IMPROVING CIRCULARITY WITHIN THE PLASTICS SUPPLY CHAIN OF THE NETHERLANDS

Bachelor Thesis, Industrial Engineering & Management

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I. Preface

Dear reader,

In this research, an effort was made to close the knowledge gap on the existing literature about the coherence between cooperation and circularity in the plastics recycling sector. My goal was to conduct a supply chain analysis of the plastics chain in The Netherlands. Based on the results of the research, recommendations are given to increase both circularity as well as profitability by increasing cooperation within the supply chain.

The research helped me to better understand the dynamic world of the plastics industry in The Netherlands. By having a better understanding of the economics behind the plastic products we all know and use, it puts the challenge that the supply chain is facing in a whole new perspective. One cannot simply change one thing in the operations and hope that the circularity is suddenly increased, it is a combined effort that is needed to succeed. Therefore, I want to emphasize the importance of cooperation and communication.

"Coming together is a beginning, Keeping together is progress, Working together is Success."

– Henry Ford

I want to thank Dr. Luca Fraccascia and Dr. Devrim Yazan for the supervision and support during this research. I also want to thank Prof. Dr. Joy Clancy for offering me this research opportunity and the support throughout the research. Throughout the research, you have provided me with the new insights, information, and support that have led to the final version of this report. I also want to thank the representatives of the companies that I have interviewed. Thank you for giving me a good insight into the plastics supply chain and the challenges you are facing.

Thomas W. Bos

II. Summary

The use of plastics and the pollution it is causing to the environment have been a hot topic for years. With growing attention for recycling worldwide, The plastic waste problem is no longer neglectable. To find a solution to this growing problem, the source of the problem has to be found and a fitting solution has to be made to be successful. There are multiple sources for this problem. Therefore, it is important to focus on one problem and solution at a time. This thesis is focused on the plastics supply chain of the Netherlands specifically. By analysing the current situation and comparing this to the norm set by governments to reach in the future, we can indicate the challenges that the plastics supply chain is facing.

By analysing the situation in the Netherlands, the literature and the research on which this thesis is based, the following research question was formulated:

How can the cooperation in the plastic supply chain be increased to achieve an increase of circularity in the sector?

To goal was to indicate the demand for increased cooperation within the plastics supply chain in the Netherlands, and how this could increase the circularity of the plastic materials. By increasing circularity, it is possible to extend the life cycle of a resource. By extending the life cycle, fewer resources are needed to fulfil the demand of the consumer. Using fewer resources leads to less fossil fuel used, but re-using materials also leads to less waste. This waste then again does not end up in landfills or leaks into the environment.

The research started with a supply chain analysis of the current situation of the plastics supply chain. this visualises the “reality” and gives us a clear starting point to work from. After this, existing literature on plastics recycling and circularity improving measures was studied. This is done to increase knowledge on the possible solutions for the growing plastics problem. Then, interviews have been conducted. The respondents to the interviews were selected based on their extensive experience and knowledge on either producing plastic products, recycling plastic products or the chemical and technical properties of plastic materials. By combining the knowledge of these experts, the knowledge gap between literature/theory and practice is closed.

From the research and the interviews, new insights have been acquired. The three most important findings of this research are shortly summarised below:

- The demand for shared knowledge by increased cooperation will lead to a more transparent supply chain.
- To create a transparent and competitive supply chain, rules and regulations have to be made for the material characteristics of recycled plastics. Fluctuating quality of recycled materials will lead to operational risks for manufacturers.
- Plastic products should be recycled for recycling. By using mono-materials instead of combining multiple plastics in one product, the sorting and recycling process is drastically improved, and contamination is reduced significantly. This leads to a direct increase in recyclability of products.

The bottom line of this research is prevention is better than cure. If manufacturers produce products that are easier to recycle, recyclers will be able to lower their operational costs. This then results in lower prices and higher quality for recycled plastics, from which manufacturers could benefit.

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III. Glossary

Alternative sustainable materials	Materials with a smaller carbon footprint than the materials currently being used.
Biobased plastics	Plastics made from sustainably produced biomass and which have a smaller carbon footprint than comparable fossil-based plastics.
Circular economy	An alternative to a traditional linear economy (make, use, dispose) in which resources are being (re-)used if possible before disposal. At the end-of-life phase, resources are recovered, regenerated, and recycled to serve another service life.
EPR	Extended producers Responsibility.
PE	polyethylene, commonly used type of polymer (e.g., disposable plastic bags).
PET	Polyethylene terephthalate, commonly used type of polymer (e.g., plastic beverage bottles).
Plastic packaging	All plastic-containing materials which can be used for the containment, protection, handling, delivery, and presentation of other products, from raw materials to processed goods, from the producer to the user or the consumer.
PP	polypropylene, commonly used type of polymer (e.g., plastic bottlecaps).
Recyclability	To what extend recycling and re-use of resources and materials is possible.
Recyclate	Plastic materials resulting from a mechanical, physical, or chemical recycling process, which can be reused in new products and packaging.
Reducers	Companies within the plastics supply chain that focus on collection, sorting and recycling of the waste streams. Also landfilling and incineration are considered.
Reverse logistics	Reverse logistics stands for all operations related to the reuse of products and materials.
Single-use plastic products and packaging	Consumer goods that are made wholly or partly from plastics and that are not conceived, designed, or placed on the market to accomplish, within their life span, multiple trips, or rotations by being returned to the producer for refill or by being reused for the same purpose for which they were conceived.

1. Introduction

In the introduction, the research is first elaborated. After that, the motivation for the research is described together with core problems that are faced during the research. Lastly, the research question and sub-questions are introduced to act as a guideline for this thesis.

1.1 Research information

With growing concerns about plastics pollution and the use of fossil fuels worldwide, a research project is created by the University of Twente to find solutions that could increase the recyclability and circularity of plastics. The professors, Prof. Dr. J.P. Lange, Prof. Dr. S.R.A. Kersten, Prof. Dr. J. S. Clancy and Dr. M.L. Franco Garcia, are specialized on the topics of Chemistry, environment, sustainability and circularity. Together they have started this research project to face the ongoing problems that are caused by plastic on environmental and socio-economical levels.

The research project is split up into four work packages (WP's) where both professionals and students are asked to participate. Students will work on any of the four WPs and will use the topic for their bachelor and master assignment. The research methods to be used in general will comprise, systematic literature review and interviews with experts. For a few WPs, some calculations would also be necessary.

The research group will focus on recycling the plastic contained in municipal solid waste, the most challenging source of plastic waste, realizing that industrial waste could also branch at some point into this supply chain.

1.2 Research motivation

McKinsey and Company has recently estimated[1] large profitable opportunities to build a branch based on recycled plastics, about $55 billion a year worldwide by 2030[2]. This, aside from the benefits that recycled plastics can bring to the environment and society, has attracted the attention of the petrochemical industry which has delivered important wealth and convenience to society by developing plastics for a multitude of applications (e.g., plastic bags, pens, furniture, packaging). However, the petrochemical industry has also failed in securing responsible management of plastic waste, as about 60% ends up in the environment (e.g. 19% leakage and 40% in landfills), 25% is incinerated and only 12% is recycled to plastic[1]. One of the reasons for the low levels of recycled plastic used in new products is due to the price of recycled plastics versus the price of virgin materials and the quality of it. The current oil price is lowering the material costs for virgin plastics. While the prices of recycled plastics are staying at the same price level. Due to the large media campaigns and TV programs, society is becoming more aware of the plastic leakages through its consumption-production system and, at present, society is calling the stop on landfilling and waste leakage of plastics, to reduce waste incineration, clean-up of the environment and, specifically to the industry, to develop a credible circularity proposition of its plastics.

In this regard, different initiatives trying to drive the *transition* towards circularity of plastics by including some targets, e.g. the Dutch Plastic Pact[3] indicated that by 2025, 70% of the plastic should

[1] Hundertmark, T., McNally, C., Simons, T.J. and Vanthournout, H. (2018). *No time to waste: What plastics recycling could offer*. McKinsey & Company.
[2] McKinsey & Company. Forthcoming report, The circular economy petrochemicals: plastic recycling.
[3] Marc Seijlhouwer (2019) Een miljard minder plastic producten in 2020. Retrieved on January 3, 2020 from https://www.duurzaambedrijfsleven.nl/recycling/32995/minder-plastic-2020

be recycled (in 2019 this was approximately 15%[4]) and plastics must consist of 30% second-hand package material(2017-2018 was around 6%[5]). Even further, the European Commission pronounced the target of the fully recyclable plastic packaging[6] production by 2025.

1.3 Problem context

The current situation where plastics still cause high levels of pollution, both on the production and the end-of-life- phase, is far from desirable. Polluting through poor waste management, emitting toxic materials while producing or incinerating the materials and even micro-plastics that are causing harm to organisms and the eco-system. Plastics are very versatile and cheap but come with great ecological consequences. To tackle this problem, the situation and supply chain will be analysed. Currently, it is known that using recycled plastics in new products is done too little and products are also often not being recycled.

If more plastics are being recycled, fewer materials end up in incineration plants, landfills or the environment. By using more recycled materials instead of virgin materials, the demand for fossil fuels as a resource for virgin plastics will be reduced.

1.3.1 Problem identification

By using a systematic approach that helps to solve business and management problems. The solution to a business problem can be found by following a methodological checklist. This method is called "The Management Problem Solving Method (MPSM)" as described by Heerkens & Van Winden (2012).

The MPSM describes that research can start when the problem has been identified clearly. To figure out the core problem, 4 steps can be followed according to the MPSM.

1. Problem inventory.
2. Give Cause-effect relations and create a problem cluster.
3. Core problem selection.
4. Action problem definition.

During step one, the research project is analysed from multiple perspectives. When taken inventory of the problems, all problems are treated equally.

[4] https://www.trouw.nl/nieuws/zo-n-15-procent-van-de-totale-hoeveelheid-plastics-wordt-gerecycled-dat-moet-beter~b974549f/?referrer=https%3A%2F%2Fwww.google.com%2F

[5] Monitoring compliance with the Dutch Plastic Pact: The Baseline Measurement (2017-2018)

[6] Plastics Recyclers Europe (2019) *Flexible Polyethylene Recycling In Europe: Accelerating the Transition Towards Circular Economy*. Brussels: Plastics Recyclers Europe. Retrieved on December 7, 2019 from https://www.plasticsrecyclers.eu/

The following problems came to light after analysis of the research project and the existing literature.

There is no one true definition of what "recyclability" means.

If the goal is to increase recyclability and circularity, the definition of recyclability must be clear. Different parties use different definitions of what they think is recyclability. So, boundaries must be set to focus on finding an applicable solution.

The limits of chemical and mechanical recycling.

Currently, it is known that chemical and mechanical recycling of plastics is possible, but how far can we go in terms of optimizing the process and what are the chemical boundaries of the products itself. Current techniques must be analysed for optimization and new methods and techniques can be developed.

Products made of multiple types of plastics are hard to sort.

During the process of collecting plastics by waste companies, all sorts of plastics are thrown on a big pile. When sorting the plastics in a later stage, impurities and products that are made from multiple types of plastics (or other materials) are hard to sort out. This results in lots of plastic being landfilled or incinerated. Therefore, the recovery-purity trade-off must be analysed for different approaches.

Products are not designed to be recycled.

There is a lack of attention for material recycling when designing a new product. When designing a new product, the designer should consider the use of recycled materials or make the product fit for recycling so it could be used in other production processes. The limits of cascading therefore must be analysed to extend the usability of materials.

Lack of cooperation in the supply chain of plastics.

Due to the logistics of garbage collection, the complexity and inefficiency of sorting, the small scale of recycling and the limited market demand for recycled plastic, costs of plastic recycling tend to be high. So, the question arises: how can we organise plastic waste recycling? What are the market potential and the barriers to entry?

1.3.2 Problem cluster

Step two of the MPSM is to see which problems are influencing one another and which problems do not, they are put in a problem cluster. The cluster shows the relations between the separate problems and shows their interdependence and independence.

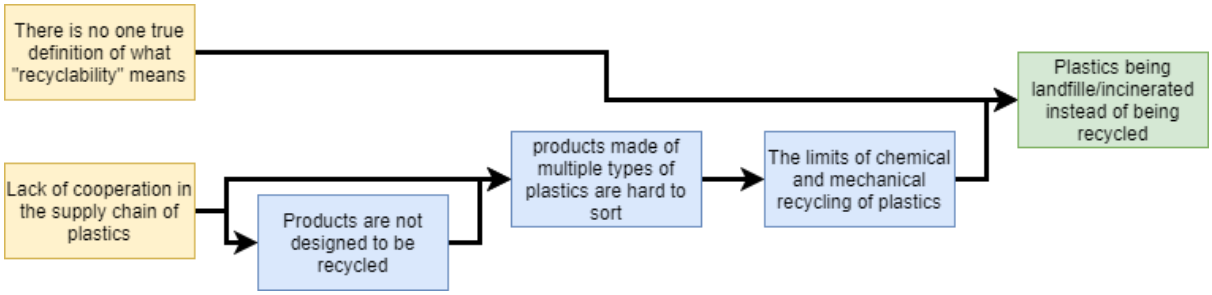

Figure 1 Problem Cluster

According to Heerkens (2012), the two problems in the yellow squares can be defined as core problems. These problems do not have other causes other than themselves. According to Heerkens, solving these core problems, instead of the other problems, will result in the greatest effect. The criteria that must be met, will be elaborated upon in chapter 3.3.3. For example, the lack of cooperation in the supply chain of plastics causes that products are not designed for recycling. When parties in the supply chain from start to end communicate with each other, they could implement small details in their design. These details could be beneficial for the recyclers in the process. This will result in higher levels of recyclability and reduced costs of operations. This is directly connected to the problem that products are made of multiple types of plastics and other materials and therefore are hard to sort and recycle.

1.3.3 Core problem

Based on the problem cluster, by analysing the situation methodologically and in consultation with my supervisors, the core problem is selected.

"The lack of cooperation between the contributors of the plastics supply chain of the Netherlands."

These contributors can be identified as producers of plastics, the recycling companies, the customers, and the petrochemical industry supplying the raw resources for the materials.

What is meant by the lack of cooperation between these parties? The producers of plastic materials do not keep in mind the process of a recycler/reducer while designing a product. This leads to, for example, products consisting of multiple types of plastics that are hard to separate. When producers and reducers can design products "together", it is easier and cheaper for reducers to recycle the products. This will then again lead to a reduction in the price of recycled materials, from which the producers could benefit. To analyse the lack of cooperation in the supply chain of plastics, the supply chain first must be mapped. By doing this, the bottlenecks become visible and a solution to the problem can be given. By increasing the level of cooperation in the supply chain, other core problems are most likely affected as well.

1.3.4 Norm and reality

Following the MPSM method of Heerkens & van Winden, it is necessary to assess whether a problem is solved within the research. With the MPSM methodology, the norm and the reality must be comparable for the results to become measurable.

The current situation, the reality, is that the plastic supply chain in the Netherlands must become more circular due to increasing pressure from society, politics, and non-governmental organisations (NGO's). The economic pressure is also considered but due to the prices of resources and manufacturing, recycling plastics is in most cases not economically viable, yet. The current situation is further analysed and described in chapter two.

The norm is stated earlier in the research motivation, being the goals of the initiatives already started in the European Union.

- The Dutch Plastic Pact[7] indicated that by 2025, 70% of the plastic should be recycled (in 2019 this was approximately 15%[8]) and plastics must consist of 30% second-hand package material(2017-2018 was around 6%[9]).
- The European Commission pronounced the target of the fully recyclable plastic packaging[10] production by 2025.

The core problem describes the discrepancy between the norm and reality. The goal is to create measures that will bring the reality closer to the desired norm. In this case, increasing the recyclability of plastics and increase the use of recycled materials in new products.

1.4 Research questions

The research questions will provide a structure to the research itself. The goal of this research is to find an answer to the main question and by doing so, increasing the circularity within the plastics supply chain of the Netherlands.

1.4.1 Main question

Based on the research information, the literature available and the problem cluster that is made, the main research question is formulated. The main research question is as follows:

How can the cooperation in the plastic supply chain be increased to achieve an increase of circularity in the sector?

By answering this research question, we will be able to bundle these in an effective and useful set of rules, a guideline, that is beneficial for all parties in the supply chain. Increasing the circularity within the plastics supply chain in the Netherlands in a cost-efficient way.

[7] Marc Seijlhouwer (2019) Een miljard minder plastic producten in 2020. Retrieved on January 3, 2020 from https://www.duurzaambedrijfsleven.nl/recycling/32995/minder-plastic-2020

[8] https://www.trouw.nl/nieuws/zo-n-15-procent-van-de-totale-hoeveelheid-plastics-wordt-gerecycled-dat-moet-beter~b974549f/?referrer=https%3A%2F%2Fwww.google.com%2F

[9] Monitoring compliance with the Dutch Plastic Pact: The Baseline Measurement (2017-2018)

[10] Plastics Recyclers Europe (2019) *Flexible Polyethylene Recycling In Europe: Accelerating the Transition Towards Circular Economy*. Brussels: Plastics Recyclers Europe. Retrieved on December 7, 2019 from https://www.plasticsrecyclers.eu/

1.4.2 Sub-questions

To answer the main research question, several sub-questions have been formulated to approach the answer more systematically.

By dividing each of the research questions into sub-categories, a good structure is added to the research.

Current situation

1) What is the current situation of the plastics supply chain in the Netherlands regarding circularity and recycling?

2) How does the oil price affect the price and demand for recycled plastics versus virgin plastics?

These questions can be answered by investigating historical data and publicly available data presented by contributors to the plastics supply chain and governmental institutes. The goal of these questions is to understand the situation the plastics supply chain is currently in and understanding the challenges it is currently facing. By looking into already present data and information, we can create a clear visualisation of the "reality". This is useful in later stages of the research to compare the "norm" with the "reality".

Literature research

3) What types of plastic products are currently designed with recycling kept in mind?

4) What are key elements in the process of designing recyclable plastic products?

These questions can be answered by investigating the literature. By performing a systematic literature review, the already existing literature is used to create a base understanding of the already available measures used to increase circularity and recyclability in the plastics supply chain. By performing this systematic literature review, the knowledge gap in the existing literature on this matter is also visualised.

Methodology

5) What production bottlenecks will be caused by an increase in demand for recycled plastics?

6) What does the supply chain need to regulate and maintain the circularity of plastics?

By conducting interviews with experts within the plastics supply chain of the Netherlands, these questions can be answered. The interviews will have a semi-structured design, inviting the respondents to have an open conversation on the research topic, while still receiving the data required to answer the research question. By doing so, not only the questions will be answered, but relevant information concerning the research can be acquired by having a good conversation on the matter. The combined years of experience and knowledge can provide the research with interesting new insights. The ethics committee of the University of Twente has approved the way of doing research. In appendix F the approval can be seen.

Implementation and results

7) How will the recommendations be implemented into the supply chain?

This question evaluates the insights acquired during the research and has to prove the practicality and viability. By creating a list of recommendations paired with an action plan for the plastics supply chain to follow, the goal is to have a positive impact on the circularity within the supply chain.

1.5 Research design

This chapter will go further in-depth on how the problem is isolated and how it can be approached to solve it successfully.

1.5.1 Thesis structure

The structure of this thesis is provided by the following chapters:

- Chapter 2 will provide information on the current situation within the plastic supply chain and the challenges its stakeholders are currently facing. Sub-questions 1 and 2 will be answered in this chapter.
- Chapter 3 provides a systematic literature review and gives the theoretical framework of the research. Already existing initiatives on plastic recycling and circularity are being investigated. Sub-questions 3 and 4 will be answered in this chapter.
- Chapter 4 is used to answer sub-question 5 and partially to answer sub-question 6. The semi-structured interviews are used to acquire the expertise of experienced contributors within the plastic supply chain of the Netherlands.
- Chapter 5 will provide newly acquired insights on the demand for regulation and quality control. As stated by various respondents of the interviews, regulation and control is deemed necessary to scale up plastics recycling. Sub-question 6 is elaborated in this chapter.
- Chapter 6 answers sub-question 7 by providing an action plan for the following years and giving a list of recommendations for the plastics supply chain to improve circularity.

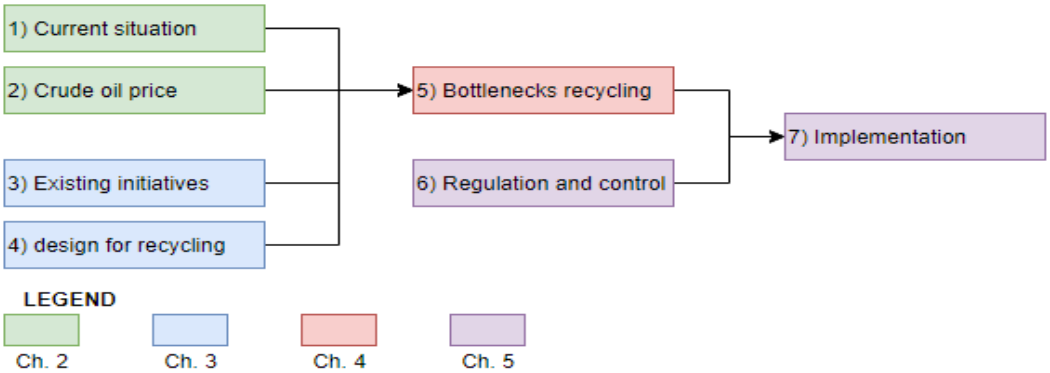

Figure 2 Thesis structure concerning sub-questions

1.5.2 Limitation and scope

The limitations and the scope help to guide the research towards a specific goal while keeping boundaries in mind. Without set boundaries, it is hard to focus and work towards the set goal.

Limitations

The first limitation being the time. A bachelor assignment takes up approximately 10 weeks to complete. This limits the work that can be done on this subject. To fully analyse the entire plastic supply chain is therefore not possible. It is decided that only a few types of plastics are looked into.

The second limitation is the current ongoing Covid-19 crisis. This limits the possibility in terms of being able to visit companies, have face-to-face conversations and have a personal interaction with the respondents. This influences the quantity of the results and also the sample size.

The Covid-19 crisis, unfortunately, did result in the problems described above but have resulted in a situation where it was possible to put extra time towards the research. This was beneficial for the research results.

Scope

First, the research will focus on the increase of circularity of the supply chain of plastics in the Netherlands. The boundaries have been set to be in the Netherlands, and no other countries. The increase of circularity is mentioned and there are no claims of it being the solution to a fully circular economy.

Second, the research will focus on making a good supply chain analysis and indicating its bottlenecks. Based on that, a list of recommendations is created to help the supply chain as a guideline. Due to time constraints, the research can be used as a basis to work from for future research.

1.5.3 Methodology

The Managerial Problem-Solving Method (MPSM) (Heerkens & van Winden, 2012) is used as the methodology to guide the research. MPSM is used to give a solid structure to the research and helps to keep the focus on the final results.

MPSM is used to approach larger seemingly hard to tackle problems systematically. MPSM consists of 7 phases:

1. Defining the problem
2. Formulating the approach
3. Analysing the problem
4. Formulating (alternative) solutions
5. Choosing a solution
6. Implementing the solution
7. Evaluating the solution

The first step, Defining the problem, is already covered in the previous chapter. So now the research approach is formulated to give a good structure to the research.

The two phases that follow after that are, ‘analysing the problem’ and ‘formulating (alternative) solutions. These steps are approached by using both quantitative and qualitative research methods.

The quantitative research methods that are used in this research are based on historical data provided by both governmental institutes and contributors to the plastic supply chain. This data consists of price and demand for both virgin and recycled plastics, crude oil prices and waste streams. This data is publicly available.

The qualitative research methods will primarily consist of the interviews conducted from experts within the plastics supply chain of the Netherlands. Their experience and knowledge will function as a solid foundation for the thesis. As stated in previous chapters, the interviews will be semi-structured. This method invites the respondents to have an open conversation on the research topic while still receiving the data required to answer the research question (Cooper & Schindler, 2014). By doing so, not only the questions will be answered, but relevant information concerning the research can be acquired by having a good conversation on the matter.

To accomplish success in research, a good support structure is needed. As mentioned by Cooper & Schindler (2014), there are four types of structures that could help to guide the research. For this research, the exploratory study is chosen to be the leading research structure. According to Cooper & Schindler (2014), exploratory research is needed when a study tends towards a loose structure to discover future research tasks. In terms of data collection, it is stated that a communication study is suitable when a researcher wants to collect responses directly from subjects (Cooper & Schindler, 2014).

The purpose of the study is reporting. According to Cooper & Schindler (2014), a reporting study provides a summation of data, often recasting data to achieve a deeper understanding. Based on the data that will be collected during the study, a recommendation (or policy) is given to increase circularity in the supply chain of plastics in the Netherlands.

At last, the final steps of the MPSM ‘choosing a solution’ and ‘implementing the solution’ are addressed in chapter 6. A list of recommendations will be created, supported by the results of the research. Since it is an open recommendation for the plastics supply chain and not a direct assignment, implementation of the solution does not lie within the scope of the research. However, the list of recommendations should be ready to implement for the plastics supply chain in practice. Evaluating the solution is the final step of the MPSM, and the research will be reflected upon in chapter 7. Considering the research, limitations, and recommendations for further research.

1.5.4 Deliverables

By answering the research questions, new insights are acquired. These new insights will be used to create a practical solution for the plastics supply chain in the Netherlands. Therefore, the main deliverable is the following:

- A list of recommendations for the plastic supply chain in the Netherlands that both increases circularity and profitability through enhancing the collaboration/cooperation between the contributors of the supply chain.

To support not only the main question but also the sub-questions of the research, other deliverables will also be made. These additional deliverables will consist of:

- A supply chain analysis of the supply chain of plastics in The Netherlands.
- A stakeholder analysis of the circular economy of plastics.
- A report containing the acquired insights and results of the research.

1.5.5 Validity and reliability

In this chapter, the validity and reliability of the research design are explained. So, both the validity and reliability are tested and elaborated systematically and a reflection on the chosen research method is given.

Reliability test

The reliability test helps to reflect on the possibilities that research results could vary under different testing situations. It is necessary to reduce the chance of fluctuating answers as much as possible. If test results are depending on the researchers or the selected sample, the results are deemed less reliable. Therefore, to minimise the chance of the reliability of the research being jeopardised, multiple sources are used to define the final research results.

This research will use three data gathering methods to validate the results of each source. This reduces the bias and increases the reliability of the results. This method is called *"Triangulation"* and is often used to increase the credibility of a research study. To collect the data, we make use of semi-structured interviews, the existing literature that is already available, and publicly accessible databases of relevant data. These three methods are then used to validate each other. Since all of the data collection methods have their strengths and weaknesses, using all three will help to reduce the bias and increase the validation.

- The interviews that are conducted have the possibility that transparency and honesty are jeopardised, e.g., when a company wants to sugar-coat their operations and results. The interviews also allow us to get more context on the research topics and provide the research with expert knowledge.
- For the data collection through annual reports and public data, the validity is rather high, but the data must be analysed correctly to reach its full potential. The data described, also often lack context. This increases the chance that data is misinterpreted and therefore used wrongly in the research. The data could be useful to validate the response from the interviews.
- The literature research is used to analyse to gain information on the research that is already done on the research topic. The literature research mainly exists of scientific reports and studies, therefore we can assume that the reliability of the data is good. Nonetheless, if an earlier study has misinterpreted data, the validity of the research is also affected and therefore could easily affect the reliability of this research if the results are not validated by other sources.

Validity test

Since this is a descriptive/exploratory study, the validity of the research is determined by the construct validity and the external validity.

The construct validity of the research is depicted by measuring and comparing the results of the research with different credible sources. This could be achieved by using external validators to check the results and compare those with results of similar research. By having the report reviewed by experts within the industry, the logic of the report is checked and validated. An external (expert) party is used to review the report and make sure that the research is structured in a good and logical way and the test results are constructed out of solid and reliable evidence.

The external validity of the research is to what extend the research results are usable in different settings. This research is focused on the plastics supply chain in the Netherlands and did not analyse other countries or situations in depth. Therefore, the research is applicable and generalizable for situations and cases in the Netherlands. The results could be used for different (European) countries as well since the plastics supply chain is not structured that different between countries in Europe. The specifics of the numbers and results could vary between different situations or countries, but the general recommendations should apply to the plastics supply chain in general.

2. Current Situation

This chapter explains the current situation of the plastics supply chain and the challenges it is currently facing. The research questions that are answered in this chapter are:

1) What is the current situation of the plastics supply chain in the Netherlands regarding circularity and recycling?

2) How does the oil price affect the price and demand for recycled plastics versus virgin plastics?

2.1 Supply chain visualisation – Global perspective

The global consumption of natural resources such as fossil fuels, metals, minerals, and biomass is expected to be doubled by 2050, while the annual generation of waste is expected to increase by 70% by 2050.[11] Therefore, the European Green Deal will focus on scaling up the circular economy to reach a climate-neutral and resource-efficient economy whilst creating a competitive environment for the companies from an economical point of view. The European green deal is an initiative by the European Union to transform the current economy in the EU, into a sustainable variant. The three main goals of this deal are, no net emissions of greenhouse gasses by 2050, economic growth is decoupled from resource use, and no person and no place are left behind.

By decoupling economic growth from the use of resources, the European Green Deal increases long-term competitiveness by enabling also smaller companies to increase their market potential.[12] If this plan will not succeed, the environmental repercussions could be great and will affect the ecosystem as well.

The current supply chain can be divided into three main sectors:

1. The production of raw plastic materials.
2. The manufacturing and use of plastics products.
3. The disposal and end of life treatment of those plastic materials and products.

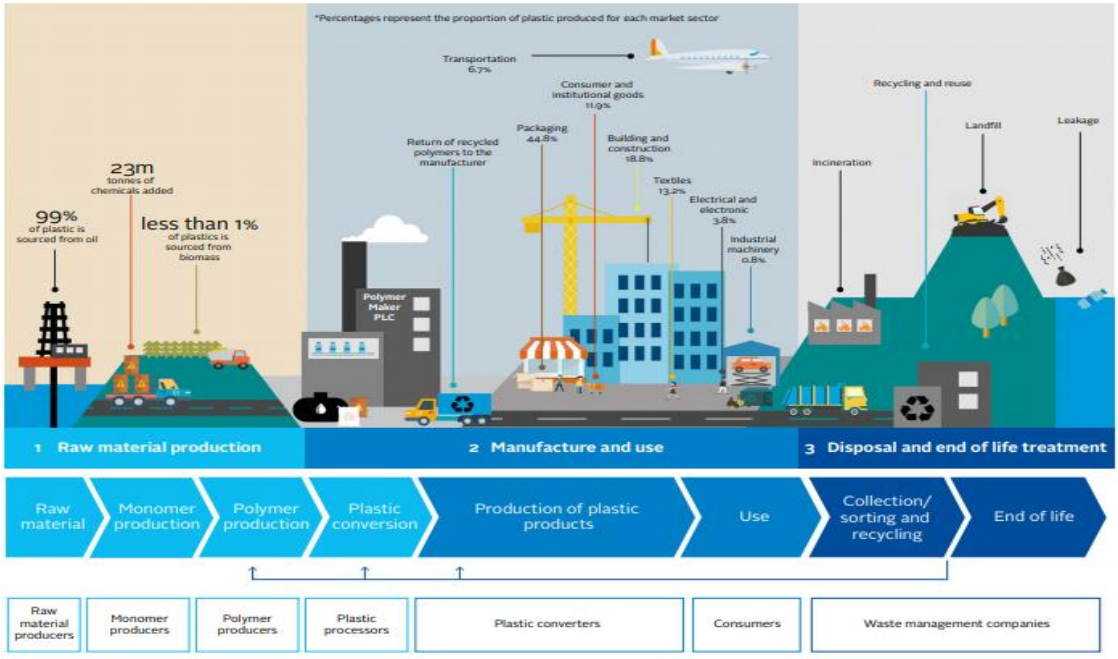

Figure 3 Visualization of the global plastic supply chain(PRI,2019).

[11] World Bank (2018), What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050.
[12] new_circular_economy_action_plan.pdf (europa.eu)

Since plastic was introduced, the global interest in the material, as well as the dependence, is enormous. Plastics being a versatile product, it knows many uses and therefore plastics can be found in nearly all business sectors globally.

The production of raw plastic materials can be split into two different streams: the production of plastic from oil and gas and the production of plastic from agricultural products. The production of plastic accounts for 6% of global oil and gas consumption.[13] The plastics that are being produced from agricultural products are 1-3% of the plastic material made globally. Although these biomass-based plastics may seem a good solution, the scalability of this type of plastic production is low. This is due to the impact that the production of renewable feedstock could have on the biodiversity of a region.

The primary plastic production consists for 97-99% out of plastics being made from petrochemical resources sourced from fossil fuel constitutes.[14] The remaining 1-3% is produced from bio (plant)-based plastics.[15] Large petrochemical companies control most of the production of fuel-based plastics. More than 30 different types of primary plastics are commonly used worldwide. Each of them having specific properties and therefore have different applications. This makes plastic a very versatile product to work with. While there are more than 30 types commonly used, nearly three-quarters of the plastics consists of five types of primary plastics.

1. Polyethylene terephthalate (PET) – both rigid and flexible. Can be both water and gas resistant. Commonly used in drinking bottles, fleece clothing and packaging trays.
2. High-density polyethylene (HDPE) – High density, strong, can withstand high temperatures and chemicals. Commonly used in shopping bags, insulation, bottle caps and protective helmets.
3. Low-Density Polyethylene (LDPE) – Less strong but higher resilience than HDPE. Commonly used in plastic bags, computer hardware, inflatables.
4. Polypropylene (PP) – Strong and flexible plastic. Commonly used in bottle caps, straws and food containers.
5. Polyvinyl chloride (PVC) – Easy to mould. Commonly used in pipes, clothing, and vinyl records.

The goal is to increase the circularity of these plastics by integrating recycling companies in the production and designing process earlier in the supply chain. This way, products can be made with recycling kept in mind, reducing the labour needed to recycle the products and therefore reducing the costs of plastic recyclate. By reducing the costs of recycled plastic, companies will tend to increase the usage of recycled plastics in their production process. This will increase the circularity of the plastic supply chain.

Plastics and polymers are causing harm to the environment in multiple ways. The production of virgin polymers often requires natural resources like oil. During the production of plastic products, defects may lead to waste. The post-consumer plastics and polymers are often combined with the production waste and are either collected for recycling (16%), incinerated (25%), landfilled (40%) or end up on unmanaged dumpsites or leak into nature (19%) (McKinsey&Co., 2016). Especially those last two are unwelcome.

[13] Ellen MacArthur Foundation, 2016. The New Plastics Economy: Rethinking the future of plastics
[14] CIEL, 2017. Fueling Plastics: Fossils, Plastics, & Petrochemical Feedstocks.
[15] European Bioplastics, 2019b. Bioplastic market data 2016.

Landfilling and discarding it into nature will result in total loss of energy and will also cause harm to nature. Though incinerating waste can emit harmful emissions, it makes use of the energy that is still stored in these products.

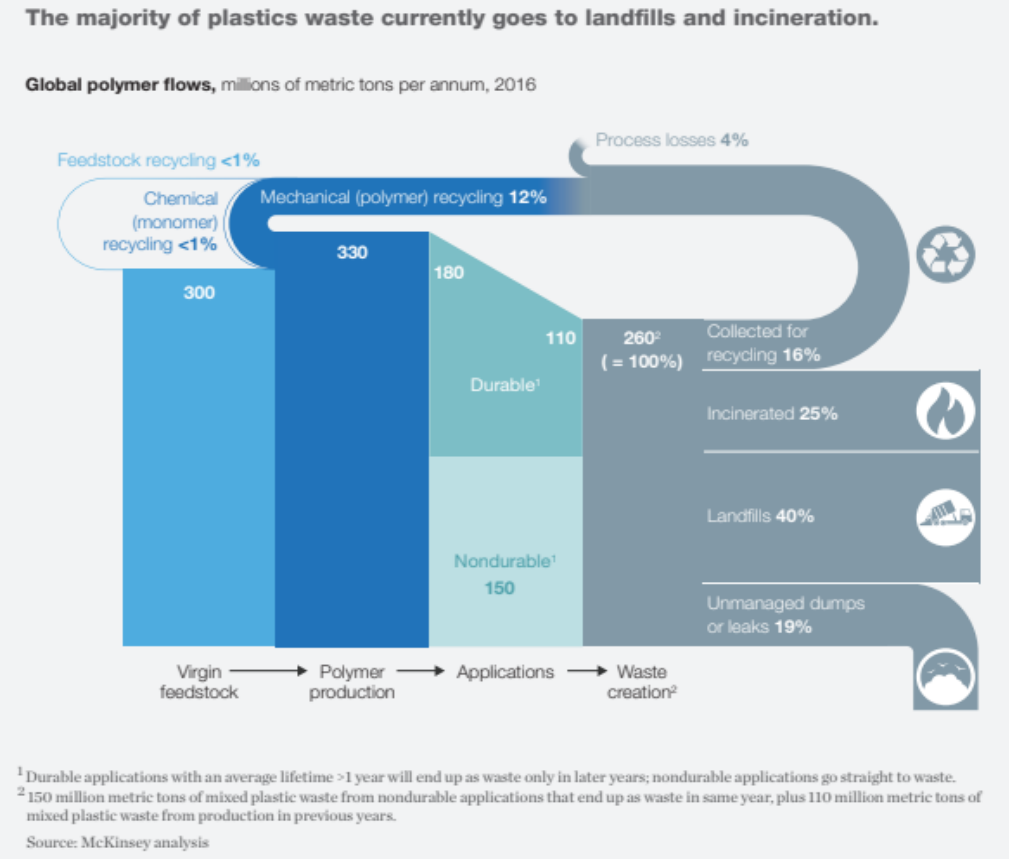

Figure 4 Lifecycle of plastics worldwide (2016), Mckinsey and Company

Not only the production techniques but also the recycling techniques are still lacking the ability to fully recycle all post-consumer plastics. This is due to various causes, some influenceable and some not. For example, when plastic products have been contaminated with other materials, it is not possible to recycle them up to a virgin-polymer standard where they can be used for all purposes. With chemical recycling, it is possible to re-create the virgin polymer out of the used plastic. However, chemical recycling is still under development. Contamination is also a problem for chemical recycling, but significantly less than for mechanical recycling.

This is where the cascading model makes its introduction. The cascading model takes the degrading characteristics of polymers into account and realises that not every post-consumer product is fit for recycling up to a virgin grade. The cascading model tries to recycle the product to the highest possible level, but not necessarily virgin. For example, making jeans from old soda bottles. Since food-grade plastics must be one of the highest grades of plastics in terms of food safety, and jeans just must look good and be nice to wear. The criteria of jeans are different from those of food containers but still have an economical value. This way the product is not incinerated or landfilled, but slowly cascading down to a point where there is no possible use for it left. By using a cascading model, the use of resources can be cut drastically as well as the amount of incinerated and landfilled materials.

These models are already in use but not efficiently and effective enough. The norm that is set by the Dutch plastic pact[16] that by 2025, 70% of plastics should be recycled and new plastic products should consist of 30% second-hand packaging materials. Even further, the European Commission pronounced the target of the fully recyclable plastic packaging[17] production by 2025.

2.2 Supply chain visualisation – The Netherlands

The situation in the Netherlands is different than in other European countries or countries worldwide. This is due to the relatively large scale of both plastic production and recycling. The Dutch are producing 2,5 times more plastic than the amount of plastic used in the country itself.[18] Reasons for this are that the Netherlands exports a lot of plastic and plastic recyclate. The Dutch are good in the collection of used plastic packaging and the recycling of the packaging materials. Of the total 512 kilotons of collected packaging waste, 265 kilotons (more than 50%) are being transported to recycling facilities. Where the collection of plastic packaging material is going well, the other streams of plastic waste are collected and recycled on a much lower level.

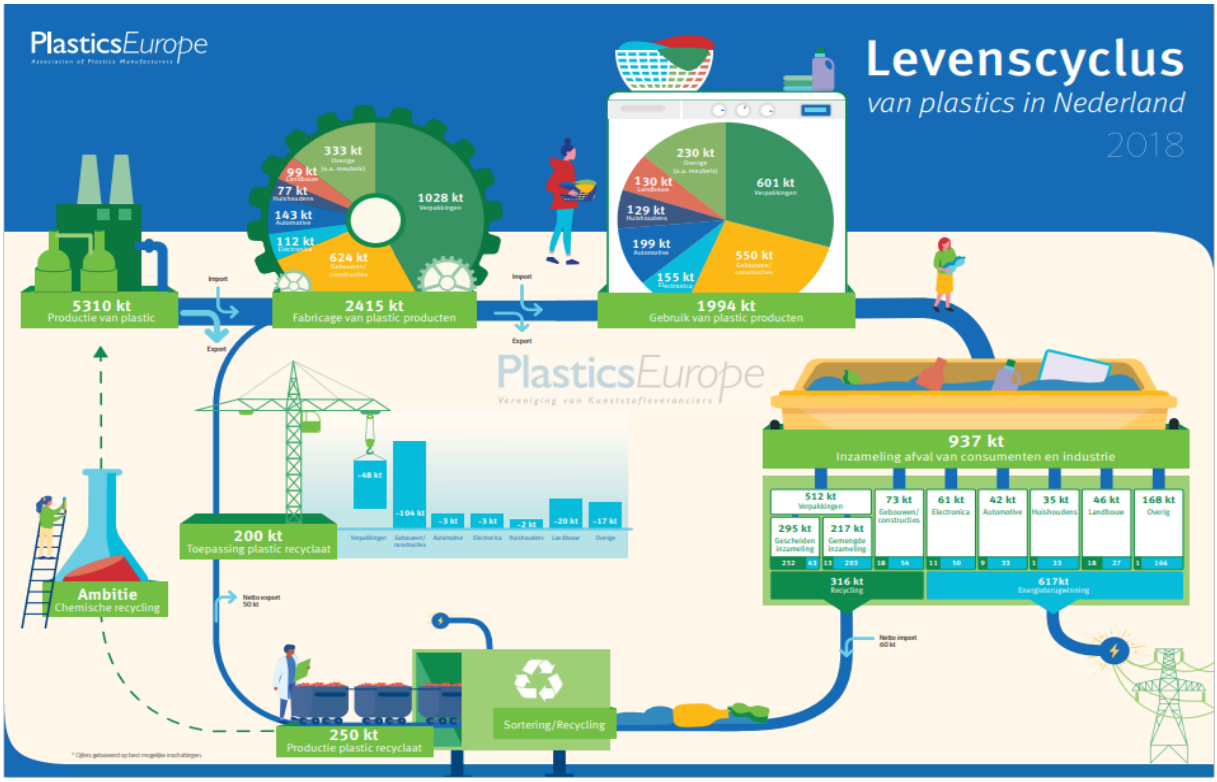

Figure 5 Lifecycle of plastics in The Netherlands (2018), PlasticEurope: [19]

The production of recycled plastic in The Netherlands is relatively high compared to other countries. this is due to the import of plastic waste. The Dutch import more than 60 kilotons of plastic waste to recycle it and make useful plastic recyclate from the waste.

[16] Marc Seijlhouwer (2019) Een miljard minder plastic producten in 2020. Retrieved in January 3, 2020 from https://www.duurzaambedrijfsleven.nl/recycling/32995/minder-plastic-2020

[17] Plastics Recyclers Europe (2019) *Flexible Polyethylene Recycling In Europe: Accelerating the Transition Towards Circular Economy*. Brussels: Plastics Recyclers Europe. Retrieved in December 7, 2019 from https://www.plasticsrecyclers.eu/

[18] Levenscyclus van plastics in Nederland - Nieuws - KunststofenRubber.nl

[19] PlasticEurope - Infographic - final2 (plasticseurope.org)

From the produced recyclate, the largest part ends up in building materials. Over 30% of the plastic building- and construction materials consist of recycled plastic.[14]

The chart in figure 4 shows the lifecycle of plastics in the Netherlands in 2016. This shows that just 12.5% of the plastic used, are being recycled. From the amount of post-consumer and industrial plastic waste that is being collected, just 33.7% is being recycled, and 66.3% is being incinerated or landfilled. A side-note to this is that due to the efficiency of the Dutch waste incineration plants, the Netherlands imports waste from other countries to incinerate. So not all waste that is being incinerated, is from Dutch sources.

2.3 Stakeholder analysis

As stated in section 2.1, the supply chain consists of 3 main sectors:

1. The production of raw plastic materials.
2. The manufacturing and use of plastics products.
3. The disposal and end-of-life treatment of those plastic materials and products.

Each sector knows its stakeholders. Sector 1, covering the production of raw plastic materials, consists largely (97-99%) of the petrochemical industry and for 1-3% of plant-based plastic producers. It can be said that the petrochemical industry controls the price and production of raw plastic materials.

Since 97-99% of the plastic material produced, is based on petrochemical products, the oil price has influenced the price of plastic. During the start of the Covid-19 crisis, spring 2020, the oil price dropped to a price of USD -37,89 per barrel. This resulted in dropping plastic prices as well.

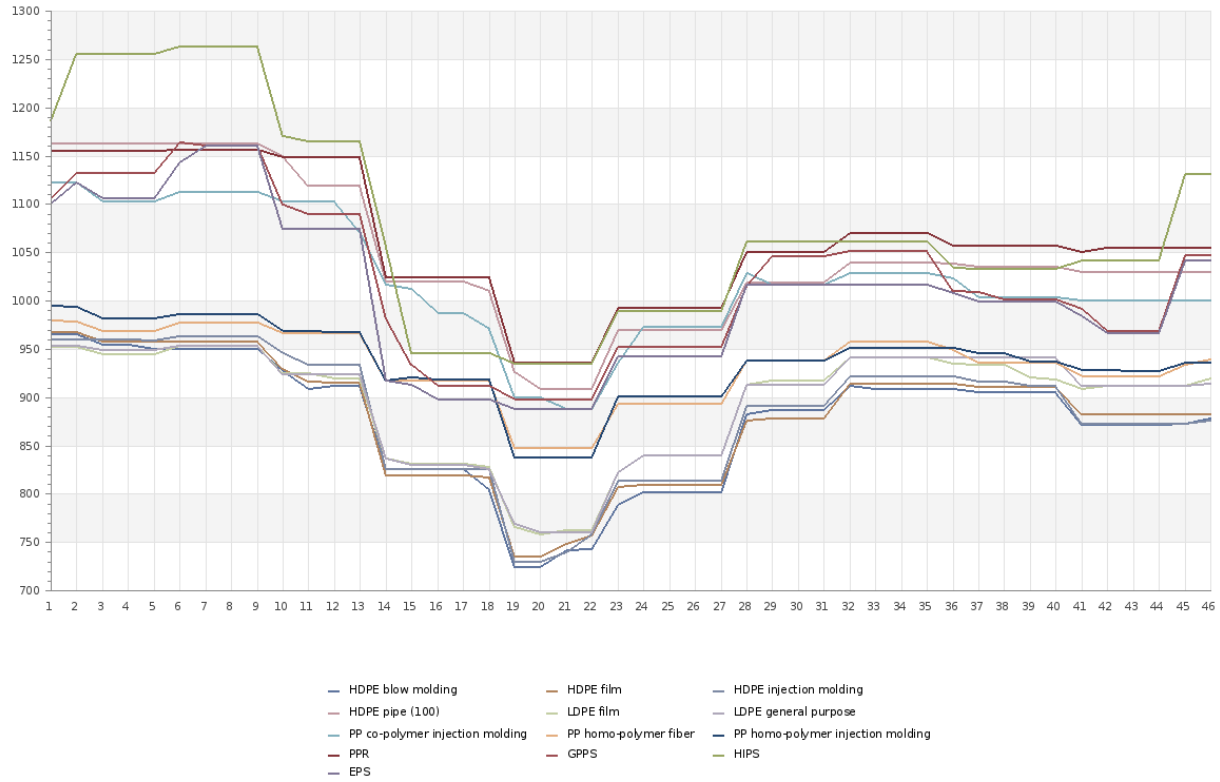

Figure 6 Plastic price throughout 2020

In the figure above, the prices of various types of plastics have been tracked throughout 2020 (Appendix C). After week 9, a sharp decline is visible in all the plastics portrayed in this chart, the first Covid-19 lockdown. If this chart is compared to the chart containing the oil price per barrel during 2020 (Appendix D), the similarities can be recognised. Considering that the price of the most used virgin polymers has dropped below the price point of the recycled version of the same material, recycling companies had to sell their stock at loss to keep cash flow. In 2020, the prices of polymer commodities like PP have seen a decline of over 30%. [20]

Figure 7 Crude oil price per barrel throughout 2020

Here it is clear that the decreasing oil price immediately affects the price of plastic. During the Covid-19 crisis, the oil demand dropped significantly due to the lack of travelling and transport between countries and the daily commute of many being stopped almost entirely. The decreasing price of plastic is also due to another factor, plastic produced with natural gas as a feedstock. natural gas contains ethane, this is one of the building blocks of plastics. With the expected growth of ethane consumption and production, the feedstock for plastic production is expected to lower in price even further. The decreasing price of plastics hurts the demand for recycled plastics. Recycled plastics remain roughly at the same price point since the costs for collection, sorting and processing the waste materials stay the same. This while virgin plastics prices are continuing to decline. During this Covid-19 crisis, virgin plastics have become less expensive than recycled plastics. This has resulted in a significant decrease in demand for recycled plastics since the difference in price in some cases could be up to € 0,10 per kg in favour of the virgin materials.[21]

[20] Richtprijzen kunststoffen week 52 - Nieuws - KunststofenRubber.nl
[21] Interview with Agricon Nederland

For the second category of the supply chain, the manufacturing and use of plastics products is an important link in the supply chain. In this category, we see the production factories of plastic and the consuming parties. Raw plastic (virgin and recycled) is being fed into this sector and de production facilities will produce the plastic products that the consumers will use. Stakeholders in this segment will argue that the price of the feedstock must decrease. When feedstock prices are lower, the costs for them will drop and margins will increase. Therefore, if virgin material is cheaper than recycled plastics, they will be drawn towards virgin materials. Currently, there is an upcoming social-political movement that is focussing on consumer awareness on ecological consequences of using virgin feedstock instead of recycled feedstock. This movement is slowly increasing the demand for recycled feedstock. When virgin materials are costing less than recycled materials, the economically viable and preferable option will be to use virgin materials. Either by social responsibility or governmental regulations, consumers will be guided towards using recycled materials instead of virgin materials.

The disposal and end-of-life treatment phase in the supply chain is often mentioned in research done towards making a circular plastic economy. The stakeholders in this segment are mostly the waste plants, waste incinerators and recycling companies. Currently, most of the plastics that are being recycled, are being recycled mechanically. The products are being pulverised or palletised and the material characteristics stay the same. These pallets can then again be used as feedstock for new products. The main problems in this segment are sorting products, products consisting of multiple types of plastics, products not being designed for recycling and the low price for virgin plastics.

These factors are causing that currently recycling post-consumer plastics can be a difficult process. If a process gets more difficult, it often becomes more expensive. This leads to the current situation where recycled plastics can be more expensive than the virgin variant of the plastic. In this research, the focus mostly lies on the increase of circularity within the supply chain by improving the communication between the chain links. Products that have not been recycled for recycling is an example of a lack of communication and cooperation in the supply chain. Often products are being designed with either user comfort or low production costs kept in mind.

2.4 Conclusion

The plastics supply chain is dynamic and is forming a large part of the economy worldwide. The use of plastics has brought the economy much comfort and wealth, but it has come at great environmental costs. To answer the research questions stated earlier.

1) What is the current situation of the plastics supply chain in the Netherlands regarding circularity and recycling?

The current situation of the plastics supply chain in the Netherlands requires attention. The goal is to recycle 70% of the produced plastics by 2025, in 2016 this was 33.7%. To support the demanded increase in circularity, governments and the plastic industry have to come up with a solution to support a sustainable change in the economy.

2) How does the oil price affect the price and demand for recycled plastics versus virgin plastics?

As described in the previous chapter, the correlation between crude oil prices and the price of both virgin and recycled plastic is clearly noticed. This brings another challenge and risk to the challenge of increasing the use of recycled plastics. If virgin plastics remain significantly less expensive than recycled plastics, the incentive for the manufacturers of plastic products to use recycled materials as feedstock will lag behind.

3. Theoretical Framework

By performing a systematic literature review, the already existing literature is used to create a base understanding of the already available measures used to increase circularity and recyclability in the plastics supply chain. By performing this systematic literature review, the knowledge gap in the existing literature on this matter is also visualised. The following research questions can be answered by investigating the literature.

3) What types of plastic products are currently designed with recycling kept in mind?

4) What are key elements in the process of designing recyclable plastic products?

3.1 Systematic literature review

"What methods, theories and techniques are used in literature to increase circularity in the plastics supply chain in the Netherlands?"

By conducting a systematic literature review (*appendix A*), this question can be answered. This includes a step-by-step review and references to the articles used. The articles used will be referred to as [numbers in square brackets] in this chapter.

From the literature a couple of things concerning the circularity and the recycling of plastics. There is a group that focuses more on the plastic waste problem by optimizing the reduction methods in terms of incineration. And there is research done on how a cohesive supply chain could result in fewer production waste and an increase in recyclability of those products.

Both perspectives will result in less emissions and the use of fossil fuels, there is no evidence to indicate that one path provides the solution for all problems. Therefore, we must analyse various approaches to come up with a fitting solution to this specific problem. For now, I will focus on the articles that focus on a more cohesive supply chain.

The articles that focus on reverse logistics and increase in collaboration [1,2,3,5,9,12,16] mention that in other types of industries, e.g., metallurgy, these concepts are already implemented and are both ecologically and economically viable. The articles mention that setting up a reverse logistics system for this industry will increase value all along the chain by reducing costs and waste. They mention that a strict policy and price scheme is agreed upon such that the costs and the profits of processes with shared interest are also shared among the supply chain. Thus, increasing cohesion.

Other articles are focusing on the incineration of plastic waste [4,10,14] state that incineration is one of the alternatives besides recycling. When the quality of plastics has been reduced by a certain amount such that they no longer hold practical nor economical value, the material is incinerated. This way the energy stored inside the plastics can still be used and will replace the use of fossil fuels. Therefore, decreasing the use of other types of fossil fuels.

3.2 Design for recycling

The design for recycling strategy is one of the promising approaches to help increase the recyclability of various products. Not specially designed for the plastics supply chain, but applicable to the industry. This theory is described in this chapter and used as a foundation for the research due to the wide possibilities that this strategy offers.

3.2.1 Eco-Design

Design for recycling is an eco-design strategy. Eco-design has its focus on a more environmentally friendly, systematic approach towards the design of a product. [22] Designing a product with the eco-design strategy kept in mind can be slowing down the process. Several factors slow down the design to increase the recyclability of a product. For example, technical barriers and barriers linked to the traceability of materials inside a product due to the possible contamination of it. Several factors can be considered when designing a product. With Eco-design, the focus lies on using fewer impacting materials, using less material, improving process techniques, transport, use of the product and the end-of-life strategy of a product. For products with long life cycles, the usage or energy consumption during the life cycle must be considered as well.

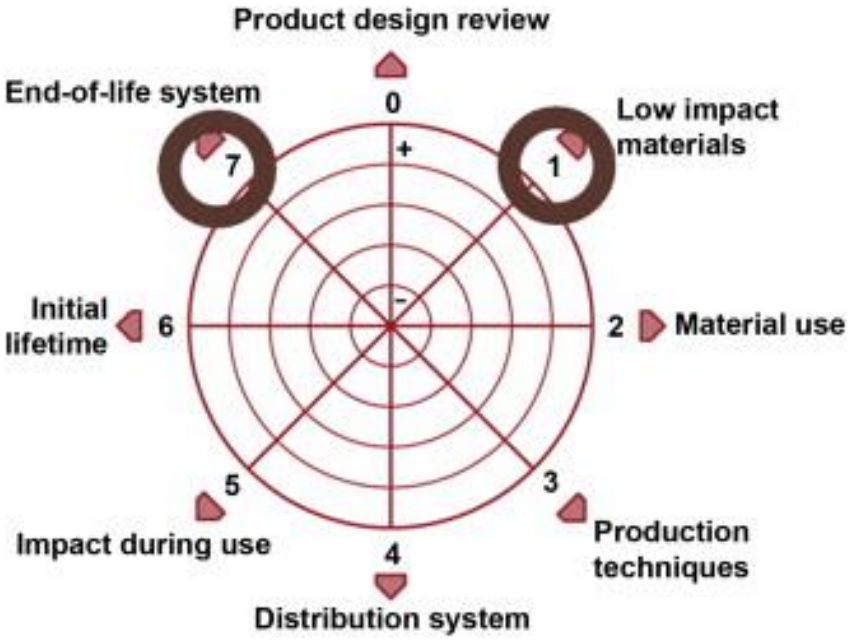

Figure 8 The wheel of eco-design strategies (Crul and Dieh, 2009)

The wheel of eco-design indicates the factors that are being considered with the eco-design strategy. The production of materials cannot be neglected since the effect of mining and usage of non-renewable resources is not to be underestimated. For material to be successfully recycled, the material must maintain its chemical and mechanical properties. Sorting is key in this process. In eco-design, the process of transforming and sorting a product should have an acceptable cost-to-performance ratio. If the cost-to-performance ratio is bad, the price of the recycled material is not competitive against the virgin material and companies will be more drawn towards the virgin material instead of the recycled material.

[22] Chapter 27 - From Recycling to Eco-design | Elsevier Enhanced Reader

The wheel of eco-design is divided into 7 strategies, strategy 1 investigates the limits of the resources that are being used on the product while strategy 7 investigates the limits of the sorting and recycling process of a product. These strategies both lead to the reconsidering the design of the product and the choice of material.

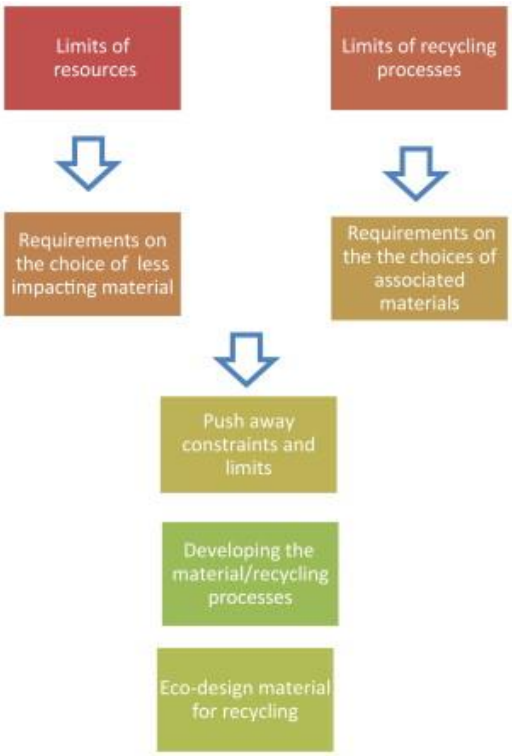

Figure 9 Principle of the eco-design of materials. (From Recycling to Eco-design, 2014)

These principles can be reconsidered and developed to increase the efficiency or quality of the process. The techniques that are used during the end-of-life stage of a product are continuously evolving and improving. This will result in better sorting of materials, less contamination in recycled materials and higher efficiency. An increase in the use of these techniques will lead to an increase in the quality of the recycled material as well as it being a more cost-efficient process. Recycling companies can be major stakeholders in the eco-design movement since it could reduce their operational costs. If operational costs can be reduced, the price of recycled plastic materials can be reduced as well. Reduced costs for recycled plastic materials will result in an increased demand for the product since the recycled material will be more competitive against the virgin material.

3.2.2 Design for recycling

Design for recycling is a strategy that comes from the Eco-design strategy. With design for recycling, the end-of-life solution is already implemented in the design of the product. Depending on numerous factors, a well thought out end-of-life strategy could increase the circularity and recyclability of a product since the reintroduction of a product back into the supply chain is also considered in these strategies. Design for recycling and design for disassembly could be seen as two strategies that target the same features in the designing process. These two designing strategies review the product and implement features thus that the recycling companies have fewer difficulties in the disassembly and sorting phase of the end-of-life cycle. If products can be disassembled and sorted more precisely, the contamination of the material is reduced and could be tracked with greater ease. Therefore, increasing the quality of the recyclate.

Another key feature of these designing methods is that since the products can be disassembled and sorted, the remaining non-recyclable portion will be reduced and less of the material is landfilled or incinerated.

Implementing the use of mono-materials in the design language will also help to increase recyclability. By having various types of polymers in one product, sorting of materials is made increasingly difficult. By using just one type of polymer in the product, contamination is reduced significantly. Mono-materials with similar molecular structures could improve the quality of recyclate by mechanical recycling. For chemical recycling, it is possible to recycle a polymer back to the virgin material even if the molecular structure of the recycling feedstock is varying. For mechanical recycling this is not possible.

3.2.3 Examples of design for recycling

There are various examples of products that have been designed for recycling, but one of the researched options is made by Signify. Signify offers lighting system where design, maintenance and operation are taken care of by Signify. If the system must be replaced or repaired, the company also directs the reverse logistics of the product and takes care of the recycling process. If possible, parts of used systems can be re-used in a new system elsewhere. This way the lifecycle of a product or part is stretched as long as possible and therefore the energy and materials that are being used to create such a product are optimised as well.

A key feature of the circular business model of Signify is that they are forming close collaborations with all the parties involved. This way they can create a sustainable solution for a circular economy. The way Signify communicates and cooperates with the parties involved, leads to a more cost-efficient and effective supply chain. Communication in this strategy is key and good partnerships make the process sustainable.

3.2.4 Extended Producer Responsibility (EPR) schemes

Extended producer responsibility schemes are schemes that put the responsibility of the life cycle and end-of-life cycle partly at the producer. By introducing EPR schemes, producers are triggered to make design decisions that will affect the life cycle and recyclability of a product. In the Netherlands, there is an authority called Afvalfonds Verpakkingen. This authority makes sure that producers of plastic products pay a certain amount per kilogram of material produced. This is called a cleaning contribution. This money then is used to support the recycling companies in the process of recycling and sorting the material. For example, if a company produces plastic products, the contribution a producing company must pay towards the Afvalfonds Verpakkingen is €0,670/kg (excluding taxes) in 2021[23]. If a company is producing plastic products that are easy to sort and recycle and have a positive market value when recycled, they can apply for the reduced fee of €0,410/kg (excluding taxes) in 2021. A very successful initiative of an EPR scheme in The Netherlands is the deposit on PET plastic beverage bottles. This scheme is currently the only recycling effort that allows used plastics to be reused for food packaging[24]. The reason that this is possible is since all bottles are originating from the food packaging sector and are not contaminated with plastic products from other (non-food) industries. Also, the amount of recycled plastic bottles has increased due to the introduction of the deposit on PET beverage bottles. In the Netherlands, large PET bottles are subject to the deposit scheme and have a recycling rate of 95%. Whereas the smaller PET beverage bottles (not subject to the deposit scheme) only reach a recycling rate of 58%.[19]

[23] Tarieven - Afvalfonds verpakkingen
[24] Statiegeld | Recycling Netwerk

3.3 Conclusion

The Eco-design offers new solutions to the growing problem of plastic waste production. By giving manufacturers of plastic products a guideline to increase the recyclability of their products, recyclers will be able to salvage more of the materials in waste streams. To reflect on the research questions stated earlier this chapter:

3) What types of plastic products are currently designed with recycling kept in mind?

One of the plastic products where recycling was kept in mind, is the PET beverage bottle. Due to the reverse logistics scheme of these bottles, up to 95% of the bottles are being recycled in the Netherlands. a side note to this is that they are subject to a deposit system. This deposit system only works for the larger PET bottles. When the deposit on the bottles is not used, like with the smaller variants, the recycling rate of the PET bottles drops to 58%.

4) What are key elements in the process of designing recyclable plastic products?

The steps of designing a recyclable product have been described in this chapter. Examples of measures that improve the recyclability of a product significantly are, the use of mono-materials, designing a product ready for disassembly, and preparing a good end-of-life solution.

4. Semi-structured interviews

There is a lack of existing literature researching the coherence between increase of circularity and cooperation between various contributors of the plastics supply chain. To overcome the existing knowledge gap, semi-structured interviews with respondents representing the cases of Agricon Nederland, Signify, Royal Dutch Shell, Frankenbos B.V., and BRBS Recycling were conducted to acquire an in-depth understanding of the position and cooperation of plastics recycling and production companies within The Netherlands. Since respondents are from both the production as well as the recycling side of the supply chain, the interviews consider the whole supply chain. The results of the interviews with experts in this supply chain provided several new insights, which will be further explained below. Discussed in the interviews are the changing environment for plastics recyclers, the corporate responsibility of plastics production companies, as well as the new challenges and regulations implemented by governmental authorities. The interview questions can be found in appendix E. The following research questions can be answered by the information acquired in this chapter:

5) What production bottlenecks will be caused by an increase in demand for recycled plastics?

6) What does the supply chain need to regulate and maintain the circularity of plastics?

4.1 Overview of the respondents

A short overview of the companies that are represented in the interview is given. While elaborating upon the companies, their fit to the research is explained. A detailed overview is provided in appendix B.

Company	***Position within company***	***Fit to research***
Agricon Nederland BV	CEO, Director	Specialised in consultancy on circular product development, waste streams and exploitation.
Signify	Sr. Marketing Manager	Frontrunner in design for recycling strategy and circular operations.
Royal Dutch Shell	Principal Research Scientist	Petrochemical industry, large producer of plastics and resources for plastics, currently researching chemical recycling of plastics.
BRBS Recycling	Director	Branch organisation of the recycling industry in the Netherlands. Focussing on shared knowledge and representing the interests of recycling companies.
Frankenbos BV	Director	Consultancy on circular operations management, 30+ years of experience in the recycling of textiles and plastics.

4.2 Interview results

4.2.1 Changing environment for plastic recyclers

Although all representing other firms within the plastics supply chain in the Netherlands, all respondents highlighted the changing market of plastic recyclates. Due to the cheaper and higher availability of virgin plastic materials, the demand for recycled plastic feedstock has been reduced.

As Agricon Nederland stated: *"The introduction of American shale gas industry has driven the price of virgin plastics downward due to the ethane in the gas, which can be used as a building block of plastic.".*

With the reduction of the price of virgin feedstock for plastic production, and the price of plastic recyclate staying the same, the economic aspect is not appealing to producers at this moment. The (current) global Covid-19 crisis also affects the plastic recycling market. Since the price of crude oil has dropped significantly, the price of virgin plastics has decreased as well.

According to Frankenbos B.V. *"The crude oil price used to be around $70-$90 per barrel. Currently, it is around $45-$50. This decrease cannot be compensated by the recyclate market."* Leaving the recycling companies in a position where they are outcompeted by virgin plastics manufacturers. Although, this is seen as temporary.

Branch organisations, like BRBS, are initiating the dialogue between both recycling companies and manufacturers of plastic products. Stated by all respondents, is that manufacturers are sometimes hesitant to use recycled feedstock in their production. 4 out of 5 respondents stated that this was due to common misconceptions about material characteristics of the recyclate, like colour or scent of the material. For products with high material requirements, contamination of the recyclate could result in not using it as a feedstock for new products.

The response from Signify on the use of recycled materials as feedstock: "*Virgin materials are completely available up to any specification and material characteristic needed, recycled materials are often contaminated with additives and therefore have different characteristics. Contamination is the main issue. Also, virgin materials are currently cheaper than recycled materials in terms of operating costs.".*

From the interviews, it becomes clear that for economic reasons, the demand for recycled feedstock is currently very low. Intentions of using more recyclate as feedstock for new products are not stimulated when the economics of the operations are not favourable.

4.2.2 Corporate responsibility of increasing circularity

This is the case in the food packaging sector. For food packaging it is not possible to use recycled materials as feedstock at this moment. The only exception to this is the material PET.

"*The PET bottle deposit system is one system where recycling materials back into food packaging, works. This is where ownership but more important, responsibility is placed at the producer, not at the consumer or recycling company. This way they will produce products that are better recyclable since they will be punished if not."* Agricon Nederland says.

Part of the challenge is to design for recycling. A frontrunner in the design for recycling strategy is Signify.

"*Products have been recycled with the design for disassembly strategy. This reduces services costs, enables re-use of products and materials, and makes it easier to recycle products. Certain products at signify are already designed such that they can be replaced or removed easily to save time, money and materials."* Signify states.

4 of 5 respondents stated that a key step in the progress of increasing circularity is to design for recycling. *"If producers were to pay attention in the manufacturing and designing phase, recyclers can disassemble the parts more efficient. This increases recyclability and will most likely reduce costs and material contamination."* Was stated by Frankenbos B.V..

Initiatives from manufacturers to become increasingly circular increase in popularity. Design for recycling is said to be one of the key elements in the progress on increasing circularity within the plastics supply chain in The Netherlands. Corporate responsibility is still neglected in many cases. By having the manufacturers cooperate with the recyclers, it is possible to optimize the design for recycling strategy and therefore increase circularity.

4.2.3 Demand for governmental regulations

As stated earlier, the intentions of manufacturers of plastic products to increase the use of recycled feedstock have been noticed. Although, with the economic perspective of using recycled feedstock versus using virgin feedstock currently being unfavourable for manufacturers, the actual increase of use of recyclate as feedstock is still lacking.

"*Most of the initiatives to increase the use of recycled feedstock are either released by the government or EU. Other smaller initiatives are started by companies within the supply chain, trying to increase their circularity and profitability. Most initiatives originate from recycling companies."* According to Agricon Nederland.

Also stated by Agricon Nederland is that "*From within the supply chain, a lot of initiatives to increase the use of recycled feedstock are set up. But without government regulations, the initiatives have shown to be significantly less successful.".*

From the manufacturer's perspective regulations are also in demand. Due to the lack of regulations and certification, material contamination could pose a risk for many manufacturers. Signify states that one of the main concerns is to have a good and consequent quality of the material. Without governmental regulations on quality control and monitoring of recycled feedstock, it is very difficult for manufacturers to have a steady quality throughout their operations. Therefore, virgin materials are preferred since those are available up to specifications and not contaminated.

"*If there are for example EU regulations where a company has to use a certain percentage of recycled material in their feedstock, the main challenge is to have a good and consequent quality of the material."* As stated by Signify.

The demand for increased regulations on plastic recyclates is endorsed by all the respondents. It is stated that without control over the quality of the materials, the regulations are not viable due to the possible fluctuating quality of the recycled feedstock.

Although, Shell states "*Plastics are a performance product. If mechanical recycling is used, good certification is very hard to set up due to the possible varying molecular structure of different products made from the same type of plastic.".*

This means that if it is possible to sort plastics by polymer, their molecular arrangement could still cause contamination due to the varying characteristics different types of molecular structures give to the material.

"Through chemical recycling, it is possible to "reset" the molecular structure of a polymer and bring it back to the virgin material." Shell says.

This makes chemical recycling less sensitive to contamination. However, it is still sensitive if contaminated with other types of polymers.

4.2.4 Increase in demand for recycled plastics

A concern of all respondents is that the use of recycled materials in new plastic products is increased.

As stated by BRBS "Amount of usable plastic in the current waste streams is sufficient and could support the increase in demand for recycled plastics.".

Meant by this is that the number of plastics in waste streams that are currently incinerated or landfilled, could still be increased, and used for recycling. This could be achieved with more effective sorting and extended producer responsibility schemes, stated by Agricon Nederland.

According to Agricon Nederland: *"A problem caused by increasing demand for recycled plastics could be the availability of equipment needed for the recycling of plastics. The waiting period for some of the machines and equipment could sometimes be up to 3 to 4 years. If there would be a sudden increase in demand for recycled plastics surpassing the current capacity of recycling plants, growth could stagnate."*

For manufacturers, it is stated that material contamination, certification and quality control are still the core problems if the demand for recycled plastics in new products should suddenly increase.

4.3 Conclusion

The interviews have shed a light on previously unknown challenges that the plastic supply chain is currently facing. The semi-structured interviews allowed us to have an open conversation on the experience of the experts within the supply chain. through this, context is given to the challenges described by the literature. The following questions have been answered by conducting these interviews:

5) What production bottlenecks will be caused by the increase in demand for recycled plastics?

There are two main bottlenecks described by the respondents. One being the recycling capacity of the currently existing recycling plants. While still having an adequate capacity for the current demand, expanding the recycling capacity takes time. This is due to the machinery required to process the waste streams and create usable recyclate from them. The time it takes to manufacture such machinery and the queue could be up to several years.

Another problem described by the respondents is the quality of the recyclate. There are no uniform guidelines or quality standards that the recyclate has to meet. This leads to varying quality standards per recycler. Manufacturers looking to use the recyclate as feedstock for new products are therefore struggling with the fluctuating and unpredictable quality of their feedstock. This poses a risk for their operations.

6) What does the supply chain need to regulate and maintain the circularity of plastics?

As stated in the answer to the previous question, one of the main challenges for the industry is the fluctuating quality of the recycled feedstock. Therefore, the respondents stated that quality regulation and monitoring is essential for manufacturers to increase the use of recycled materials as feedstock for their new products.

To create equal standards for manufacturers within the supply chain, governments must regulate the amount of recycled feedstock that is used in a new product. By doing so, there is an extra incentive for the manufacturers to use recycled feedstock. It will no longer be optional to use recycled materials as feedstock. Also, manufacturers that excel in creating recyclable products, should be rewarded for doing so. Manufacturers scoring below the requirements shall be fined. This topic is elaborated on in chapter 5.

5. Conclusions & recommendations

This chapter will reflect on the insights obtained throughout the research and the interviews. Based on these insights, recommendations and a conclusion can be drawn, and further explanation is given on why certain recommendations were given.

From the interviews came forward that there is a high demand or increased regulation and control of quality for the recycled plastics market. The respondents of the interviews have mentioned that fluctuating quality poses a serious risk to their operations. This section (5.1) will therefore also focus on the quality regulation and monitoring options that can be put in place to create equal standards across the plastics supply chain. The first section (5.1) will therefore also help to answer the following research question:

6) What does the supply chain need to regulate and maintain the circularity of plastics?

After answering the previous research question, the recommendations for the supply chain in the Netherlands will be given. These recommendations use the insights acquired through this research as their foundation. Based on existing literature, data, and years of experience a practical and implementable guideline is created. This section (5.2) will also answer the following research question:

7) How will the recommendations be implemented into the supply chain?

In the final section of this chapter, the results and insights of the research will be reflected upon. The earlier stated research questions will be answered according to the findings and theory corresponding to the questions. The goal of the research is also discussed, and a reflection is given on whether the goal was reached up to satisfaction.

5.1. Regulation and control

5.1.1. Regulations

To reintroduce recycled materials in the feedstock for new plastic products, certain levels of quality must be reached. Especially for the food-packaging industry, this is hard to reach the quality conform EU regulations and safety standards. One of the main arguments against the use of recycled plastic materials in food packaging is the unknown level of contamination in the material. At the end-of-life stage of a product, the first step is often disassembly and collection, then comes sorting and finally mechanical or chemical recycling. The contamination of a material takes place when various materials are blended. This makes it hard to trace back the origin of the materials and the material characteristics. Sorting plastics can be done with increasing precision and materials can be divided into categories like PE and PP. However, within the category Polypropylene, not every product has the same material characteristics. For this reason, the recyclates are deemed contaminated.

Producing companies currently have the option to choose from virgin materials or recycled materials as the feedstock for their products. Since virgin plastic materials have decreased in price over time, the demand for recycled material has been reduced. For producers it is also easier to use virgin materials as feedstock, since they can get these materials completely up to the desired specifications, with lower effort than the recycled materials. For the manufacturers to use the recyclates, either the price of virgin materials must increase, the price of recyclate must be reduced or the governmental authorities must regulate the number of recyclates used in a new plastic product. The norm that is

set by the Dutch plastic pact[25] that by 2025, 70% of plastics should be recycled and plastic products produced should consist of 30% second-hand packaging materials. Even further, the European Commission pronounced the target of the fully recyclable plastic packaging[26] production by 2025. The measures could lead to an increase in demand for plastic recyclates. However, these are goals and not clear regulations. This means that it is still optional for companies to use the recycled materials, and not obligatory. By regulating the amount of recycled feedstock that has to be used in a new plastic product, the demand will increase by itself without the need for subsidizing the initiatives. This will then trigger the manufacturers to increase the amount of recycled feedstock, but also triggers them to design products for recycling. Since design for recycling will reduce the effort that is needed to recycle a product, and therefore also the price of recycled materials. The manufacturers of plastic products benefit from low material costs.

5.1.2 Monitoring of quality and contamination

During the research, all parties stated during the interview that contamination in recyclates is still one of the main issues in the recycling process. Due to contamination, the recyclates have varying material characteristics. When materials are sorted poorly, contamination increases. For manufacturers that are using the recyclate as a feedstock, it is necessary to know the characteristics of the materials they are working with. If the feedstock of recyclate has a fluctuating quality, it becomes more challenging for them to process and use this feedstock in their operations. Therefore, it is easier for a manufacturer to use virgin plastic as feedstock. To increase quality of the recyclates, contamination must be reduced. One of the methods to do this is by monitoring and controlling the waste streams from various industries. The PET beverage bottle system is a good exhibit where a reverse logistics scheme is reducing the contamination in the materials. With the PET bottle system, it is known that the products in the recycling process are certainly originating from the food packaging industry. Therefore, it is possible to re-use these materials for food packaging again.

To increase the recyclability of products, material flows must be monitored. This allows recycling companies to better sort the material as well as trace the material characteristics of the recyclates. This creates a better understanding of where waste is coming from and the specific characteristics of those materials. For manufacturers, it is then easier to use these recyclates as feedstock.

To create a good monitoring system, manufacturers and recyclers must cooperate to chart out where the waste is coming from and how it is produced. If a good reverse logistics scheme is adopted with increased ERP, it will increase the recyclability of plastic waste.

5.1.3 Certification

The plastic recycling industry in The Netherlands as well as the plastic recycling industry in Europe lacks uniform standards and certification schemes.[27] Without these standards or certification schemes, the quality of recyclates could be different for each recycling plant. If the quality of plastic recyclate is not consistent, manufacturers do not have a reliable feedstock to produce new plastic

[25] Marc Seijlhouwer (2019) Een miljard minder plastic producten in 2020. Retrieved on January 3, 2020, from https://www.duurzaambedrijfsleven.nl/recycling/32995/minder-plastic-2020

[26] Plastics Recyclers Europe (2019) *Flexible Polyethylene Recycling In Europe: Accelerating the Transition Towards Circular Economy*. Brussels: Plastics Recyclers Europe. Retrieved on December 7, 2019, from https://www.plasticsrecyclers.eu/

[27] Recyclers Certification | Plastics Recyclers Europe

products. A uniform standard throughout Europe could strengthen the secondary raw materials market as well as encourage the use of recyclates in new products. If uniform regulations are implemented in the European plastic recycling industry, there must also come uniform quality standards and certification schemes. By implementing these standards, regulations and certifications, the European plastic recycling industry will have a fair market where all parties within the EU must oblige to the same rules.

5.1.4 Conclusion

The demand and possibilities for regulating the quality of recycled plastic have been made clear in this section. The following research question is therefore answered:

6) What does the supply chain need to regulate and maintain the circularity of plastics?

By having clear and approachable regulations, the industry is guided towards more sustainable operations. By creating clear guidelines and quality standards, it becomes more attractive for manufacturers to use recycled plastics in their feedstock. By involving recyclers when designing a product, products can be recycled with greater ease. This will also result in less contamination and therefore improved quality of the plastic recyclate.

5.2 Recommendations for plastics supply chain in the Netherlands

1) Cooperation in the design phase of a product. – When manufacturer and recycler cooperate during the design phase of a new product, the eco-design strategy could be utilised with greater efficiency. Recyclers can point out the bottlenecks they face if certain decisions are taken in the designing phase (e.g., use of mono-materials instead of products consisting of multiple types of materials). By considering this approach, products can be produced ready for recycling, therefore increasing transparency within the supply chain and increase shared knowledge.

2) Use of mono-materials in new products. – When products will consist of just one material, contamination will occur much less. Getting rid of products that are composed of multiple materials could result in higher initial costs, since some materials are cheaper to use than others, but will reduce the price of recycled materials since the operational costs of sorting and recycling will be reduced. The quality of the recycled material will also increase due to the reduced contamination by using mono-materials.

3) Monitoring material streams. – By monitoring the streams of materials used in products from the manufacturer to the recycler, the level of contamination in plastic recyclate can be reduced. It creates transparency for both manufacturer and recycler. This will also help to regulate and control the quality of the recyclate.

4) Extended producer responsibility schemes. – The end-of-life phase of a product should be considered by the manufacturer. By placing the responsibility of the end-of-life solution at the producer, circularity could be increased. By placing the responsibility of collection and recycling of products at the manufacturer, waste streams can be monitored with greater efficiency, resulting in less contamination and higher recyclate quality. A good example of a successful EPR scheme is the PET bottle deposit system.

5) Quality control and monitoring of recycled plastics. – Recyclers and manufacturers must come up with a system where the material characteristics of recyclate are graded. Certain blends of materials should be certified and standardised. By doing so, manufacturers can order their recycled feedstock up to the needed specifications and quality standards. This reduces risks during operations and gives them a controlled quality of their feedstock.

6) Increase the sharing of knowledge across the supply chain. – Manufacturers and recyclers could create a platform where knowledge and experience are shared between different parties. This will help increase the transparency within the supply chain. By doing so, cohesion is also improved. It could lead towards more sustainable product designing since manufacturers have more know-how on the plastics recycling process and can therefore keep that process in mind while designing a new product.

5.2.1 Conclusion

By following these recommendations, the plastics supply chain in The Netherlands could benefit from the increased circularity as a result. The EU and governments will start to regulate an increased use of recycled material in the feedstock of new plastic products in the next few years. By anticipating these regulations, the companies involved can profit from being a frontrunner when regulations are endorsed. The goal of these recommendations is also to decrease operational costs within the supply chain and therefore increase profitability for both manufacturers and recyclers.

5.3 Discussion

In this section, the results and insights of the research will be reflected upon. The earlier stated research questions will be answered according to the findings and theory corresponding to the questions. The goal of the research is also discussed, and a reflection is given on whether the goal was reached up to satisfaction.

5.3.1 Sub-questions

By answering the sub-questions, an adequate answer for the main research question will be formulated.

1) What is the current situation of the plastics supply chain in the Netherlands regarding circularity and recycling?

The current situation of the plastics supply chain in the Netherlands requires attention. The goal is to recycle 70% of the produced plastics by 2025, in 2016 this was 33.7%. To support the demanded increase in circularity, governments and the plastic industry have to come up with a solution to support a sustainable change in the economy.

2) How does the oil price affect the price and demand for recycled plastics versus virgin plastics?

As described in chapter 2 and confirmed by the respondents of the interview, the decreasing price of crude oil has a great influence on the price of virgin plastics. To maintain cash flow, recycling companies therefore also reduced the price of recycled commodities. However, not only the decreasing crude oil prices have affected the price of plastics. The US shale gas “Boom” created a new, inexpensive source of ethane. Ethane being one of the key ingredients to produce plastic materials has driven the price down of plastics as well.

3) What types of plastic products are currently designed with recycling kept in mind?

Unfortunately, the number of products that are being designed for recycling is still lacking behind. Although, as described in the research, the Eco-Design movement is picking up attention. Manufacturers are facing an upcoming socio-economic movement that demands that efforts are made to reduce the ecological footprint of a product as much as possible. Signify is an example of a company that has designed its products around a circular model. Their products are designed such that they can be installed as well as disassembled with great ease, therefore reducing maintenance costs, and increasing modularity as well as reusability.

4) What are key elements in the process of designing recyclable plastic products**?**

Key elements of designing a product according to the design for recycling strategy is the choice of material used and considering the end-of-life phase of a product. By designing a product ready for disassembly, recyclability will be increased. This is due to that sorting of the waste materials can be done with higher efficiency, as well as the reuse of still working elements of a product. Design for recycling and Eco-design are elaborated upon in chapter 3.

5) What production bottlenecks will be caused by an increase in demand for recycled plastics?

The expected bottlenecks for recycling companies lie with the recycling capacity. The number of usable materials in existing waste streams is expected to be sufficient in case of an increase in demand for recycled plastics. There is still room for an increase in the current industry. Although, if the increase will grow significantly, the production capacity is not expanded easily since waiting times for the equipment needed for the recycling of plastics can be up to 3-4 years.

For the production companies, the bottlenecks in case of an increase in demand for the use of recycled feedstock will be the quality of the material. If the EU or the government is going to regulate the minimum amount of recycled feedstock used in a plastic product, the main challenge for manufacturers will be the quality of the recycled feedstock. Since there are no general quality standards for recycled materials, the fluctuating quality can cause problems and bring risk to the operations of a manufacturer.

6) What does the supply chain need to regulate and maintain the circularity of plastics?

As stated by both manufacturing and recycling companies within the supply chain of plastics in The Netherlands, quality control and monitoring are needed to succeed. The level of contamination of materials must be monitored and based on that, quality certification is needed to ensure a certain baseline of material characteristics for manufacturers. This will increase the possibilities and transparency within the supply chain.

7) How will the recommendations be implemented into the supply chain?

In chapter 6, a list of recommendations for both the plastics supply chain as well as governmental institutes are given. This elaborated on the practical implementations that are needed to support a sustainable and circular plastic economy.

5.3.2 Main research question

Based on the results of the research and the sub-questions, the main research question will be answered.

How can the cooperation in the plastic supply chain be increased to achieve an increase of circularity in the sector?

First, we must ask whether cooperation within the plastic supply chain would increase the circularity within the sector. The answer to this is yes. From both theory and the interviews, it became clear that there is a large demand for shared knowledge and an increase of transparency between manufacturer and recycler. It is inevitable that the amount of recycled feedstock required in new plastic products will be increased within the next 5 to 10 years. This means that the entire supply chain must be ready for this transition. Communicating and sharing knowledge is key in this process. Manufacturers demand less fluctuation in the quality of the recycled feedstock. Recyclers can only increase the quality of recyclate if sorting and disassembly are more effective. This is made possible with extended producer responsibility schemes. Recyclers must be invited at the design phase of the product to indicate the bottlenecks they face when sorting and recycling products. By doing this, manufacturers can design products ready for disassembly and recycling.

5.4 Conclusion

The research has led to many new insights and the closing of a knowledge gap on the effect of cooperation on circularity within the plastic supply chain in the Netherlands. The focus of this research was specific to The Netherlands, but after reflecting on the results, most recommendations are also suitable for the plastic supply chain in other countries and continents. Based on that, this study contributes to the increase of circularity within the plastic supply chain, by setting out clear and achievable recommendations. Achievable is key in this sentence since lots of earlier research was done with a theoretical approach towards the plastic problem. This research was done with a pragmatical and practical approach, also focussing on the economic aspects rather than just the environment.

During the research came to light that the greatest demands from within the plastics supply chain in The Netherlands is to have increased quality control and certification. Most parties involved in the supply chain are aware of the increased demand for the use of recycled material for new plastic products. Most of the companies are also struggling with a lack of knowledge and regulation. This means that there currently is too much uncertainty within the supply chain. By cooperating, knowledge can be shared and transparency is increased. This reduces the uncertainty for companies and therefore makes it easier to innovate towards sustainable product design.

This thesis has visualised the demands from the supply chain in the Netherlands. By listening to their demands, circularity can be increased significantly. The recommendations mostly imply the importance of a solid regulatory system where both producer and recycler are participating in the creation and can deliver their knowledge as input.

The importance of collaboration during the product design phase is also emphasised. Creating a product that was designed for recycling, the struggle of reintroducing the product or material after its lifecycle is reduced significantly. The problems that are occurring in the end-of-life phase of a product, are solved by already tackling them in the design phase.

Manufacturers could also benefit from increasing the recyclability of products. Hence, by using mono-materials in their products, sorting and recycling of a product can be done with greater ease. This then influences the operations of the recycler. Easier operations result in lower operational costs

and the recycler is then able to reduce the prices of recycled material, increase the quality, or do both. The manufacturer can then again benefit from the increased quality of the recyclate or the reduced price of it.

This underlines the importance of shared knowledge and collaboration within the plastics supply chain of the Netherlands.

5.5 Recommendations & limitations

5.5.1 limitations

During the research, certain factors were limiting the bias and outcome of the research. The two main factors limiting this study deserve to be elaborated. The first limitation relates to the nature of the respondents. The interviews have been conducted with representatives of companies within the supply chain that already focus on the increase of recyclability of plastic and circularity. It is possible that their bias towards plastic recycling could have affected the results of the study. While the respondents have been selected based on their field of expertise and the sample group has been composed such that all sides of the supply chain were represented.

The second limitation that was encountered during the research, was the upcoming Covid-19 crisis. The initial plan was to visit companies and have a more in-depth look into their operations. Due to health concerns, unnecessary travelling was not recommended. This meant that instead of conducting face-to-face interviews, these were conducted over the phone or by using video call software. When visiting a company, seeing operations, and talking to someone face-to-face, context is added to a story. This was one of the obstacles. Also due to the Covid-19 crisis, a lot of intended respondents cancelled their appointments due to related factors. This factor has also reduced the sample size for the interviews.

5.5.2 Recommendations

This thesis visualises the demand for regulation and increased cooperation by the plastic supply chain in the Netherlands. For further research it might be interesting to research the following aspects:

When looking at this thesis, the actual effectiveness of the recommendations for the supply chain has still to be analysed. This thesis was focused on the demand of the plastics supply chain in the Netherlands in terms of increased circularity. The demands from the supply chain have now been visualised, now it is important on how effective the suggested measures are, and how they could be improved.

Further research could also look into the technicalities of the proposed regulations. To create solid guidelines, it is necessary to know what the parameters should be. The supply chain could benefit from having a clear set of rules and regulations to operate from. Material characteristics are key in these regulations.

Recommendations for the plastics supply chain of the Netherlands have been elaborated in chapter 6.

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Appendix A. Systematic literature review

Research question

The research question aims towards finding already published work on the recycling of plastics and what previous researcher have found concerning the methods, techniques, and theories on the recycling of plastics. By obtaining this knowledge, I hope to get a clear visualization on what is already possible and the measures that are taken or did not work. The research question is as follows

"What methods, theories and techniques are used in literature to increase circularity of the plastics supply chain?"

The inclusion and exclusion criteria

To select articles fitting to the research, information specialist Peter Noort (2019) states that inclusion criteria are must-haves for an article to be included in the review and exclusion criteria are factors that determine that an article is ineligible to be included in the review. In table 1 the selected criteria are shown.

Table 1 Inclusion and exclusion criteria

Number	Exclusion criteria	Reason for exclusion
1	Pre 2010-articles.	Recycling of plastics is a huge topic all around the world and a lot of research is done every year. By focusing on the more recent findings, it is possible to obtain the most up-to-date information.
2	Social studies concerning plastic recycling.	There are a lot of social studies on the matter of plastic recycling mostly focusing on the public opinion. This research will be more focused on a business perspective instead of satisfying the need of the customer.
Number	Inclusion criteria	Reason for inclusion
1	Articles covering new recycling techniques.	The goal is to increase overall recyclability. If there are new findings on how that could be achieved, it is valuable to know.
2	Articles covering economic benefits of recycling.	Since this research will be focused on the business perspective. A large factor in the research is to make it economically viable.

The used databases

Primarily Scopus and Web of Science have been used to retrieve useful articles. According to Peter Noort (2019), both qualify as multidisciplinary scientific databases giving access to tens of millions of articles and reports.

The search terms and the used strategy

The search terms are based on the main concepts of the research question. The main concepts are:

- Recycling
- Plastics
- Supply Chain
- Reducing costs
- Recycling methods

The search terms are distinguished in the four categories of the main concepts. The terms used are:

- Recycl*, Cascading, circular*
- Plastic*, polymer*, Polyethylene, PE, Polypropylene, PP
- Supply chain, branch, sector, industry, market
- Economy, cost*, profit*,
- Techni*, method*, Proces*

by starting to search in a very broad way and then narrowing it down to more specific search, I can filter out the more useful articles. Since both Scopus and Web of Science have many scientific articles, I start of by entering a search term containing each of the four main constructs in the Article tile, Abstract or keywords (Scopus) This will result in a lot of entries, so the scope is gradually narrowed down until a more manageable number of entries is left. For Web of science the approach is rather similar.

Search-documentation

The process of narrowing down the search results by altering the scope and changing the strategy is documented in table 2. The corresponding number of entries is given for each search strategy.

Table 2 Search documentation

Search string	Scope	Date of search	Data range	Number of entries
Search protocol for Scopus				
(recycl* OR cascading OR circular*) AND (plastic* OR polymer* OR PE OR PP) AND (supply chain* OR branch OR sector OR industry OR market) AND (economy OR cost* OR profit*) AND (Techni*, method*, Proces*)	Article title, Abstract or Keywords	24-05-2020	2010 - 2020	175 (not too much but still quite a lot)
(recycl* OR cascading OR circular*) AND (plastic* OR polymer* OR PE OR PP) AND (supply chain* OR branch OR sector OR industry OR market) AND (economy OR cost* OR profit*) AND (Techni*, method*, Proces*)	Keywords	24-05-2020	2010 - 2020	31
Search protocol for Web of Science				
(recycl* OR cascading OR circular*) AND (plastic* OR polymer* OR PE OR PP) AND (supply chain* OR branch OR sector OR industry OR market) AND ((economy OR cost* OR profit*) OR (Techni*, method*, Proces*))	Topic	24-05-2020	2010 - 2020	751 (too much / not useful)
(recycl* OR cascading OR circular*) AND (plastic* OR polymer* OR PE OR PP) AND (supply chain* OR branch OR sector OR industry OR market) AND ((economy OR cost* OR profit*) OR (Techni*, method*, Proces*))	Title	24-05-2020	2010 - 2020	7 (on the fewer side)
Total				38
Removing duplicates				-0
Selecting based on exclusion / inclusion criteria				-12
Removed after reading				-10
Total selected for review				16

Conceptual matrix with articles and summary of the main findings

Table 3 provides an overview of the articles selected for the review. It contains the basic reference information about the article, as well as the research method and the key findings regarding the main constructs of the research question. The number in the first column will be used for referencing in step 7.

Table 3 Conceptual matrix with key findings

Number	Article	Authors (year)	Method	Key findings
1	Investigation into circular economy of plastics: the case of the UK fast moving consumer goods industry	Gong, Yu; Putnam, Ellis; You, Weimu; Zhao, Changping (2020)	Case study	Plastic recycling initiatives are most successful if led by NGOs and collaboration.
2	The Commitment of Packaging Industry in the Framework of the European Strategy for Plastics in a Circular Economy	Foschi, Eleonora; Bonoli, Alessandra (2019)	Case study	The study shows hoe European Commission has robustly worked to regulate production and consumption patterns on plastic carrier bags and packaging. In reaction, industrial stakeholders of the plastic supply chain responded with greater alliances and integration.
3	Options to feed plastic waste back into the manufacturing industry to achieve a circular carbon economy	Guran, Serpil (2019)	Social study + case study	The effect of near or long term technical and policy changes and how they can change climate change by feeding plastic waste back in the circular carbon economy.
4	Measuring the environmental performance of a circular system: Emergy and LCA approach on a recycle polystyrene system	De Souza junior, H.R.A.; Dantas, T.E.T; Zanghelini, G.M.; Cherubini, E.; Soares, S.R. (2020)	Emergy analysis and LCA	For reverse logistics in plastic goods, energy use and the pollution from landfills and transport have been considered to demonstrate the environmental performance with adapted production processes.
5	A GIS-based green supply chain model for assessing the effects of carbon price uncertainty on plastic recycling	Ren, H.; Zhou, W.; Guo, Y.; Huang, L.; Liu, Y.; Yu. Y.; Hong, L.; Ma, T. (2020)	Case study with GIS information	The results show that a carbon price threshold is required for the industry to successfully implement reverse logistics for plastic recycling. Currently the carbon price is too low.
6	Circular economy transition in Italy. Achievements, perspectives and constraints	Ghisellini, P.; Ulgiati, S. (2020)	Case study	Prevention and reduction of waste is the first step in this transition and is still not implemented correctly with most companies.
7	Sustainable development by reusing old recyclables in a textile industry including two collectors and three firms: A game-theoretic approach for pricing decisions	Jafari, H (2019)	Simulation + case study	The most value added to the plastic supply chain is achieved with a centralized game for pricing decisions.
8	From trash to treasure: The impact of consumer perception of bio-waste	Russo, I.; Confente, I; Scarpi, D.; Hazen, B.T. (2019	Case study + social study	Bio-waste could help reduce carbon footprints and help replace plastic alternatives.

	products in closed-loop supply chains			
9	Quality of resources: A typology for supporting transitions towards resource efficiency using the single-use plastic bottle as an example	Lacovidou, E.; Velenturf, A.p.M.; Purnell, P. (2019)	Case study	The ban on low quality recyclates in China supports the movement of early adaptation in the plastic supply chain, that enables repairing and recycling of products down the line.
10	Circular economy of supply chain of recycled plastic bottle waste	Kristina, H.J.; Christiani, A.; Jobiliong, E. (2018	Conference paper	Optimizing the recycling of plastics is key. But when there are no alternatives, the incineration process could be optimized to reduce CO2 emissions and increase energy output.
11	Profitability and environmental friendliness of a closed-loop supply chain for PET components: A case study of the Mexican automobile market	Chavez, R.; Sharma, M. (2018)	PESTLE analysis + case study	The paper shows that under the umbrella of Mexico's current infrastructure, political and legal frameworks, CLSC is profitable. The results are 79% less energy and 73% less CO2 generated.
12	Closing the loop on plastic packaging materials: What is quality and how does it affect their circularity?	Hahladakis, J.n.; Lacovidou, E. (2018)	Case study	The purpose of the article is to underpin the need for research that integrates systemic thinking, with technological innovations and regulations at all stages of the supply chain, to promote sustainable practices to become established.
13	Designing an optimized supply network for sustainable conversion of waste agricultural plastics into higher value products	Rentizelas, A.; Shpakova, A; Mašek, O. (2018)	Case study + simulation	The study shows that pyrolysis is possible and profitable for agricultural plastic waste. Increasing the value of the plastics and reducing waste materials.
14	Efficient energy recovery through a combination of waste-to-energy systems for a low-carbon city	Ohnishi, S.; Fujii, M.; Ohata, M.; Rokuta, I.: Fujita, T. (2018)	Case study	The results show that a certain mixture between plastic, paper and RPF and the usage of waste for wet methane fermentation, will result in the most efficient incineration of waste.
15	Global reverse supply chain redesign for household plastic waste under the emission trading scheme	Bing, X.; Bloemhof-Ruwaard, J.; Chaabane, A.; Van Der Vorst, J. (2015)	Case study	Emission trading Schemes (ETS) can function as policy instruments for controlling emissions. Optimization shows that relocating of re-processors leads to both a reduction of total costs and total transportation emissions.
16	Reverse logistics processes in supply chains of plastics	Witowski, K. (2012)	Case study	By looking at the reverse logistics of the metallurgy industry, this could be a template for how the plastic industry could manage reverse logistics.

Integration of the theory

This chapter is focusing on the integration of the information obtained from the literature into the theory behind my research.by filtering the information that is useful from multiple sources, it is possible to deduct a theory that supports the research. To answer the next question:

“What methods, theories and techniques are used in literature to increase circularity of the plastics supply chain?”

From the literature a couple of things concerning the circularity and the recycling of plastics. There is a group that focusses more on the plastic waste problem by optimizing the reduction methods in terms of incineration. And there is research done on how a cohesive supply chain could result in less production waste and an increase in recyclability of those products.

Both perspectives will result in less emissions and use of fossil fuels, so I believe that a not 1 path is better than the other. For now, I will focus on the articles that focus on a more cohesive supply chain. The articles that focus on the reverse logistics and increase in collaboration [1,2,3,5,9,12,16] mention that in other types of industries, e.g., metallurgy, these concepts are already implemented and are both ecologically and economically viable. The articles mention that by setting up a reverse logistics system for this industry, will increase value all along the chain by reducing costs and waste. They mention that a strict policy and price scheme is agreed upon such that the costs and the profits of processes with shared interest are also shared among the supply chain. Thus, increasing cohesion.

Other articles are focusing on the incineration of plastic waste [4,10,14] state that incineration is the best alternative besides after recycling. When there is the quality of plastics have been reduced by a certain amount such that they no longer hold practical nor economical value, it is incinerated. This way the energy stored inside the plastics can still be used and will replace the use of fossil fuels. Therefore, decreasing the use of fossil fuels.

By combining both approaches, first to recycle as much as possible and using a cascading model to extend the life cycle of a polymer as much as possible. And finally, to choose for highly optimized incineration, the environmental harm of this supply chain could be minimized.

Appendix B. Detailed overview respondents

The company, position within the company and the fit to the research is elaborated below.

Agricon Nederland BV – Agricon Nederland is an advice- and consultancy firm specialised in the circular economy. Agricon Nederland Offers products, services, and solutions in the field of circular product development, waste streams and exploitation. They create material passports, resource dashboards and manage destruction of confidential archives and data-electronics. This company has a good fit to the research due to their experience in circular economy and knowledge on recycling processes and facilities.

Signify – Signify is the world leader in lighting for professionals, consumers, and lighting for the Internet of Things. Their energy efficient lighting products, systems and services enable our customers to enjoy good quality sustainable lighting solutions.[28]
Signify has a good fit to the research due to their circular lighting initiative. By cooperating with other companies, they can provide a circular lighting system where production, installation, reverse-logistics, and waste management is offered in one package. They are experienced on how cooperation could increase circularity.

Royal Dutch Shell – Royal Dutch Shell is one of the largest petrochemical companies worldwide. Since most plastics are petroleum based, Shell also takes interest in the production of plastics and delivers the resources needed to produce virgin plastic materials. Their Chemical expertise helps to understand the possibilities of chemical recycling, which is currently under development at Shell.

BRBS Recycling – BRBS Recycling is a branch organisation that represents the interests of recycling companies of all sorts in the Netherlands. Their vision is to share knowledge within the recycling branch to promote the transition towards a circular economy by providing knowledge on effective sorting and recycling measures.

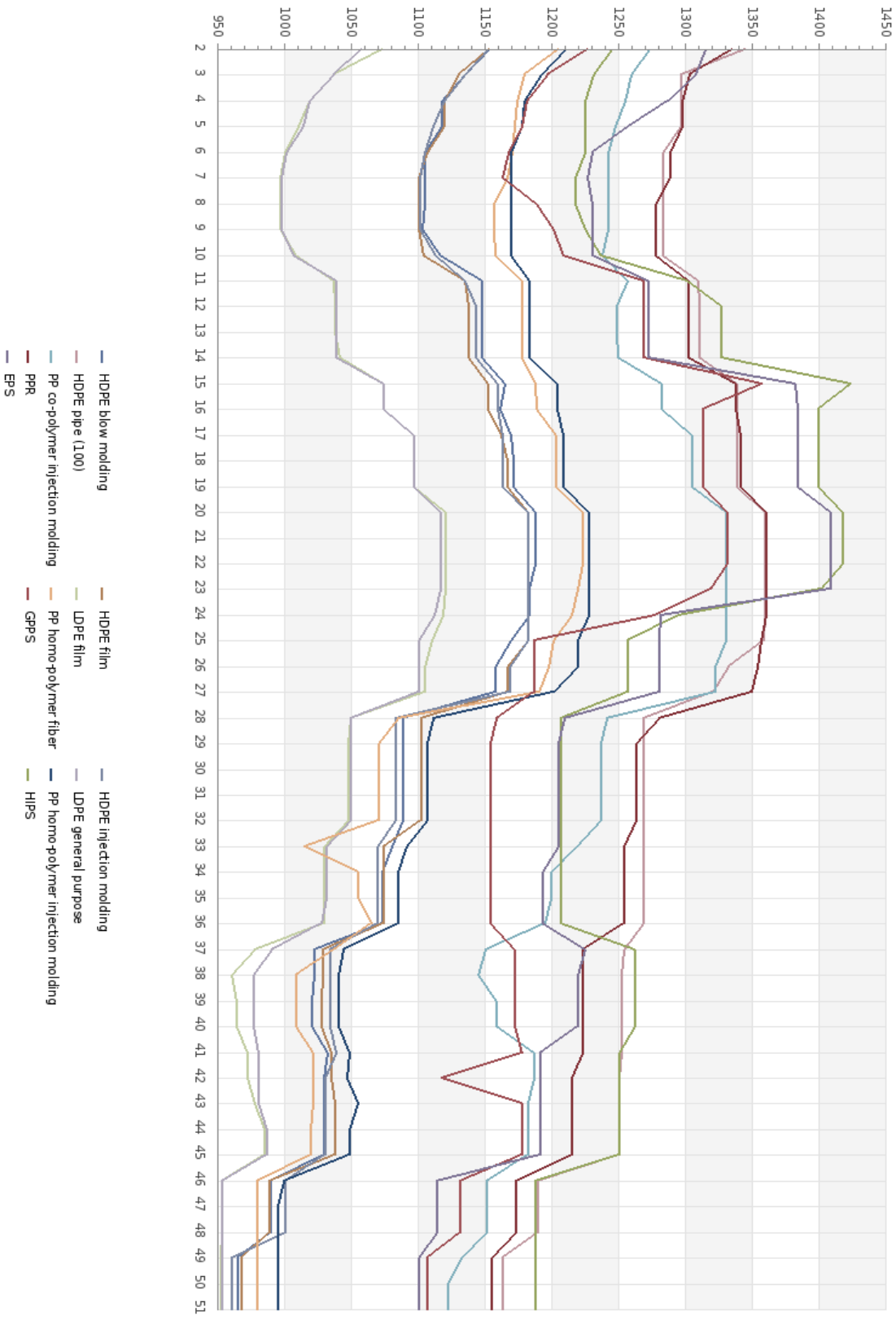
Frankenbos B.V. – Frankenbos B.V. has over 30 years of experience on the recycling of both polymers and textiles. They are currently consulting on various projects within the plastics supply chain that focus on circularity and recycling of high-tech polymers. Their experience with the plastics supply chain of the Netherlands could deliver various new insights on the bottlenecks that the industry is currently facing.

Company	***Position within company***	***Fit to research***
Agricon Nederland BV	CEO, Director	Specialised in consultancy on circular product development, waste streams and exploitation.
Signify	Sr. Marketing Manager	Frontrunner in design for recycling strategy and circular operations.
Royal Dutch Shell	Principal Research Scientist	Petrochemical industry, large producer of plastics and resources for plastics, currently researching chemical recycling of plastics.

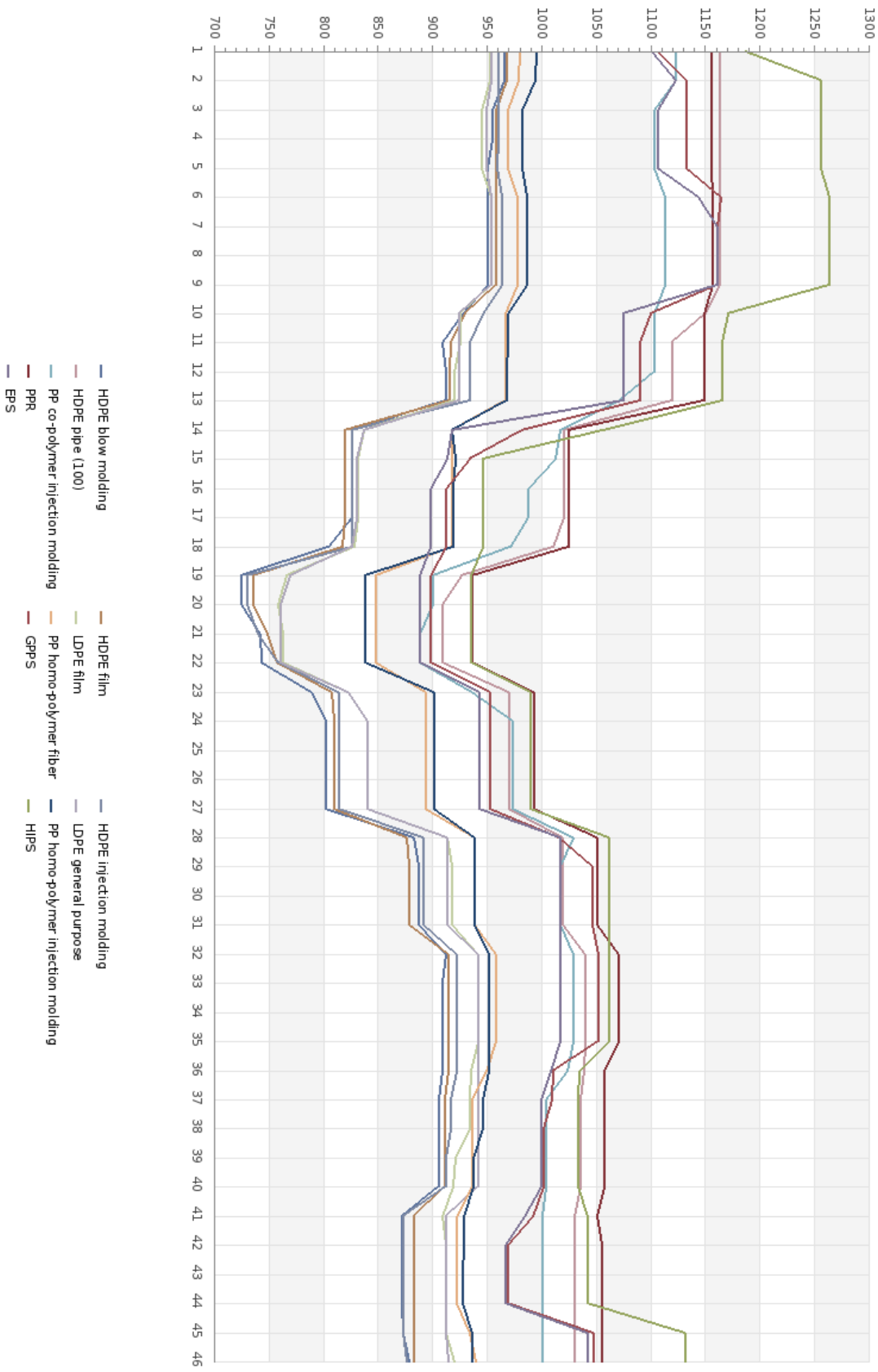
[28] About us | Signify Company Website

BRBS Recycling	Director	Branch organisation of the recycling industry in the Netherlands. Focussing on shared knowledge and representing interests of recycling companies.
Frankenbos BV	Director	Consultancy on circular operations management, 30+ years of experience in recycling of textiles and plastics.

Appendix C. Graph of plastic price 2019 and 2020.

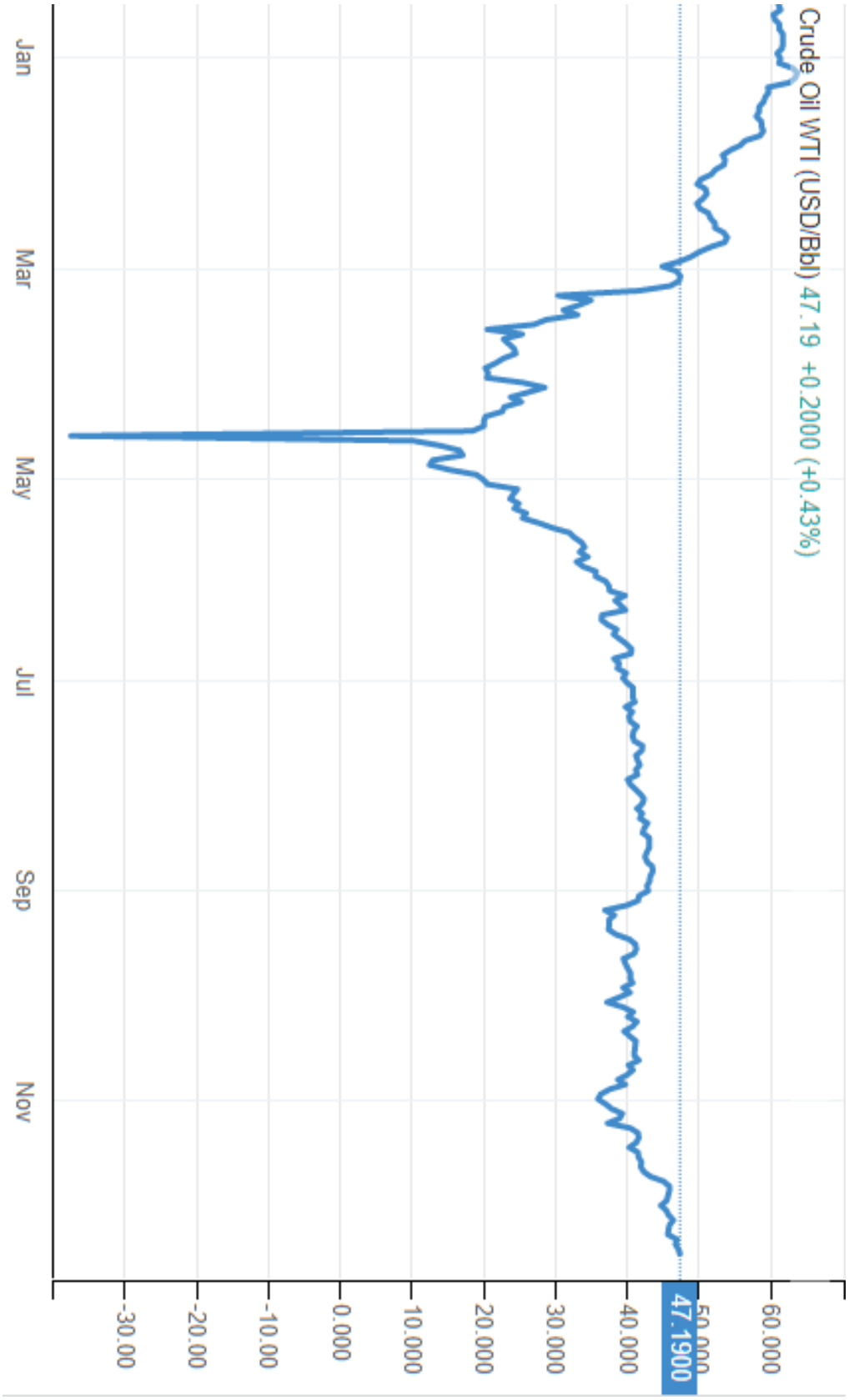


Price of various types of plastics throughout 2019.



Price of various types of plastics throughout 2020.

Appendix D. Graph of crude oil price (per barrel) during 2020.



Oil price throughout 2020.

Appendix E. Interview questions

Interview

This interview is meant to increase the knowledge on how the different actors within the plastic supply chain, cooperate with each other. The plastic supply chain is defined as the sector of plastic production until the recycling of the products such that manufacturers, design, recycling, and circularity is considered. By analysing the level of cooperation within the supply chain, we hope to be able to define the current problems and come up with a fitting solution for them.

Terminology:

- Supply chain: All parties that influence the products production, design, price, and recycling.
- Circularity: Products that can be held in the supply chain by means of recycling and re-use.
- Cooperation: How actors within the supply chain communicate with each other and the agreements that (already) have been made.

General questions for both recyclers and manufacturers

1. Do you think the current level of cooperation between the companies withing the supply chain is sufficient?
   Goal: Getting a perspective on how much already has been accomplished.

2. How do you define the cooperation within the supply chain?
   Goal: Creating a common understanding of what is meant by cooperation.

3. How is cooperation within the supply chain stimulated?
   Goal: Getting to know previous agreements and initiatives.

4. How are initiatives to increase circularity along the supply chain introduced?
   Goal: Know which methods were deemed effective and which were not.

5. Are there initiatives to increase circularity introduced by the companies within the supply chain or only by external parties?
   Goal: More insight on the already existing initiatives.

6. Will cooperation and communication between manufacturer and recycler improve the recyclability of the products?
   Goal: Getting insights on whether cooperation increasing efforts are useful.

Questions for recyclers specific

1. What could a product designer/ manufacturer change about its product/designing method, to increase the recyclability of the product.
   Goal: Finding out effective measures.

2. What types of plastic products are already being designed/produced with recycling kept in mind?
   Goal: Figuring out successful efforts.

3. How does the fluctuation of the crude oil price affect the demand for recycled plastics?
   Goal: Estimating the costs against the benefits with fluctuation in oil prices.

4. If there is a way to suddenly increase the demand for recycled plastics, what would be the effect for the recycling process?
   Goal: Define bottlenecks in the existing supply chain structure.

Questions for manufacturers specific

1. If there is a way to suddenly increase the demand for recycled plastics, what would be the effect for the producers of virgin plastic materials?
   Goal: Define bottlenecks in the existing supply chain structure

2. What efforts have been made to increase the recyclability of a product?
   Goal: Identifying successful and failed attempts to increase recyclability.

3. What are the measurable differences between virgin plastics and recycled plastics?

Goal: Identifying material characteristics that may cause a problem.

Appendix F. Approval of the Ethics committee of the University of Twente

APPROVED BMS EC RESEARCH PROJECT REQUEST

Dear researcher,

This is a notification from the BMS Ethics Committee concerning the web application form for the ethical review of research projects.

Requestnr. :	200330
Title :	Performing a supply chain analysis on the consumer plastics chain.
Date of application :	2020-03-13
Researcher :	Bos, T.W.
Supervisor :	Clancy, J.S.
Commission :	Jansen, G.
Usage of SONA :	Y

Your research has been approved by the Ethics Committee.

The ethical committee has assessed the ethical aspects of your research project. On the basis of the information you provided, the committee does not have any ethical concerns regarding this research project.

It is your responsibility to ensure that the research is carried out in line with the information provided in the application you submitted for ethical review. If you make changes to the proposal that affect the approach to research on humans, you must resubmit the changed project or grant agreement to the ethical committee with these changes highlighted.

Moreover, novel ethical issues may emerge while carrying out your research. It is important that you re-consider and discuss the ethical aspects and implications of your research regularly, and that you proceed as a responsible scientist.

Finally, your research is subject to regulations such as the EU General Data Protection Regulation (GDPR), the Code of Conduct for the use of personal data in Scientific Research by VSNU (the Association of Universities in the Netherlands), further codes of conduct that are applicable in your field, and the obligation to report a security incident (data breach or otherwise) at the UT.

Jansen, G. (06-04-2020 13:47):

Thank you for the update on the mode of interviewing (telephone/skype)

Clancy, J.S. (21-03-2020 13:52):

Under the present circumstances, the interviews will not be face to face but through phone, skype etc.