorate?*	
Is the product easy to disassemble?	*Will the economic value of the product decline when used?*	
Does the material have to be tested before reprocessing?	*Does the product have to be separated because of different materials?*	
Is the shape of the material easy to transport?	*Is selecting relevant to recover the material?*	
Is the size of the material easy to transport?	*Is sorting relevant to recover the material?*	
Is the weight of the material easy to transport?	*Is the recovery method a direct recovery?*	
Are collection methods relevant for the material chain?	*Is the alliance to find a partner to buy-in raw materials?*	
Is testing relevant to recover in the material chain?	*Is the material chain initiated by the OEM?*	
Is the recovery method a process recovery?		
Is the alliance to find a dedicated partner to recover products?		
Is the alliance to find a partner to recover certain kind of waste?		
Is the material chain initiated by a third party?		
Is it unknown when products are discarded by the end-user?		
Is the material chain initiated by the consumer?		
Are there no proven techniques to reprocess the materials?		
Is there no market for the recycled material?		
Is there a lot of uncertain data of prognoses for recovery?		

Table 4: PVC material chain questions sorting

5.4 Case study: Mattress material chain

5.4.1 Introduction

Joost Lommelaars from NL Agency is an advisor on Dutch legislation within several programmes for organisations about policies within waste management. One of this focuses is on domestic waste, carpet and mattress material chains. He advises within these material chains to work towards an efficient and effective material chain. For a long time he is working on advising organisations how to process waste in a good manner. Despite his knowledge of multiple material chains, this case will handle only the mattress material chain. The goal of this case study is to compare if practical experience in the mattress material chain are coherent with the theoretical framework. Objectives are to find practical bottlenecks, specific success factors, and to find out if elements are missing or should be added to the diagrams. By conducting this case study, we will understand in detail how the mattress material chain works.

5.4.2 Interview

According to Lommelaars the reason that businesses want to receive their products back in his field of expertise are because of economic benefits. In this chain, the drive to recover products is because of indirect economic benefits. Being distinguishing in comparison to competitors gives them the opportunity to enter the new market of 'green' products, appealing to customers that purposely choose 'green' products. In the legal responsibility motivations, it is often seen that there is a producers' responsibility to take upon the problems of materials after usage.

Although these are the motivations from the viewpoint when initiation of a closed-loop material chain is done by the producer, in practice in the mattress material chain, initiation is done by recyclers. They are the ones that recover used material, select it and sell it back to producers. They have a direct economic benefit, it is their business strategy, but unknowingly they are the pioneers and initiators of a closed-loop material chain.

The reason why recyclers are the pioneers in this field is because producers do not care about recovering unless it is their intention to gain (in)direct benefits from it. Otherwise producers see their current way of business, as the way of business. They are not open-minded to change current settings and maybe save costs when recycling can take place. The waste processing costs are just another debit that has to be paid. According to Lommelaars they should self-reflect their position in business and seek out for possibilities like saving costs in waste processing by recovering their old products. When this will not change, the pioneers in the business to create closed-loop supply chains are mostly done by the recyclers. The ones that see business in collecting waste, recovering it, and selling it back to producers.

The motivation to return products in the mattress material chain is because of the end-of use. They are not especially at their end of their lifetime, but often just replaced for a newer product. This gives possibilities in some cases, being replaced means that it could be that the new product is brought and the old product could immediately be returned with the same transportation.

As a note, Lommelaars thinks that producers need to look into the possibility to lease their products. In this way, producers are certain about the amount of recovered products. They could even create a new possibility to service their products for additional income. A lease contract and service contracts are not a new phenomenon, but are just not that common in some business sectors. Newer sectors like information technologies are already doing business in this way. Leasing their computers or other hardware, and often service them with a service contract. A simpler example is the heating boiler in Dutch houses; all current and new boilers are leased to the house owner, additional there is a service contract with it to service the boiler. These are simple practical benefits that already proven their advantages in practice. According to Lommelaars current conventional sectors like furniture for consumers are still not open-minded for these kinds of possibilities. Of course this approach is also very dependable on the users; users often have the state of mind to own things. At this point there are some initiators to introduce carpet leasing to companies and consumers.

One of the important bottlenecks is often in the characteristics of a product or material. For this reason it is important to evaluate the product properties. For example, the mattress industry endures a lot of problems in the transportability of mattresses. It is heavy and a difficult size to transport. Next to this the composition of mattresses is difficult to distinguish. It is a heterogeneous product existing of several different materials that are difficult to disassemble. Next to all this, another characteristic is the diffuse recovery of mattresses. There is no standard known collection point, and if there is one, the bottleneck of transportability limits a lot of consumers to bring it there. This validates how crucial it is to analyze the material or product that is intended to recover.

The better is known what the characteristics are, the better to anticipate the problems and successes of the material chain.

During the interview another big practical problem comes to light. In the industry, any organisation that processes recycled material to be reintegrated into new products is waste treatment facilities. Organisations that create new products do not want to be associated with this; therefore the threshold to enter this market is very high. There is a possibility that recyclers already reprocess it for the producer to be used again as raw materials. The producer, in this case, buys a new raw material instead of unprocessed recovered material. However, this possibility is very uncommon. According to van Nieuwenhoven, the specialist from the case study paper & cardboard material chain, there are recent developments within the European Union to define end-of-waste criteria. At this point they are defining it for the materials iron, aluminium and paper.

Furthermore it is important for material chains to have a central foundation or branch organisation to direct the whole material chain. This foundation or branch organisation exists of all concerning parties in the material chain.

Alliances in the material chains of this case study were also important. Alliances were formed to buy-in raw materials. The purpose of these alliances is to ensure the quality of bought materials. This adds to product characteristics, a certainty and a possibility to easily recycle the product, and knowing what is being recycled to ensure quality for the next product.

5.4.3 Conclusion mattress material chain

Comparing this case with the theoretical framework brings the following. There are only indirect economic benefits and philanthropic motivation that this chain is focussing on at the moment. The material is returned by consumers and are not used or at the end of its lifetime. The material is not used in bulk. Further deterioration is in economic value and physical sense. The product is not easy to transport. Consumers can not simply just drive the mattress to a recycling point for mattresses, it is simply too big for that and individual pick up is very costly. This is a great bottleneck for this material chain. Another bottleneck in this chain is the unknown time when the material is discarded.

What we have discovered thanks to this material chain is a new bottleneck that was not included in the theoretical framework. The diffuse spread of the material can be a problem for collection. Another bottleneck that came to the attention in case study, like in the case study paper and cardboard, was the end-of waste criteria. The licensing problem needed once a producer wants to recover and reprocess the material. To conclude, the important new issues from the mattress material chain are the following.

- There are only economical and legal benefits
- The spread of the material

Other risks that are also from the theoretical framework are:

- Little economic or any legal benefits
- No economies of scale created
- Difficult to transport
- Difficult to disassemble
- Unknown time of disposal

The following table shows an overview of the given answers to the table of questions from the theoretical framework. When a question is relevant for the material chain it will be under the column Relevant questions ✓. When a question is not relevant for that specific material chain, but possible relevant for other material chains, it will be noted in the column Relevant questions for other. If a question is not relevant at all, it will then be placed in the column Not relevant questions ✗.

Relevant question ✓	Relevant question for other	Not relevant question ✗
Is there an indirect economic benefit?	*Does the chain save costs on waste processing?*	*Are businesses returning the materials in this chain?*
Is the consideration to recover for philanthropic reasons?	*Will costs be reduced by direct recovery of materials?*	*Are consumers returning the materials in this chain?*
Are products returned because they are not used anymore?	*Is there a possible future legislation effecting the chain?*	*How often is the product used to deteriorate?*
Are products returned because they do not function anymore?	*Are there current legislation effecting the chain?*	
Will the material physically deteriorate?	*Is the usage in bulk?*	
Will the economic value of the product decline when used?	*Is the product easy to disassemble?*	
Does the product have to be separated because of different materials?	*Is selecting relevant to recover the material?*	
Does the material have to be tested before reprocessing?	*Is sorting relevant to recover the material?*	
Does the material have to be tested before reprocessing?	*Is the recovery method a direct recovery?*	
Is the shape of the material easy to transport?	*Is the alliance to find a partner to buy-in raw materials?*	
Is the size of the material easy to transport?	*Is the material chain initiated by the OEM?*	
Is the weight of the material easy to transport?	*Is the material chain initiated by the consumer?*	
Are collection methods relevant for the material chain?	*Is there a lot of uncertain data of prognoses for recovery?*	
Is testing relevant to recover in the material chain?		
Is the recovery method a process recovery?		
Is the alliance to find a dedicated partner to recover products?		
Is the alliance to find a partner to recover certain kind of waste?		
Is the material chain initiated by a third party?		
Is it unknown when products are discarded by the end-user?		
Are there no proven techniques to reprocess the materials?		
Is there no market for the recycled material?		

Table 5: Mattress material chain questions sorting

5.5 Case study conclusions

After doing four case studies, the findings in the literature review were not complete. The found literature tends to be more describing than to be a practical tool to use for organisations. It looked complete in first impressions, but after intensively talking about the practice of material chains, some additional problems arose that would not be found in the literature.

But there are also some strong advantages in the literature and the derived theoretical framework. Just like the case studies complete the theoretical framework, the theoretical framework completes

the case studies. The theoretical framework brought a lot of aspects of material chains and reverse logistics to the attention. By creating the theoretical, it gave the interviewed experts a complete graphical overview of material chains. They were not surprised that the mentioned aspects in the theoretical framework existed, but seeing it structured gave them the opportunity to approach the problem from other viewpoints. It stimulated them to understand the material chain better.

The theoretical framework opened up ideas and problems to confront during the case studies. The table of questions from the theoretical framework was used to note which aspects where important from the viewpoint of the experts and their material chain. The next stage is to bring both the case studies and literature review together. This results in a final framework for closed-loop material chains so feasibility and efficiency can be apparent.

The lessons learned from both the case studies and the literature review is that the issues about collaborations and alliances need to be integrated. In all case studies the collaborations between organisations are very important. One organisation cannot maintain a total material chain; the word chain already implies several links. It is a necessity to work on alliances, as van Groen tells that there are cases that material chains failed because of a mismatched alliance. For this reason, van Nieuwenhoven suggested that a solution could be to minimize the number of links within the closed-loop supply chain, or to use the same links for the reverse logistics as used for the forward logistics. This creates the advantage that the partner is known, and is familiar to collaborate with. Another solution is to setup branch organisations covering the whole sector to guide the material chain to a success. This is done in all other chains and creates a type of collaboration to in-line all goals in developing the closed-loop material chain. They can also adopt the role to be the initiators of the closed-loop material chain. Van Nieuwenhoven implied also the crucial step to use reprocess methods within the closed-loop material chain that are proven to work. To enhance the feasibility of the material chain, it is important to research these reprocess methods that are used when the closed-loop material chain is set up. The literature review and the empirical research result in new developments for the final results of this research. In the mattress case study it became clear that product characteristics are an important aspect for the feasibility of the material chain.

After the interviews we can conclude the following. Aspects from the theoretical framework

- Are businesses returning the materials in this chain?,
- Are consumers returning the materials in this chain? and
- How often is the product used to deteriorate?

are not important to include in the final closed-loop material chain framework and questionnaire. The aspects concerning

- costs;
- continuity and
- license

are added to the final closed-loop material chain framework and questionnaire.

6 Framework building

The aspects that should be added or deleted for the final closed-loop material chain framework and questionnaire are confirmed thanks to the theoretical framework. Knowing the results of all aspects, the aim is to combine only relevant aspects in one framework plus questionnaire. The following section describes the process of combining the aspects to one final framework plus questionnaire.

First, an explanation is given in section 6.1 Findings and interpretation, how to interpret the findings. These leads to a final list of aspects, that has to be included in the framework. After that, aspects that are formed into a general framework are set out in section 6.2 Closed-loop material chain framework. Section 6.3 Framework questionnaire, explains the difficulties and gradation of the questionnaire. Finally the framework and questionnaire are tested with the case studies in chapter 5. Next to this, three new case studies are evaluated, to establish if the framework and questionnaire are realistic for practical usage.

6.1 Findings and interpretation

Using the Cradle to Cradle concept as an inspiration to solve the central problem of this research, results in creating a framework and questionnaire for closed-loop material chains. These tools create insight to recover materials in a material chain and calculate the feasibility of a material chain. The solution is created by using joined literature reviews as well as case studies. The difference in the new introduced closed-loop material chain to all current studies is that the possibilities of the material chain are determined on the basis of the product characteristics. Case studies showed that there is an important relation between the product characteristics and the possibilities in recycling. Therefore, the framework and questionnaire focuses on product characteristics. An advantage of this approach is that the created tools can be used in creating new closed-loop material chains and measure existing material chains. Next to this, it also includes the capability to identify any of the bottlenecks in material chains. The interpretation of the findings is done by evaluating the theoretical framework and the findings of the case studies.

Topics economical benefit, legal responsibility and philanthropic responsibility. The topics of the theoretical framework economic benefit, legal responsibility and philanthropic responsibility are narrowed down to only the aspects of economic or legal benefits. As Lommelaars implied that these motivations are the only possibilities why organisations would want to recover. Organisations hope that philanthropic reasons eventually create profit by creating new types of 'green' markets. This is also in-line with the findings of the objectives of organisations, to create profit.

Topics B2B and C2B returns. The topics B2B and C2B returns are not taken into account in the final closed-loop material chain framework. Conclusion of the case-studies is that these topics are not relevant for recovery. In the case of the paper and cardboard material chain, is this aspect important, but used from a different angle to sort the quality of the material by it. Experts of all case studies, including the paper and cardboard material chain concluded that it does not matter whether the recovery is B2B or C2B; the recovery has to be done no matter what the origin is. B2B and C2B returns would not affect the possibilities in closed-loop material chains. It is of course imaginable, that differences in C2B and B2B returns are in higher volumes or shorter life-time. Although this is true, these issues are taken into account in other aspects that are mentioned in the final framework.

Topics use pattern, deterioration, composition and easiness of transportation. The use pattern of the material or product, bulk usage or not, is important because of the possibilities to predict the return rate and scale advantages for recovery. The theoretical framework aspect: "How often is the product used to deteriorate?" is deleted from the final framework because all experts concluded that it would not make a difference for the recovery. A product is used, and at some point not disposed. It is irrelevant whether it is used 1 time or 100 times. A more important topic is the deterioration in physical or economic value. This determines what can be done with the recovered material. The topics composition and easiness of transportation are all important, and are taken into account in the final framework.

Topics collection, testing, selecting, sorting and recovery. All mentioned topics concerning how products are recovered, are important in the case studies. Although not all aspects are directly relevant to the expert's material chain, they all thought it could be relevant to other material chains. This is translated in the final framework by creating two separate categories, recovery and selecting. The reason for the separation is done because it creates a better understanding in the single issue recovery and selecting.

Topic alliance awareness. The alliance questions, mentioned in the theoretical framework, are relevant according to the case studies. The practical experience from the experts of the case studies concluded that all stages of an alliance, mentioned in literature review, are important. These stages will stay the same, regardless of the motivation to start an alliance. Therefore, the final framework only asks if alliances need to be formed or not.

Topics recovery by manufacturer, third part or consumer. According to the experts, it does not matter who initiates the recovery. It is important who is responsible and who benefits from it. That is why these topics are included in the category responsibility of the final framework.

Topics risks in end-of-life moment, technique to reintroduce, market demand and uncertain data. The last topics mentioned in the theoretical framework are the risks that are present in recovery. These risks are in both the literature and case studies important factors. The risks named in the theoretical framework are dispersed in the total final framework. They are translated back in questions concerning demand, continuity, proven technology to reprocess and life-time of a material.

Added category cost. There are also new findings from the case studies that are added to the final framework. The first added category is cost. The PVC case study made it clear that the comparison in costs of waste disposal methods and recovery methods need to be assessed. The same case study brought the aspects costs of virgin material, price fluctuations and scarcity to the attention. If something becomes scarce, prices for it rises and substitution in recovered material becomes a more interesting option for organisations. Price fluctuations have a narrow correlation with scarcity and can influence the decision to recover materials.

Added category continuity. The category continuity brings a lot of new aspects to be aware of. Economies of scale give information about the availability and continuity of the recovered material. It also gives economic benefits when an economy of scale is created; it creates availability to process more in onetime costs. The continuity of demand and supply of recovered material has to be analyzed to discover the potential of a material chain. Furthermore, there are aspects that boosts continuity at the end-user, by making aware what end-users can do, and how to benefit when they recover materials. This is one of the conclusions from the paper and cardboard material chain.

Added category license. The last new category to be introduced is license. This is not mentioned in any literature, but forms a big issue in practice. It is brought to the attention by the case studies mattress and paper and cardboard. Any company that recovers and processes material is by law a waste processor. Many licenses and strict regulation accompany this way of recovering, and hold back most companies to get involved with such practices. Awareness of this fact comes too late; the framework creates clarity about it.

The decision to keep the framework general to be used for; all products and materials, all types of organisations in the material chain (producer or third party) and for existing or new closed-loop material chains, made it difficult to create an effective result. Making a general framework always includes the risk that the results are to general and useless. The main goal of the framework is to create practical insight in the feasibility to recover materials. This is the reason why not all aspects are too detailed. It brings the problems that can occur to the attention, yet it is the responsibility of the user to develop an approach to tackle the problem raised by the framework.

6.2 Closed-loop material chain framework

It is important to structure the approach of creating the closed-loop material chain framework. How to do this and make it general useable for every product and material, brought the solution to create the framework viewed from the perspective of product characteristics. The findings and interpretations in the previous paragraph were seen as specific product characteristics. This approach made it possible to note which detailed issues should be taken into account for the final framework. For practicality, the categories are categorized in themes of the closed-loop material chain. The advantage of these themes will become clear when using and grading the feasibility of a material chain in practice. By using the themes, categories and issues are matched. It will precisely indicate what theme of the chain has high or low probability on the feasibility. In this way, the total framework will cover all aspects and bottlenecks in a structured method. This creates a consistency and logical structure in the framework.

The themes and categories that were identified are:

- Strategy
  - Motivation
  - Responsibility
  - License
  - Alliance
- Product
  - Costs
  - Continuity
  - Usage
- Retrieving
  - Transportation
  - Recovery
  - Selecting

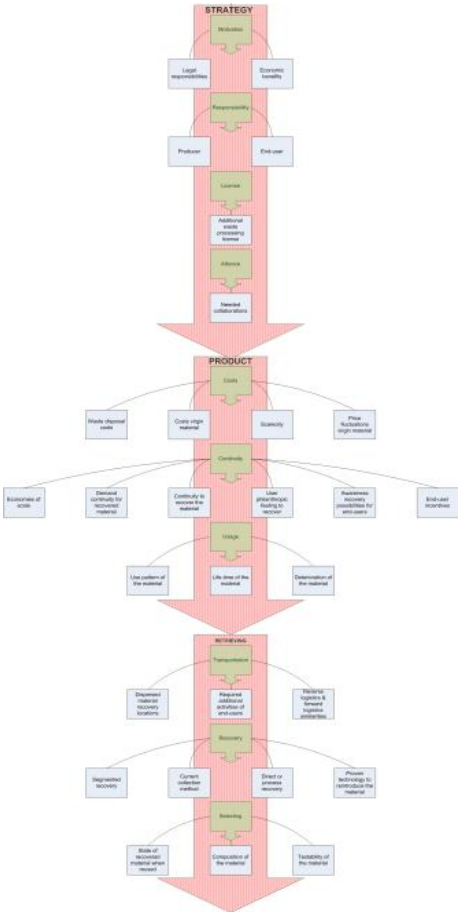


Figure 8: Miniature closed-loop material chain framework

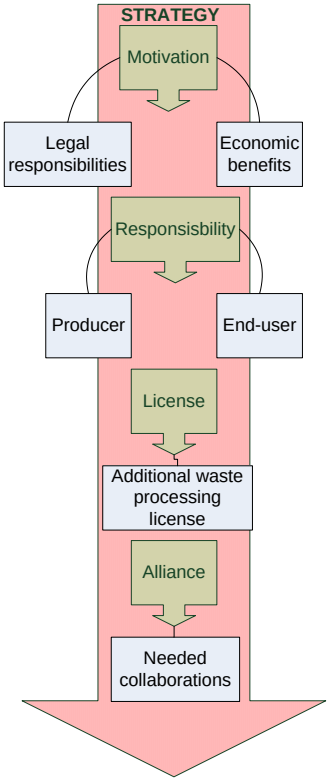
The 3 arrows represent the themes in the framework.

In the middle of the framework, the green blocked arrows pointing down are the 10 categories mentioned previous in the text. They are the guide-line through the closed-loop material chain framework.

The 29 blue blocks between each green blocked arrow are the issues. Every blue block is a part of the green blocked arrow above it.

Reviewing the categories made it clear that it is possible to estimate which category has an impact on which area of the chain. This led to four themes, namely reason, strategy, product, and retrieving. The themes product and retrieving are the same as already described. The theme strategy was divided in two themes. Reason with the categories motivation and responsibility. Strategy with the categories license and alliance. The problem of having separate themes is that the aspects within the themes would not represent a reliable advice. The categories license and alliance consisted of only two aspects, implying that each weighing factor would be around 50% per aspect. This problem had to be solved, and after reviewing the categories they would perfectly fit next to motivation and responsibility. These categories also determine a part of the strategy, just like license and alliance. In this way, the final result is a framework with 3 themes, 10 categories and 29 aspects.

The order of the themes and categories is purposely chosen to get a better understanding of the material chain. Walking through the framework creates understanding and awareness about the possibilities, bottlenecks and feasibility of the closed-loop material chain.



The theme Strategy includes categories motivation, responsibility, licenses and alliances. *Motivation* gives the reader an insight in the reasons and drive to enter and set-up the closed-loop material chain, economics benefits or legal responsibilities. *Responsibility* gives the reader the understanding which parties in the material chain are the driving force to recover the material. *License* and *Alliance* concern possible needed licenses and possible collaborations to recover. When knowing the motivation and responsibility of the chain, it will be possible to assess if additional licensing or alliances are needed.

Figure 9: Framework theme strategy

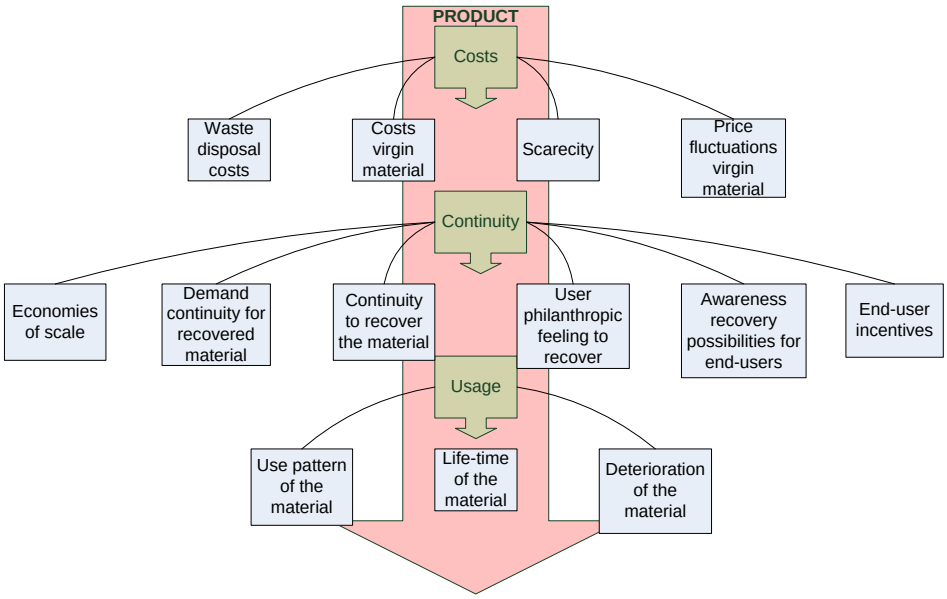
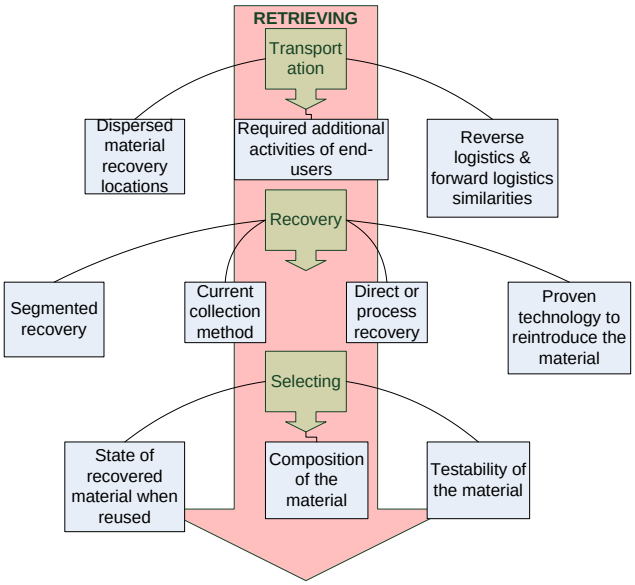


Figure 10: Framework theme product

The theme Product includes costs, continuity and usage. The category *Costs* will cope with the aspects that will influence costs within the material chain plus important cost comparisons that gives insight about the other alternatives. *Continuity* handles all issues that will influence the stream of material to recover it. These vary from scale, demand to user behaviour. *Usage* of the material determines the possibilities and duration to retrieve the material.



When knowing these factors, the theme Retrieving makes it possible to conclude the method of recovery. *Transportation* in this theme deepens this area by analyzing the existing possibilities, dispersion and user requirements. The following categories *Recovery* and *Selecting* notifies the reader in what manner or form these steps must be done, or at least must take into account.

Figure 11: Framework theme retrieving

All these themes, categories and issues are displayed in the final closed-loop material chain framework. It is a top-down approach leading the reader through all issues.

6.3 Framework questionnaire

To use the closed-loop material chain framework there is an additional questionnaire that needs to be filled, to calculate expectations and grade feasibility of the intended material chain. The questionnaire consists of 29 closed-ended questions with a dichotomous respond. Both options per question will be awarded points in percentage. Each theme in the questionnaire can receive a maximum of 100%. All points will be added up. The higher the total percentage is in that theme, the better the feasibility to recover is in that material chain theme.

The relevance of the questions is graded by multiple experts in the field of material recovery from NL Agency and the Erasmus University. This has an impact on the awarded point per answers for each question. The gradation of the experts can vary. Expert answered the questions based upon personal experience and gained knowledge over the years. For example, one expert has encountered the problem; the other one not and therefore grades it lower. When noticing this effect of varieties, and actually being aware that the research concluded that all these question were important, it is logical that there are fluctuations in the gradation. But what is reached in this gradation is that we can clearly distinct which questions are important or not important for all types of material chains.

6.3.1 Gradation of the questions

The gradation of the questions is done by 7 experts. They can grade each question (***A)*** with a value (***X)***. This value has a maximum of 5 points and an interval of 1, being 1 the lowest grade and 5 the highest grade. The gradation is done to determine the importance of each question to the total of a closed-loop material chain. With 7 experts (***k)*** grading the questions and 5 maximum points that can be awarded to a question, it results in a maximum score (***Y)*** = 35 points for each question.

The points awarded to each question will be the total sum (***X)*** and divided by the value (***Y)*** times 100%. This gives the relevant percentage (***Z)*** of that particular question (***A)***.

$$Z(A) = (\frac{\sum_{k=1}^{7}(X_k)}{Y}) * 100\%$$

This formula is done for all 29 questions, each receiving their own relevant percentage. This indicates how relevant that question is according to the experts considering the total material chain.

To calculate what the impact is of a question in a theme of the framework (Strategy, Product or Retrieving), all percentages ***Z (A)*** of the theme are accumulated; this score is ***(U)***.

- Theme Strategy ***(U)*** = 5
    - Additional note: *(U)* = Sum *Z (A)* of the theme strategy (*A* = questions 1 -6)
- Theme Product ***(U)*** = 9,42
    - Additional note: *(U)* = Sum *Z (A)* of the theme product (*A* = questions 7 – 19)
- Theme Retrieving ***(U)*** = 7,17
    - Additional note: *(U)* = Sum *Z (A)* of the theme retrieving (*A* = questions 20 – 29)

This means that the important part in percentage = ***(I)*** of a question ***(A)*** is the relevant percentage for that particular question ***Z (A)*** divided in ***(U)***.

$$I(A) = \left(\frac{Z(A)}{U}\right) * 100\%$$

These calculations can be viewed in the appendix: Questionnaire grading results. Because the framework and questionnaire is divided into three themes, each theme receives a feasibility between 0% and 100%. The higher the percentage, the higher the feasibility of that theme in the material chain is. When only one score of feasibility if given over the total chain, it is hard to interpret that score to the problem areas of the material chain.

6.3.2 Differences in impact of answers

Al questions are now separately graded in their relevance of impact to the closed-loop material chain. However, the relevance of impact only suggests how important a question is, not what the influence of it is. Some questions that are not completely in balance, meaning that one of the 2 options can have a higher weighing factor than the other option to a material chain.

For example, question 1 in the questionnaire. “Is there a legal responsibility to recover that material?” The positive answer is yes, there are legal responsibilities. This results in a boost of the feasibility of the material chain because all parties in the chain need to undertake action to keep existing in the material chain. They support each other and focus on the goal to create the closed-loop material chain. The other option is the negative answer. No, there are no legal responsibilities. This does not mean that the positive boost will be the same effect negatively when there are no legal responsibilities. When there are legal responsibilities it will just boost the feasibility, but when this is not the case, it will not negatively affect the feasibility. This means that it would be unfair to not credit the negative answer. For this reason, the negative answer in question 1 is awarded with half the point that can be received.

The questionnaire has these irregularities taken into account. In this way, the results of the framework and questionnaire will not be deceiving to the reality. There are only 4 irregular

questions in the questionnaire. The irregular questions have a unique point awarding rule. These questions are:

- Question 1: Is there a legal responsibility to recover that material?
    - Positive answer will award full points; this answer will boost the feasibility of the material chain.
    - Negative answer will award half points; this answer will not boost the feasibility, but will also not be directly negative to the feasibility of the material chain.

- Question 10: Are the price fluctuations in virgin material?
    - Positive answer will award full points; this answer will boost the feasibility of the material chain.
    - Negative answer will award half points; this answer will not boost the feasibility, but will also not be directly negative to the feasibility of the material chain.

- Question 18: What is the life-time of the material?
    - Short life-time will award full points, this option will provide fast possible recovery and high and constant continuity.
    - Long life-time will award half point; this does not directly mean that the advantages in the positive answer are negative in this answer. It could be that history analyses brings forward that there is a high continuity because of past dispersion of the material.

- Question 25: What recovery method will be used, process or direct recovery?
    - Both direct and process recovery will get the full points awarded. The reason for this question, although both options get the full points awarded is to generate awareness with the user to what option the reintroduction of the material will be to the forward stream.

All other question get with the positive answers the full points awarded, and with the negative answers no points awarded. In these questions we recognize that the impacts of the positive and negative answers are each other's opposites.

6.3.3 Using the closed-loop material chain framework and questionnaire

All questions in the questionnaire always have 2 answers. The questions for this framework are designed specifically to be answered in 2 options. When the user chooses one of the options as their answer that best fits the situation of the user, it provides an immediate advice and description of the possibilities awareness's and dangers of that option. When the option best fitted is an negative answer, the user can seek advice by reading the other option that suggests what changes need to be done to mitigate the risks concerning the question.

The questionnaire creates clarity in the feasibility of the intended closed-loop material chain. Points are awarded for each option; accumulating these points' gives the user the estimated feasibility of the material chain in that theme. The estimated feasibility is graded on a scale from 0 – 100%. All points where scores could be higher are identified as bottlenecks that need to be dealt with to improve the closed-loop material chain. It is possible to view the full final questionnaire in the appendix: Closed-loop material chain questionnaire.

6.4 Testing

To validate the tools in reliability, it is first tested with the material chains that are used for the empirical research of this research. Afterwards, the framework and questionnaire are tested with new introduced material chains to validate the effectiveness in other material chains.

The framework does not really need to be tested. It is a graphical overview linking contexts with each other showing how the relations between each issues are situated. The framework is coherent to the questionnaire that is tested in detail.

To measure the questionnaire, the outcomes of it are compared to reality. We can assume that when a material chain works in reality, the feasibility scores in the 3 themes of the questionnaire will be high. When the material chain in reality does not work, the feasibility will be a lower score.

6.4.1 Testing the questionnaire with the asphalt material chain

The asphalt material chain scored the following feasibility percentages.

- Strategy: 70%
- Product: 65%
- Retrieving: 72%

In practice the asphalt material chain is considered a success when it comes to recovery. The chain is fully operating and recovers and recycles asphalt that is used in the Netherlands. According to van Groen, the expert in this material chain, all asphalt is currently 100% recovered, 40% of all recovered material is re-cycled to new asphalt. This success is also shown in the results of the questionnaire. The questionnaire identified a few bottlenecks, although the chain is fully operating in practice. The bottlenecks could be improved when critically analysing the asphalt material chain. They are discussed in the following sections.

The questionnaire identified 2 bottlenecks in the strategy theme.

- Question 4: The end-user is not responsible for the disposed material. It could be that the material will never be recovered because end-users do not feel responsible.
- Question 5: There is a need for additional licenses to process the recycled material. This results in additional costs and difficulties to recover the material.

The questionnaire identified 6 bottlenecks in the product theme.

- Question 9: The virgin material is not scarce. It could be cheaper for manufactures to buy new virgin material instead of recovered material.
- Question 10: There are no price fluctuations in the virgin material. When there is no price fluctuation in the virgin material, there is no additional pressure to invest in recovered material. Stakeholders are not scared for sudden price changes.
- Question 14: User does not return the product for philanthropic reasons. This discourages the end-users to offer the materials back to the manufacturer for recovery.
- Question 16: There are no incentives for end-users when they participate in the recovery of the material. This discourages the end-users to offer the materials back to the manufacturer for recovery.
- Question 18: The product has a long life-time. This can result in a longer period of time before recovery can finally be done. It is than needed to analyse historical data in detail to estimate returns.

- Question 19: The material deteriorates physical. This means that the material quality has lowered, and there is a need to reprocess it to upgrade the quality of the material again.

The questionnaire identified 3 bottlenecks in the retrieving theme.

- Question 27: The recovered material will be sold back in an unprocessed state. This means that other parties will earn less money on it. It will be less interesting for other organisations to benefit from the recover process and will result in a more difficult material chain to set up.
- Question 28: The material is heterogeneity. It exists of many different parts all needed to separated before reprocessing. This additional task can cost a lot.
- Question 29: There is additional testing needed to reprocess the material. This results in additional costs to test.

6.4.2 Testing the questionnaire with the paper and cardboard material chain

The paper and cardboard material chain scored the following feasibility percentages.

- Strategy: 70%
- Product: 89%
- Retrieving: 92%

This chain is successful in practice, as it is indicated by the questionnaire. The paper and cardboard material chain is currently fully operating in the Dutch industry and recovers in 2008, 45% from the consumers and 55% from the businesses. The recycle percentage of both recoveries is 80% of paper and cardboard waste in 2008 (Papier Recycling Nederland (PRN) 2009). Surprisingly, the paper and cardboard material chain scored very high points indicating an almost perfect chain. The questionnaire identified a few bottlenecks, although the chain is fully operating in practice. They are discussed in the following sections.

The questionnaire identified 2 bottlenecks in the strategy theme.

- Question 4: The end-user is not responsible for the disposed material. It could be that the material will never be recovered because end-users do not feel responsible.
- Question 5: There is a need for additional licenses to process the recycled material. This results in additional costs and difficulties to recover the material.

The questionnaire identified 2 bottlenecks in the product theme.

- Question 10: There are no price fluctuations in the virgin material. When there is no price fluctuation in the virgin material, there is no additional pressure to invest in recovered material. Stakeholders are not scared for sudden price changes.
- Question 16: There are no incentives for end-users when they participate in the recovery of the material. This discourages the end-users to offer the materials back to the manufacturer for recovery.

The questionnaire identified 1 bottleneck in the retrieving theme.

- Question 27: The recovered material will be sold back in an unprocessed state. This means that other parties will earn less money on it. It will be less interesting for other organisations to benefit from the recover process and will result in a more difficult material chain to set up.

6.4.3 Testing the questionnaire with the PVC material chain

The PVC material chain scored the following feasibility percentages.

- Strategy: 27,5%
- Product: 51%
- Retrieving: 61%

The scores of the PVC material chain are not that high compared to the previous cases. The chain is currently not operational. The questionnaire indicates that most problems are located in the strategy of the chain. The themes product and retrieving score almost sufficient and slightly sufficient. Surprisingly, during the case study, the interviewee Klaas van der Sterren already indicated that the organisations in the chain are the biggest bottleneck. They were not operating together and were not convinced that the chain would be the next step to develop in the PVC material chain. This confirms and validates the reliability of the questionnaire.

The questionnaire identified 5 bottlenecks in the strategy theme.

- Question 1: There is no legal responsibility to recover the material. There are no legal pressures for organisations in this chain to improve the recovery of this material chain.
- Question 2: There is currently no proven economic benefit to recover the material. This is an important reason why organisations in this field are not committed to recover.
- Question 3: The producer of the material is not responsible for the material. There are not penalties for the producer when the material is not disposed of correctly.
- Question 4: The end-user is not responsible for the disposed material. It could be that the material will never be recovered because end-users do not feel responsible.
- Question 5: There is a need for additional licenses to process the recycled material. This results in additional costs and difficulties to recover the material.

The questionnaire identified 6 bottlenecks in the product theme.

- Question 7: Costs for waste disposal compared to material recovery are cheaper. An organisation is often seeking for the lowest cost, and would prefer the waste disposal method considering it is cheaper than to recover the material.
- Question 12: It is uncertain what the continuity of demand is for that recovered material. The industry does not see the advantages of the recovered material, therefore not stimulating it resulting in an unsure demand of it.
- Question 13: It is uncertain what the potential continuity is to recover the material. The industry does not know how much material is currently used, this results in unknown information how much can be recovered.
- Question 14: User does not return the product for philanthropic reasons. This discourages the end-users to offer the materials back to the manufacturer for recovery.
- Question 15: End-users are not aware of the recovery possibilities of this material. When the end-users are unknown to the possibilities of recovery, it will be probable that recovery cannot be done.
- Question 16: There are no incentives for end-users when they participate in the recovery of the material. This discourages the end-users to offer the materials back to the manufacturer for recovery.

The questionnaire identified 4 bottlenecks in the retrieving theme.

- Question 20: The material has a diffuse spread amongst the end-users. When the material has to be retrieved it will be dispersed at the end-users. This makes it more difficult to retrieve and will also create higher costs.
- Question 22: This material cannot be retrieved by the same partners used for the forward logistics. The reverse logistics of this material needs additional partners to recover the material.
- Question 24: The disposed material is currently not collected at all. This means that it is currently disposed in the normal waste disposal methods. This challenges to create a total new retrieving system.
- Question 27: The recovered material will be sold back in an unprocessed state. This means that other parties will earn less money on it. It will be less interesting for other organisations to benefit from the recover process and will result in a more difficult material chain to set up.

Seeing the scores, and locating the bottlenecks, makes it possible to realize where the biggest problem is of this chain. Although the low scores, it is also noticeable that the chain has potential to be a successful material chain. In the themes product and retrieving are possibilities to improve. Only the strategy theme is the biggest bottleneck that needs to undergo a re-evaluation.

6.4.4 Testing the questionnaire with the mattress material chain

The mattress material chain scored the following feasibility percentages.

- Strategy: 74,5%
- Product: 26%
- Retrieving: 29%

The mattress material chain is currently not operational. Comparing the results from the questionnaire with the practical experience of the chain, are according to Lommelaars consistent to each other. Compared to the PVC material chain, the mattress material chain scored high on the theme strategy and low in themes product and retrieving. This is the complete opposite of the PVC material chain. The PVC material chain organisations are not committed to make the chain, the mattress material chain is committed to a successful chain but encounters bottlenecks in the themes product and retrieving. This is also what Lommelaars indicated during the case study. The mattress material chain really wants to set up this chain, but endures a lot of problems with the product and retrieving of the product. This also confirms and validates the reliability of the questionnaire.

The questionnaire identified 2 bottlenecks in the strategy theme.

- Question 1: There is no legal responsibility to recover the material. There are no legal pressures for organisations in this chain to improve the recovery of this material chain.
- Question 3: The producer of the material is not responsible for the material. There are not penalties for the producer when the material is not disposed of correctly.

The questionnaire identified 10 bottlenecks in the product theme.

- Question 7: Costs for waste disposal compared to material recovery are cheaper. An organisation is often seeking for the lowest cost, and would prefer the waste disposal method considering it is cheaper than to recover the material.
- Question 8: The costs for recovered material are more expensive compared to virgin material. As long as the recovered material is more expensive compared to virgin material, producers will keep using the virgin materials.
- Question 9: The virgin material is not scarce. It could be cheaper for manufactures to buy new virgin material instead of recovered material.
- Question 10: There are no price fluctuations in the virgin material. When there is no price fluctuation in the virgin material, there is no additional pressure to invest in recovered material. Stakeholders are not scared for sudden price changes.
- Question 11: There is no economy of scale created with this material. This results in possible high costs for recovery. An economy of scale creates an advantage that much can be achieved in onetime costs. When this does not apply to a material chain, it will be probable that higher costs are the result.
- Question 15: End-users are not aware of the recovery possibilities of this material. When the end-users are unknown to the possibilities of recovery, it will be probable that recovery cannot be done.
- Question 16: There are no incentives for end-users when they participate in the recovery of the material. This discourages the end-users to offer the materials back to the manufacturer for recovery.
- Question 17: The virgin material is not scarce. It could be cheaper for manufactures to buy new virgin material instead of recovered material.
- Question 18: The product has a long life-time. This can result in a longer period of time before recovery can finally be done. It is than needed to analyse historical data in detail to estimate returns.
- Question 19: The material deteriorates physical. This means that the material quality has lowered, and there is a need to reprocess it to upgrade the quality of the material again.

The questionnaire identified 4 bottlenecks in the retrieving theme.

- Question 20: The material has a diffuse spread amongst the end-users. When the material has to be retrieved it will be dispersed at the end-users. This makes it more difficult to retrieve and will also create higher costs.
- Question 21: The end-user has to input an effort to let the material be recovered. This results that end-users are not willing to recover the material, making is more difficult to retrieve it.
- Question 23: Collection of the material cannot be segmented, this results that there is no immediate distinction between one product retrieval and the other. There has to be an extra selection to determine the differences in the retrieved material.
- Question 26: There is no proven technology to use to reprocess the material and reintroduce it back to the forward stream of the material chain. It is uncertain what the costs will be to recover the product. This makes it very difficult to not possible to create a material chain, when costs of it are unknown.

6.4.5 Testing the questionnaire with the EPS greenhouse material chain

The EPS (expanded polystyrene) greenhouse material chain scored the following feasibility percentages.

- Strategy: 54%
- Product: 78%
- Retrieving: 73%

Frerik van de Pas is the contact person within the EPS greenhouse material chain. He is familiar with the EPS greenhouse material chain because of his position to consult from the government to organisations in this sector. The scores achieved during the questionnaire conclude that the material chain has a high feasibility as a product to close the material chain. There are some bottlenecks that could be improved in the strategy theme. The exact figures of recycling and recovering in the EPS greenhouse material chain are unknown, but the chain already exists for the last couple of years. This indicates that the material chain is at least a success to keep it standing. But there are some studies investigating EPS and its product characteristics in a chain approach. These studies concern EPS in the packaging industry and in the construction industry (INTRON 2008). The same bottlenecks identified in this study are also coherent to the identified bottlenecks of the questionnaire. Clear and important examples of these bottlenecks are the problems with license, and the uncertain continuity of recovered material. The INTRON study and this study conclude on these points the same issues. Unfortunately, the two studies concern other material chains; this makes it impossible to conclude a 100% reliable validation.

The questionnaire identified 3 bottlenecks in the strategy theme.

- Question 3: The producer of the material is not responsible for the material. There are not penalties for the producer when the material is not disposed of correctly.
- Question 4: The end-user is not responsible for the disposed material. It could be that the material will never be recovered because end-users do not feel responsible.
- Question 5: There is a need for additional licenses to process the recycled material. This results in additional costs and difficulties to recover the material.

The questionnaire identified 3 bottlenecks in the product theme.

- Question 9: The virgin material is not scarce. It could be cheaper for manufactures to buy new virgin material instead of recovered material.
- Question 13: It is uncertain what the potential continuity is to recover the material. The industry does not know how much material is currently used, this results in unknown information how much can be recovered.
- Question 14: User do not return the product for philanthropic reasons. This discourages the end-users to offer the materials back to the manufacturer for recovery.

The questionnaire identified 3 bottlenecks in the retrieving theme.

- Question 20: The material has a diffuse spread amongst the end-users. When the material has to be retrieved it will be dispersed at the end-users. This makes it more difficult to retrieve and will also create higher costs.
- Question 22: This material cannot be retrieved by the same partners used for the forward logistics. The reverse logistics of this material needs additional partners to recover the material.
- Question 27: The recovered material will be sold back in an unprocessed state. This means that other parties will earn less money on it. It will be less interesting for other

organisations to benefit from the recover process and will result in a more difficult material chain to set up.

6.4.6 Testing the questionnaire with the gypsum material chain

The gypsum material chain scored the following feasibility percentages.

- Strategy: 84%
- Product: 61%
- Retrieving: 82%

Joost Lommelaars, who is also the expert in the mattress material chain, also is the expert in the gypsum material chain. The gypsum material chain is currently active but encounters problems. Gypsum became in the last decade an important material to use in construction. The result is that more gypsum material is disposed in the construction industry (Ambient 2010).

There are goals set in 2008 in a covenant for the gypsum material chain. One of them was to recycle 20% of the gypsum waste in 2008, 40% in 2010, and leading gypsum recycler by 2015. The goal of 2010 is not reached, and it remains a big task to reach the goal for 2015 (Convenant: voor publiek-private samenwerking; voor het sluiten van de kringloop van gips in de bouwsector 2008). Although the material chain is active, it encounters problems. The discussion have to be noticed if this material chain is a success because it is active and working, or not a success because the goals are not reached. This discussion is relevant for the organisations in the material chain, but irrelevant for the scope of this research. This research only focuses on creating insight and grading feasibility of the material chain recovery. How the recovery is measured, and what the goals of the chain must be are outside the scope.

One of the bottlenecks that is relevant for this chain is the comparison in costs for material recovery to waste disposal methods. The gypsum material chain can easily be transported to other countries like Germany to process the gypsum waste in a cheaper manner than the process to recover. This problem is also identified by the questionnaire. Joost was not surprised with the outcome of the questionnaire, He thinks that the gypsum material chain holds a lot of potential to be one of the best closed-loop material chains; the questionnaire validates this by the high scores received in the 3 themes. The identified bottleneck is one of the reasons why the theme product in this material chain has a lower score. The questionnaire results and the studies done to the gypsum material chain in the Ambient rapport are consistent.

The questionnaire identified 1 bottleneck in the strategy theme.

- Question 3: The producer of the material is not responsible for the material. There are not penalties for the producer when the material is not disposed of correctly.

The questionnaire identified 4 bottlenecks in the product theme.

- Question 7: Costs for waste disposal compared to material recovery are cheaper. An organisation is often seeking for the lowest cost, and would prefer the waste disposal method considering it is cheaper than to recover the material.
- Question 9: The virgin material is not scarce. It could be cheaper for manufactures to buy new virgin material instead of recovered material.
- Question 11: There is no economies of scale created with this material. This results in possible high costs for recovery. Economies of scale creates an advantage that much can be

achieved in onetime costs. When this does not apply to a material chain, it will be probable that higher costs are the result.
- Question 14: User do not return the product for philanthropic reasons. This discourages the end-users to offer the materials back to the manufacturer for recovery.

The questionnaire identified 2 bottlenecks in the retrieving theme.

- Question 22: This material cannot be retrieved by the same partners used for the forward logistics. The reverse logistics of this material needs additional partners to recover the material.
- Question 23: Collection of the material cannot be segmented, this results that there is no immediate distinction between one product retrieval and the other. There has to be an extra selection to determine the differences in the retrieved material.

6.4.7 Testing the questionnaire with a confidential carpet material chain

This section shows the results of the questionnaire tested with a possible new material chain. It is a confidential organisation that investigates the possibilities to recover carpets and recycle the material nylon from it. This chain scored the following feasibility percentages.

- Strategy: 36,5%
- Product: 48%
- Retrieving: 51%

The interviewee for this material chain is Hanneke op den Brouw. She is a consultant at NL Agency specialized in closed-loop supply chains. She is also involved with the process and studies of this specific material chain and the concerning organisation. According to op den Brouw, the results from the questionnaire are a good reflection of the problem areas also identified by the material chain itself. A confidential study done by a German party for the Dutch carpet industry verifies this and indicate the same problem areas.

The questionnaire identified 4 bottlenecks in the strategy theme.

- Question 1: There is no legal responsibility to recover the material. There are no legal pressures for organisations in this chain to improve the recovery of this material chain.
- Question 3: The producer of the material is not responsible for the material. There are not penalties for the producer when the material is not disposed of correctly.
- Question 4: The end-user is not responsible for the disposed material. It could be that the material will never be recovered because end-users do not feel responsible.
- Question 5: There is a need for additional licenses to process the recycled material. This results in additional costs and difficulties to recover the material.

The questionnaire identified 7 bottlenecks in the product theme.

- Question 7: Costs for waste disposal compared to material recovery are cheaper. An organisation is often seeking for the lowest cost, and would prefer the waste disposal method considering it is cheaper than to recover the material.
- Question 9: The virgin material is not scarce. It could be cheaper for manufactures to buy new virgin material instead of recovered material.

- Question 10: There are no price fluctuations in the virgin material. When there is no price fluctuation in the virgin material, there is no additional pressure to invest in recovered material. Stakeholders are not scared for sudden price changes.
- Question 11: There is no economies of scale created with this material. This results in possible high costs for recovery. Economies of scale creates an advantage that much can be achieved in onetime costs. When this does not apply to a material chain, it will be probable that higher costs are the result.
- Question 15: End-users are not aware of the recovery possibilities of this material. When the end-users are unknown to the possibilities of recovery, it will be probable that recovery cannot be done.
- Question 16: There are no incentives for end-users when they participate in the recovery of the material. This discourages the end-users to offer the materials back to the manufacturer for recovery.
- Question 18: The product has a long life-time. This can result in a longer period of time before recovery can finally be done. It is than needed to analyse historical data in detail to estimate returns.

The questionnaire identified 5 bottlenecks in the retrieving theme.

- Question 20: The material has a diffuse spread amongst the end-users. When the material has to be retrieved it will be dispersed at the end-users. This makes it more difficult to retrieve and will also create higher costs.
- Question 21: The end-user has to input an effort to let the material be recovered. This results that end-users are not willing to recover the material, making is more difficult to retrieve it.
- Question 23: Collection of the material cannot be segmented, this results that there is no immediate distinction between one product retrieval and the other. There has to be an extra selection to determine the differences in the retrieved material.
- Question 28: The material is heterogeneity. It exists of many different parts all needed to separated before reprocessing. This additional task can cost a lot.
- Question 29: There is additional testing needed to reprocess the material. This results in additional costs to test.

6.5 Validation and discussion

The questionnaire is tested with the same material chains used for the case studies of this research. This is done to validate the reliability of the questionnaire to known results. The feasibility scores in these tests are coherent the practical experience of the chains. The chains that were not a success received low feasibility scores, the chains that were a success received high feasibility scores. This concludes that at the questionnaire represents the studied material chains. The next stage is to investigate if the framework and questionnaire can be validated by using other material chains. Three new material chains are introduced, namely EPS greenhouse, gypsum and carpet material chain. The results of all material chains are set out in the following table.

	Theme strategy	*Theme product*	*Theme retrieving*	*Validation*
Asphalt material chain	70%	65%	72%	100% recovery of which 40% is recycled
Paper and cardboard material chain	70%	89%	92%	45% from consumers and 55% from businesses is recovered of which in total 80% is recycled.
PVC material chain	27,5%	51%	61%	Not operational material chain, thus no figures known about recycling and recovering. But according to van der Sterren, problems are in commitment of organisations.
Mattress material chain	74,5%	26%	29%	Not operational material chain, thus no figures known about recycling and recovering. But according to Lommelaars, problems are in spread of the material and difficult disassembly.
EPS greenhouse material chain	54%	78%	73%	Currently an existing material chain but unfortunately no exact figures available about recycling and recovering. Identified bottlenecks compared to other studies of other EPS material chains conclude a relation between general material bottlenecks.
Gypsum material chain	84%	61%	82%	Currently an existing material chain but not considered as a success. Unfortunately no exact figure o
Carpet material chain	36,5%	48%	51%	Not operational material chain, thus no exact figures known about recycling and recovering. Validation done by experience of the expert.

Table 6: Questionnaire test results

It becomes possible to directly notice in which area of the material chain the most bottlenecks are. Each question answered negatively is a bottleneck, but the themes indicate what problem area scores the lowest and has the most problems. It is difficult to give exact definitions to the percentage scored in each theme. A high score means that the feasibility is high to recover the material in the chain, but does not mean that it is immediately a success in recovery and recycling. This also applies vice-versa. But comparing the results to facts, studies or opinions from the material chain, conclude that the percentages from each theme represent the reality. It is arbitrary, but it is possible to distinguish three main partitions in the scale from 0% to 100%.

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- Scores per theme in the range of 0% - 40% are a priority to solve the bottlenecks. If these bottlenecks are not solved, it is probable that the material chain will fail.
- Score per theme in the range of 40% - 70% are second priority to solve the bottlenecks. It is probable that a material chain will be successful to create, but solving the bottlenecks creates a higher chance of a better and more efficient material chain.
- Score per theme in the range of 70% - 100% are a low priority to solve. It is recommended to critically analyse the bottlenecks to consider improvements, but scores in this range conclude a successful material chain.

6.6 Conclusion

The research findings existed of lot of data from the case studies and theoretical framework that represent an overview of the literature review. The conversion from the found data to an end result for this research complying with the objectives set in chapter 1 was difficult. Questions arose how to:

- Create a tool that can be used by any user within the material chain.
- Create a tool that is general so it can be used with all types of materials and products.
- Create a tool that can give clarity to the feasibility of the closed-loop material chain.
- Create a tool that will identify bottlenecks.
- Create a tool that will advise the user to increase feasibility of the closed-loop material chain.
- Create a tool that can be used for new or existing material chains.

The first step is to discover a way to create a framework general to use for all types of products or materials. To do this, it was important to seek an approach that would be the same for all products and materials. This eventually led to the idea that all products and materials have their own characteristics. When approaching the closed-loop material chain from the perspective of product characteristics it solves the issue that the framework can be used by all materials and products. This made it possible to deliver a framework that is general to use and is detailed in advice for that product or material.

Because all findings need to be transformed to product characteristics, some aspects needed to be combined and re-categorized. It resulted in the 29 product characteristics divided into 10 categories. These 10 categories are then placed in 3 themes. The themes are to specify the final advice for the user and the categories are to structure the questions to a logical sequence.

By creating a questionnaire that resulted in the 29 issues, it was possible to let the user think critically about each issue concerning their specific closed-loop material chain. By formulating each issue in a question with only two possible answers, the tool was able to give advice on each issue. Also because of these two possibilities it was easy to identify which question had a positive or negative impact on the material chain. In this way, the questionnaire could identify a bottleneck for new or existing chains.

To tackle the problem to credit each question with a feasibility score, the questionnaire is graded by experts in the field of recovery. The experts had to grade each question to relevance and impact to a closed-loop material chain. In this way it became clear which questions had more impact than the other. Then the separate answers needed to have separate weighing contributions to the feasibility.

Only the questions 1, 10, 18 and 25 had other weighing factors. All other questions received full points for positive answers, and no points for negative answers.

Testing the questionnaire with 7 material chains validates that the questionnaire and framework is reliable and coherent to the results in other studies and in practice. The tools can be used in practice to give insight in material chain recovery, and indicate the recovery problem areas in the material chain by grading the feasibility of each theme.

7 Conclusion and recommendations

The concluding chapter of this research thesis is an overview of all findings and conclusions drawn from the investigation. It motivates and explains decisions and proves the validation of this research thesis. In paragraph 7.1 Main findings, all important discoveries in this research are shown and explained. It concludes if the problem defined in the main question is answered. Paragraph 7.2 Lessons learned, re-evaluates the total approach, design, process and problems that occurred during the research to solve the problem that was defined in the main question. This section recapitulates the actions taken to come to the end results, and explains what benefits and disappointments certain steps were. It also motivates what problems and other issues did occur as obstacles and what was learned from it. Paragraph 7.3 Research conclusions, brings the final conclusion of this research to the attention and motivates why and how it solves the problem initially defined in the main question. Paragraph 7.4 Research limitations and recommendations, explains what limitations there are in this research and how these can be used in future research. It provides ideas how the results of this thesis can be improved to provide better information to the users of the tools.

7.1 Main findings

The beginning of this research started with a problem in recovery of materials and products by organisations. Analysing this problem, brought to the attention that there are a lot of studies available and written by academia. The question arose why these studies were not contributing to a solution of the defined problem. Brainstorm sessions and interviews helped indentifying the problems organisations still had with recovery. Analysing these problems and reviewing the current literature about recovery, brought to the attention that current theories are only describing the subject recovery. It did not give enough useful information to organisations to use it in their practical issues.

A closed-loop material chain framework and questionnaire solves this problem. The current available literature is used and combined with practical knowledge. By deriving a theoretical framework from the literature review, and joining and comparing this with four case studies that represent practical experience, it was possible to incorporate practical issues in the theoretical knowledge. This gives organisations their needed information to use theory in practical issues. This information is used in the form of the framework for an graphical overview, and a questionnaire to give more insight and grade the feasibility of the material chain recovery.

The review of literature on theoretical developments of reverse logistics from Brito is the basis to build de theoretical framework from. Additional topics to her study were risks of recovery and alliances in recovery. With this complete theoretical framework, comparisons are done with four case studies. The case studies are two successful material chains, and two unsuccessful material chains. The asphalt material chain recovers 100% and re-cycles 40% according to van Groen. The paper and cardboard material chain recycled in 2008, 80% of all recovered material (Papier Recycling Nederland (PRN) 2009). The two unsuccessful material chains, PVC and mattress, are not yet operating. They are still in a pilot phase but experience problems in the process.

The added topics to Brito's studies completed the theoretical framework. The theoretical framework had 2 functions, structuring the case study interviews and easily compare case study

findings to theory. After conducting the case studies some aspects were deleted from the theoretical framework, and new topics were included to the final framework and questionnaire. The deleted aspects are:

- Are businesses returning the materials in this chain?
- Are consumers returning the materials in this chain?
- How often is the product used to deteriorate?

All topics from the theoretical framework that are not deleted are used in the final framework and questionnaire. There are some adjustments in these topics.

- Economical, legal and philanthropic responsibilities are joined to only economical benefits and legal responsibilities
- Collection, testing, selecting, sorting and recovery are merges as only two categories namely recovery and selecting.
- Alliance awareness resulted in one question to consider collaborations or not in a material chain
- Recovery by manufacturer, third party or consumer is merged in the question who is responsible for the recovery.
- Risks from the theoretical framework are transformed in the questions concerning demand, continuity, proven technology and life-time of the material.

The added topics from the case studies that are incorporated in the final framework and questionnaire are:

- Costs
- Continuity
- License

To create a general closed-loop material chain framework and questionnaire from all these issues was a problem. It was unknown how to form all different topics logical, practical and easy to use so it can be used by any new or existing material chains, no matter what the material is. The solution is found in product characteristics. Making the tools revolve around product characteristics, and asking the questions in the questionnaire from the perspective of product characteristics, made it possible to achieve a practical and general end-result. It resulted in 29 aspects that are mentioned in the final framework and questionnaire. To structure these 29 aspects, they were categorized in 10 categories. This makes it possible to have a logical sequence in the questionnaire. By dividing these 10 categories in 3 themes, made it possible for the questionnaire to focus on the identified bottleneck areas in a material chain. The final questionnaire calculates the feasibility of the material chain in three areas, coherent to the three themes: strategy, product and retrieving. This makes it possible that an organization can identify where the bottlenecks of the material chain is located, and can better concentrate on the solutions for that area. When the questionnaire would calculate one feasibility grade, it is still unknown in what areas the material chain fails.

To make the final framework and questionnaire a reliable representation of the reality, all 29 aspects are graded by 7 experts from NL Agency and the Erasmus University. They all have an affiliation with material chains and recovery. Their task is to grade each aspect to its relevance considering the total material chain. It was then possible to determine which aspects should receive a higher weighing factor, compared to other aspects. The gradation of the experts can vary. Expert answered the questions based upon personal experience and gained knowledge over the years. For example, one expert has encountered the problem; the other one not and therefore grades it lower.

When noticing this effect of varieties, and actually being aware that the research concluded that all these question were important, it is logical that there are fluctuations in the gradation. Thanks to the gradation of the questions it was possible to calculate the percentage of relevance per question in relation to its theme. It was a difficult decision to determine what the best practice is to award points. It finally resulted in the most simple and effective manner, from 0% to 100%. When the questionnaire is used, it provides a clear percentage per theme about the feasibility of that theme in the material chain.

Because the question answers are already known, it was important to evaluate each answer on their impact. The experts only graded the questions, but not the separate answers. The reason for this is simple; it is too detailed for the experts to give each answer a different weighing factor. By critically analyzing each question and their answers brought to the conclusion that only 4 questions in the final questionnaire had to have a special weighing factor. The weighing factor for the positive answer is not the same factor for the negative answer to this question. These are questions:

- Question 1: Is there a legal responsibility to recover that material?
- Question 10: Are the price fluctuations in virgin material?
- Question 18: What is the life-time of the material?
- Question 25: What recovery method will be used, process or direct recovery?

The tests of the final closed-loop material chain framework and questionnaire brought positive reactions. The tools are first tested to the same material chain case studies as used for this research. The conclusions of these tests were that the tools are working correctly. The material chains that are a success scored in the questionnaire a high feasibility score on all aspects. For the material chains that were not a success, the questionnaire graded the feasibility score low on at least one theme. Looking at the result brought the user immediately to the attention in what bottlenecks any improvements could be done. We could conclude that the tools represent at least the already studies cases.

To confirm the reliability of the framework and questionnaire, it is tested with additional material chains. These are the EPS (expanded polystyrene) material chain, the gypsum material chain and the carpet material chain. The EPS and gypsum material chain are currently operational. EPS is considered a successful material chain. The gypsum material chain is considered an unsuccessful material chain because it did not reach its appointed goals. The carpet material chain is not operational; it is currently investigated if this chain is feasible. Because there were no exact figures of the performances of the chains, the assessment of the questionnaire is done by comparing it with studies, experiences and opinions of the chain experts. These findings in relation to the results of the questionnaire validate the reliability of the tools.

Information and communication technology (ICT) is in the field of recovery a supporting tool. Some innovative possibilities are described in the literature review. ICT can be used in many ways in recovery, often supporting recovery in the sense of controlling information. Providing secure information in time. As seen in this research, the determined risks in recovery are also information sensitive. ICT can mitigate this by providing in-time and secure information. It is important to realize that ICT is an investment to support recovery, and a balance has to be found in how much will be invested and how much will be profited from ICT. Because ICT is outside of the scope for the defined problem in this research, it is not discussed in detail. But certainly has a role in recovery for possible further research.

7.2 Lessons learned

Next to all new findings and discoveries in subjects recovery, sustainability and cradle to cradle, some additional "lessons learned" are remembered. It is important to be determined to reach the goals that are defined. Possible problems that will be encountered need to be overcome, especially in a research where a lot of unknown options are encountered. Difficult decisions in this research are in the following issues summarized.

- Holding on to the requirements personally defined at the beginning of the research. Requirements like a general tool that can be used in practice by everybody, a framework for new or existing material chains for any material or product.
- Deciding what data will be taken into account without loss of quality in the final results.
- Deciding how to measure results of individual findings.
- Deciding how to design the framework considering the requirements.
- Deciding how to create the questionnaire that represents the reality considering the requirements.

In this type of research with much unknown options, it is probable to encounter a problem that seems not solvable at all. It is important in this situation to experiment with the possibilities. Eventually after much experimenting, it leads to a solution fitted to the requirements. Failing, retrying committing and be determined are important steps when investigating a new and unknown research area. This is an important lesson learned during this research.

7.3 Research conclusions

In paragraph 1.2 Problem definition, the main question for this research is formulated as:

"How can the Dutch industry get better practical insight in the feasibility to recover materials with closed-loop material chains to be more sustainable in practice?"

The answer to this question is: By using the closed-loop material chain framework and the questionnaire. These tools are directly accessible for organisations without intensive preparations, and directly useable to provide insight and a feasibility probability. The closed-loop material chain framework gives organisations insight in the possible problems that can be encountered when setting up a closed-loop material chain for recovery. This framework is derived from combined information in theoretical and practical knowledge. The questionnaire provides feasibility scores, and indentifies and advises on bottlenecks in the material chain. Organisations can create a plan to mitigate possible bottlenecks to make the material chain more successful.

To come to the conclusion for the main question it is divided in 6 sub-questions. All sub-questions contribute to solve the main question.

1. What are the overall basic principles of C2C and their stakeholders' objectives?
2. What are the bottlenecks in C2C and recovery?
3. What are the bottlenecks of recovery in practice?
4. What is the gap between current studies and the industry?
5. What is needed to overcome the gap between current studies and the industry?
6. How to give practical insight in the feasibility of closed-loop material chain recovery?

Research sub-question 1 and 2 are answered in the literature review. C2C focuses on product redesign to reuse all products and materials. The Dutch government wants to have a cleaner climate. The Dutch industry wants to make profit and the consumers want to have the lowest

possible cost and effort for their product expectations. The bottleneck of C2C that concerns this research area is the recovery. The C2C technical cycle describes that products must reused in the same or better quality. A bottleneck in this idea is that the product first must be recovered. Bottlenecks identified in theoretical knowledge are limitations in information about recovery. These limitations make recovery uncertain and difficult to predict possible profit or losses.

Research sub-question 3 is answered in the empirical research. The bottlenecks of recovery in practice that are not identified in the literature are costs, continuity and licenses. These bottlenecks are added as topics in the final tools to create a framework and questionnaire that handles all possible problems.

Research sub-question 4, 5 and 6 is answered in the framework building chapter. The gap between current studies and the industry are the added bottlenecks in sub-question 3, and the deleted aspects from the theoretical framework. These deleted aspects are B2B and C2B returns and the frequency of usage before deterioration. Next to the gap in contents, there was also a gap in availability and usage of information concerning recovery. It was needed to join literature with practical experience and form it in an accessible tool to be used for recovery in material chains. A framework and questionnaire gives organisations more insight in material chain aspects and the feasibility of the material chain.

Joining all answers of the sub-questions, lead to the answer given to the main question. This makes it also possible to solve the problem defined in this research.

7.4 Research limitations and recommendations

The limited studies to C2C made it impossible to determine the scientific view of C2C in the industry and their recovery. It is difficult to determine when recovery is coherent to the principles of C2C. This asks for future research in the area of C2C and its possibilities in recovery.

It is also possible to conduct future research in the area of the indentified issues of the final tools. All issues can be investigated separately and measured more intense to the impact of the material chain. This research did this by analysing the opinions of several experts. It is imaginable that a more in-depth research to all specific questions creates a more reliable weighing factor for each aspect. This results in a better graded framework and questionnaire, thus a better tool for the users.

In extension of the previous recommendation, it is also possible to further analyse complex aspects mentioned, like collaborations licences and several assessments mentioned in the tools. This framework and questionnaire creates awareness and a simplified advice for identified bottlenecks. The advice only considers what the organisation should change to mitigate, not what the exact approach is. Further research could provide these methods and approaches to tackle these bottlenecks.

In case of the formulation of the framework and questionnaire, critical analyses would help to improve the understanding of each question. It is recommendable to identify with the users which questions are misinterpreted, and how to formulate this to improve it.

The possibilities of ICT in this field are recommended for further research. There are a lot of possibilities created with ICT; it is interesting to investigate how ICT can create these possibilities to benefit from it. Studies in recovery and ICT revolve around possibilities as a supporting tool for information management. It is important to seek answers to identify how ICT can be used, not only for information management, but also for boosting recovery and retrieving possibilities.

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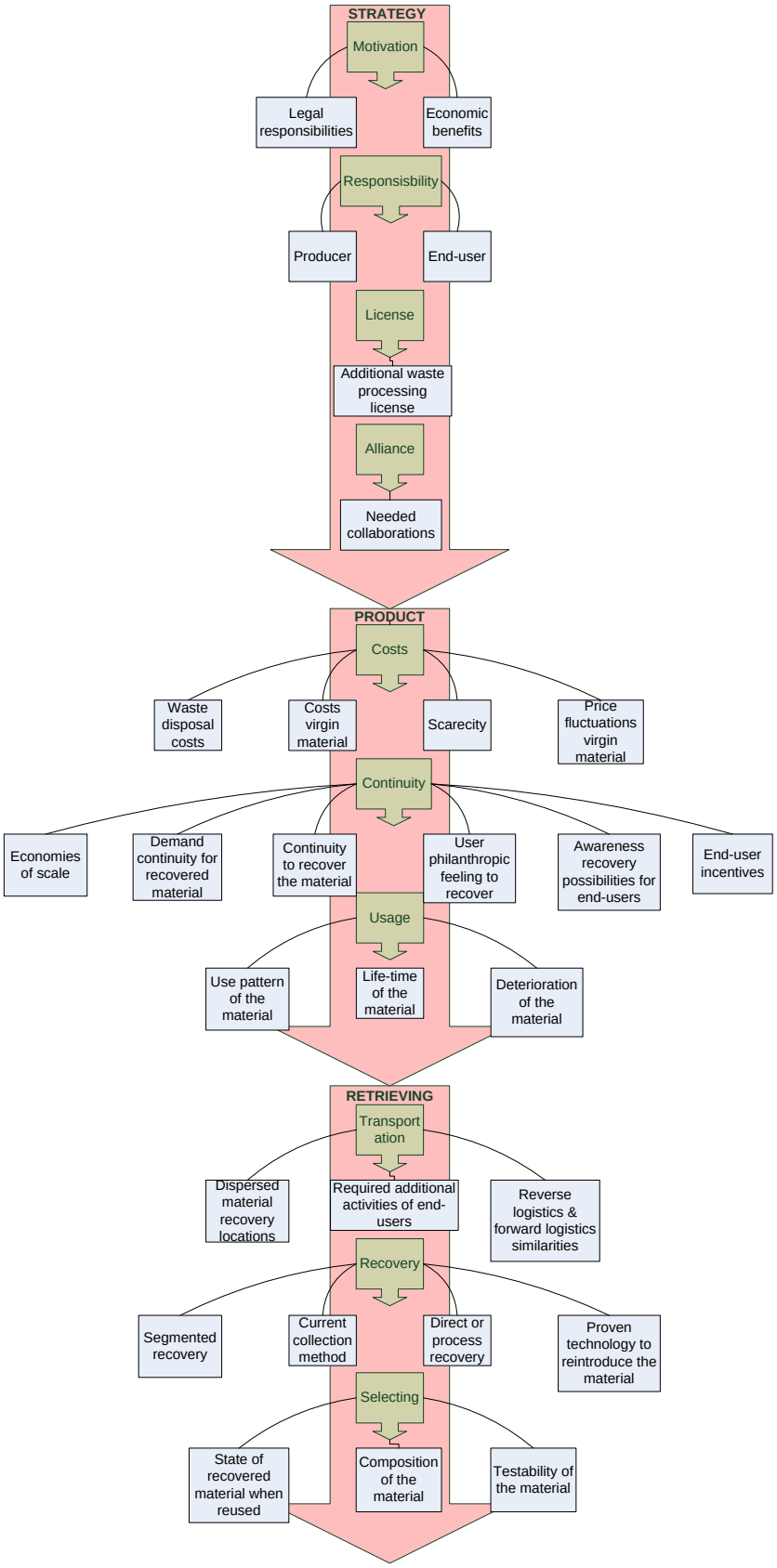
Appendix A: Closed-loop material chain framework



Appendix B: Questionnaire grading results

Questionnairre grading results closed-loop material chain framework

Question#	Expert	I	II	III	IV	V	VI	VII	Relevant percentage **Z (A)**	total **(U)**	**I (A) = Z(A) / (U) * 100%** Important part of material chain in % **(I)**
1		4	5	5	4	5	5	5	94,29%	5	18,85714286
2		4	4	5	4	4	5	4	85,71%	5	17,14285714
3		4	3	3	4	4	5	5	80,00%	5	16
4		1	2	3	4	4	5	3	62,86%	5	12,57142857
5		5	4	5	4	4	4	5	88,57%	5	17,71428571
6		5	4	4	5	4	5	4	88,57%	5	17,71428571
	U = Theme Strategy total Z(A)								**5**		
7		5	3	5	5	5	5	3	88,57%	9,428571429	9,393939394
8		5	3	5	5	2	5	4	82,86%	9,428571429	8,787878787
9		5	4	5	4	1	5	5	82,86%	9,428571429	8,787878787
10		3	4	5	5	3	4	3	77,14%	9,428571429	8,181818181
11		5	3	4	4	3	3	3	71,43%	9,428571429	7,57575575
12		4	4	4	5	3	5	5	85,71%	9,428571429	9,09090909
13		4	5	4	3	2	5	5	80,00%	9,428571429	8,484848484
14		3	1	4	2	1	3	3	48,57%	9,428571429	5,151515151
15		3	2	4	3	2	5	3	62,86%	9,428571429	6,666666666
16		2	3	4	3	2	5	4	65,71%	9,428571429	6,969696969
17		2	2	5	3	3	5	5	71,43%	9,428571429	7,57575575
18		3	3	5	4	1	5	4	71,43%	9,428571429	7,57575575
19		2	1	3	3	1	5	4	54,29%	9,428571429	5,75757557
	U = Theme Product total Z(A)								**9,428571429**		
20		4	3	4	4	2	5	4	74,29%	7,171428571	10,35856574
21		3	3	3	4	4	4	4	71,43%	7,171428571	9,960159363
22		2	2	5	4	3	5	3	68,57%	7,171428571	9,561752989
23		4	3	3	4	2	4	4	68,57%	7,171428571	9,561752989
24		3	4	5	4	4	5	4	82,86%	7,171428571	11,55378486
25		1	1	2	3	2	5	3	48,57%	7,171428571	6,772908367
26		5	5	5	5	4	5	5	97,14%	7,171428571	13,54581673
27		2	2	3	3	3	4	4	60,00%	7,171428571	8,366533865
28		4	4	4	4	2	5	4	77,14%	7,171428571	10,75697211
29		3	3	2	4	3	5	4	68,57%	7,171428571	9,561752989
	U = Theme Retrieving total Z(A)								**7,171428571**		

Appendix C: Closed-loop material chain questionnaire

#	Question	Answer	Points

Start of theme Strategy in closed-loop material chains

1	**Is there a legal responsibility to recover that material?**	Yes, legal responsibilities are applied by legislation. Everybody in the material chain has a commitment to participate, it will benefit in their existence to stay in business in this sector. For this reason there are many parties available struggling with the same problems and collaborations can be made easier.	**19%**
		No, there is no legal responsibility. Producer of the material may not be interested or committed to recover the material and not everybody in the material chain will commit to the idea. There is a high probability that the set-up of the material chain will be individually done.	**9,5%**

2	**Is there an economic benefit to recover that material?**	Yes, the material chain will open new possibilities to create profit. An advantage is that there is a direct benefit because of the materials chain; this will be often in the form of savings in costs. Other forms can be by creating a niche, a new market because not everybody in the chain is doing it. End-users will pick up on this new market and will commit to its products. The created benefit does can address multiple links in the material chain. Different reasons like in-house technical benefits, creating new green market segment so they can sell their new products, expensive production, save money, incentives are just a few benefit possibilities.	**17%**
		No, there is no economical benefit. It could even create more costs. It has no sense to start a closed-loop material chain. Motivation will primarily be legal responsibilities. Material chain will cost money but is a necessity.	**0%**

3	**Is the producer responsible for the disposed material?**	Yes, the producer has to pay for processing the disposed material. The producer of the material will be interested and committed in recovering their material and possibly save money in disposing costs	**16%**
		No, the producer is not responsible, and does not have additional costs to dispose the material. The producer will probably not commit to recover the material. There is no direct interest in both economical and legal aspects. This is important to the continuity of the closed-loop material chain.	**0%**

4	**Is the end-user responsible for the disposed material?**	Yes, end-users are responsible to dispose the material. This will often be calculated in the price the user pays for the material or the additional cost to let the material be picked up. The producer of the material will not immediately be interested in recovering the material because there are not directly any economical benefits for him. However the costs of processing the material is paid by the user, producers could benefit from it to recover and have lower costs.	**12%**
		No, end-users are not responsible to dispose the material. Possible option is that the producer is responsible, or that the government pays the processing of the material.	**0%**

5	**Will the processing manufacturer of the recycled material need additional licenses?**	No, the recovered material is sold back the processing manufacturer as a raw material. The manufacturer does not need to worry about the issue of licensing, he is buying raw material to use for production.	**18%**
		Yes, licenses to be a waste processing organisation are needed With the end-of-waste criteria it is important to determine if this is needed for the specific material. Many organisations do not want additional licensing to be a waste processing organisation and often back down to retake the materials. The material chain will then fall apart. Strict regulations are needed to accomplish this. End-of-waste criteria can offer solutions in future. It is not buying raw material but waste to process for production.	**0%**

6	**Is there an alliance needed for recovery?**	Yes, collaborations are needed in form of alliances There are many risks with an alliance because of collaboration problems. This can be mitigated by good agreements and narrow collaborations. There is an additional diagram in how to set-up collaborations. When alliances are set-up it will create much more benefits economies of scale, spread of risks etc. Of course this also means that profits must be shared too.	**18%**
		No, everything will be done by the initiator self. This will mean that all risks concerning alliances are gone, but difficulties in creating economies of scale and efficient manners to recover will arise. Where the alliance risks can easily be mitigated by good agreements and commitment, individual material chains are costly and difficult to do for one organisation.	**0%**

End of the theme Strategy. Accumulate the received points.

Received points for the theme Strategy in closed-loop material chain is:

.....

This percentage represents the feasibility of the strategy in the intended material chain. Discover on what issues the strategy can be improved by reviewing the questions where no points were credited.

<u>Start of theme Product in closed-loop material chains</u>

7	**Are the costs for material recovery cheaper than waste disposal methods?**	Yes, the costs to recover the material are cheaper than disposing the material. This will save money in processing the disposed material for incineration or dump. Producers and manufactures are very interested in recovering the material and save money in costs in waste processing methods.	**9%**
		No, the costs to recover the material are more expensive than disposing the material. Initial recovery will cost money. This means the material chain will be an investment and benefits will come later in other forms like cost reductions in other processes. These investment costs need to be considered, but at the same time improvements must be done to make the material cheaper to compete with disposing methods.	**0%**

8	Are the costs for recovered material cheaper than buy-in virgin material?	**Yes, the costs for recovered material are cheaper than new virgin material.** **This gives producers the possibility the directly save costs in the purchase of virgin material. Producers will be interested in recovering.**	9%
		No, the costs for recovered material are more expensive than new virgin material. Results in difficult survival of the closed-loop material chain. It is needed to find methods to reduce costs in processing recovered material. Virgin material is cheaper than recycled material, and therefore will be bought over the recovered material. Without a demand in recovered material it will be impossible to the existing for the material chain. It is important to show what the benefits are for recovered material.	**0%**

9	**Is the virgin material scarce?**	Yes, the material is scarce and could lead to rising prices for the material. Probability to look into recycled material to replace virgin material is very interesting for organisations.	**9%**
		No, the material is not scarce. This will often create a very cheap price for the virgin material. Smaller chance that recycled material is cheaper than virgin material. Organisations than prefer the cheapest option virgin material.	**0%**

10	**Are there price fluctuations in the virgin material?**	Yes, fluctuations in price are important when comparing prices between recycled and virgin material Results in uncertainty and possible risks when virgin material prices are high. Recycled material will then be interesting to reduce costs.	**8%**
		No, there are no fluctuations. There is a need to compare virgin and recycled material. It brings certainty if it is always cheap or always expensive to use virgin or recycled material.	**4%**

11	**Is there a scale advantage created (economies of scale)?**	Yes, an economy of scale is created. The material chain will be faster profitable. Because of economies of scale it means that there is enough supply of material streams and enough demand for it. It will be possible to do large quantities and reduce costs in processing within the material chain.	**8%**
		No, an economy of scale is not created. It is essential to create economies of scale to reduce costs. Otherwise the material chain could cost a lot because of all individual costs instead of bulk procedures. Economies of scale can be created by grouping materials. To create economies of scale, one of the methods could be to create collection points for pick up.	**0%**

12	**Is there a potential continuity of the demand for the recovered material?**	Yes, the industry has an interest in that recovered material. This recovered material benefits the industry and they want to purchase it. The industry will then support the initiation of the closed-loop material chain for this material. This could often have to do with the issue of scarcity. Producers will commit to the material chain when they benefit from it,	**9%**
		No, the continuity of demand for that recovered material is uncertain. If demand of recovered material is not stable it will have to do with possible negative outcomes. Reasons could be because of price fluctuations and others; it will result in low commitment of producers. Once they don't see the advantages of the recovered material, it will be impossible for the material chain to exist. It is important to let producers and manufactures see that the recovered material can be reused for their new production.	**0%**

13	**Is there a potential continuity to recover the material?**	Yes, there is a potential continuity to recover the material History shows there is a lot of disposed material currently from the end-of-use or reaching the end-of-lifetime. These materials can soon be recovered for recycling options and can determine the continuity. This is a great benefit for the existence of the material chain, without the supply of disposed material it will be impossible to keep a material chain standing.	**8%**
		No, there is no or uncertain potential to recover the material. No studies have shown that the material can be recovered or can soon be recovered from end-users. This results in the unclarity of the potential continuity of recovered material. More studies have to be done to get an insight view of the historical data of the material to know how much can be recovered in the upcoming years. Also a study has to be done to determine what the sales of the material will do for future recovery.	**0%**

14	**Is the material a product that end-users return for philanthropic reason?**	Yes, users feel the need to return the product. This results in a higher continuity of the recovered material and will stimulate the existence of the closed-loop material chain.	**5%**
		No, users do not care or it is too difficult to return the product. This results in a difficult continuity of the recovered material. Incentive could take this away. Materials need to be clean and easy to transport and save to collect at once like this is with the paper and cardboard industry. The material after usage must be improved by being cleaner, easy to transport and store etc.	**0%**

15	**Are users aware of the recovery possibilities of the material?**	Yes, users are aware of the recovery possibilities. This brings a potential higher material recovery continuity and will benefit the material chain in awareness	**7%**
		No, users do not know what they can do to recover that certain material. Users have to know what the possibilities and earnings are when they recycle that material, it will influence the recovery stream in a positive way when this is known. This result in more costs and effort to select the material from general waste. A simple solution is to reduce quality selection to find more potential material that can be recovered.	**0%**

16	**Are there incentives for end-users when recycling?**	Yes, users have incentives when they are recycling This brings a probable higher stream of material recovery. When users are aware of what they gain, they will often participate with the program of recycling.	**7%**
		No, users do not have an incentive or are not aware of their incentive. It is important to make users aware of their benefits, to stimulate their approach to recycling that material.	**0%**

17	**What is the use pattern of the material?**	The use pattern of the material is in bulk usage. This makes it easier to create economies of scale and profit from the scale size. No individual costs but all in bulks. This increases the possibility to recover more, it benefits from the continuity of incoming waste.	**7%**
		The use pattern of the material is not used in bulk. The first important aspect is to study if there is a possibility to create economies of scale. Even without bulk usage, collection of that material could still create economies of scale to save costs. When this is not possible, it is important to investigate if the material chain can exist.	**0%**

18	**What is the life-time of the material?**	The material has a short life-time. Short life-time results in fast possible recovery and high and constant continuity.	**8%**
		The material has a long life-time. Long life-time results in history analyses, and investigating what possible recovery can be done for this material in the near future. This will conclude if the existence of a material chain has it wanted purpose with such a long life-time. The analysis will focus on how much is already used and how much can be recovered during the upcoming periods.	**4%**

19	**How does the material deteriorate?**	The material deteriorates economical. This means that the material will decline in economical value because consumers are not interested in it anymore. This results in a high reusable product material, it is important to then decide if the material needs to be reused or recycle it	**6%**
		The material deteriorates physical. This means that the material will decline because of usage of the material. This results in analyses if the product is going to be interesting to be recovered or it has to be recycled. There is a high probability to recycle this type of material and make it a raw material to process it again for production.	**0%**

End of the theme Product. Accumulate the received points.

Received points for the theme Product in closed-loop material chain is:

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This percentage represents the feasibility of the product in the intended material chain. Discover on what issues the product can be improved by reviewing the questions where no points were credited.

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Start of theme Retrieving in closed-loop material chains

20	**What is the spread of the material when collected?**	The material will be collected at central collection points. This is a great advantage. Not only can collection be done at once in larger scale, it also gives possibilities to collect the material in selected categories. The collection points can often specify the origin of the material, thereby selecting quality differences between collection points.	**10%**
		The material collection is diffuse or dispersed at the end-users. This is a great disadvantage. It will be very difficult to collect because of diffuse spread of the product. Besides this fact, it is also very costly to separate each pick up. It is advisable to investigate in the options to create collection points at for example retailers or other distribution points.	**0%**

21	**Does the end-user have to do tasks to let the material be recovered?**	No, pick-up is done at the end-user; the only preparation is to offer it for pick-up. This could give additional costs because of diffuse pick-up but more material will be offered what will contribute to the continuity.	**10%**
		Yes, the end-user has to bring it to collection points. The risk exists that the end-user will not offer the material for recycling. The end-user will consider the benefits when recycling in philanthropic feeling and economic benefits. Users are often not prepared to do extra tasks, this result in less material that can be retrieved.	**0%**

22	**Can the same links be used from the forward logistics for the reverse logistics?**	Yes, same alliances and partners can be used to recover products. This will mitigate risks in new alliances. All parties could also earn more when spreading and collecting at the same time. They are already there to bring materials, why not also picking them up.	**9%**
		No, new alliances and partners need to be found. Additional risks and costs in new partnerships. It is advisable to consult with current partners in possibilities to recover.	**0%**

23	**Can collection be segmented in selected material types?**	Yes, when collected there can be selections made in recovered material quality. This saves selection costs and time. Pick-up of the materials is done in segments of quality. An example is the paper industry where offices, businesses and kiosk always provide good quality paper and packaging manufactures often have cardboard.	**9%**
		No, selecting of material still has to be done. Additional cost and time to select the material on quality differences.	**0%**

24	**Is the disposed material currently collected?**	Yes, than they could be collected at fixed points where they can be recovered Collection for material chain is already there it only needs slight adjustments to improve.	**12%**
		No, the disposed material is currently not at all collected In this case the disposed material has to be collected in waste organisations for recovery. It is advisable to investigate possibilities to separate this material waste from general waste.	**0%**

25	**What recovery method will be used, process or direct recovery?**	Direct recovery is applied Material will be selected and disassembled but used and sold as parts. More secure testing is needed in comparison to process recovery but processing of waste is a lot less intense.	**8%**
		Process recovery is applied. Material will be processed and re- or up cycled as material to use in a new production process. This is the most common process for material when recovered.	**8%**

26	**Is there a proven technology to be used to reprocess the material and introduce it back to the forward steam of the chain?**	There is a proven technique that works and will be used to reprocess the material and introduce it back to the forward stream. The technique that will be used is known and tested. The results, costs and duration of reprocessing are known. This advantage will take away any surprises you may encounter when reprocessing the material.	**14%**
		There is no proven technique that works to reprocess the material. If there is no proven technique to reprocess the material, it is not advisable to start the recovery process. It is a high priority to first discover the possibilities of techniques to reprocess and recover that certain material. When it is known what the results, costs and duration of the technique is that will be used to reprocess, you can assess if the chain will be beneficial or not.	**0%**

27	**In what state must the recovered material have to be, to resell it back to the producers?**	Raw material Producers use it for production, and are probable not conflicted with licensing for waste processing. But processing it to raw material will then not be done by producer but other parties in the material chain. They make a new raw material of the recovered material and will become a supplier of raw materials for production. This will take away licensing problems for the producer, but will cost more money for the third parties to not only recover but also to process it for the manufactures.	**8%**
		Unprocessed material Producers will pay less money for unprocessed material. Advantage is that producers can use the material in any way they want it.	**0%**

28	**What is the composition of the material?**	The material is homogeneity, This results in no additional efforts to disassemble the product. A Simple product, simple to select	**11%**
		The material is heterogeneity This results in additional problems with disassembly. It is a diverse product; it will need extra selecting that costs money and time.	**0%**

29	**What is the testability of the product?**	No need for additional testing of the product. Quality of recovered material is known or can be process to not be an issue.	**9%**
		Testing is relevant for quality purposes when reused in new products This means that the material can consist of several materials and need to be tested for quality purposes. This will cost more money and time and can influence the profitability of the material chain.	**0%**

End of the theme Retrieving. Accumulate the received points.

Received points for the theme Retrieving in closed-loop material chain is:

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This percentage represents the feasibility of the product in the intended material chain. Discover on what issues the retrieving can be improved by reviewing the questions where no points were credited.

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Cradle to Cradle: Incorporating closed-loop material chains in the industry

Master thesis to obtain the degree of Master of Science from the Erasmus University Rotterdam

Contact: kth.lie@gmail.com

For NL Agency in collaboration with the Erasmus University Rotterdam