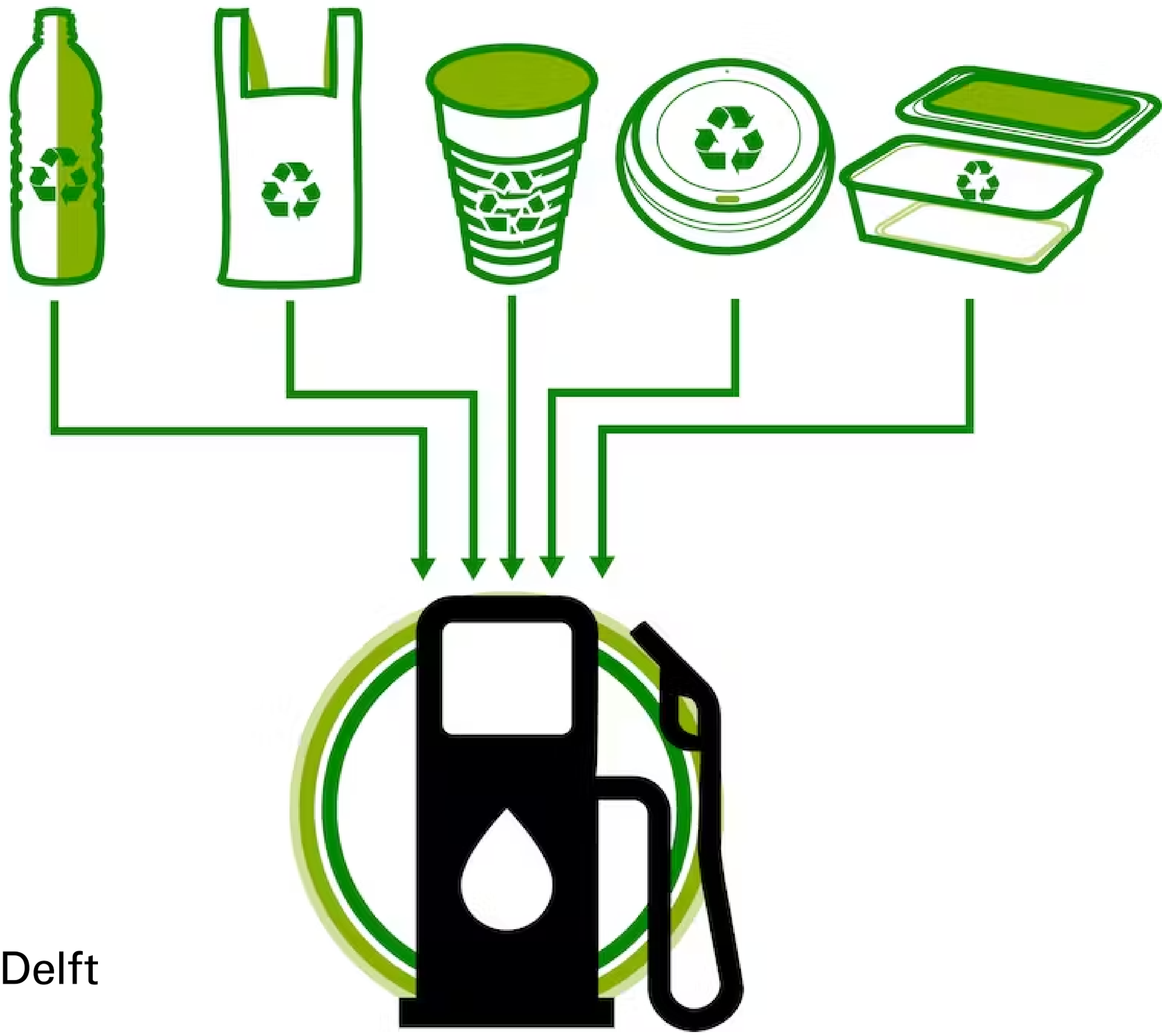
Plastic Waste as a Fuel for Transportation

A stated choice experiment on the personal preference and acceptability towards adoption to a plastic-based fuel

Complex Systems Engineering and Management

P.J. Six



TU Delft

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by

P.J. Six

Student Name	Student Number
Pascale Juliette Six	5641896

First supervisor:	Dr. A.F. (Aad) Correljé
Second supervisor:	I. (Ivo) Bouwmans
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Preface

Before you lies the Master thesis "Plastic Waste as a Fuel for Transportation" which has been written to fulfil my graduation at Delft University of Technology. When searching for a subject of interest to conduct my research in, the excess of plastic waste in the world triggered me as I would like to contribute to finding a solution to this problem. When conducting my Bachelor thesis, I found a lot of information about the process of converting plastic waste into a usable fuel. Unfortunately, further research in that domain was not possible as I had an assigned subject to research. Now, with my Master's thesis, the freedom to choose my own thesis topic allowed me to dive deeper into the conversion of plastic waste into fuel. Additionally, the increasing demand for substitutes for fossil fuels and the relevance to the energy track I have chosen in my Master's in Complex Systems Engineering and Management allowed this subject to perfectly suit my final step in finishing my Master's.

I would like to thank my supervisors Dr. A.F (Aad) Correljé and I. (Ivo) Bouwmans for supporting me in conducting this research. From the beginning, both of you shared a mutual interest in the topic and their curiosity about the topic gave motivation in writing this thesis. The knowledge of my supervisors within this domain ensured that we had some interesting discussions during the meetings, ensuring critical points in my topic which allowed me to further think about the relevance and possibilities of implementation of a plastic fuel. Finally, the freedom how to conduct my research gave me the possibility to fully design my own research making the final step to graduation a pleasant journey.

Finally, I would like to thank my friends and family who have supported me during this journey and have broaden my network for obtaining respondents for my survey. I would also like to thank everyone who has taken the time to respond to the survey which provided a lot of added value to my research.

P.J. Six
Delft, February 2024

Summary

Plastic is one of the major pollutants in the world and currently, more than 300 million tons of plastic are produced worldwide (Miandad et al. 2019). Since only 9.5% of plastic waste is being recycled, littering has caused a lot of non-recyclable plastics (NRP) that wander around damaging the environment and ending up in landfills, oceans and other natural environments (Benavides et al. 2017). This overload of plastic demands action to prevent a worsening situation. Therefore, alternative use of plastic waste is sought whereas a promising solution is to use plastic waste as a fuel for transportation. Plastic waste can be converted into various types of fuels, such as gasoline, diesel and jet fuels. To create these fuels, plastic waste undergoes a process called pyrolysis (Manickavelan et al. 2022). This research is done by first gathering information on the social influences on choice-making when consumers have to choose a fuel type. With this information, a survey is constructed existing of a stated choice experiment. With the results of the survey, further information is sought on the policy frameworks and infrastructures necessary for the implementation of a plastic-based fuel and the environmental impacts of using plastic as a fuel, as these aspects seem to impact the consumers most considering a fuel choice. Combining and analysing the information and degree of importance of each attribute can conclude whether the implementation of using plastic fuel will be feasible and socially acceptable. The outcome will be evaluated concerning the feasibility, performance limitations and social acceptance. The results showed the degree of importance for consumers of price, emissions and infrastructure, from most influential to least, regarding making a fuel choice researched with an unlabelled SCE (Stated Choice Experiment). However, when transmitting from gasoline to plastic, the labelled SCE showed the degree of importance for infrastructure, emissions and price from high influence to low influence. Since using plastic fuel is a transition of fuel, the main focus will lie on the results of the labelled SCE. Concerning emissions, the most optimal solution to implement a plastic fuel is by providing the fuel as a blend. From research, a blend existing of 75-80% fossil fuel and 20-25% plastic shows improvement in tailpipe emissions reducing CO_2 emissions and smoke. For NO_x emissions, discussion is still ongoing on whether more or less emissions are produced compared to fossil fuels. However, with the blend range of 75-80% fossil fuel and 20-25%, the least NO_x are produced compared to other blend ratios. Since a blend is the most optimal implementation strategy, the ease of having access to plastic-based fuel will not differ from fossil fuels as it will be blended into the currently used fuels. Adding plastic oil to fossil fuels will therefore provide a solution to the excess of plastic waste worldwide with an additional advantage of producing less emissions during combustion compared to the currently used fossil fuels.

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Nomenclature

Abbreviations

Abbreviation	Definition
AFV	Alternative Fuel Vehicle
ASC	Alternative Specific Constant
CO_2	Carbon-dioxide
CO_2-eq	Carbon-dioxide equalivant
ETF	Enhanced Transparency Framework
EU	European Union
GHG	Greenhouse gasses
GWP	Global Warming Potential
HBE	Hernieuwbare energie
LPG	Liquified Petroleum Gas
MLP	Multi Level Perspective
MJ/ kg	Mega-joule per kilogram
Mt	Megatons
Mt CO_2-eq	Megatons of carbon-dioxide equalivant
NDC	Nationally Determined Contribution
NRP	Non-recyclable Plastic
NO_x	Nitrogen
PE/PP	Polyethene and Polypropylene
RED	Renewable Energy Directive
SCE	Stated Choice Experiment
SDG	Sustainable Development Goals

1 Introduction

In recent years, plastic soup has become more of a bigger issue. **Plastic is one of the major pollutants** in the world and currently, more than 300 million tons of plastic is produced worldwide (Nuraiti Tengku Izhar and Voon May 2020). The behavioural issue of littering has increased parallel to using disposable products and packaging (Thompson et al. 2009). In the EU only 14% of plastic waste is being recycled, whereas 8% is mismanaged and uncollected. This causes a lot of littered plastic waste that wanders around damaging the environment and ending up in landfills, oceans and other natural environments (OECD 2022). Also, landfills are reaching their maximum capacity since plastic does not weigh much but has a large volume (Thompson et al. 2009). This **plastic overload** demands action to prevent a worsening situation for the environment and the planet. Additionally, plastic eventually gets too old to be recycled to generate new plastic products resulting in the existence of non-recyclable plastics (NRP) all over the world which have become useless. Therefore, alternative use of plastic waste is sought whereas a promising solution is to use plastic waste as a fuel for transportation.

Transport is responsible for a high amount of the emission of greenhouse gases (GHG). In 2022 **the transport sector had a 23% share of all emitted GHGs** in the world producing 7.98 GtCO2eq (IEA 2023). Within the transport sector in the EU, road transport had a 77% share in emissions (Lamb et al. 2021,EEA 2023). The demand for alternative solutions for transportation fuels is increasing rapidly. Thus, what if plastic waste can have a different purpose?

The technology exists to **convert plastic waste into various types of fuels**, such as gasoline, diesel and jet fuels. To create these fuels, plastic waste undergoes a process called pyrolysis. **Pyrolysis** is a thermal process which degrades long chain polymer into smaller, less complex molecules with the use of heat and pressure (Anuar Sharuddin et al. 2016). This advanced conversion technology produces clean, high-value oil from plastic waste. Typically, **the calorific value of the produced fuel is 41.7-44.2 MJ/kg which is comparable to the calorific value of fossil fuels and can be used in combustion engines** (Miandad et al. 2019). Pyrolysis is feasible for waste which is difficult to depolymerize, mainly mixed PE/PP and for plastics that have become useless and non-recyclable (NRP). Environmentally, pyrolysis ensures an alternative solution for landfilling which reduces plastic waste and gives extra value to useless plastics, maintaining circularity. Also, pyrolysis provides an alternative to fossil fuels which have a larger impact on greenhouse gasses and CO_2 emissions (Al-Salem, Lettieri, and Baeyens 2009Anuar Sharuddin et al. 2016).

Unfortunately, the use of plastic waste as a fuel also has several barriers concerning industrial implementation, economic feasibility, performance limitations and social acceptance (Pacheco-López et al. 2021). Further developing the technology of pyrolysis to reduce harmful emissions during the process and making pyrolysis economically feasible, ensures a decrease in plastic waste and that the world becomes less dependent on fossil fuels, reducing the negative impact on the planet.

This thesis subjects to a socio-technical system of the relevance of the decrease in plastic and innovative sources of fuels needed in the world. The process of pyrolysis already exists whereas the implementation of a plastic fuel needs to be analysed to research if the use of plastic waste as a transportation fuel is beneficial for use and acceptable for society. This research will bridge the technology of pyrolysis and research the limitations and possibilities of implementing plastic fuel into society. Within my Master of Complex Systems Engineering and Management where I choose the energy track, researching a socio-technical system concerning alternative fuel (energy) for transportation, suits the master's program.

Thus, this research focuses on the use of plastic waste as a transportation fuel. First by analysing the research problem which is provided in chapter 2. Hereafter, a literature review is done where the research gap is determined and an appropriate research question is formulated. **The research question focuses on whether the implementation of plastic fuel is feasible considering the social and environmental influences on the acceptance of plastic waste as fuel for transportation**. With the described research question, the research approach is determined where the sub-questions are mentioned. An elaboration on the methods and tools to answer the sub-questions is provided in chapter 3. The chapters 4 until 7 will simultaneously elaborate on each sub-question and provide answers to the sub-questions. Afterwards, the results of each chapter can be combined to create a deliberate conclusion of the research. Finally, this thesis will end with a discussion where the limitations of this research and possible future research are discussed.

2

Research Problem

To further analyse the difficulties with the implementation of plastic fuel, the problem that exists of plastic processing must be determined as well as the societal impact of using alternative fuel sources. This chapter will provide a summary of the problems concerning plastic waste processing and the use of alternative fuel sources.

2.1. Plastic Waste Processing

The problem of this research originates from plastic processing in the Netherlands. **The Netherlands had a plastic demand of approximately 2100 kilotons of plastic in 2020** Plastics Europe 2022. Here 39% of the converters' demand was for packaging, 21% for building and construction materials and 15% for vehicles and electric devices (Plastics Europe 2022). From this 2100 kilotons of plastic, **87% of the plastic is processed whereas 45% of the plastic is recycled, and 55% is burnt.** The other 13% is mismanaged which eventually ends up in nature. A large problem of plastic use is that more plastic is produced than processed (Lynn Snijder and Sanne Nusselder 2019). This is because more plastic is demanded. The three main problems with plastic processing in the Netherlands are:

1. a part of the plastics are littered causing these plastic to increase plastic soup, damaging the environment.
2. there is still a part of the plastic waste is insufficiently understood.
3. a part of the plastics that is collected is not recycled but burnt

2.1.1. Plastic Soup

The behavioural issue of littering has increased parallel to using disposable products and packaging (Thompson et al. 2009). Since only 45% of plastic waste is being recycled, littering has caused a lot of plastic waste that wander around damaging the environment and ending up in oceans and other natural environments (Lynn Snijder and Sanne Nusselder 2019). Plastic which is not collected properly or which is littered into the environment eventually ends up in the seas and oceans resulting in "plastic soup". **In the Netherlands, approximately 9 kilotons of plastic end up in the environment.** The factors that cause plastic to contribute to the increase in plastic soup are the location of where the plastic is littered, what the chances are that the plastic will eventually be collected anyway and in what way the plastic can wander through nature (Lynn Snijder and Sanne Nusselder 2019).

2.1.2. Plastic Waste not Understood

For certain sectors, the amount of plastic which is produced is easy to measure and understand such as plastic from households and from electric devices and cars (Lynn Snijder and Sanne Nusselder 2019). However, **the most uncertain sector where a lot of plastic waste is produced in the industry sector**. The main reason for this is because there exists a lot of **im- and export of plastic** between countries that range beyond Europe. Europe itself maintains the same regulations concerning recycling of plastic waste but, when trading plastic with China, there is no insight into what happens with the plastic and whether this is recycled or not.

2.1.3. Burning Plastic

In 2016, 7,8 Megatons of waste were burnt whereas 10 megatons of CO_2 were released (Lynn Snijder and Sanne Nusselder 2019). **Burning of waste in the Netherlands is responsible for 5% of the climate impact.** Concerning the climate impact of plastic, this is more difficult to determine. The amount of plastic which is burnt ranges between 500 and 1000 kilotons of plastic. This represents 33% to 60%, respectively, of the total plastic waste in 2017 in the Netherlands (Lynn Snijder and Sanne Nusselder 2019). During the burning of the 250 kilotons of plastics, 330 kilotons CO_2eq were produced. Therefore in the Netherlands, at least 660 kilotons CO_2eq is produced which could range to a maximum of 2640 kilotons CO_2eq resulting in **causing 6-26% of the greenhouse gas emissions in the Netherlands** (Lynn Snijder and Sanne Nusselder 2019).

From these three problems, the third problem will be further analysed: "A part of the plastic that is collected is not recycled but burnt". This is now seen as a problem, but what if the burning process can generate added value?

2.2. Plastic waste-to-energy

Incineration, gasification and pyrolysis are three types of plastic waste treatment to reduce the volume of landfilled plastic waste and recovery of energy (Kwon et al. 2023). A disadvantage of these processes is that they cause severe carbon emissions. Studies show that the emissions produced could be even more damaging than the currently used fossil fuels.

Currently, plastic waste is treated in three ways: landfilling, recycling and incineration. Landfilling is a method of collecting plastic in a landfill where no further actions are taken (Kwon et al. 2023). An advantage of landfilling is that less carbon dioxide is generated since decomposition is not done (Kwon et al. 2023). However, the increasing amount of plastic waste leads to landfills that are reaching their capacities since plastic has a high volume-to-mass ratio (Kwon et al. 2023, Thompson et al. 2009). Recycling is a process of converting waste into new products (Kwon et al. 2023). The main disadvantage of recycling plastic is that plastics cannot indefinitely be recycled due to the degradation of the product resulting in non-recyclable plastics which have become useless (Kwon et al. 2023). Lastly, incineration is the combustion method where heat is released and recovered in the form of energy. According to Kwon et al. (2023), incineration is the most practical way of treating plastic as it can reduce the volume of waste and also produce energy simultaneously reducing the consumption of conventional fuels which can result in potential carbon emission reduction (Kwon et al. 2023). Since incineration is still not carbon neutral, many countries are **looking for ways to minimize GHG emissions while still recovering energy from plastic waste.** Two methods which can be further researched and optimized are gasification and pyrolysis.

2.2.1. Pyrolysis

Pyrolysis is a process of degrading plastic to its original product using heat. Normally, this product is used to reproduce new plastics. However, some plastics that undergo pyrolysis are not suitable for reproducing new plastics since their characteristics are not applicable for safe use. Pyrolysis converts wastes and plastics into a gas and a range of liquid products compatible with diesel-based fuels (Ahmad et al. 2015). The pyrolysis process is a process of thermally degrading long-chain polymers into smaller molecules with intense heat and under pressure with the absence of oxygen (Anuar Sharuddin et al. 2016). The three main products that are produced in the pyrolysis process are oil, gas and residue. The process parameters can be adjusted to obtain most of the preferable process outputs making the pyrolysis process flexible (Manickavelan et al. 2022). The ease of use is that **pyrolysis can handle various types of plastics without prior separation** (Ahmad et al. 2015). According to Manickavelan et al. (2022), the pyrolysis process decreases the overall CO_2 emissions and is an easier recycling method since separation is not needed.

2.2.2. Gasification

Gasification converts solid waste to fuels or gases through gas-forming reactions. During the gasification process, the fuel that is produced is burned to provide heat that is needed to gasify the rest (Al-Salem, Lettieri, and Baeyens 2009). The product of the gasification process is hot fuel gas containing large amounts of not entirely oxidized products. The main advantage is that normal air is used instead of pure O_2 which makes the process simpler and reduces costs (Al-Salem, Lettieri, and Baeyens 2009).

Since the goal is to minimize GHG emissions by energy recovery, the three waste-to-energy processes are compared by Kwon et al. (2023). In figure 2.1 the three energy recovery processes are shown and their CO_2 emissions are provided per process type. The ranges that exist per process type are due to the variance of plastic used in the process. Each type of plastic has a different composition, whereas the mixture of the plastic used in the process can differ, meaning that the emissions produced also vary resulting in a wide range.

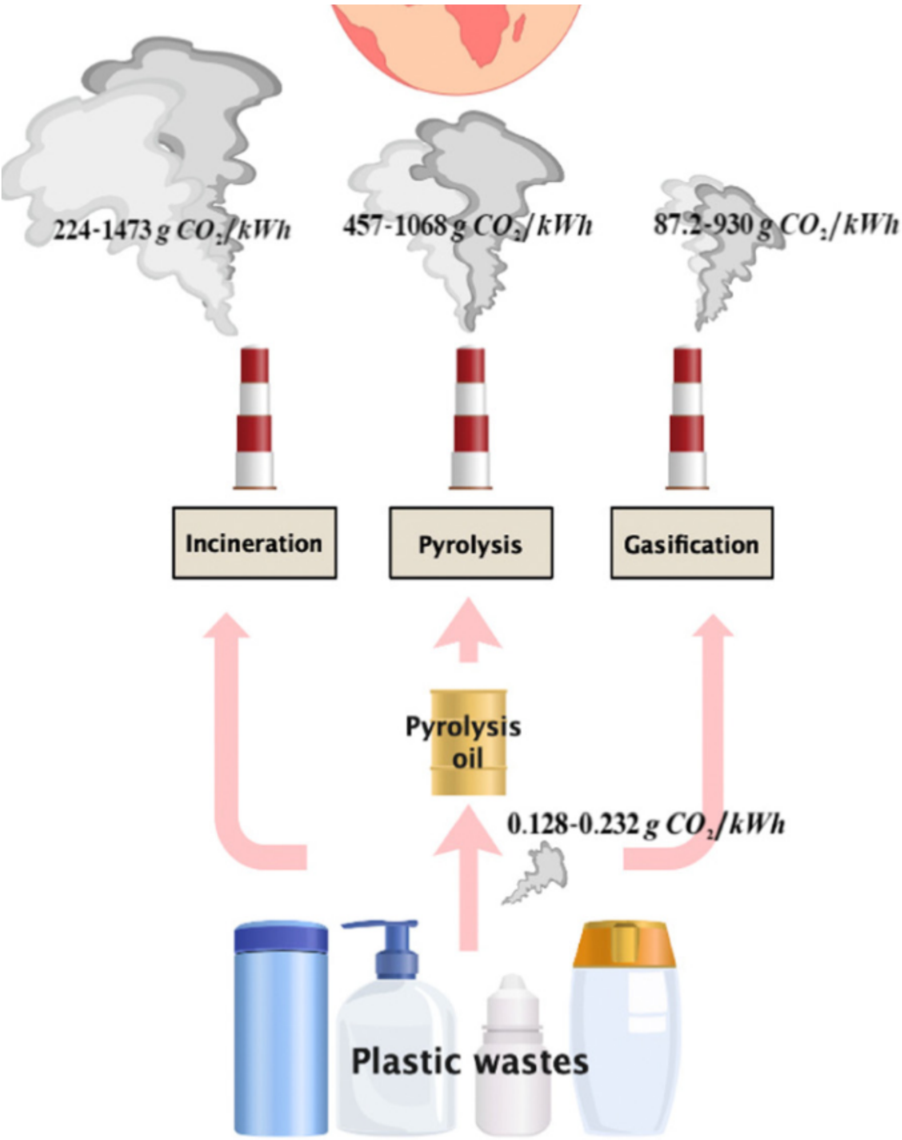

Figure 2.1: The three plastic-to-energy processes represented with their CO_2 emissions provided by Kwon et al., 2023

2.3. Alternative Fuel Sources

In 2020, within the transportation sector, road transportation was responsible for 77% of greenhouse gas emissions in the EU (EEA 2023). **Since fossil fuels are becoming scarce, the search for alternative fuels is becoming more necessary. Additionally, fossil fuels produce a lot of CO_2 emissions, damaging the environment,** and the use of fossil fuels leads to a large number of EU countries that are dependent on other countries that supply them with these fuels, positioning them in an unfair trade position (Sobrino, Monroy, and Pérez 2010). With the

Kyoto Agreement which was launched in 2005, the goal was to transit from fuel sources to decrease polluting GHG emissions. Therefore, multiple replacements of conventional fuels are sought. Nowadays, electric vehicles seem to be the solution but even if the required estimation of IEA of 600 million electric vehicles in 2040, only 13% of the currently used fossil fuel for transportation will be covered (Neste 2021). However, there are other solutions: **renewable fuels. These are fuels made from residues and waste** (Neste 2021). When new (raw) materials are being explored to function as renewable fuels, even more fossil fuels can be replaced resulting in a prediction of 40% less use of fossil fuels in 2040 (Neste 2021). Plastic might have the potential to be explored and developed as a renewable fuel.

2.3.1. Public Responses Towards Implementation of Alternative Fuel Sources

Since the transport sector is highly responsible for environmental degradation, the transport sector is becoming very important for achieving sustainable development goals. Through policies, governments try to stimulate more sustainable modes of transportation. These policies, consumers can respond in two separate ways: either they accept the policy or they support the policy. In this section, an elaboration is provided on these responses to understand the eventual transition towards AFV.
According to Jansson et al. (2019), the definition of **public acceptance** is that an individual's **attitude is positive** towards a policy and there exists a possibility that the public will transit (Jansson and Rezvani 2019). However, there exists a gap between public acceptance and public support. With public acceptance, the actual engagement or action-taking to making a transition often is not executed (Jansson and Rezvani 2019). Therefore, **public support is seen as the movement that is made in order to accomplish public acceptance** (Jansson and Rezvani 2019). From the study conducted by Jansson et al., (2019), the key to ensuring public support is communication and awareness which raises acceptance as acceptance is needed before public support can be reached (Jansson and Rezvani 2019).
Concerning plastic as an alternative fuel, the public misses a lot of knowledge on the use of plastic as a fuel as well as the current waste management of plastics. The issue with pyrolysis and gasification is that these processes store and release hazardous chemicals on site, encounter difficulty scaling up, produce contaminated end products, create a fuel which generates the same amount of harmful air pollutants as currently used fuels and requires ongoing production of virgin plastic (Singla and Wardle 2022). Within this research, more information is provided on the use and production of plastic fuel to determine whether plastic-based fuel is acceptable for implementation in the current scene where the world is looking for alternate, less harmful sources of fuel.

3 Research Approach and Methods

This chapter will elaborate on the research problem by conducting literature research. Here reports, articles and scientific studies concerning plastic waste as a fuel as well as alternative fuel sources are gathered and analysed. This literature is important as a starting point to determine what the exact problem is considering the implementation and acceptance of plastic fuel. After the literature review, each literature study is discussed to determine the knowledge gap which is required to properly formulate the main research question. From the main research question, multiple sub-questions are constructed to answer the main research question and each sub-question is elaborated with the research approach and method.

3.1. Literature Review

To determine the existing research gap and properly formulate the research question, a literature review is conducted. Here, the most relevant articles are collected. Before conducting a literature review, a lot of articles concerning the pyrolysis process were collected to create an understanding of the way of working and the possibilities of the use of pyrolysis. Here information and numbers mentioned in the introduction were found. It is important to keep these references as these resources have also led to the understanding of the research gap which needs to be determined.

When searching for articles, two different subjects of the research were divided. This division is done by the use of specific keywords concerning fuel for transportation and the implementation or adoption of a fuel transition.

All articles searched were filtered by use of keywords concerning the topic of using plastic waste as a fuel for transportation. The keywords used were: (”alternative fuel vehicle”) AND (transition) AND (”adoption” OR ”implementation”) AND (

"challenges OR limitations") AND ("plastic waste"). In order to reduce this number of articles, the search results were limited to "open-access" and English", resulting in more than a thousand articles in Google Scholar. Since a lot of articles appeared to contain information on the use of plastic as fuel and the existence of the pyrolysis process and the process itself rather than on the implementation of the use of plastic-based fuel into society, the keyword "plastic waste" was eliminated from the search. Now, previous fuel transitions appear in the search. These previous transitions provide an example of the limitations and possibilities of fuel transitions. Eventually, after reviewing some articles, the "snowball effect" appeared. The snowball effect is where a relevant article is found and the resources from that article are used to further obtain literature on the subject (Hurkmans 2023). The articles that were found that seem most relevant were titled "*Transition challenges for alternative fuel vehicle and transportation systems*" and *"Public responses to an environmental transport policy in Sweden: Differentiating between acceptance and support for conventional and alternative fuel vehicles"*. The reason why these articles seemed relevant is that they discuss the transition to alternative fuels and the social responses to the transition. The key factors of reasoning for a transition and factors affecting the overall implementation of alternative fuels for transportation are discussed in these two articles and examples are given.

3.1.1. Overview of Literature

In order to obtain insight into the information given in each article, the aim of the articles was determined. The articles are structured based on their research purposes and are shown in Table 3.1. The different research purposes are: " Case study fuel transition", "System dynamics of consumer behaviour (AFV's)" and "Forecasting alternative fuel use".

From this overview, the aim of the article can be determined and indicate what article is useful for which subject. Here can be seen that the "case study" and "system dynamics of consumer behaviour" were mostly used in research design. Therefore, within this research, there will exist a focus on previous transitions and how consumers react to a certain transition. When comparing these different situations, it becomes more clear what the main challenges and limitations of the implementation of plastic waste as fuel are. Comparing these strengths and weaknesses provides insight into the feasibility, acceptability and environmental impact of implementing plastic waste as a transportation fuel.

3.1.2. Discussion

In this section, the information obtained from the collected articles is analysed. By discussing the results and conclusions of each obtained article, the relevant aspects of this research are discussed to determine what the knowledge gap is, concerning the use of a plastic fuel.

First, the articles where the "snowball" effect started are discussed. Struben & Sterman (2007) discuss that **the adoption of alternative vehicles is a complex tran-**

Table 3.1: Synthesis of articles

Aim	Research Purposes	Authors
(1) A strategy for introducing hydrogen into transportation	Case study fuel transition	A.E. Farrell et al, (2003)
(2) Commercializing an alternate vehicle fuel: lessons learned from natural gas for vehicles		P.C. Flynn, (2002)
(3) Identifying challenges for sustained adoption of alternative fuel vehicles and infrastructure		J. Struben., (2006)
(4) Lessons Learned in the Deployment of Alternative Fueled Vehicles		B.I. Robertson & L.K. Beard, (2004)
(5) Consumer choice between ethanol and gasoline: Lessons from Brazil and Sweden		H. Pacini & S. Silveira (2011)
(6) Public acceptance of biofuels		E. Savvanidou et al. (2010)
(7) Exploring policy options with a behavioral climate–economy model	System dynamics of consumer behaviour (AFV's)	T.S. Fiddaman, (2002)
(8) Joint mixed logit models of stated and revealed preferences for alternative-fuel vehicles		D. Brownstone et al., (2000)
(9) Potential demand for alternative fuel vehicles		J.K. Dagsvik et al., (2002)
(10) Individual characteristics and stated preferences for alternative energy sources and propulsion technologies in vehicles: A discrete choice analysis for Germany		A. Ziegler (2012)
(11) Prelaunch Forecasting of New Automobiles	Forecasting alternative fuel use	G.L. Urban et al., (1990)
(12) Vehicle ownership to 2015: implications for energy use and emissions		J. Dargay & D. Gately (2002)
(13) A framework for analyzing rank-ordered data with application to automobile demand		J.K Dagsvik & G. Lui (2009)

sition (J. J. R. Struben 2007). A model is presented which includes behavioural factors conditioning consumer choice. According to the model, there exists a tipping point for alternative fuel vehicles (AFVs) whereas a successful transition is achieved by policies for fueling infrastructure and financial policies such as subsidies. Due to the broad model boundary chosen, the model is able to capture the wide array of interactions and feedback determining the dynamics of adaption. Furthermore, Jansson & Rezvani (2019) discuss that the **understanding of consumers' responses** to an environmental policy supports the transition to alternative fuels (Jansson and Rezvani 2019). This research focuses mainly on public acceptance and public support meaning there exists a difference between accepting the policy and actually making use of the policy. Jansson & Rezvani (2019) also state that **understanding the different types of responses is crucial for recognizing positive and negative influences that have an effect on successfully implementing a policy** and affecting communication with the public (Jansson and Rezvani 2019).

Secondly, the articles concerning case studies with fuel transitions are discussed. Here more insight into fuel transitions and its **implementation strategies** can be obtained and **relevant aspects or motivations to transition from fuel** can be analysed. Farrell et al. (2003) mention that the main motivation to transition to hydrogen fuel is the **demand for CO_2 reduction and the prospect of scarcity of petroleum** in the future (Farrell, Keith, and Corbett 2003). The strategy used by Farrel et al. is to implement hydrogen fuel in protected niches. In the **protected niches, innovation and competition can eliminate lower-performance technologies and stimulate companies to transition to hydrogen by achieving learning by doing** (Farrell, Keith, and Corbett 2003). P.C. Flynn (2002) considers the fuel transition to natural gas as an important lesson for future transitions to alternative fuels (Flynn 2002). The findings are that **the infrastructure is more important** than the technologies; (further) investment in fueling stations needs to be stimulated; and lastly, **promotional programs** (for environmental benefit) need to be designed. Furthermore, Struben (2008) discusses the **co-evolution between alternative fuel vehicle demand and infrastructure and that they are complementary to each other** resulting in the "chicken-and-egg" problem (Struben and Sterman 2008). The dynamics of the introduction and diffusion of alternative fuel vehicles are complex and influenced by many positive and negative feedbacks. According to Robertson & Beard (2004), **any alternative fuel vehicle (AFV) program needs to be part of an accepted national energy policy** with goals of achievable and measurable levels (Robertson and Beard 2004). Also, the AFV program must rely on a total life-cycle analysis and must be seen as a system. Furthermore, the **competitiveness of petroleum** needs to be taken into account whereas the government is responsible for "levelling the playing field". However, the replacement must eventually be cost-effective and successful by itself (Robertson and Beard 2004). Furthermore, Pacini & Silveira (2011) argue that maintaining the **price-attractiveness of biofuels is important**. However, maintaining this price attractiveness is difficult as there exists free-choice and market competition

(Pacini and Silveira 2011). Addiotionally, concerning biofuels, Savvanidou et al (2010) examine the acceptability of biofuels in Greece. The research shows that there **exists an information gap** about biofuels. Also, the demand for fossil fuels and the price of biofuels are big factors in acceptance (Savvanidou, Zervas, and Tsagarakis 2010).

Thirdly, the articles concerning the system **dynamics of consumer behaviour** towards the adoption of AFVs are discussed. Most articles describe a model where consumer behaviour is simulated. Consumer behaviour is an important influence on the fuel transition since consumers are eventually the group that needs to adopt and make an alternative fuel vehicle successful. The model of the research of Brownstone et al (2000) models the stated preferences (SP) for automobiles within households. Here the consumers had to respond to a hypothetical alternative to analyse the consumer's reaction. However, a constraint of hypothetical choice is that consumers might react differently in the real market. Therefore, the use of revealed preference data, which contains actual choice situation behaviour, is combined with SP to **forecast the choice behaviour of alternative fuel vehicles**. Furthermore, the research of Dagsvik et al (2002) conducted a survey where each respondent was exposed to 15 experiments where they had to rank three hypothetical vehicles. Different models were formulated and estimated where the model with taste persistence and random technology parameters suits the data best. An outcome of this model is that an **alternative fuel vehicle is fully competitive with conventional petroleum vehicles, given that the infrastructure remains the same**. Lastly, Ziegler (2012) examines the preference for alternative energy sources for vehicles with a main focus on electric vehicles conducted through a stated preference discrete choice experiment. This experiment results in data that younger potential car buyers **prefer alternate energy sources with less CO_2 emissions**. Also, the results show that **policy instruments need to be supplemented by strategies in order to increase social acceptance**.

Lastly, research into forecasting automotive adoption is an important design element. This is relevant for researching the use of plastic fuel as this fuel is not yet implemented and a forecast can give information on which possibilities and challenges need to be highlighted during potential implementation. First, Urban et al (1990) developed a consumer flow model which monitors consumers' transitions according to their **response to marketing.** In this research is stated that comparison of the predictions of the model towards actual sales data are reasonably accurate when the implementation strategy matches the planned strategy. Secondly, Dargay & Gately (2015) argue that the forecasting of car ownership is dependent on income, population and assumptions in trends of vehicle use considering fuel efficiency, fuel prices and emissions produced. Results of the research show that an **overall rise in income will increase the demand for car transportation** resulting in more demand for oil and that a transition to low-carbon fuel needs external stimulus. **A substantial price increase is required to lower fuel demand and the related environmental impacts.** However, higher prices lead to a **negative**

impact on the economy, demand and ease of mobility. Therefore, a higher demand for alternative solutions is required and more accepted. Lastly, Dagsvik & Lui provide a framework for analyzing data on individuals' rank ordering including with a first-choice probability. The framework is applied to analyze the demand for currently used vehicles and alternative fuel vehicles in Shanghai. The data for the model is obtained through a stated preference survey. The results show that **high-income households prefer to transit to AFVs whereas low-income households are indifferent to AFVs or conventional cars.**

From the discussed articles above, a lot of research has already been conducted on the transition of alternate fuels. However, no specific research has been found on the transition towards plastic fuel. The process of converting plastic to fuel exists, and in theory, plastic can already be used as fuel for transportation. However, there is no knowledge of how to feasibly implement the fuel transition where it is socially, economically and environmentally accepted that plastic is used as a fuel. Also, the replacement of fossil fuels and a demand for a decrease in plastic waste, impact the need for research on the possibilities of using plastic waste as fuel concerning cost-efficiency, feasibility and social acceptability. As seen above, much research is done on transitioning towards AFVs and forecasting fuel adoption. However, these researches already seem outdated whereas new research towards a new transition (plastic fuel) has not been covered at all. Therefore, researching the possibilities, barriers and challenges of implementation of plastic waste as a transportation fuel is an interesting topic to work on and which has also not been researched quite often yet.

3.2. Research Question

The idea of using plastic waste as a fuel for transportation is still very new. As mentioned in the previous section, various researches have been conducted on the implementation of other fuels and the social aspects concerning transition. However, there still exists a knowledge gap. Since a lot of research has already been done on optimizing the conversion of plastic waste into fuels, the reasoning behind why plastic fuels have not been implemented yet is now the main question. The long-term effect of plastic fuel needs to be investigated concerning its social and environmental impact to ensure the feasibility and social acceptance of plastic transportation fuel compared to the currently used fuels. Therefore, the research question follows:

"How do the social and environmental factors influence the acceptance and feasibility of implementation strategies which can promote the adoption of using plastic waste as a fuel source for transportation?"

3.3. Research Approach and Methods

3.3.1. Research Approach

This research aims to evaluate the process of plastic waste and how it can be implemented as a source of fuel. This research will mainly be done with a qualitative research approach. However, with the use of a model for statistical analysis, the research will also contain a bit of a quantitative research approach. This approach will contain desk research, secondary data, surveys, and modelling. Desk research will provide knowledge on the pyrolysis process and the past developments of pyrolysis providing information on the environmental impact. Also, desk research will provide information on needed policy regulations and infrastructure to make the realisation of plastic-based fuels possible. Furthermore, surveys will be conducted to create an understanding of the social aspects concerning the implementation and consumer choice behaviour. Finally, all the gathered data can then be implemented into a model for statistical analysis. With the model, the preference weight of each influential factor is analysed determining the most influential factor when choosing a fuel. These influential factors are then further researched to conclude whether the implementation of plastic fuel is feasible or not.

3.3.2. Sub-questions and Research Methods

This section will elaborate on the research methods and research tools used per sub-question in order to provide an answer to the sub-questions. With the answers to the sub-questions, the main research question can also be answered.

Are there any social barriers or incentives that affect the willingness of individuals to adopt using plastic waste as a transportation fuel?

This research question focuses on the socio part of the research. Here the reasoning behind the potential failure of implementation can be figured out. After analysing the social barriers and incentives that affect the willingness to transit, the negative influences can be further analysed and what impact the influences make on the implementation as a whole. In order to do so, a comparison between various transitions is necessary and can be conducted with meta-analysis. With meta-analysis, multiple pieces of research on various combinations can be compared and analyzed (Corbin and Strauss 2008). Here reports articles and documents are searched for concerning previous fuel transitions such as the transition to natural gas. Also, previous research on the implementation of fuel transitions is sought to determine the factors that influence adoption. With information on the influence factors, a survey is constructed to examine the willingness to transit and to inform on what the social barriers of individuals might be. This survey is structured by applying a stated choice experiment with two alternatives: currently used fuel and plastic fuel.

What policy frameworks and infrastructure investments are necessary to support the widespread adoption of a plastic-based transportation fuel?
To ensure that the use of plastic waste as a fuel for transportation is possible, the feasibility of implementation needs to be researched. As mentioned before, here the focus lies on the policy and regulations needed and the needed infrastructure which defines the use of plastic fuels. Also, the economic feasibility is taken into account considering the investments that need to be taken and the construction of the fuel market to ensure feasible implementation. To answer this question, desk research is done on the needed infrastructure and the existing regulations. Desk research is a method used to obtain an understanding and elicit meaning to eventually develop knowledge about a certain subject by collecting and examining documents, reports, academic publications and other materials concerning that subject (Corbin and Strauss 2008). A constraint of this method is that the availability of documents might be scarce or that there are too many different types of documents.

What are the environmental benefits and drawbacks of using plastic waste as a fuel source, including its impact on greenhouse gas emissions and air quality, compared to the currently used fossil fuels?
For this research question, desk research is conducted. With desk research, information is gathered on the various types of transportation fuels that are currently used with the use of document analysis. Document analysis has briefly been explained previously. After gathering the data on which transportation fuels are used, data concerning emissions produced and durability of the currently used transportation fuels need to be found which is also done with document analysis. This information is needed to compare the performance and ease of use of the currently used fuels with the performance and ease of use of plastic-based fuels to determine whether plastic fuel will be an improvement in the use of fuel concerning the environment and feasibility. Additionally, research must be done on the environmental impact of using plastic fuel. Information on combustion emissions of plastic fuel and information regarding the pyrolysis process are gathered through document analysis. Data on the emissions produced will provide the necessary information to compare with the data on the currently used fuels. Information concerning the pyrolysis process will provide data on the output of the process and thus data on the emissions produced during pyrolysis. Using this information provides insight into the environmental impact the pyrolysis process has. The outcome parameters of the pyrolysis process are essential to analyse the emitted (greenhouse) gasses and toxic by-products. Also, the fact that a lot of plastic is already burnt during waste management needs to be taken into account. Here the environmental influence might affect the possibility of implementation as the process has already been conducted. Furthermore, the environmental impact also concerns the circularity of using plastic waste as a fuel and reducing the overall volume of plastic waste in the world which needs to be analysed. The needed information is gathered through desk research. Finding secondary data such as articles, documents and reports on the input and output parameters, will help research the overall en-

vironmental impact of the whole process of using plastic as a fuel for transportation.

How do the social and environmental factors influence the adoption towards the use of a plastic-based transportation fuel?
Lastly, this research question will be researched by combining the data outcome of the survey with the obtained information from the qualitative research. When combining the received information from the previous questions, the factors influencing the simulation of the transition to a plastic fuel can be analysed to determine whether implementation is feasible, and if so, in what way implementation is possible. Thus, this last question determines whether the use of plastic waste is applicable as a fuel for transport and whether plastic waste as a fuel is ready to be implemented and accepted for use.

4

Conjoint Analysis

Conjoint analysis is used to elaborate a range of stated-preference methods. These methods include ranking, respondent rate or **choice experiment** with a controlled profile with multiple attributes and varying levels (Hauber et al. 2016). A common method that is applied is the stated-choice experiment (SCE). This chapter will elaborate on the influencing attributes considering a fuel choice where the most important attributes are determined. After determining the most important attributes, the influences of these attributes on consumers' choices will be further researched in this chapter by an SCE conducted through a survey. This chapter provides an overview of which steps must be made to construct a valuable SCE whereas each step is elaborated and motivated for experimenting with a fuel choice.

4.1. Social Aspects

The acceptance of a plastic fuel must be analysed throughout the whole process to determine the feasibility and likelihood of implementation. Therefore, this section will focus on the social influences of the pyrolysis process as well as previous fuel transitions to determine which aspects influence the acceptance of consumers the most. These influences can be further used to construct a survey, examining the precise importance factor of each chosen social aspect.

4.1.1. Public Responses to Chemical Recycling

Plastic can be found everywhere. Not just as waste but in nearly all the products we use (Buranyi 2018). Only in the past few years, have people developed a backlash to the use of plastic (Buranyi 2018). Nowadays many plastic products are marked with the recycling symbol, claiming that most of the plastic can be recycled. However, this is not the case (Alberts 2023). Not all plastics used are suitable for recycling due to contamination (Brunn 2022). Furthermore, the **recycling rates are also very low** (Alberts 2023). **Chemical recycling is seen as an alternative for processing non-recyclable plastics** whereas there exist a lot of claims of improving recyclability and contributing to a circular economy (Alberts 2023). However, multiple studies have examined the chemical recycling claims and showed that these claims have never been proven whereas the **chemical recycling facilities might even exacerbate the pollution problem** (Alberts 2023). Fossil fuel companies and plastic producers claim that chemical recycling provides a solution to the plastic problem in the world. However, chemical recycling is also seen as a risky business as the facilities for **chemical recycling create large amounts of toxic waste and emissions,** claiming that the process will contribute to even creating 100 times more damage to the environmental climate impact than producing virgin plastics (Alberts 2023). However, other study shows that **making plastic with an amount of 5% pyrolysis oil ensures a decrease of 18-23% of the GHG emissions than making plastic from crude oil** (Boerner 2023). From both these claims can be seen that **there exists a lot of uncertainty and discussion about the process of chemical recycling** and its (negative) effects. However, before discussing whether the chemical recycling process has a higher negative impact on the world, it should be researched if there even exists any potential in using a fuel made out of plastic. Therefore it is important to discuss and research the reasoning why consumers would or would not use plastic fuel. In the upcoming section, a literature study will be conducted on previous fuel transitions to determine what influences the choices made by consumers concerning a fuel choice.

4.1.2. Previous Fuel Transitions and Influencing Attributes

In history, the first adoption of horse-carriage towards electric vehicles was when the inventor Thomas Edison discussed the electric car which had a record speed of 61 miles per hour (Struben and Sterman 2008). After, the combustion engines quickly became a dominant design since the combustion engines were able to transport for longer distances (Struben and Sterman 2008). The transition towards electric cars nowadays is again trying to become the dominant design but the lack of technology and the high costs still result in a low transition rate (Struben and Sterman 2008). **The reason why certain vehicle types are adopted or fail to be adopted depends on consumers' choice and its installed base**. The consumer choice will be further analysed in this research whereas in this section, research of multiple fuel transitions is discussed and analysed.

For constructing a valuable survey, the importance of analysing the influencing attributes of a fuel transition is high. When the correct attributes are questioned, valuable results can be obtained on the degree of importance of a transition. Therefore, multiple studies on previous fuel transitions and studies concerning choice experiments for alternative fuels have been gathered and analysed. This is done **to determine which attributes have come forward that motivate people the most concerning a fuel choice**. These attributes will then be examined for a specific transition towards a plastic fuel during a survey consisting of a stated choice experiment to determine the possibility and feasibility of the implementation of a plastic fuel.

Struben and Streman discuss that drivers will not transit to alternative fuel vehicles whenever there exists no easy access to fuel, parts or repair (Struben and Sterman 2008). Therefore, the infrastructure of the alternative fuel must be comparable to the current access of combustion vehicles. According to Struben and Streman, the attractiveness of an alternative fuel depends on price (operating costs), driving range, performance, ecological impact and fuel and service availability (Struben and Sterman 2008). These attributes can be merged to influences of **price, infrastructure** and **emissions** produced. According to research conducted in Germany on stated preference for alternative energy sources in vehicles, the research shows the attributes involving engine performance and (service) station availability have a positive influence on the alternative energy choice whereas the fuel costs and CO_2 emissions have a negative impact on the fuel choice (Ziegler 2012). Savvanidou et al. (2010) conducted research on the acceptance of biofuels in Greece. The results show that there exists a lack of knowledge about biofuels (Savvanidou, Zervas, and Tsagarakis 2010). Also, the research states that the willingness to pay has a large influence on the transition to biofuels. Futhermore, they discuss that the use of biofuels can have a positive effect on climate change, and positively change their willingness to adopt (Savvanidou, Zervas, and Tsagarakis 2010). In the joint mixed model of stated and revealed preferences for AFVs of Brownstone et al. (2000), the variables that were chosen to research were purchase price against income, the operating costs, the range of the car, the acceleration and top speed, the pollution and lastly the station availability (Brownstone, Bunch, and Train 2000).

Considering all these four pieces of research, a correlation between chosen attributes for vehicle choice can be seen. An overview of these attributes is present in table 4.1.

Attribute	Struben (2008)	Ziegler (2012)	Savvonidou (2010)	Brownstone (2000)
Operating costs	x	x	x	x
Station availibility	x	x		x
Driving range	x			x
Engine performance	x	x		x
Emission produced	x	x	x	x
Knowledge of fuel			x	

Table 4.1: Attributes obtained from previous research that influence the choice of fuel

From this table, the conclusion can be made that operating costs (the fuel costs per kilometre of travel) and the emissions produced (tailpipe emissions) are the most relevant aspects to base a vehicle choice on. Furthermore, engine performance (acceleration and top speed) and station availability (access to fuel and service) are the second most relevant attributes affecting fuel choice. As mentioned in chapter 1, the calorific value of plastic fuel is comparable with that of fossil fuels. Therefore, the assumption is made that the engine performance will be closely comparable to the current combustion engine and thus will the attribute of engine performance and driving range not be further taken into account. Thus, within this research, **the main attributes that seem most relevant in the choice-making of fuel are the**

operating costs, the station availability and the emissions produced. This information is important for the construction of a survey. The construction of the survey is further explained in the upcoming section.

4.2. Stated Choice Experiment (SCE)

SCEs are conducted to determine which factors influence an individual's choice (Rose and Bliemer 2009). These factors are called design attributes. Each attribute of the choice made can be observed by the respondents undertaking the experiment (Rose and Bliemer 2009). A SCE is constructed in a way that **respondents need to make choices among hypothetical alternatives.** Within these alternatives, the levels of attributes vary. By controlling the attribute levels in an experiment, the impact of a change in attribute level on a respondent's choice is represented. Therefore, **every choice made creates a certain choice profile which represents the respondent's preference, relative importance and the trade-off made among other attributes** (Hauber et al. 2016). Thus, for this research, an SCE is conducted on the use of a plastic fuel which will provide a prediction on choices in the market of fuels. Also, the levels of attributes that are necessary for the acceptability of a plastic fuel are determined and whether the pyrolysis process and fuel use that exists now are comparable with these attribute levels.

The results of the SCE will provide statistical values. To structure this, a null hypothesis and an alternative hypothesis are created. The null hypothesis represents the situation in which no relation exists between the attributes and influence on choice behaviour whereas the alternative hypothesis does represent a relation of the attributes influencing the choice of consumers. To summarize:

- H(0) = there exists no relation between the attributes and the decision being made
- H(1) = there exists influence on the choice by the attributes

The results of the statistical analysis will determine whether the H(0) will be confirmed or whether the H(0) is rejected and H(1) is confirmed.

For designing an SCE, a process of developing, testing and optimizing the questions for the experiment is necessary (Kløjgaard, Bech, and Søgaard 2012). This process is important for the validity of results. The setup for a design of choice experiments can be done in several steps which are (Rose and Bliemer 2014):

1. Determine if the experiment is labelled or unlabelled
2. Determine the alternatives and attributes to include in the experiment
3. Determine the alternative attribute levels and their coding
4. Determine the number of choice tasks that the respondents need to take
5. Choose experimental design strategy
6. Conduct pilot study

7. Conduct the main study

These seven steps will be briefly explained and related to the research of using plastic fuel in the upcoming sections

4.3. Labelled or Unlabelled Experiment

First, a choice needs to be made between labelled and unlabelled alternatives. With **labelled alternatives, the respondent will know the name of the alternative which will provide substantive meaning to the alternative**, influencing the choice of the respondent. With **unlabelled alternatives, the alternatives have the same label and the label is kept vague** and does not play a role in choice (e.g. alternative A, alternative B and alternative C) (Rose and Bliemer 2014). The choice of using a labelled or unlabelled experiment depends on the research questions that are being researched. According to J. Rose & M. Bliemer (2014), **unlabelled experiments** are more suitable in **determining the willingness to pay for a product or determining the relative importance of attributes** within decision-making. Considering **labelled experiments** would be more suitable if the research is focused on **determining market shares of a product type or its demand elasticities.**

4.3.1. Labelled or Unlabelled Experiment: Plastic Waste as a Fuel

Using the word ”plastic” creates a lot of judgment. People see plastic as a damaging product and see it as even more damaging when it is burned (Buranyi 2018). To determine whether a plastic fuel is acceptable, first, a choice set is made with an unlabelled experiment, eliminating the potential judgment of one origin of the fuel. The results of the first choice set will show the motivation of what factors influence the choice of fuel for car users. After that, a similar, but smaller choice set is given included with a labelled experiment. Comparing the results from both choice sets will result in knowing what the main factors are for respondents to transition to an alternative fuel and what the response is to a plastic fuel.

4.4. Selecting Alternatives and Attributes

To define the attributes properly, the combined set of attributes must describe what the choice consists of. However, the **attributes must be selected in a way that ensures respondents will be willing to make trade-offs between the alternatives whereas the attributes must also reflect the true motivation of the respondents** given in a real choice situation (Kløjgaard, Bech, and Søgaard 2012). The formulation of the attributes must be clear and concise for the respondents to understand the content of the attribute (Kløjgaard, Bech, and Søgaard 2012). Also, during the selection of attributes, attention must be given to casual relationships and interconnections between attributes. Whenever this is the case, one of the attributes must be eliminated from the experiment (Kløjgaard, Bech, and Søgaard 2012). For any experiment, **there must exist at least two alternatives in the choice task** (Rose and Bliemer 2014). Important to notice is that the more levels of attributes you use, the more choice tasks the respondent will get (Rose and Bliemer 2009). When more alternatives are used, more information is captured but also, the more choice tasks the respondent must do, making the task time-consuming and requiring higher cognitive burden (Rose and Bliemer 2014). For an unlabelled experiment, the use of two or three generic alternatives satisfies the experiment. For a labelled experiment, the number of choice tasks is dependent on the number of labels that are examined since each label requires one alternative (Rose and Bliemer 2014). According to J. Rose & M. Bliemer (2009), a limitation of conducting an SCE is that the number of respondents needs to be large to produce statistically reliable results (Rose and Bliemer 2009). This problem is to be overcome by reaching out to multiple networks from my network to generate a large range to obtain as many responses as possible.

4.4.1. Selecting Alternative and Attributes: Plastic Waste as a Fuel

A literature review of alternative fuel vehicles has been conducted to gather previous studies and determine potential attributes. These attributes are based upon reasoning why certain alternative fuel vehicles or earlier fuel transitions have or have not taken place. From this literature review, the conclusion is made that **price, infrastructure and emissions produced are the three main attributes which influence the choice of the consumer** (Table 4.1). To set alternatives, this experiment wants to examine what influences the consumer the most when choosing a fuel. Therefore a choice is given for two alternatives: Fuel A and Fuel B. For this unlabelled experiment, all attributes will vary in the choice set. As mentioned before, to conclude what attributes are most influential when transiting from fuel, a choice set is given with labelled alternatives. For the currently used fuel, this research will take gasoline as a reference since this is the most used fuel source in the Netherlands (78,5%) (CBS 2023). The alternatives for the labelled experiment are ”plastic fuel” and ”gasoline”.

4.5. Attribute Levels and Coding

After selecting the attributes, the level of each attribute must be determined. Whenever the levels of attributes are not in scope, the respondents might assume attributes to be unimportant or very important which will result in **dominance in levels** which affects the willingness of respondents to make trade-offs (Kløjgaard, Bech, and Søgaard 2012). Attributes are considered to be quantitative (numerical) or qualitative (categorical) and based on knowledge gathered from literature reviews, interviews and expert opinions (Kløjgaard, Bech, and Søgaard 2012). Due to the time constraints of this research, the main focus of selecting attributes was done through literature reviews mentioned in section 4.1. For the SCE, whenever each attribute level appears an equal number of times, each attribute is considered as **attribute level balance** ensuring that the attributes can be estimated properly. Furthermore, the **levels of attributes** need to be determined. The number of levels for each attribute can be seen as the number of choices each attribute gets (e.g. The fuel price is €0,25 €1,00 and €1,50). Studies show that using a wide range for the **attribute level range** is statistically preferable as it will lead to parameter estimates with a smaller standard error. However, the **attribute levels must be acceptable in real-world situations for respondents to make a realistic choice.** Therefore there exists a trade-off between the statistical preference of a wide range and the real-world situation limiting the range (Rose and Bliemer 2009).

4.5.1. Attribute Levels and Coding: Plastic Waste as a Fuel

The attributes in this choice experiment will exist on three levels per attribute to maintain attribute level balance. For the attribute price, there will be a qualitative range where the respondents can choose between 0,50, 1,50 and 2,50. The reasoning for choosing this range is that these prices can be realistic fuel prices. For example, the LPG price is between 0,70 and 0,80 cents whereas currently, the fuel price for gasoline ranges around €2. For infrastructure, the levels that will be examined will be represented by ”accessible at every station”, ”accessible at 75% of the stations” and ”accessible at 50% of the stations”. Lastly, the levels for the attribute emissions are chosen to be ”produces less CO_2 emissions than your currently used fuel” ”produces equal CO_2 emissions than your currently used fuel” and ”produces more CO_2 emissions than your currently used fuel”. An overview of the attributes and level of attributes is shown in table 4.2. Since ”more”, ”equal” and ”less” need a reference point, it is chosen to refer to the respondent’s currently used vehicle. This will ensure that the transit in his perspective will take place under the circumstances where the respondent lives. The attribute levels of gasoline in the labelled experiment will kept constant and refer to the current situation. In the Netherlands, at every gas station, a consumer can buy gasoline. The CO_2 emissions will not vary as the input to the engine is the same and lastly, the approximate current price is chosen as a reference point (around €2,-).

Attribute	Level
Price	L1: 0,50 L2: 1,50 L3: 2,50
Infrastructure	L1: accessible at all gas stations L2: accessible at 75% of the gas stations L3: accessible 50% of the gas stations
Emissions	L1: less CO_2 emissions L2: equal CO_2 emissions L3: more CO_2 emissions

Table 4.2: Attributes with their corresponding levels

4.6. Number of Choice Tasks

An SCE contains **a profile of all the choice tasks** (*S*) and can be represented in a matrix *X*. Each column represents the attributes of an alternative and each row consists of a choice task. Whenever each respondent is given the same choice task, then *X* is to be a homogeneous design. Whenever each respondent or group of respondents are shown different choice tasks, then *X* is heterogeneous (Rose and Bliemer 2014). The size of the matrix *X* is defined by the number of choice tasks |*S*|. The required size is dependent on the number of parameters (*K*) needed to estimate where there needs to exist variation in the design matrix to estimate the *K* parameters. Agents make choices among |*J*| alternatives where the chosen alternative is preferred over the other |J|-1 alternatives. Rephrasing, the minimum size of the design can be determined by finding the smallest |*S*| that satisfies $|S| \geq \frac{K}{|J|-1}$ (Rose and Bliemer 2014). The difference between the minimum required design size and the actual number of choice tasks is referred to as the **degrees of freedom**. A response to adding more attributes, and thus more choice tasks, is that respondents tend to choose the status quo. Since the choice task will be too large, their cognitive burden will drop and the respondent will choose what is easiest or most recognisable. According to Oehlmann et al. (2017), **a choice task between 10 and 15 is optimal in practice** (Oehlmann et al. 2017).

4.6.1. Number of Choice Tasks: Plastic Waste as a Fuel

Considering two alternatives with three attributes each consisting of three levels will result in a **choice set of 9 choices** ($|S| \geq \frac{3*3}{|2|-1}$ =9). As mentioned previously, first, a choice experiment is done with an unlabelled choice. After, a choice set is done with a labelled experiment. The labelled experiment will exist in a choice between plastic fuel and gasoline. The attributes for gasoline become constant in the labelled experiment as it can refer to a real-world situation. Therefore, the attribute levels of price, emissions produced and infrastructure will be set to €2, equal CO_2 emissions, and accessible at all gas stations, respectively, referring to the current situation. The labelled experiment will therefore **consist of three choice tasks resulting in a total of 12 choices** the respondent must make. Then all the alternatives with all possible attributes are covered. In table 4.3 the initial choice sets are shown.

4.7. Experimental Design Strategy

There exist two different design types which can be used for SCE. First, a **full factorial design** consists of all possible different choice situations. However, with a full factorial design, the choice situation are mostly too large for respondents to undergo the experiment. Secondly, the **fractional factorial design** which consists of a section of the full factorial (Rose and Bliemer 2009). For both design types, different strategies exist. This section represents the main design strategies discussed by Rose & Bliemer (2014). The three main types of design strategies are **random designs, efficient designs** and **orthogonal designs**. Each design type is briefly explained

4.7.1. Random Designs

The **random design is structured by randomly selecting choice tasks for each respondent**. The randomly chosen choice tasks are generated from the full factorial design where all possible choice tasks are given (Rose and Bliemer 2014). This design strategy avoids dominant alternatives and allows the application of constraints. An advantage of this design strategy is that it **does not require any experimental design skills**. However, the main disadvantage is to obtain efficient data for results, **a large sample size is required, exceeding the 1000 respondents** (Rose and Bliemer 2014).

4.7.2. Efficient Designs

The aim of the **efficient design is to generate a design which is efficient without making the claim that the design is optimal**. This is because it is impossible to determine the most efficient design. The design is seen as efficient when the design matrix X captures a large amount of information. This is done by maximizing the volume matrix which is obtained by minimizing the volume of the variance-covariance matrix (Rose and Bliemer 2014). An advantage of using the efficient design is that this design captures almost maximum information ensuring significant and reliable parameter estimates when small sample sizes are used. This design is mostly chosen when **an experiment is restricted by budget or by limited respondents** that can be reached. A disadvantage of the efficient design is that the **design cannot be determined manually and requires algorithms** (Rose and Bliemer 2014).

4.7.3. Orthogonal Designs

For the **orthogonal design the attributes of the design matrix X are balanced in level** and if for each attribute, each pair of levels appears the same amount of time in the choice tasks (Rose and Bliemer 2014). The aim of the orthogonal design is to **minimize the correlation between attribute levels** in the various choice situations (Rose and Bliemer 2009). An advantage of orthogonal design is that the **attribute space is covered and no algorithms are needed.** However, a disadvantage is that the orthogonal design **can only be used for specific combinations of the number of attributes and their levels which need to be balanced** (Rose and Bliemer 2014).

4.7.4. Experimental Design Strategy: Plastic Waste as a Fuel

After analysing the theory behind each experiment design strategy, the conclusion is made to work with **orthogonal designs**. The reasoning behind this is due to the high number of respondents necessary for random design which is not achievable with the use of my network and the time within the research that needs to be conducted. Furthermore, the efficient design is not optimal because of the incapability of finding the most efficient design. This design type is mostly used for restricted research. The orthogonal design, however, can only be used when there exists a balance in levels. Therefore, we have chosen to use three levels for each attribute to tackle this problem which is shown in table 4.3. The chosen design strategy is implemented to generate the choice tasks the respondents must undergo. Table 4.3 shows these choice tasks and is constructed by using a choice metrics tool Ngene. In Appendix A.1, the syntax as input for the matrix is given.

	Fuel 1			Fuel 2		
Task	Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
1	€2,50	access at 50% of stations	equal CO_2	€1,50	access at 75% of stations	less CO_2
2	€1,50	access at 75% of stations	equal CO_2	€0,50	access at all stations	less CO_2
3	€0,50	access all stations	equal CO_2	€2,50	access at 50% of stations	less CO_2
4	€1,50	access at 50% of stations	less CO_2	€0,50	access at 75% of stations	more CO_2
5	€0,50	access at 75% of stations	less CO_2	€2,50	access at all stations	more CO_2
6	€2,50	access at all stations	less CO_2	€1,50	access at 50% of stations	more CO_2
7	€0,50	access at 50% of stations	more CO_2	€2,50	access at 75% of stations	equal CO_2
8	€2,50	access at 75% of stations	more CO_2	€1,50	access at all stations	equal CO_2
9	€1,50	access at all stations	more CO_2	€0,50	access at 50% of stations	equal CO_2

Table 4.3: Unlabelled Choice Tasks for Fuel Choice

After the unlabelled choice experiment, a **labelled choice experiment** is done to examine the respondent's response towards using plastic as fuel. To examine this, there is a choice set made between plastic fuel and gasoline. The attributes and their corresponding levels for gasoline are kept constant resulting in this choice set **consisting of a fixed-alternative** (gasoline). The goal of using a fixed alternative is to compare the preferences of respondents for different versions of a single alternative (Giles Atkinson et al. 2018). In this case, a different version of the single alternative "fuel", namely plastic fuel. An advantage of using a fixed alternative is that the analysis of data is more simplified since less number of parameters need to be estimated (Giles Atkinson et al. 2018).

Since the goal is to keep the survey as short as possible, only three extra scenarios for the unlabeled choice experiment are given. To obtain the most relevant choice options, an algorithm is made in Ngene that generates various opportunities for choice sets. With the syntax given in Appendix A.2, three different choice sets were generated (Appendix A.3) with the use of **efficient design**. The reason for using the efficient design is due to the incapability of balanced levels and attributes required for orthogonal design (due to the fixed-alternative) and the restriction of a large sample size required for the random design. After analysing the generated choice sets, the decision is made to choose the choice set with the **least dominant choice tasks.** The chosen choice set can be seen in Table 4.4. The reason for reconsidering the choice tasks is due to the probability of choice tasks having a too dominant choice. For example, in Appendix A4.2 can be seen that where a more expensive option, accessibility becomes less and the emissions do not differ, there will be no motivation to choose a different vehicle and therefore no information can be obtained on what attribute ensured the respondent to choose for an alternative.

	Plastic			Gasoline		
Task	Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
1	€2,50	access at all stations	less CO_2	€2,00	access at all stations	equal CO_2
2	€0,50	access at 75% of stations	more CO_2	€2,00	access at all stations	equal CO_2
3	€1,50	access at 50% of stations	equal CO_2	€2,00	access at all stations	equal CO_2

Table 4.4: Labelled Choice Tasks for Fuel Choice

4.8. Pilot Study

Before the main study can be executed, the survey needs to be pre-tested. The reasoning behind pretesting is to find out whether the survey is well understood and sufficient for the potential respondents keeping in mind that all respondents have different backgrounds and education levels (Rose and Bliemer 2014). By sending the survey to a small amount of potential respondents, the survey can be conducted and the respondent can provide feedback about the choice experiment. With this feedback, the main survey can be adjusted to obtain better data results (Rose and Bliemer 2014).

4.8.1. Pilot Study: Plastic Waste as a Fuel

To test the survey before collecting answers, the survey was sent to a handful of people with research expertise or people who could give feedback on the layout and information given in the questions. Hereafter, a **better visualisation of the alternative choices is made to ensure clearance** and maybe even shorter duration of the survey. In Appendix B, the first and second versions of the choice tasks are shown. Also, a new question is added where the respondents can rank their importance per variable. This **ranking question is added to test the cognitive burden** of the respondents. Since the choice tasks in the questions before have a higher cognitive demand, the rank question gives the respondents the possibility to indicate what attribute they find most important without complex choice situations (Giles Atkinson et al. 2018). Here **the results of the ranking can be compared to their actual choices in a forced decision of two alternatives.** After adding the rankings, the survey was sent to other people. Here the feedback was given to add a degree to the variable to properly rank the variables (*low* tailpipe emissions, *low* price, *short* refuelling time, *high* driving range and availability at *all* gas stations). The variables that were not questioned in the survey are added to the ranking to determine whether these variables might also impact a consumer's choice. However, since the infrastructure of a plastic fuel will not differ much, as the assumption is made based on corresponding calorific values, the variables of driving range and time to refuel are not considered relevant and kept constant throughout the scenarios. Furthermore, **the price range for the fuels seemed to be too unrealistic** whereas a dominant choice was easily made. For this reason, **the levels of price were adjusted** to 0.75, 1.50, and 2.25. The new set of the complete choice set for the respondents is given in table 4.5 and 4.6. Lastly, to indicate whether providing information on plastic processing and how this can be applied to produce plastic fuel, the survey tests whether there exists a pre-determined judgement on burning plastic.

	Fuel 1			Fuel 2		
Task	Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
1	€2,25	access at 50% of stations	equal CO_2	€1,50	access at 75% of stations	less CO_2
2	€1,50	access at 75% of stations	equal CO_2	€0,75	access at all stations	less CO_2
3	€0,75	access all stations	equal CO_2	€2,25	access at 50% of stations	less CO_2
4	€1,50	access at 50% of stations	less CO_2	€0,75	access at 75% of stations	more CO_2
5	€0,75	access at 75% of stations	less CO_2	€2,25	access at all stations	more CO_2
6	€2,25	access at all stations	less CO_2	€1,50	access at 50% of stations	more CO_2
7	€0,75	access at 50% of stations	more CO_2	€2,25	access at 75% of stations	equal CO_2
8	€2,25	access at 75% of stations	more CO_2	€1,50	access at all stations	equal CO_2
9	€1,50	access at all stations	more CO_2	€0,75	access at 50% of stations	equal CO_2
10	€2,25	access at all stations	less CO_2	€2,00	access at all stations	equal CO_2
11	€0,75	access at 75% of stations	more CO_2	€2,00	access at all stations	equal CO_2
12	€1,50	access at 50% of stations	equal CO_2	€2,00	access at all stations	equal CO_2

Table 4.5: Unlabelled Choice Tasks for Fuel Choice After Pilot Study

	Plastic			Gasoline		
Choice	Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
1	€2,25	access at all stations	less CO_2	€2,00	access at all stations	equal CO_2
2	€0,75	access at 75% of stations	more CO_2	€2,00	access at all stations	equal CO_2
3	€1,50	access at 50% of stations	equal CO_2	€2,00	access at all stations	equal CO_2

Table 4.6: Labelled Choice Tasks for Fuel Choice After Pilot Study

4.9. Main Study

After document analysis of each step that is needed to construct a reliable choice experiment, all information, design choices and feedback can be combined to create the final SCE which can be sent out to respondents to receive results on choice behaviour. In conclusion, the design for the choice experiment will contain an unlabelled and labelled experiment since the unlabelled experiment will provide information on the influence factors when making a choice for a fuel source and the labelled experiment provides information on whether consumers are willing to transition to a plastic fuel. Furthermore, the design will consist of two alternatives. For the labelled experiment the alternatives are gasoline (as this is the most used fuel source in the Netherlands) and plastic fuel. Each alternative has three attributes (price, infrastructure and emissions). **The design strategy for the unlabelled choice tasks that will be applied is orthogonal design** since the combinations of attributes are balanced, which was the main disadvantage of using the orthogonal design but did not occur in this study. **For the labelled choice experiment, it was chosen to use the efficient design** since there existed no attribute level balance for an orthogonal design and random design required too many respondents. Before conducting the SCE, information about respondents is gathered to determine if the received answers are comparable to the Dutch population to examine the validity of the experiment. The outline of the survey can be found in Appendix C. To obtain the most valid conclusions, the survey must reach a minimum number of respondents. This number can be calculated by the rule of thumb proposed by Johnson and Omre (Bekker-Grob et al. 2015). The suggestion is made that the minimum number of respondents depends on the number of choice tasks (t), the number of alternatives (a) and the number of analysis cells (c) referring to the highest number of levels for an attribute. Together this will provide the following equation:

$$N > \frac{500c}{(t * a)} \tag{4.1}$$

- number of choice tasks (t) = 12
- number of alternatives (a) = 2
- number of analysis cells (c) = 3

Resulting in a **minimum of** $N > \frac{500*3}{12*2} > 63$ **respondents**. The respondents were mostly channelled throughout sending the link of the survey in a message to my closest network (friends and family). The link was forwarded to their friends resulting in a large network and therefore a variance in the type of respondents. Furthermore, a post on Linked-In was placed to obtain a few extra respondents to reach the people I did not reach with messaging. After closing the survey, **a total of 118 respondents were counted**.

5

Statisical Analysis

To generate reasonable conclusions, the results of the survey must be processed correctly. Therefore, this section will discuss the methods concerning the processing of data obtained from a choice experiment. As mentioned in the introduction of chapter 4, the goal is to determine which attribute levels have the highest influence on the choice made by the respondents. First, the weights of each attribute level must be determined. Simplified, this means that for each attribute level, the number of times one respondent chooses that level will determine its preference above the other attribute levels. This method is seen as the linear probability model given by the following equation (Hauber et al. 2016):

$$Pr(choice) = \beta_0 + \sum_i \beta_i X_i \tag{5.1}$$

with

- X_i is the level of attribute *i*
- β_0 is the intercept
- β_i is the preference weight of attribute *i*

The focus of the statistical analysis is to determine the preference weights of each attribute examined during the survey, providing information on what the respondents find most important when choosing a fuel.

5.1. Preperation of Data Set

To apply such a method, the data generated by the choice experiment needs to be categorised by coding. With coding binary choice variables are applied to the alternatives and each attribute level. (e.g. a high price = 0, a medium price = 1 and low price = 2). For a two-alternative SCE, each row must represent a respondent's choice. Thus each respondent has twelve rows of data (one for each choice task). To reduce the inconsistency of data obtained per question, only the respondents who have fully completed the survey are taken into account. The reason for this is to maintain an **equal weighing quota**. In other words, all the choice tasks receive the same amount of data output, resulting in more reliable results for the total data set. For example, if a respondent who did not finish the survey has a strong motivation for choosing emissions, only half of his motivation is taken into account, resulting in lower scores for emissions compared to a fully completed survey. Applying the elimination of partial responses leads to the elimination of 8 respondents resulting in a **total of 110 received respondents**. Each respondent then fulfilled 12 choice tasks consisting of two alternatives **resulting in a data frame of 2640 rows of data**. The data is split up into a labelled and unlabelled output since both data need to be analysed differently as the statistical analysis differs for a labelled experiment and an unlabeled experiment. Per fuel, different attribute levels apply where the existing attribute levels are represented by their associated value in the data set. In table 5.1 the data of respondent 1 with the first five choice tasks up until the last five choice tasks of the last respondent are shown to summarize and provide a visualisation of the full data set of the unlabeled choice tasks. This structure is kept for all respondents and all choice tasks.

Respondent_ID	Choice_Task	Price_A	Price_B	Infra_A	Infra_B	Emission_A	Emission_B	Choice
1	1	3	2	1	2	2	1	2
1	2	2	1	2	3	2	1	2
1	3	1	3	3	1	2	1	1
1	4	2	1	1	2	1	3	2
1	5	1	3	2	3	1	3	1
...	...	...	...	...	...	...	...	...
110	5	1	3	2	3	1	3	1
110	6	3	2	3	1	1	3	1
110	7	1	3	1	2	3	2	1
110	8	3	2	2	3	3	2	2
110	9	2	1	3	1	3	2	2

Figure 5.1: Example of data setup for the respondents

Each number given for each attribute in figure 5.1 refers to the level of the chosen attribute. The according levels are given in table 4.2. In the last column, the chosen fuel is represented by a 1 for ”Fuel A” and a 2 for ”Fuel B”. Thus, for example, respondent 1 has chosen Fuel B (2) in his first choice task which has the characteristics of price level 2 (€1,50), infrastructure level 2 (available at 75% of the gas stations) and an emission level of 1 (less CO_2 emissions).

For the labelled choice task a similar data set was prepared. However, since the choice task of the labelled data set contains 4 different price attribute levels (€0,75; €1,50; €2,00; €2,25), the scale of each attribute level needed to be adjusted. For generating statistical data, the steps between each attribute level must be balanced (*attribute level balance* explained in section 4.5). The scale of price has a step of €0,25 since this is the difference between the gasoline price (€2) and the highest price for plastic (€2,25). In table 5.1 the attribute levels according to the new scale are shown. The levels in bold represent the levels used for the data set.

Level	Price
1	€0,25
2	€0,50
3	**€0,75**
4	€1,00
5	€1,25
6	**€1,50**
7	€1,75
8	**€2,00**
9	**€2,25**

Table 5.1: Corresponding levels for price value in the labelled choice experiment

5.2. Statistical Analysis Methods

After preparing the data set, an applicable method needs to be applied to determine what attribute levels influence the choices of car users the most. In this section, an explanation is given of the chosen model whereas Appendix D will provide more information on other methods to use and why these methods were not chosen. In this section, a brief explanation of the methods is provided.

Conditional logit, mixed logit and multinominal logit are the three most common methods to estimate the preferences of a population. Conditional logit estimates the mean preference weights of the sample, multinominal logit estimates the preference based on individual characteristics and mixed logit is a combination which estimates both the mean preference weight and the expected distribution of preference weights of the sample. Furthermore, the HB model analyses each individual's response rather than the whole sample at once. Finally, the latent class mixture model assumes different groups and classes and each group or class has identical preference weights.

This research will apply the conditional logit model since this model focuses on the probability of a choice which is made concerning the attributes. Other methods explained earlier take individual characteristics into account or are grouped by classes. Since this research wants to determine which attributes are most influential on the acceptance of a plastic fuel, and not who is willing to transit, the conditional logit seems the most suitable method. This method focuses on the research of the influence of each attribute, the characteristics of the individuals are not taken into account and the respondents are seen as a whole representing the population in which the market the plastic fuel will be situated.

For this method, the **random utility theory** is applied. The random utility theory assumes that an alternative is chosen as a function of the characteristics of the attributes (attribute levels), as well as the individual's motivation to choose an alternative that maximizes his or her utility. The utility function is given by the attribute levels of an alternative plus a random error term reflecting the researcher's inability to measure utility (Hauber et al. 2016):

$$U_i = V_{ij}(\beta, X_i) + \varepsilon_i \tag{5.2}$$

with

- V_{ij} function defined by the level of attribute for alternative *i* in set of alternatives *j* (represented in formula 5.3 and 5.4)
- ε_i the random parameter error term
- X_i vector of attribute levels defining alternative *i*
- β_i a vector of estimate coefficients (each estimated coefficient is a preference weight)

$$\begin{aligned} V_{FuelA} = ASC_{FuelA} + (\beta Price_A * Price_A) + (\beta Infrastructure_A * \\ Infrastructure_A) + (\beta Emissions_A * Emissions_A) + \varepsilon_i \end{aligned} \tag{5.3}$$

$$\begin{aligned} V_{FuelB} = ASC_{FuelB} + (\beta Price_B * Price_B) + (\beta Infrastructure_B * \\ Infrastructure_B) + (\beta Emissions_B * Emissions_B) + \varepsilon_i \end{aligned} \tag{5.4}$$

In both equations, the ASC stands for "**alternative specific constant**" which captures the variation of choice which is not motivated by the attributes (Giles Atkinson et al. 2018). For the **labelled experiment, the ASC is applied** since the fuel choice can be motivated by the product name since there already exists a judgement of the product.

5.3. Software

For analysing the data obtained from the survey and using certain methods to create results, software programs are used to generate useful results. Since the conditional logit model was chosen, the software program requires that it stimulates the conditional logit model. This section describes and motivates which software is used for obtaining the results from the survey.

5.3.1. Biogeme in Python

Initially, the statistical program of SPSS would be used. The reasoning for this is that SPSS has an outlook similar to Excel and the data obtained from Qualitrics could be exported directly into SPSS. Also, SPSS is a program that specialises in statistical data analysis. However, there was a problem with the data output of SPSS. Since the tables presented in the survey question (Appendix C) were presented by a picture, the underlying attributes with their corresponding level for each alternative were not registered in the data output. To fix the problem, the data needed to be restructured according to section 5.1. For restructuring, each answer needed to obtain underlying values for the chosen alternative. To make this as easy as possible, the data output was exported to Excel. In the Excel file, the IF statement was used to generate the underlying values of the chosen alternative. For example, respondent 1 chose Fuel B for the first choice task with the corresponding attribute values of level 2 for price, level 2 for infrastructure and level 1 for emissions. Then verbally explained: the IF statement will be as follows: IF ”Respondent ID” chooses ”Fuel A” then ”Price =3. ”Infra=1” and ”Emissions=2” IF NOT then ”Price=2”, ”Infra=2” and ”Emissions=1”. This formula can then be repeated for all respondents and all choice tasks resulting in the file represented in figure 5.1. First, an attempt was made to restructure the data outcome of the survey with Python. Due to learning by doing for the restructuring, the programming language of Python became more familiar. Additionally, python has a package called Biogeme which is designed for likelihood estimation of models in general and has a special emphasis on discrete choice models (Biogeme 2024). Therefore the Biogeme package was chosen. Furthermore, the reason for not further working with SPSS is due to a constrained structure in SPSS to perform the data analysis. The restructuring of the underlying information of the choice sets was already very time-consuming whereas an extra restructuring for the use of SPSS was not feasible.

5.4. Results Survey

This section will discuss the results obtained from the survey. First, the descriptive data is provided with the distribution of the individual’s characteristics. Then the choice distribution of the scenario questions is presented. After, the importance of attributes is analysed by the ranking question and textual argumentation provided by the respondents. These results are necessary to determine the validity of the survey and can be used to compare the outcome of the scenario analysis which will be conducted in section 5.5.

5.4.1. Descriptive Data

As mentioned at the end of chapter 4, the respondents were gathered mainly through the distribution of a link via messaging which was forwarded to other networks. Here the respondent’s statistics are provided to introduce the data set. The individual’s characteristics are represented by the frequency and percentage of the data set and then compared to the Dutch population percentages to estimate whether a comparable data set is obtained.

Category	Choice	Freq.	%	Dutch %
Age	<20	3	3	21
	21-40	48	42	26
	41-65	62	54	33
	65+	2	2	20
Gender	Male	74	64	50,3
	Female	40	35	49,7
	Non-binary	1	1	-
	Prefer not to say	0	0	-
Driver's license	Yes	110	96	80
	No	5	4	20
Car owner	Yes	92	80	-
	No	23	20	-
Fuel type	Petrol	68	59	78,5
	Diesel	6	5	11
	LPG	8	7	1
	Hybride	15	13	-
	Electric	10	9	3,1
	No applicable	8	7	-

Table 5.2: Individual's descriptive data compared to the Dutch statistics (obtained from CBS (CBS 2024, CBS 2023))

5.4.2. Choice Distribution

To provide an overview of the distribution of choices made among the respondents, figure 5.2 and 5.3 show the distribution of the given scenarios.

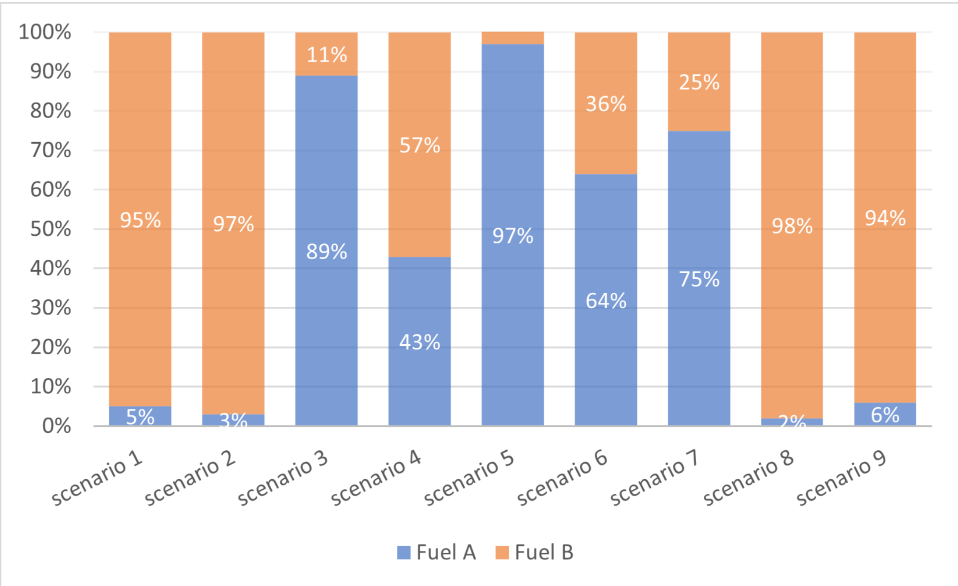

Figure 5.2: Choice distribution of all respondents choosing between alternative Fuel A or Fuel B for 9 scenarios

Since "Fuel A" and "Fuel B" are unlabelled alternatives which differ from attribute levels in each scenario, the meaning behind what "Fuel A" and "Fuel B" represent is important to analyse. This analysis is done by the use of Python Biogeme described in section 5.3 and the results will be elaborated on in section 5.5. However, figure 5.2 shows which scenarios the respondents had comparable answers and which scenarios had a larger choice difference. This shows which scenario's had a dominant choice and which scenarios were indifferable. The scenarios with high variance will provide more information on what attribute motivated a respondent to choose Fuel A or Fuel B.

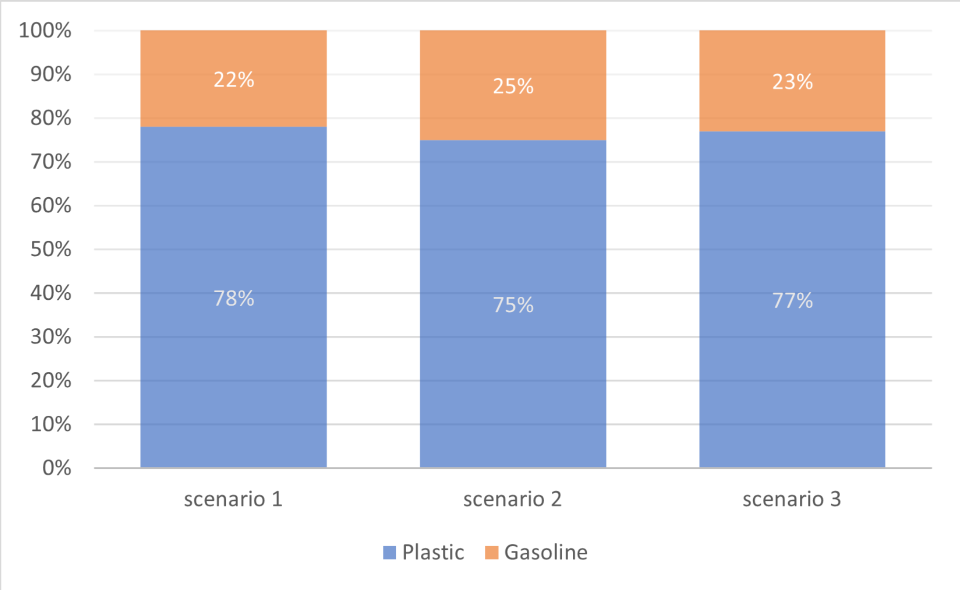

Figure 5.3: Choice distribution of all respondents choosing between alternative Plastic or Gasoline for 3 scenarios

Figure 5.3 represents the distribution of choices of the alternatives in choosing plastic fuel or gasoline. Here a clear outcome is that the respondents prefer plastic fuel over gasoline. However, in this case, the attribute levels behind the plastic fuel are still important to analyse since these attributes represent why an individual has more frequently chosen the plastic fuel.

5.4.3. Importance of Attributes

After the scenario questions, the respondents were asked to give a ranking on what attribute they find most important when choosing a fuel. The reasoning behind questioning the importance of each attribute is as a **control question** to test whether the results from the scenario questions are comparable to the answers given in the ranking question. Five different attributes were questioned: *low tailpipe emissions* (the amount of CO_2 emissions produced from the engine combustion), *high driving range* (the number of kilometres an individual can drive on one tank), *low fuel price* (the costs an individual pays for one litre of fuel), *availability at all gas stations* (the number of gas stations that sell the fuel the individual wants to refuel) and *short refuelling time* (the time it takes to refuel your tank). The reasoning for including attributes that were not questioned in the scenario questions is that these attributes will be constant when using a plastic fuel. The reason for this is that the oil obtained from plastics has comparable calorific values, meaning that the implementation in the same engine is possible. Therefore the assumption is made that plastic fuel will have approximately the same driving range and refuelling time. However, when different technologies are found to transform plastic into a usable energy source, these attributes might not be constant anymore, and therefore the importance of these attributes needs to be taken into account. These values can also be used for more elaborate research in the future. In table 5.3 an overview is provided on a scale of 0 (not important) to 10 (very important) on how important the respondents each attribute finds.

Attribute	Min	Max	Average
Low fuel price	1	10	7,79
High driving range	3	10	7,76
Low tailpipe emissions	0	10	6,77
Availability at all gasstations	1	10	6,07
Short refueling time	0	10	5,96

Table 5.3: Degree of the importance of respondents based on a ranking from 0 (not important) to 10 (very important)

From table 5.3 the conclusion can be made that a **low fuel price and high driving range are the two most important attributes** influencing the respondent's fuel choice. **The emissions** produced during motor combustion are the **third most important attribute followed by the availability and short refuelling time.** This means that from the results of the scenario questions, a low fuel price would have the highest coefficient followed by low emissions and high availability which will be examined in the data set obtained from the scenario questions.

After the ranking question, some information is given on the plastic handling required to create a plastic fuel and that the fuel can directly be used in the engine. After providing this information, the respondents were asked if they would be willing to transition to a plastic fuel. 61% of the respondents say they would transit to a plastic-based fuel whereas 10% would not transit and 29% of the respondents are still in doubt. When the answer was given "No" or "Depends on", a textual argumentation was provided. The textual motivation provides extra insight into what barriers might exist when the implementation of plastic fuel is to be realised. These textual motivations were analysed and categorised to make a distinction between the most influential considerations provided in order from most to least used argumentation. The categories that applied the answer "Depends on" are:

1. Sustainability: emissions, environmental impact, energy required
2. Costs: price per litre, costs to produce
3. Infrastructure: driving range, availability, efficiency, ease of refuelling
4. Engine: lifespan, type of engine, usable in the current engine, damage to the engine
5. Information: more information required

Within these categories, "sustainability" was mostly reasoned on why the respondents were doubting. The main motivation to transit would be if the overall environmental impact of using plastic fuel would decrease compared to the currently used fuels. Secondly, the "costs" influence the possible transition to a plastic fuel in case of a price reduction followed by "infrastructure" meaning that there should be no inconvenience in using plastic fuel. Lastly, the damage to the engine must be non-existent to consider transition where more information is required towards the consumers.

For the answer "No", the categories are as follows:

1. Plastic: reduce burning of plastic, reduce plastic use
2. Electric: drives a fully electric car
3. Engine: damage that might occur to the engine, safety
4. Sustainability: does not solve emission problems

Here, the most answered category was motivated to reduce plastic or the burning of plastic instead of using it as a fuel. Secondly, the answer to not transit to a plastic fuel is due to driving an electric car. Thirdly, the damage to the engine seems to be a concern of the respondents. Lastly, the doubt if using a plastic fuel will solve environmental problems.

5.5. Results and Interpretation of Choice Experiments

As mentioned at the beginning of this chapter, the main goal of the research is to determine the **value for β (estimation parameter) representing the preference weight.** This section will elaborate on the results obtained from the survey and how these results need to be interpreted. A positive estimate parameter is that with an increase in the attribute level, the respondent is more likely to choose that alternative. A negative parameter estimate works in reverse where a negative value means that a decrease in attribute level will obtain more motivation to choose that attribute (Giles Atkinson et al. 2018). The results from the statistical analysis give the values for β, the standard error, the t-test and the p-value. As mentioned before, β refers to the preference weight of the respondents for each attribute providing the most necessary information. The other three values are given to check the validity of the research. The **the standard error indicates how well the parameter estimation reflects the sample data compared to the whole population** (Bhandari 2020). The value of the standard error **represents the range** of which the parameter estimation can vary. For example, if the value of parameter estimation is 1 and the standard error is 0.5 the parameter estimation ranges 0.5<1<1.5. **The t-test is a statistical test used to compare the means of two respondents where the test is seen as sufficient if the result obtained for the t-test is > 1,96** (Bevans 2020). Often, the t-test is presented as a negative value but when interpreting the results, the absolute value of the t-test is important. Finally, **the p-value, also known as the probability value, describes the likelihood that the data described a particular set of observations if the null hypothesis was true.** The p-value is used to state whether the outcome of the data is **statistically significant**, thus if the statistical test is small enough to reject the null hypothesis. The threshold for the **p-value lies at p<0.05** (Rebecca Bevans 2020).

5.5.1. Results Unlabelled Scenarios

As mentioned before, with the use of Python Biogeme, the value of the parameter estimates was generated. The syntax of the Python script can be found in Appendix E. These parameter estimates indicate which attributes are most valuable for the respondents. Concerning the unlabelled parameters that were determined in the utility function (equation 5.3 and 5.4), the outcome of the syntax will generate a parameter estimation for 6 attributes (Emissions$_A$, Emissions$_B$, Price$_A$, Price$_B$, Infrastructure$_A$ and Infrastructure$_B$) as the ASC is not applied during the unlabeled choice experiment. In table 5.4 the obtained results are shown.

	Parameter Estimation	Std error	t-test	p-value
Emissions$_A$	-1.0639	0.1518	-7.0091	0.0000
Emissions$_B$	-0.9413	0.1447	-6.5065	0.0000
Price$_A$	-1.3955	0.1805	-7.7308	0.0000
Price$_B$	-1.5772	0.1495	-10.5493	0.0000
Infrastructure$_A$	0.1219	0.1543	0.7901	0.4295
Infrastructure$_B$	0.5088	0.2031	2.5048	0.0123

Table 5.4: Results from Unlabelled scenario experiment

Looking at the parameter estimation, the highest absolute value obtained from the data is for price (|-1.395|= 1.395 and |-1.577|=1.577). Since the attribute levels are provided with coding (level 1 represented by a value of 1, level 2 represented by a value of 2 and so on) and the same coding is applied for all attributes, the highest parameter estimation value is then the most influential factor. Therefore, the attribute which influences the choice of fuel the most is the price of the fuel. Since the parameter estimation has a negative value, respondents are more likely to choose a fuel with a lower price. So a price decrease will lead to a higher probability of choosing that alternative. The same for emissions, lower emissions result in more preferred choices. For infrastructure, a higher value (more availability) results in a higher chance of choosing an alternative and therefore the parameter estimation has a positive value. **From these results the conclusion can be made that price has the highest influence on the choice of the respondent. Thereafter emissions are the second most important and finally infrastructure. These results correlate to the ranking question mentioned in section 5.4.3** .

To verify these conclusions, table 5.4 also shows a standard error with a minimum value of 0.145 and a maximum value of 0.20. Since the differences between the lowest value of price and highest value of emissions are larger than 0.20 (|-1.395|-|-1.064| = 0.331) and the lowest value of emissions and highest value of infrastructure is also larger than 0.20 ((|-0.941|-|0.509| = 0.432), **the standard error does not impact the sequence** of the parameter estimations and thus not influence which attribute has more impact on the motivation of choice.

Furthermore, for all attributes except "Infrastructure$_A$", the t-tests and p-values are all greater than 1.96 and less than 0.05, respectively, meaning that **the results**

obtained are statistically significant. The reason why *Infrastructure*$_A$ is not significant can be due to a small sample size. The reason why a small sample size limits the outcome of the data analysis is due to a limited network whereas most respondents lie within the same classes (for example, same education level). The diversity of the respondents is thus biased.

5.5.2. Results Labelled Scenarios

For the labelled scenario results, the ASC (alternative specific constant) of both choices is considered. The reason why this is included in the labelled results is due to that respondents will choose a product (plastic or gasoline) rather than looking at the attributes meaning that there exists a probability of choosing the constant. In table 5.5 the results of the labelled experiment are shown

	Parameter Estimation	Std error	t-test	p-value
Emissions$_{Gas}$	-0.0280	0.0099	-2.8148	0.0049
Emissions$_{Plastic}$	0.0101	0.0182	0.5563	0.5780
Price$_{Gas}$	-0.1118	0.0397	-2.8148	0.0049
Price$_{Plastic}$	0.0304	0.0547	0.5563	0.5780
Infrastructure$_{Gas}$	-0.0419	0.0149	-2.8148	0.0049
Infrastructure$_{Plastic}$	0.0020	0.1847	0.0107	0.9915

Table 5.5: Results from Labelled Scenario Experiment

An concern when looking at the attribute parameters for the plastic alternative is that **all attributes score too high on the t-test as well as on the p-value meaning that the results obtained are statistically not significant**. Since the values of the attributes for gas can be considered constant (fixed-alternative) and the values of the attributes for plastic are not significant, the three labelled scenario questions seemed to **obtain irrelevant results where no valuable conclusions can be made**. The reason for this is that the number of choice tasks in combination with a not very large sample size, made that the three choice tasks were not enough to generate valuable results as the distinction between the choices was not big enough. **Therefore, an additional questionnaire is made** to examine the choice behaviour of the respondents when choosing between plastic fuel and gasoline which is described in the next section.

5.5.3. Second Survey

The survey design has the same set-up as the previous survey. However, since there exists a fixed alternative, the orthogonal design is not applicable as there exists no attribute level balance. Therefore, the efficient design is chosen to set the new choice tasks for the scenarios of plastic fuel and gasoline. Ngene is used again and the syntax can be found in Appendix A. For this survey, the choice tasks obtained from Ngene are presented in table 5.6. To ensure that enough respondents will be obtained, the survey only consists of 12 scenario questions. This is due to reaching out to the same network whereas the threshold to fill in another survey is quite high. By only presenting them with the 12 scenario questions with no additional (personal) information questions, the survey is less time-consuming and therefore increases the chance of reaching enough respondents. After sending the survey to the same network described in section 4.9, a total of 65 respondents replied to the survey. This is just enough to reach the minimum sample size calculated with a value of 63 respondents.

	Plastic			Gasoline		
Task	Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
1	€0,75	access at 75% of stations	more CO_2	€2,00	access at all stations	equal CO_2
2	€2,25	access at all stations	equal CO_2	€2,00	access at all stations	equal CO_2
3	€1,50	access at 75% of stations	more CO_2	€2,00	access at all stations	equal CO_2
4	€1,50	access at all stations	less CO_2	€2,00	access at all stations	equal CO_2
5	€0,75	access at 50% of stations	equal CO_2	€2,00	access at all stations	equal CO_2
6	€0,75	access at 50% of stations	less CO_2	€2,00	access at all stations	equal CO_2
7	€2,25	access at 50% of stations	equal CO_2	€2,00	access at all stations	equal CO_2
8	€2,25	access at 75% of stations	equal CO_2	€2,00	access at all stations	equal CO_2
9	€1,50	access at 75% of stations	less CO_2	€2,00	access at all stations	equal CO_2
10	€1,50	access at all stations	more CO_2	€2,00	access at all stations	equal CO_2
11	€2,25	access at all stations	less CO_2	€2,00	access at all stations	equal CO_2
12	€0,75	access at 50% of stations	more CO_2	€2,00	access at all stations	equal CO_2

Table 5.6: Second Survey Scenarios for Labelled Choice Tasks for Fuel Choice

The data obtained was restructured similarly to the data from the previous survey. The reason for this is due to the possibility of applying the old script whereas only the file input must be changed to the newly obtained data. The script for obtaining the results and the full result output can be found in Appendix E. Table 5.7 also presents the output of the second survey. **Due to the fixed characteristics of the choice for gasoline, the expected result will be that the parameter estimations for the attributes for gas will be 0 or near zero.** This is due to researching the choice between plastic and gasoline and therefore the results of comparing gasoline with gasoline will become 0. As expected, the conclusion can be made that the attributes for gasoline can be set to zero. This is also confirmed by the fact that the t-test values and p-values for all gasoline attributes are insignificant and therefore constant. Since gasoline is a fixed alternative, this has no impact on analysing the results of the plastic attributes. In table 5.7 the obtained results for the plastic attributes are shown.

	Parameter Estimation	Std error	t-test	p-value
Emissions$_{Gas}$	-0.0043	0.0089	-0.4860	0.6269
Emissions$_{Plastic}$	-1.5007	0.1385	10.8341	0.0000
Price$_{Gas}$	-0.0174	0.0357	-0.4861	0.6269
Price$_{Plastic}$	-1.2422	0.0763	-16.2876	0.0000
Infrastructure$_{Gas}$	-0.0065	0.0134	-0.4861	0.6269
Infrastructure$_{Plastic}$	2.1561	0.0763	-16.2876	0.0000

Table 5.7: Results from Labelled Scenario Experiment

When interpreting the results, it should be kept in mind that with a labelled fixed alternative scenario experiment, the outcome will present the most influential attributes that have a role in using a different version of the already existing fuel (gasoline) (Giles Atkinson et al. 2018). Here the attributes influencing the shift are determined. A remarkable thing that can be seen from these results, is that **when shifting to another fuel, infrastructure is most influential** (value 2.156082).

This shows that people are willing to transit only when there is no extra effort required to have access to the fuel. This parameter estimate has a positive value since the preference weight has a positive impact when more gas stations provide access to plastic fuel. This result can be confirmed by the research conducted by J. Struben and Sterman (2008). They mention that there exists no motivation to transit to alternative fuel whenever there exists no easy access (Struben and Sterman 2008). **Secondly, the emissions are a concern when using plastic fuel**. The negative value of -1.500700 shows that when tailpipe emissions decrease, the preference for choosing plastic fuel increases. The importance of this attribute can be validated by the increasing awareness of the importance of seeking solutions to reduce emissions produced worldwide. However, here can be seen that **consumers will still choose their ease of use above a socially desired solution. Finally, the price is seen as least important** with a value of -1.242247 meaning that the lower the price for plastic fuel will be, the higher the preference for that fuel will become.

Looking at the standard error for these results, the highest standard error for attribute parameters is 0.13816 and the lowest is 0.076270. Despite the high standard error for emissions, the respondent still finds emissions more important than the price (|-1.500700| - 0.13816 = 1.36254 > Price$_{Plastic}$ =|-1.242247|) and therefore **the standard error does not impact the sequence** of the preference weight, and thus the motivation of the respondent's choices.

Finally, to determine whether the obtained results are valuable for interpretation, the obtained values for the t-test and p-value need to be analysed. From table 5.7 can be seen that for all attribute parameters, **the t-test as well as the p-value are significant. The p-value of 0.00000 shows that there even exists a high significance in the data meaning that the null hypothesis is fully rejected.**

5.6. Conclusion from Survey Results

To conclude, in this research, three attributes were examined. According to the ranking question in the first survey, the degree of importance of each attribute influencing a fuel choice was a low fuel price, low tailpipe emissions and high availability at all gas stations in the corresponding order. This degree of importance is confirmed by the unlabelled choice experiment where **the results show the highest preference weight (negative value) for the price** meaning that consumers will be more likely to use plastic fuel when the price decreases (importance of low fuel price). **Secondly, the (negative) preference weight for emissions** means that consumers find a decrease in emissions important (importance for low emissions). **Lastly, a (positive) preference weight for infrastructure** means that when there is more availability, consumers have a higher intention to choose a fuel (importance of more availability). These values were described in the corresponding order of most important/influential to least important/influential.

For the labelled experiment, the choice tasks developed were not suitable for use. A constrained number of choice tasks and a too small sample size resulted in insignificant results that were not valuable for conclusions. Therefore, an **additional survey was constructed where the results show a high preference weight for infrastructure followed by the emissions produced and lastly the price.** Since in this choice experiment, there existed a fixed alternative, the choice experiment provides information on what attributes the respondents find most important when switching towards a different alternative fuel. Thus, to ensure that the transition towards a plastic fuel will be feasible, the infrastructure of the plastic fuel must not differ much from the currently used gasoline. Secondly, people will be more motivated to choose a plastic fuel when it is proven that the emissions produced during combustion are lower than the currently used gasoline. Lastly, the willingness to transit will also be influenced by the price but will have the least impact on choosing to transit considering these three attributes. Therefore, the upcoming chapters will provide qualitative research on the current situation and values to determine what the possibilities are for the implementation of plastic fuel considering the importance of each attribute.

6

Policy Framework and Infrastructure Adoption

After obtaining the results of the survey, the possibilities concerning the implementation of plastic fuel, taking the importance of each attribute into account, must be determined. Therefore in this chapter, the implementation strategies, policies and necessary infrastructure are discussed to determine what the possibilities are of implementing plastic fuel and whether this is feasible or not.

6.1. Policy Framework

The way society looks at plastic determines which policies can be applied to stimulate plastic fuel. Plastic is made from oil which is seen as a raw material whereas oil can also be used as a fuel. However, when plastic is created and then disposed, plastic is seen as waste. This results in a discussion of whether plastic is a waste or a raw material. Since these are two different ways of looking at plastic and the regulations for handling each type is different, a thorough analysis of handling plastic is researched to determine an efficient policy framework for the implementation of plastic fuel. The origin of plastic waste needs to be analysed to determine what policy framework applies to plastic fuels. Is plastic seen as a fuel, since it originates from oil, and do fuel regulations apply or is it seen as a waste and will the waste regulations apply? To answer this, existing policies on both subjects are analysed and discussed in the upcoming sections.

6.1.1. Laws and Regulations in the Netherlands: Waste Management

The current Dutch and European laws and regulations are directed towards plastic processing rather than plastic reduction. Thus, the regulations that exist are more focused on properly recycling plastic and thereby reducing burning plastic or landfilling. The EU Directive 2008/98/EC sets the waste policy. This Directive aims to reduce the negative impact of waste on human health and the environment by ensuring more efficient waste management and reducing waste (EU 2008). Within Directive 2008/98/EC, certain goals are relevant for waste management of plastic waste. First, 50% of plastic waste from households must be recycled or be suitable for reuse before 2020 (Lynn Snijder and Sanne Nusselder 2019). Secondly, 70% of the plastic waste that is produced in the construction sector must be made useful before 2020, and lastly, before 2024, the European Commission must decide on the implementation of goals for recycling or reuse of construction waste, textile waste, shop waste and industry waste (Lynn Snijder and Sanne Nusselder 2019).

6.1.2. Laws and Regulation in the Netherlands: Fuels (RED regulation)

In Europe, there exists the Renewable Energy Directive (RED). With this regulation, the European Union obligates their members to ensure renewable energy to the market for transportation. Recently a new RED was implemented **(REDII) where the European Union obligates fuel suppliers to deliver a share of 14% of renewable energy.** The goal of the REDII is to decrease GHG emissions within transportation and reduce the use of fossil fuels (Rijksdienst voor Ondernemend Nederland 2017). The framework which is applied works as follows: **In the Netherlands, a fuel supplier which supplies fuel for more than 500,000 litres is obligated to supply a share in renewable energy (hernieuwbare energie (HBE))**. The fuel suppliers must register themselves at the NEa (Dutch Emissions Authority) and receive HBE's in exchange for supplying renewable energy. These HBE's are necessary to secure their obligations. Whenever a fuel supplier supplies more renewable energy than they are obligated to, they can market their surplus to other fuel suppliers which have a shortage (Emissieautoriteit 2023b). The NEa is responsible for controlling the trade of HBE's and checks whether the bio-fuels are indeed sustainable (Emissieautoriteit 2023b). The sustainability of the biofuel is determined by the reduction of greenhouse gas emissions measured over the entire chain. **The biofuel must show a reduction of 50% compared to fossil fuels to receive a sustainable certificate** (NEa 2021). To determine whether plastic is approved as a bio-fuel to enhance a more sustainable outcome, chapter 7 will elaborate on the emissions produced during combustion in the engine as well as the emissions produced during the pyrolysis process. There are four types of HBE's (Emissieautoriteit 2023a):

- HBE-G: originate from bio-fuels from certain waste streams and residues
- HBE-C: originate from bio-fuels from agriculture crops
- HBE-O: originate from electricity
- HBE-B: originate from bio-fuels from raw materials

Within these four types, and as mentioned before, plastic fuel can be discussed for two types: **the HBE-G type and the HBE-B type, depending on whether plastic is seen as a waste or as a raw material.**

6.1.3. Agreements and Protocols

Worldwide, the awareness of the negative effects of fossil fuels and GHG emissions is increasing and the severe problem of climate change is being acknowledged. Therefore, more countries and nations are seeking collaboration in reducing these negative effects through agreements and directives. In the following section, two large Agreements are discussed and their goals are presented and how this will affect the potential implementation of a plastic fuel.

EU Paris Agreement

The Paris Agreement has the goal of tackling the problem of climate change (Nations 2023). On December 12th 2015, the Agreement was adopted. Currently, 195 parties have agreed to collaborate to reach the goals stated in the Agreement where the Agreement ensures the commitment of all collaborating countries to reduce their emissions and work together to mitigate the impacts of climate change (Nations 2023). The three main prospects of the Paris Agreement are:

- Limit the GHG emissions to limit the global temperature rise to 1.5 degrees.
- Review countries' commitment to cutting emissions every five years
- Provide climate finance to developing countries

The second item mentions a review every five years. This is done through Nationally Determined Contribution (NDC) where every five years, each country submits an updated national climate action plan (NDC). These NDCs communicate what actions each country will take to reduce their GHG emissions which will help them to reach the goals of the Paris Agreement (*The Paris Agreement | UNFCCC* 2023). From 2024, the enhanced transparency framework (ETF) will be applied. This is a framework where countries will have to report their actions taken towards climate change mitigation, support, and adoption measures with full transparency (*The Paris Agreement | UNFCCC* 2023).

Since the goals of the **Paris Agreement** are reaching towards a **zero-carbon solution**, the solution of using plastic fuel will not apply to these goals. **Plastic fuel still produces production emissions and tail-pipe emissions which are not in line with the zero-carbon solution**. Therefore, this solution is not able to be applied as a strategy in the climate action plan of the EU Paris Agreement

Kyoto Protocol

The **Kyoto Protocol** was created in 1997 and a legal framework was established towards the reduction of GHGs by applying targets (Emissieautoriteit 2023a). These targets differ per county as the situation and ability to reduce GHG emissions per country differ. The collaborative goal of the Kyoto Protocol is to ensure an **overall target reduction of 5% GHG emissions relative to 1990** (Emissieautoriteit 2023a). The Kyoto Protocol allowed trading in emissions among member states which is known as the Kyoto mechanisms (Emissieautoriteit 2023a). The reasoning behind the Kyoto mechanism is that in fighting for global climate change, there exists no difference in where the emissions are reduced, as long as the global target of 5% is reached (Emissieautoriteit 2023a). Whether the Kyoto Protocol can stimulate the implementation of plastic fuel, further research on emissions during production and combustion of plastic fuel needs to be done. This research will be further elaborated in chapter 7.

6.2. Necessary Infrastructure

To determine the needed infrastructure, research must be done in what aspects need to change in the infrastructure and what can remain the same. Here the possibilities of plastic fuel handling and possibilities of implementation need to be analysed. A study conducted by Ndiaye et al. (2023) concluded that a mixture of plastic waste is suitable for use as an alternative energy source (Ndiaye, Derkyi, and Amankwah 2023). According to the calorific value, kinematic viscosity, density and pour point, shows that the oil produced from plastics can be used as a source of energy in current engines (Ndiaye, Derkyi, and Amankwah 2023). Since the plastic does not require any engine changes, the ability to transfer to plastic fuels will not require any extra changes to a vehicle or new vehicle purchase. Another study by Quesada et al. (2020) obtains results from the pyrolysis experiments resulting in approximately the same values for plastic oil as for a fossil fuel. Quesada et al., also review other studies, confirming these ranges of values compared to a fossil fuel.

Infrastructure plays a large role in the adoption of fuel. Consumers will not switch to an alternative fuel when the accessibility of this fuel is not easy, or when repair and services are difficult to obtain (Struben and Sterman 2008). This statement is confirmed by the results obtained from the survey conducted during this research. Also, the government does not want to invest in alternative fuel technology or infrastructure whenever there exist no prospects in a large market (Struben and Sterman 2008). Since not much adoption is required for the transition towards plastic fuels, considering the infrastructure of obtaining the fuel, this will have not much effect on the process of implementation. However, there still exists a problem at the start of the accessibility chain. The plastic oil must be created whereafter, the plastic oil is transported to the gas stations. **The accessibility concerning plastic fuels is dependent on where the plants are located**. The distribution of these pyrolysis plants affects the ratio of the availability of plastic fuels for each gas station. For example, the pyrolysis plant based in Amsterdam can easily distribute the plastic fuel towards its surrounding cities and villages using vehicle transport. However, when plastic fuel is transported to, for example, Groningen, this requires more transportation and therefore more efficient infrastructure. Therefore, at first, the infrastructure will lack accessibility which might cause a failure of implementation. A consideration must be made to fully implement the plastic fuel and ensure that this fuel is accessible at every gas station. As seen from the results in chapter 5.4, infrastructure is an important factor when considering a fuel transition to create an installed base and prevent market failure. When the availability of the fuel is easily accessible, it is more likely that consumers are willing to use the fuel.

6.2.1. Investments

Currently, the burning of plastics is done through ”normal” burning (incineration). However, to maintain the value of the oil created from burning plastics, the use of the pyrolysis process is necessary. Therefore, investment costs need to be made in a plant which performs the pyrolysis process. Also, currently, the waste that is burnt is mixed waste which does not only contain plastics but contains all the waste produced by households and companies. To produce a fully plastic fuel, only plastic needs to be burnt during the pyrolysis process. Therefore, an investment must be made in improving the waste management and handling process within the Netherlands.

6.2.2. Infleunce on Market Growth

The transition of a new vehicle fuel is seen as complex since the size and importance of the installed base are dependent on various influence attributes providing either a positive or negative feedback loop towards the installed base (Struben and Sterman 2008). In this section, the aspects influencing the attractiveness of transition within the market are determined. The attractiveness of choosing a platform is influenced by consumers' consideration set and the belonging attractiveness (Struben and Sterman 2008). Consumers will only choose an option when they are known with the platform. The knowledge of the existence of the platform, and thus the willingness of a consumer to transit, is influenced by marketing, media attention and word of mouth (Struben and Sterman 2008). These types of communication improve the awareness of a platform. Concerning the technology of a platform, positive feedback can be provided by scale and scoop economies, research and development, learning by doing and driver's experience (J. J. R. Struben 2007).

Specifically, this section further analyses the attractiveness of transitioning to plastic fuel and the way to bring plastic fuel to the market. As mentioned above, the awareness of the product's existence as well as knowledge of the technology is necessary to attract consumers to transit. Therefore, more (understandable) information must be provided on the current handling of plastic waste as well as the side effects of the technology and the further development of the pyrolysis process. Bringing a new product to a market ensures that consumers will question the product at first. Questions concerning emissions produced and possible stimulation of plastic production will arise. These questions show that there exists uncertainty among consumers about whether plastic fuel is an improvement of the currently used fossil fuels. A risk of promoting plastic fuel and stating that it will solve the plastic waste problem and simultaneously reduce emissions is that consumers are frequently more alert to marketing strategies that might occur as greenwashing. Therefore, it is important to thoroughly analyse the technology of producing plastic fuel. As stated in chapter 2, using plastic fuel will not necessarily eliminate emissions but has the possibility of reducing emissions. Therefore, it is important to market plastic fuel as a temporary solution to bridge the transition towards the elimination of fossil fuels. Presenting it as a temporary solution will help reduce plastic overload but will not stimulate the extra production of plastic since plastic fuel will not be a main source of transportation fuels. To reach this temporary solution, the infrastructure for accessing plastic fuel needs to be easily convertible. Since the calorific values of plastic fuel are nearly similar to fossil fuels, the possibility of using a blend of fossil fuels and plastic waste might be a promising solution. Fuel suppliers would need to adjust their composition of the fuel whereas the infrastructure remains the same. In the next chapter, comparisons are made on emissions produced from fossil fuels, blended plastic fuel and fully plastic fuel. From the results of the next chapter, a conclusion can be made as to whether a blended fuel would be feasible for implementation.

6.3. Conclusion

Thus, the main goal in the Netherlands concerning waste management is to reduce plastic waste. When combining the reduction of waste with the RED regulation, **plastic oil could contribute to receiving HBE credits for fuel suppliers**. However, the main discussion still applies to which HBE category the waste of plastic will apply. Here HBE-G and HBE-B seem most relevant for the implementation of plastic oil to the fuel. The conclusion can be made that **there exists a combination of the waste policy Directive of reducing waste and then applying this reduction to the RED regulation.** The next chapter will collect information on emissions produced during the entire chain to determine whether the restrictions for applying the RED regulation can be met (50% reduction). Furthermore, there also exist European and global goals for reducing negative effects on the environment. The Paris Agreement will not be in line with the use of plastic fuel as the main goal is to reach a zero-carbon solution whereas plastic fuel will still produce emissions. However, the Kyoto Protocol aims towards a world-wide CO_2 reduction of 5% compared to 1990. **If plastic fuel produces less CO_2 emissions than the current fossil fuels, the Kyoto Protocol will apply to plastic fuel.** Moreover, multiple studies have shown that the parameter outcome values of plastic fuel are comparable to fossil fuel. Therefore, the implementation process of using plastic fuel will not ensure difficult investments in infrastructure. **The main problem of using plastic waste as a fuel concerns the collection process of plastic and the conversion of the plastic. New plants must be installed to produce the plastic fuel.** Additionally, market growth is an important factor for implementation as the willingness to adopt is influenced by the size of the platform, marketing strategies, media attention and word-of-mouth. Also, concern and questions about using plastic fuel arise and attention must be given to providing knowledge to the consumers about the process of creating plastic fuel and its use. A risk that must be taken into account is consumers being alert for greenwashing and therefore, **plastic fuel must be marketed as a temporary solution to bridge the fuel transition towards carbon neutrality**. The temporary solution can be realised by creating a blend with the currently used fuels, so that when the overload of plastic has been reduced, that conversion to another alternative, or in the worst case, back to fossil fuels, can easily be realised. The next chapter will elaborate on the possibilities and feasibility of using a blended fuel and in what ratio.

7 Environmental Benefits and Drawbacks

In this chapter, the emissions of current fossil fuels and a plastic fuel are compared and discussed. As seen from the survey results, emissions are the second most influencing attribute when considering a fuel choice. This chapter provides information on the various types of emissions that are produced during the whole process of using fossil fuel as well as plastic fuel. With this information, an analysis can be made on what the emission rates are to determine whether plastic fuel is feasible for implementation or not.

According to CBS (Centraal Bureau voor de Statistiek), the Netherlands counted approximately 8,9 million passenger vehicles on the 1st of January 2023 (CBS 2023). The cars that are driven in the Netherlands are fueled by gasoline, diesel, LPG (gas) or electricity (and hybrid). **The fraction of passenger cars driving on gasoline is 78.5%, clearly dominating the fuel consumption** (CBS 2023). For each type of fuel, various emissions are produced whereas the emissions with the most impact on the environment are CO_2, NO_x and toxic by-products. Each section in this chapter elaborates on the emitted gases and describes data on the amount of released emissions per fuel type. This information is gathered through desk research.

7.1. Greenhouse Gases (GHGs)

The greenhouse effect works as follows: the sun heats the Earth whereas the Earth radiates infrared radiation to the atmosphere which is absorbed by water vapour, CO_2, methane, NO_x and ozone, also known as greenhouse gasses (GHGs). These GHGs ensure more absorption resulting in less infrared radiation leaving the atmosphere and therefore increasing the temperature on Earth (Easterbrook 2016). Water vapour ensures the largest impact of the greenhouse effect since water vapour emits and absorbs infrared radiation more than other greenhouse gases. However, there is a large correlation between water vapour and CO_2 emissions. Studies have shown that an increase of CO_2 levels causes the temperature to rise whereas more water vapour is produced (Easterbrook 2016). Concerning GHGs, passenger cars produce mainly CO_2 and NO_X and therefore, the next section will provide more information on the exact numbers that are produced during combustion of various engine types.

7.2. Emissions Produced During Engine Combustion (Tailpipe Pollution)

For plastic fuel, the air pollutants are different than for conventional fuel types since the properties of each fuel differ. During the burning of plastic fuel in the engine, multiple emissions are also released. A comparison between the fuels is made to determine the environmental impact. Each section will elaborate on the emissions or air pollutants produced, their characteristics and the amount of emissions released. The study used to obtain information about plastic fuel emissions was conducted by Sekar et al., 2021 where the **emissions produced were measured using fossil fuel, plastic fuel and a blend of fossil fuel (75%) and plastic (25%).** The result will follow in the upcoming sections. Additionally, the study of Padmanabhan et al., (2022) was used to confirm and check the validity of these results.

7.2.1. Smoke

Smoke is released when the oxygen level is too low and the carbon content too high (Sekar et al. 2021). The research of Sekar et al., (2021) shows that more smoke is produced when plastic fuel is used. However, **the blended fuel emits less smoke** than the plastic fuel and fossil fuels (Sekar et al. 2021). The reason for this is that the blended fuel increases the oxygen compounds whereas a fraction of fossil fuel is replaced, reducing the carbon content and resulting in a **more balanced oxygen-carbon level** which produces less smoke (Sekar et al. 2021). To check whether these results are valid or not, other studies are compared whereas a study conducted by Padmanabhan et al., (2022) concluded the same results.

7.2.2. Nitrogen Emissions

The air contains 21% of oxygen and 79% of nitrogen. During combustion, when the temperature is high enough, the hydrocarbons will also react with the nitrogen where mainly NO and NO_2 are produced (AMWB 2023). Road transport is responsible for more than 50% of the NO_x emissions in the air (Lozhkina and Lozhkin 2016). Nitrogen stimulates photochemical smog and participates in removing ozone from the stratosphere (Jarquin-López et al. 2009). Removal of ozone ensures ultraviolet radiation reaches Earth, causing the Earth to warm up quickly (Jarquin-López et al. 2009). The precise amount of NO_x that is emitted per fuel is difficult to determine since the emissions are affected by vehicle speed, technology and motor temperature (Lozhkina and Lozhkin 2016). However, the conclusion from research by Lozhkin et al., (2016) shows that **diesel passenger cars produce more than 20 times more NO_x than gasoline passenger cars and**

for LPG-fueled cars, the NO_x emissions are 40% less than for gasoline cars (Bellin et al. 2022, Lozhkina and Lozhkin 2016).

Concerning plastic fuel, same as with smoke production, **NO_x emissions are produced less when the blend is used.** As previously mentioned, more oxygen in the process ensures less smoke. However, more oxygen produces more NO_x emissions (Sekar et al. 2021). Since this is a contrary situation when seeking for least emissions and pollution a solution to this is to find a blend which is most optimal considering the emissions and smoke the blends produce. This will not be further analysed in this research due to time constraints but is interesting for further research to take into account. The study by Sekar et al., 2021 researched the emission output during various loads of vehicles. In Table 7.1, the NO_x emissions per load are given for fossil fuels, full plastic fuel and blended plastic fuel.

	fossil fuel [ppm]	Full plastic fuel [ppm]	Blended plastic fuel [ppm]
25% load	500	525	480
50% load	785	850	740
75% load	1050	1200	920
100 % load	1290	1380	1215

Table 7.1: NO_x emissions per fuel type conduted in the study of Sekar et al., 2021

Padmanabhan et al., (2022) conducted the same type of study with various load differences and different types of blends. The results are shown in table 7.2 where only the blend type 20% plastic and 80% fuel is used from the results as this is most comparable to the study of Sekar et al., (2021).

	fossil fuel [ppm]	Full plastic fuel [ppm]	Blended plastic fuel [ppm]
25% load	320	500	460
50% load	480	780	600
75% load	720	850	780
100 % load	880	950	900

Table 7.2: NO_x emissions per fuel type conducted in the study of Padmanabhan et al., 2022

From both studies, the conclusion can be made that fully plastic fuel in general produces more NO_x emissions than the currently used fossil fuels. However, **a blended type of plastic fuel reduces the NO_x emissions relative to full plastic fuel but does not necessarily decrease the NO_x emissions compared to fossil fuels.** The NO_x emissions are very dependent on the temperature of combustion as well as load and therefore the two studies provide different answers.

7.2.3. Carbon Dioxide Emissions

When burning a fuel, carbon (C) is released. For each fuel, oxygen (O) is needed for a burning process to happen. Each fuel type contains different amounts of carbon whereas different amounts of oxygen bounds to this fuel which eventually results in carbon dioxide. For a litre of gasoline, 2269 grams of CO_2 is released, a litre of diesel will produce 2606 grams of CO_2 and a litre of LPG produces 1610 grams of CO_2 (AMWB 2023). The CO_2 emissions are summarized in table 7.3.

Car type	**CO_2** [grams/litre]
Gasoline	2269
Diesel	2606
LPG	1610

Table 7.3: CO_2 emissions per fuel type during engine combustion

CO_2 emissions are produced when there is incomplete combustion (fraction of oxygen missing) (Sekar et al. 2021). Plastic fuel contains more hydrocarbons than other fuels whereas a logical conclusion can be made that more CO_2 emissions will be produced. Again, **when blending the plastic fuel with fossil fuel, the CO_2 emissions will be reduced due to fewer hydrocarbons that can react with oxygen** (Sekar et al. 2021). A study from Padmanabhan et al. (2022), shows the CO_2 emissions produced by pyrolysis of plastic waste with different rates of plastic added to the mixture. The overall results show that fully plastic waste as fuel in general produces more emissions and air pollutants than fossil fuel (Padmanabhan et al. 2022). However, the most optimal mixture is using 20% fuel from plastic waste with 80% fossil fuel (WEE20) which results in fewer emissions and air pollutants (Padmanabhan et al. 2022). **The results show that plastic waste (100%) as fuel produced 6.81% more CO_2 emissions than fossil fuel at maximum load. However, the optimal mixture of 20% plastic (WEE20) resulted in 13.41% less CO_2 emissions at maximum load** (Padmanabhan et al. 2022).

7.3. Emissions Produced During Pyrolysis

The research conducted towards the emissions produced during the pyrolysis process is difficult to determine since the pyrolysis process can be tweaked easily with various catalysts, temperatures and pressures which can be applied, all resulting in various outcomes. Therefore, an exact number of the CO_2 produced is difficult to obtain. However, in 2017 CE Delft conducted research on the CO_2 emissions produced during the burning of plastic. In 2017, a range between 500-1000 kilotons of plastic (33%-66% of plastic waste produced) were burnt resulting in equivalent to 660 kilotons CO_2-eq and a maximum of 2640 kilotons CO_2-eq production respectively (Lynn Snijder and Sanne Nusselder 2019). In the following sections, multiple experiments and research are mentioned to **generate an approximately rough indication of the range of emissions produced during the pyrolysis process.**

7.3.1. Carbon Footprint

As mentioned in chapter 2, there exist three types of recycling plastic waste: landfilling, recycling and incineration. These three types all have different effects on the carbon footprint which indicates the impact made on climate change. Based on life cycle assessment studies, the CE Delft (Martijn Broeren and Geert Bergsma 2020) gathered information from literature and expert judgements through companies. Treating one tonne of plastic waste is equivalent to producing a certain tonne of CO_2. The carbon footprints measured consist of **emissions and energy inputs** and **avoided products/energy carriers**. The emissions and energy inputs refer to the direct process emissions and emissions produced linked to the production and supply of the inputs to the process (Martijn Broeren and Geert Bergsma 2020). The avoided products/energy carriers include the carbon footprint of the conventional production processes to obtain an output which can also be generated by waste treatment (the technologies which otherwise are used anyways) (Martijn Broeren and Geert Bergsma 2020). In this case, the fuel is produced from the pyrolysis process. This means that less fuel needs to be generated from conventional fuel resources, whereas **pyrolysis avoids these emissions of making fuels from conventional resources.** In combination with a study conducted by Kwon et al., (2023) a comparison of the CO_2 emissions of current plastic handling and the CO_2 emissions of the current fossil fuels is visualized in figure 7.1

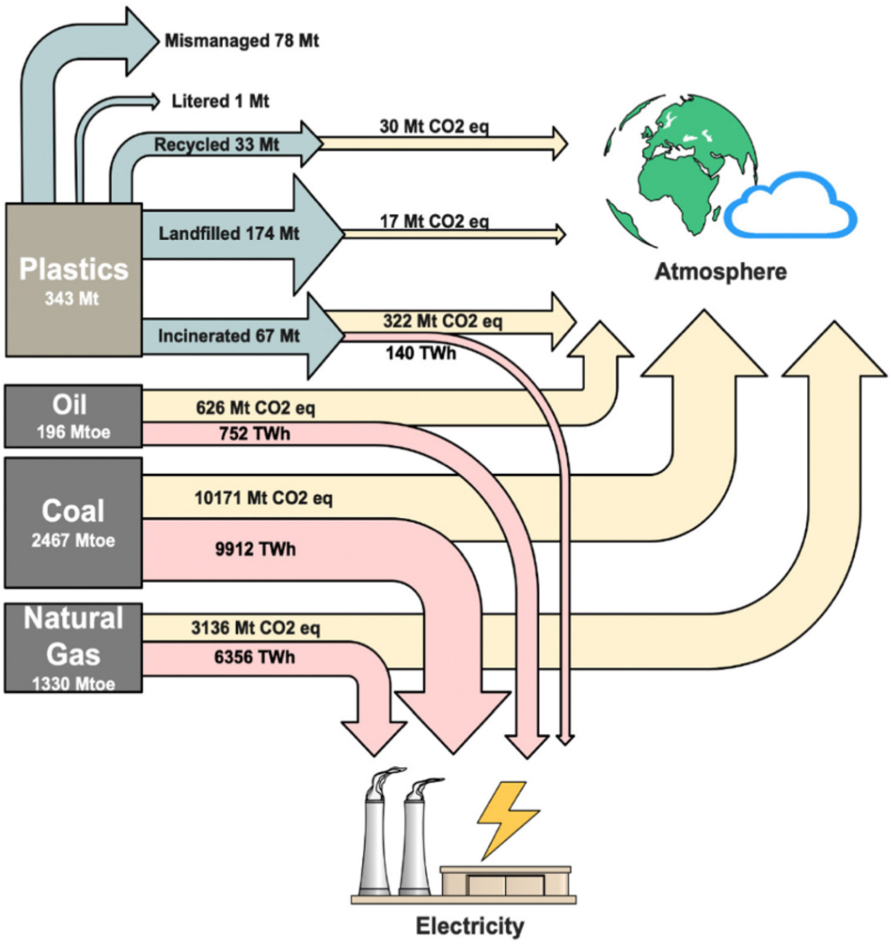

Figure 7.1: The energy produced by various energy sources and the emitted greenhouse gasses per energy source by Kwon et al., 2023

Since an additional aim of this research is to eliminate the complex process of sorting and separating plastic for recycling to obtain easier waste management, the main focus will be on the emissions produced during the pyrolysis process of mixed plastics. Therefore multiple articles and research are analysed to determine the eventual carbon footprint of the pyrolysis process for mixed plastics. The analysed researches show that the global effect would lead to a reduction of 143 Mt CO_2 eq according to the decrease in coal consumption that could be realised (Kwon et al. 2023) (Figure 7.1). The research of CE Delft shows that chemical recycling has the potential to reduce climate change impacts by 1 Mt CO_2 eq. by avoiding the current treatments of plastic in the Netherlands (Martijn Broeren and Geert Bergsma 2020). According to CBS (2022), the total emission production on the whole chain of the transport sector in 2021 was 23 Mt CO_2 eq. Thus the use of **chemical recycling will ensure a 4% reduction in CO_2 emissions** (CBS 2022).

7.3.2. Conversion Rates

A case study conducted in China reveals the economic and ecological feasibility of electricity generation from the oil produced during the pyrolysis of mixed plastic. This study finds that pyrolysis of the collected waste in China could yield 359.29 Mt oil which has the potential of producing 1060.86 GWh (Cudjoe, Brahim, and Zhu 2023). Recalculating results that **1 Mt of plastic oil can generate 2.95 GWh of electricity**. Generating electricity from mixed plastic causes a combustion reduction of 2659 tons of coal which has the potential of minimising global warming by 11278.8 kt CO_2eq over the period from 2009-2028 (Cudjoe, Brahim, and Zhu 2023). According to Cudjoe et al. (2023), the global warming potential (GWP) of mixed plastic is 1311.4 kt CO_2eq where approximately 75% of the GWP accounts for the conversion process of pyrolysis oil to electricity (Cudjoe, Brahim, and Zhu 2023). Approximately, 15% of the GWP accounts for the production of pyrolysis oil. Therefore, the conclusion can be made that **converting pyrolysis to electricity is responsible for more global warming potential than using pyrolysis oil as a fuel.**

7.4. Circularity

Circularity is becoming a more interesting subject within the sustainable development goals (SDG) which were determined during the Paris Agreement in 2015. According to Corona et al. (2019), The definition of circularity referring to materials is defined as ”economic growth is decoupled from resources use, through the reduction and recirculation of natural resources” (Corona et al. 2019). Within this definition, plastic can be seen as a recirculation of natural resources as plastics are made from oil. Plastic waste that will be recovered by the means of energy is an example of such circularity (Padmanabhan et al. 2022). Plastic waste which poses a significant problem for disposal or which is non-recycable, can be converted into energy in the form of fuel (Padmanabhan et al. 2022).

7.5. Conclusion

Thus, when comparing the tailpipe emissions produced by fossil fuels, plastic-blend and fully plastic fuel, a fully plastic fuel in all cases produces more smoke NO_x emissions and CO_2 emissions. However, when plastic oil is blended with fossil fuels, the exhaustion of smoke and CO_2 emissions is less than pure fossil fuel. The optimal blend exists of roughly 75-80% fossil fuel and 20-25% plastic. For NO_x emissions, further research is needed since the production of NO_x emissions is strongly influenced by temperature, the mixture of the fuel and excess of oxygen. However, the plastic blend does have an improvement in NO_x emissions compared to a fully plastic fuel. Thus, combining all the results of the GHG emissions, the conclusion can be made that implementing a plastic-based fuel is most feasible as fewer emissions are produced than with a fully plastic fuel. Furthermore, using plastic waste as a substitute for conventional fuel will lead to avoided products/energy carriers and thus the emissions produced during the use of conventional fuels are reduced. According to this theory, in the Netherlands, there would exist a **reduction of 1 Mt CO_2eq.** Since the process of converting plastic waste into electricity has a higher share of the GWP of mixed plastic than the conversion of plastic into oil, there exists a **motivation to produce oil from plastic rather than electricity.**

8 Conclusion and Discussion

8.1. Conclusion

The main goal of this research is to analyse the feasibility of implementing plastic waste as a source of transportation fuel. To research this, the parameters of converting plastic waste into fuel are analysed and how these parameters affect the consumer of socially accepting the use of plastic fuel. The social acceptance was tested through a survey. From this survey, the preference values of attributes for the consumers making a fuel choice were determined. Afterwards, the preference values are compared with the current situation and values available considering the use of plastic fuel regarding emissions and infrastructure to determine the feasibility of implementation. This section will provide the main conclusions made during the research and will answer the main research question:

"How do the social and environmental factors influence the acceptance and feasibility of implementation strategies which can promote the adoption of using plastic waste as a fuel source for transportation?"

The answer to the social part of the research question is strongly dependent on the situation the consumer lives in. In the situation of owning a car and the **possibility of using any fuel type for refuelling, the product choice that is made is dependent on price which is the most important influence factor, followed by emissions and then infrastructure.** These results are obtained through the unlabelled choice experiment in the first survey. However, **when transiting from one fuel to another**, specifically from gasoline to plastic fuel, the highest motivation whether to shift or not, is **influenced by the infrastructure referring to the availability of the fuel** at the gas stations. Thus the main motivation for the consumers not to use plastic fuel is when they have to put extra effort into seeking a place to refuel their car. When looking at this aspect, the **fuel must therefore have easy access to encourage the adaption to a plastic fuel**. From research done on policy frameworks and infrastructure, a strategy that can be applied to stimulate the use of plastic fuel is to **sell the fuel as a biofuel for fuel suppliers to obtain HBE points.** For a fuel to be certified as a biofuel to receive HBE points, the greenhouse gas emissions must be reduced by 50% over the entire chain compared to fossil fuels (NEa 2021). From research conducted on the emissions produced during combustion, the conclusion is made that **a blended fuel of roughly 75-80% fossil fuel and 20-25% plastic (which we further refer to as "plastic-based fuel") will ensure a 13.4% reduction of CO_2 emissions. Additionally, reducing the amount of fossil fuels used in the transportation sector will cause a reduction of 4% of CO_2 emissions. Unfortunately, the total CO_2 reduction does not reach the desired reduction of 50% of the NEa.** Therefore, the application of the HBEs system cannot stimulate the process of implementation of a plastic-based fuel. However, to further analyse the possibilities, research for the implementation of a blended plastic fuel is done. Since availability is most important for the consumer to transition to a plastic-based fuel, fuel suppliers must ensure that the application of a blended fuel has easy access and has no difficulties in refuelling. Fortunately, plastic-based fuel can be used in the current engines as the calorific values are comparable to fossil fuels. A strategy that can be applied is that **fuel suppliers decide to modify the composition of their currently sold fuel to a plastic-based fuel**. Therefore, the availability of plastic-based fuel will not become more difficult than the current access to fuel. An important aspect for fuel suppliers to keep in mind is that clear information on the process of using plastic waste as a fuel must be communicated to ensure adoption.

Considering the environmental part of the research questions, the results obtained from the surveys show that the tailpipe emissions from using the fuel are the second most important aspect of deciding whether to use plastic fuel. This is a logical motivation as the **worldwide desire to reduce CO_2 emissions** is becoming more acknowledged. As mentioned before, **a plastic-based fuel can stimulate this reduction with a 13.4% decrease of tailpipe emissions and 4% reduction due to avoided use of fossil fuels**, ensuring motivation to transit. Not only will the CO_2 emissions in the transport sector be reduced, but also **the problem of the large volumes of plastics will be tackled** as non-recyclable plastics can still generate added value. Additionally, improvement of plastic separation and management is not required as mixed plastics can be applied for the pyrolysis process. However, a major **concern about the use of plastic as a fuel is that plastic production will be stimulated, expanding the plastic problem.**

8.1.1. Recommendation

Thus, to promote the adoption of using plastic waste as a fuel source, **the fuel should be presented by a plastic-based fuel whereas roughly 75-80% is a fossil fuel blended with 20-25% plastic oil.** To reach this, fuel suppliers need to be encouraged to provide this blend by **modifying the composition** of the currently sold fuel. Hereby, the most influential factor of transiting to a plastic-based fuel is tackled due to the **easy availability for refuelling.** Furthermore, the second most influential parameter of reduction of emissions is stimulated by using plastic-based fuel as **CO_2 emissions will be reduced during combustion** compared to the currently used fossil fuels. In the above-described recommendation, the infrastructure will stay the same and the produced emissions will decrease. Since plastic-based fuel can be used in every engine, the choice consumers make is changed to a product choice rather than an adoption choice. **In the product choice (unlabelled experiment) the most important attribute was price.** Therefore, plastic-based fuel must be **brought to the market for a compatible price with gasoline.** Before implementation, thorough research must be conducted on the opportunity costs of plastic-based fuel and to what price a plastic-based fuel can be sold in the fuel market making the fuel compatible. Furthermore, **consumers must be aware of the circularity and added value** of plastic-based fuel. Highlighting the reduction of plastic waste and promotion of resource efficiency must be brought to their attention. Appropriate marketing and information sharing are therefore required. Additionally, **using plastic as a fuel by chemical recycling has greater energy potential than using chemical recycling for electricity.** This stimulates to using the excess plastic waste as fuel instead of electricity. Finally, plastic-based fuel has high potential in being a solution to **reducing plastic waste around the world** and accompanies the search for sustainable transition fuels. However, since a concern exists that using a plastic-based fuel will stimulate the production of plastics, this plastic-based fuel must be seen as a **temporary solution** which can help bridge the whole transition towards a net zero emissions society. The temporary solution will eliminate the fear of consumers thinking that using plastic-based fuel stimulates plastic production as it will only be used to reduce the current overload of plastic waste.

8.2. Discussion

Throughout this research, plastic-based fuel has become a promising solution to reduce the global problem of excess plastic waste and as a potential for more sustainable transportation fuel. However, the conclusions made in this research are limited by several aspects.

Considering the choice experiment, the results from the survey are quite biased as the respondents that have responded to the survey all exist in the same network. A lack of variance in the group results in a biased outcome. For example, the respondents that now were reached have a high preference weight for infrastructure whereas the preference of the population can differ and could have been price. To refute this limitation, a **larger sample size is required** which covers more variance in groups in the society. Another limitation of a choice experiment is that the **alternatives represented are hypothetical and therefore do not reflect a real-life situation** which cannot show how people would behave in the actual market. This phenomenon is described by Jansson et al. (2019) where he explains the difference between public acceptance and public support (Jansson and Rezvani 2019). Also, respondents might manipulate their response towards what society expects instead of what their actual motivation will be. Respondents may even strategically choose an alternative based on their understanding of the study corresponding to the expectation of the researcher (Meginnis et al. 2021). Furthermore, after publishing the second survey, the most optimal situation would be to ensure that the exact same respondents would fill in the second survey as well. As expected, the second survey received fewer respondents. This could be due to people already thinking they filled in the survey as the survey is sent from the same person, consisting of comparable research. Also, people might take less effort in filling out two surveys whereas the **cognitive burden has reached its limit**. Therefore, the second survey has an even higher potential of being biased due to an even smaller sample size. Additionally, the chosen attributes that were examined in the choice experiment were reasoned by previous studies. As seen from the textual argumentation of the respondents, **there exist more factors influencing the choice of willingness to transit to a plastic fuel**. Here, reducing plastic use, engine performance and already driving a sustainable alternative, are additional attributes which could have been examined. Due to time constraints and limitations of the network, the choice was made to only examine the attributes which, according to previous studies, seemed to be the most influential factors in previous transitions. Lastly, the survey results show a **variance in parameter estimation for the same attribute** (e.g. Price A and Price B). This difference also occurs due to the small sample size as the correlation between attribute levels may occur. Larger sample sizes will decrease the probability of two respondents selecting a fuel rather than the attribute.

The choice experiment is not the only aspect of this research that has limitations. Since the **process of pyrolysis** is still further developing, whereas a lot of parameters can be adjusted making the process more effective, various studies have shown different research outcomes resulting in a rough indication of what the truth is. Not only for the pyrolysis process but also for the emissions produced during combustion, various parameters such as oxygen availability, temperature and the ratio of plastic to fuel can have great variance in produced emissions. Since a combination of the results from multiple studies is used, the exists no precise conclusion. **There exists uncertainty about whether the studies used during this research are valid or not.** For example, two researchers have studied the emissions produced during the combustion of the engine in various stadiums and described the same parameter inputs (load of vehicle and fuel blends). Sekar et al. (2021) concluded that for all emitted products (CO_2. NO_x and smoke) the emissions were less for a blended fuel than for a fossil fuel. However, Padmanabhan et al. (2022) showed that blended fuel did perform better than a fully plastic fuel, but not less than a fossil fuel. Therefore, it is hard to determine which study is more valid and therefore better to refer to.

Finally, **this research misses a research question concerning the opportunity costs**. Due to the high uncertainty of the investment costs required and the fluctuating oil price, influencing the price of a plastic fuel, the eventual price indication for a plastic fuel is very difficult to predict.

8.2.1. Further Research

As mentioned above, there are several limitations to this research. **For further research, it is important to consider these limitations.** Future research might require **more time to obtain a larger sample size** for the survey. Also, the surveys which were sent out need to be revised and ensured that the survey consists of a combination of both surveys created during this research. This will ensure that the same respondents will answer the questionnaire resulting in more convincing and reliable results. Additionally, the attributes that have been tested in this research can be **expanded by the attributes that were now left out** such as engine performance, refuelling time and driving range. The reason for this is due to the identification of the respondents that they do find these attributes important during the consumer's choice. Before implementing a plastic-based fuel, **further research can be done on the optimal blend**. In this research, a range of 20-25% plastic is used. The exact percentage of added plastic which produces the least emissions can be further researched through experiments to generate the most optimal blend. Furthermore, to make the conclusions drawn from desk research valid, **experiments on the combustion of the engine** must be further examined to validate the conclusions made in this research. Moreover, additional research can be done to determine whether **pyrolysis is indeed the most efficient conversion technology** or whether other technologies are better applicable for creating a plastic-based fuel. If so, **further development and optimisation of the pyrolysis process** is recommended to enable the process to become more attractive from a sustainable point of view. Additionally, the fluctuating costs of oil prices made it difficult to research and predict what price would be reasonable to sell the plastic-based fuel for. In further research, the opportunity costs of using a plastic-based fuel can be determined to analyse **whether the plastic-based fuel can be sold at a compatible price in the fuel market**, making plastic-based fuel economically feasible for implementation. Lastly, a model can be made based on the influential factors considering the transition towards a plastic-based fuel. With this model, **a tipping point can be found which can provide more precise values of the level** of price reduction, infrastructure availability or reduction of emissions that will stimulate the consumers to transit.

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A

Syntax for Ngene

A.1. Syntax for Ngene: Generate optimal unlabelled choice metrics

```
design
;alts = FuelA, FuelB ? two alternatives
;rows = 9            ? design size of 9 choice tasks
;orth = ood          ? generate optimal orthogonal design ?
;model:
U(FuelA) = cost * PRICE[2.25,1.5,0.75] + infr * INFRASTRUCTURE[50,75,100]
    + ems * EMISSIONS[0,-1,1] /
U(FuelB) = cost * PRICE + infr * INFRASTRUCTURE + ems * EMISSIONS
$
```

A.2. Syntax for Ngene: Generate efficient labelled choice metric

```
design
;alts = Plastic, Gasoline ? two alternatives
;rows = 3                 ? design size of 3 choice tasks
;eff = (mnl,d)            ? generate efficient choice metric design ?
;model:
U(FuelA) = cost * PRICE[2.25,1.5,0.75] + infr * INFRASTRUCTURE[50,75,100]
    + ems * EMISSIONS[0,-1,1] /
U(FuelB) = cost * PRICEb [2] + infr * INFRASTRUCTUREb [100] + ems *
    EMISSIONSb [0]
$
```

A.3. Syntax for Ngene: Second Survey : Generate efficient labelled choice metric

```
design
;alts = Plastic, Gasoline ? two alternatives
;rows = 12                ? design size of 9 choice tasks
;eff = (mnl ,d)           ? generate efficient choice metric design ?
;model:
U(Plastic) = cost * PRICE[2.25,1.5,0.75] + infr * INFRASTRUCTURE
     [50,75,100] + ems * EMISSIONS[0,-1,1] /
U(Gasoline) = cost * PRICEb [2] + infr * INFRASTRUCTUREb [100] + ems *
     EMISSIONSb [0]
$
```

A.4. Outcome orthogonal unlabeled choice metric

	Fuel 1			Fuel 2		
Task	Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
1	€2,25	access at 50% of stations	equal CO_2	€1,50	access at 75% of stations	less CO_2
2	€1,50	access at 75% of stations	equal CO_2	€0,75	access at all stations	less CO_2
3	€0,75	access all stations	equal CO_2	€2,25	access at 50% of stations	less CO_2
4	€1,50	access at 50% of stations	less CO_2	€0,75	access at 75% of stations	more CO_2
5	€0,75	access at 75% of stations	less CO_2	€2,25	access at all stations	more CO_2
6	€2,25	access at all stations	less CO_2	€1,50	access at 50% of stations	more CO_2
7	€0,75	access at 50% of stations	more CO_2	€2,25	access at 75% of stations	equal CO_2
8	€2,25	access at 75% of stations	more CO_2	€1,50	access at all stations	equal CO_2
9	€1,50	access at all stations	more CO_2	€0,75	access at 50% of stations	equal CO_2
10	€2,25	access at all stations	less CO_2	€2,00	access at all stations	equal CO_2
11	€0,75	access at 75% of stations	more CO_2	€2,00	access at all stations	equal CO_2
12	€1,50	access at 50% of stations	equal CO_2	€2,00	access at all stations	equal CO_2

Table A.1: Unlabelled Choice Tasks for Fuel Choice

A.5. Outcome efficient labelled choice metric

A.5.1. Choice set 1

	Plastic			Gasoline		
Choice	Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
1	€1,50	access at 50% of stations	equal CO_2	€2,00	access at all stations	equal CO_2
2	€0,50	access at all stations	more CO_2	€2,00	access at all stations	equal CO_2
3	€2,50	access at 75% of stations	less CO_2	€2,00	access at all stations	equal CO_2

Table A.2: Labelled Choice Tasks for Fuel Choice Set 1

A.5.2. Choice set 2

	Plastic			Gasoline		
Choice	Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
1	€2,50	access at 50% of stations	equal CO_2	€2,00	access at all stations	equal CO_2
2	€0,50	access at 75% of stations	more CO_2	€2,00	access at all stations	equal CO_2
3	€1,50	access at all stations	less CO_2	€2,00	access at all stations	equal CO_2

Table A.3: Labelled Choice Tasks for Fuel Choice Set 2

A.5.3. Choice set 3

	Plastic			Gasoline		
Choice	Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
1	€2,25	access at all stations	less CO_2	€2,00	access at all stations	equal CO_2
2	€0,75	access at 75% of stations	more CO_2	€2,00	access at all stations	equal CO_2
3	€1,50	access at 50% of stations	equal CO_2	€2,00	access at all stations	equal CO_2

Table A.4: Labelled Choice Tasks for Fuel Choice Set 3

A.6. Outcome second version efficient labelled choice metric

	Plastic			Gasoline		
Task	Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
1	€0,75	access at 75% of stations	more CO_2	€2,00	access at all stations	equal CO_2
2	€2,25	access at all stations	equal CO_2	€2,00	access at all stations	equal CO_2
3	€1,50	access at 75% of stations	more CO_2	€2,00	access at all stations	equal CO_2
4	€1,50	access at all stations	less CO_2	€2,00	access at all stations	equal CO_2
5	€0,75	access at 50% of stations	equal CO_2	€2,00	access at all stations	equal CO_2
6	€0,75	access at 50% of stations	less CO_2	€2,00	access at all stations	equal CO_2
7	€2,25	access at 50% of stations	equal CO_2	€2,00	access at all stations	equal CO_2
8	€2,25	access at 75% of stations	equal CO_2	€2,00	access at all stations	equal CO_2
9	€1,50	access at 75% of stations	less CO_2	€2,00	access at all stations	equal CO_2
10	€1,50	access at all stations	more CO_2	€2,00	access at all stations	equal CO_2
11	€2,25	access at all stations	less CO_2	€2,00	access at all stations	equal CO_2
12	€0,75	access at 50% of stations	more CO_2	€2,00	access at all stations	equal CO_2

Table A.5: Sercond Survey Scenarios for Labelled Choice Tasks for Fuel Choice

B

Choice Sets for Survey

B.1. First Version

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
€ 2,50	accesable at 50% of the gasstations	equal CO2 emissions as your currently used fuel	€ 1,50	accesable at 75% of the gasstations	less CO2 emissions as your currently used fuel

choice set 1

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
€ 1,50	accesable at 75% of the gasstations	equal CO2 emissions as your currently used fuel	€ 0,50	accesable at all gasstations	less CO2 emissions as your currently used fuel

choice set 2

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
€ 0,50	accesable at all gasstations	equal CO2 emissions as your currently used fuel	€ 2,50	accesable at 50% of the gasstations	less CO2 emissions as your currently used fuel

choice set 3

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
€ 1,50	accesable at 50% of the gasstations	less CO2 emissions as your currently used fuel	€ 0,50	accesable at 75% of the gasstations	more CO2 emissions as your currently used fuel

choice set 4

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
€ 0,50	accesable at 75% of the gasstations	less CO2 emissions as your currently used fuel	€ 2,50	accesable at all gasstations	more CO2 emissions as your currently used fuel

choice set 5

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
€ 2,50	accesable at all gasstations	less CO2 emissions as your currently used fuel	€ 1,50	accesable at 50% of the gasstations	more CO2 emissions as your currently used fuel

choice set 6

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
€ 0,50	accesable at 50% of the gasstations	more CO2 emissions as your currently used fuel	€ 2,50	accesable at 75% of the gasstations	equal CO2 emissions as your currently used fuel

choice set 7

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
€ 2,50	accesable at 75% of the gasstations	more CO2 emissions as your currently used fuel	€ 1,50	accesable at all gasstations	equal CO2 emissions as your currently used fuel

choice set 8

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
€ 1,50	accesable at all gasstations	more CO2 emissions as your currently used fuel	€ 0,50	accesable at 50% of the gasstations	equal CO2 emissions as your currently used fuel

choice set 9

Plastic			Gasoline		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
€ 2,50	accesable at 50% of the gasstations	equal CO2 emissions as your currently used fuel	€ 2,00	accesable at all gasstations	equal CO2 emissions as your currently used fuel

choice set 10

Plastic			Gasoline		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
€ 0,50	accesable at 75% of the gasstations	more CO2 emissions as your currently used fuel	€ 2,00	accesable at all gasstations	equal CO2 emissions as your currently used fuel

choice set 11

Plastic			Gasoline		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
€ 1,50	accesable at all gasstations	less CO2 emissions as your currently used fuel	€ 2,00	accesable at all gasstations	equal CO2 emissions as your currently used fuel

choice set 12

B.2. Second Version

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
	50%	= CO_2		75%	↓ CO_2
€ 2,25	accessible at 50% of the gasstations	CO2 emissions equal to your currently used fuel	€ 1,50	accessible at 75% of the gasstations	less CO2 emissions than your currently used fuel

choice set 1

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
	75%	= CO_2		100%	↓ CO_2
€ 1,50	accessible at 75% of the gasstations	CO2 emissions equal to your currently used fuel	€ 0,75	accessible at all gasstations	less CO2 emissions than your currently used fuel

choice set 2

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
	100%	= CO_2		50%	↓ CO_2
€ 0,75	accessible at all gasstations	CO2 emissions equal to your currently used fuel	€ 2,25	accessible at 50% of the gasstations	less CO2 emissions than your currently used fuel

choice set 3

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
	50%	↓ CO_2		75%	↑ CO_2
€ 1,50	accessible at 50% of the gasstations	less CO2 emissions than your currently used fuel	€ 0,75	accessible at 75% of the gasstations	more CO2 emissions than your currently used fuel

choice set 4

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
	75%	↓ CO_2		100%	↑ CO_2
€ 0,75	accessible at 75% of the gasstations	less CO2 emissions than your currently used fuel	€ 2,25	accessible at all gasstations	more CO2 emissions than your currently used fuel

choice set 5

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
	100%	↓ CO_2		50%	↑ CO_2
€ 2,25	accessible at all gasstations	less CO2 emissions than your currently used fuel	€ 1,50	accessible at 50% of the gasstations	more CO2 emissions than your currently used fuel

choice set 6

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
	50%	↑ CO_2		75%	= CO_2
€ 0,75	accessible at 50% of the gasstations	more CO2 emissions than your currently used fuel	€ 2,25	accessible at 75% of the gasstations	CO2 emissions equal to your currently used fuel

choice set 7

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
	75%	↑ CO_2		100%	= CO_2
€ 2,25	accessible at 75% of the gasstations	more CO2 emissions than your currently used fuel	€ 1,50	accessible at all gasstations	CO2 emissions equal to your currently used fuel

choice set 8

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
	100%	↑ CO_2		50%	= CO_2
€ 1,50	accessible at all gasstations	more CO2 emissions than your currently used fuel	€ 0,75	accessible at 50% of the gasstations	CO2 emissions equal to your currently used fuel

choice set 9

Plastic			Gasoline		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
	100%	↓ CO_2		100%	= CO_2
€ 2,25	accessible at all gasstations	less CO2 emissions than your currently used fuel	€ 2,00	accessible at all gasstations	CO2 emissions equal to your currently used fuel

choice set 10

Plastic			Gasoline		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
	75%	↑ CO_2		100%	= CO_2
€ 0,75	accessible at 75% of the gasstations	more CO2 emissions than your currently used fuel	€ 2,00	accessible at all gasstations	CO2 emissions equal to your currently used fuel

choice set 11

Plastic			Gasoline		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
	50%	= CO_2		100%	= CO_2
€ 1,50	accessible at 50% of the gasstations	CO2 emissions equal to your currently used fuel	€ 2,00	accessible at all gasstations	CO2 emissions equal to your currently used fuel

choice set 12

C

Survey Questions

Introduction

Thankyou for participating in this survey.

This study is executed by Pascale Six at TU Delft as a Master thesis research. The purpose of this research is to examine the choice behaviour concerning car fuel.

We will ask you to provide some (anonymous) information on vehicle use and thereafter, in several questions you are asked to choose between two fuels. This survey will first consist of 5 questions concerning personal information about driving. After that, 9 scenario's are given where you have to choose between alternative fuels. Then, 3 new scenario's are given with specified fuels and lastly, additional questions are asked concerning your motivation to choose an alternative. This survey will take about 5 - 7 minutes.

The data will be used for analysing the most important influence factors to generate a model on implementation of an alternative fuel.

As with any online activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks by keeping the answers completely anonymous. Your participation in this study is entirely voluntary and you can withdraw at any time. The obtained data will be deleted after the research is finished. For any questions, please contact Pascale Six (p.j.six@student.tudelft.nl) By completing the survey, you agree to the use of your answers for researching the implementation of an alternative fuel.

How old are you?

- <18

- 18-20
- 21-30
- 31-40
- 41-50
- 51-60
- 61-70
- 70+

What gender do you have?

- Male
- Female
- Non-binary
- Prefer not to say

Do you have a driver's license?

- Yes
- No

Do you own (lease/often rent or borrow) a car?

- Yes
- No

What type of fuel do you (mostly) use?

- Petrol/Gasoline (Benzine)
- Diesel
- LPG (Liquified Petroleum Gas)
- Hybride
- Fully electric
- Not applicable

Explanation of the scenarios

In the next section, you will be given 9 scenarios. Each scenario represents a hypothetical question concerning a fuel choice. For each question, two alternatives are given and you must provide your preferred alternative concerning three variables: price, infrastructure (availability to refuel) and emissions (tailpipe emissions). Imagine that you are at a gas station and you want to refuel your car. Every fuel they offer can be used in your car. Which fuel would you choose?

Scenario 1

Scenario 1: If you have to choose between one of these fuel types, which fuel would you choose? Fuel A or Fuel B?

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
€ 2,25	accessible at 50% of the gasstations	CO2 emissions equal to your currently used fuel	€ 1,50	accessible at 75% of the gasstations	less CO2 emissions than your currently used fuel

- Fuel A
- Fuel B

Scenario 2

Scenario 2: If you have to choose between one of these fuel types, which fuel would you choose? Fuel A or Fuel B?

Fuel A			Fuel B		
Price	**Infrastructure**	**Emissions**	**Price**	**Infrastructure**	**Emissions**
	75%	CO_2 = CO_2		100%	CO_2 CO_2
€ 1,50	accessible at 75% of the gasstations	CO2 emissions equal to your currently used fuel	€ 0,75	accessible at all gasstations	less CO2 emissions than your currently used fuel

- Fuel A
- Fuel B

Scenario 3

Scenario 3: If you have to choose between one of these fuel types, which fuel would you choose? Fuel A or Fuel B?

Fuel A			Fuel B		
Price	**Infrastructure**	**Emissions**	**Price**	**Infrastructure**	**Emissions**
	100%	CO_2 = CO_2		50%	CO_2 CO_2
€ 0,75	accessible at all gasstations	CO2 emissions equal to your currently used fuel	€ 2,25	accessible at 50% of the gasstations	less CO2 emissions than your currently used fuel

- Fuel A
- Fuel B

Scenario 4

Scenario 4: If you have to choose between one of these fuel types, which fuel would you choose? Fuel A or Fuel B?

Fuel A			Fuel B		
Price	**Infrastructure**	**Emissions**	**Price**	**Infrastructure**	**Emissions**
€ 1,50	accessible at 50% of the gasstations	less CO2 emissions than your currently used fuel	€ 0,75	accessible at 75% of the gasstations	more CO2 emissions than your currently used fuel

- Fuel A
- Fuel B

Scenario 5

Scenario 5: If you have to choose between one of these fuel types, which fuel would you choose? Fuel A or Fuel B?

Fuel A			Fuel B		
Price	**Infrastructure**	**Emissions**	**Price**	**Infrastructure**	**Emissions**
€ 0,75	accessible at 75% of the gasstations	less CO2 emissions than your currently used fuel	€ 2,25	accessible at all gasstations	more CO2 emissions than your currently used fuel

- Fuel A
- Fuel B

Scenario 6

Scenario 6: If you have to choose between one of these fuel types, which fuel would you choose? Fuel A or Fuel B?

Fuel A			Fuel B		
Price	**Infrastructure**	**Emissions**	**Price**	**Infrastructure**	**Emissions**
€ 2,25	accessible at all gasstations	less CO2 emissions than your currently used fuel	€ 1,50	accessible at 50% of the gasstations	more CO2 emissions than your currently used fuel

- Fuel A
- Fuel B

Scenario 7

Scenario 7: If you have to choose between one of these fuel types, which fuel would you choose? Fuel A or Fuel B?

Fuel A			Fuel B		
Price	**Infrastructure**	**Emissions**	**Price**	**Infrastructure**	**Emissions**
€ 0,75	accessible at 50% of the gasstations	more CO2 emissions than your currently used fuel	€ 2,25	accessible at 75% of the gasstations	CO2 emissions equal to your currently used fuel

- Fuel A
- Fuel B

Scenario 8

Scenario 8: If you have to choose between one of these fuel types, which fuel would you choose? Fuel A or Fuel B?

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
€€€	75%	↑ CO_2 CO_2	€€	100%	CO_2 = CO_2
€ 2,25	accessible at 75% of the gasstations	more CO2 emissions than your currently used fuel	€ 1,50	accessible at all gasstations	CO2 emissions equal to your currently used fuel

- Fuel A
- Fuel B

Scenario 9

Scenario 9: If you have to choose between one of these fuel types, which fuel would you choose? Fuel A or Fuel B?

Fuel A			Fuel B		
Price	Infrastructure	Emissions	Price	Infrastructure	Emissions
€€	100%	↑ CO_2 CO_2	€	50%	CO_2 = CO_2
€ 1,50	accessible at all gasstations	more CO2 emissions than your currently used fuel	€ 0,75	accessible at 50% of the gasstations	CO2 emissions equal to your currently used fuel

- Fuel A
- Fuel B

Explanation second part of scenarios

In the upcoming questions, 3 scenarios are described as comparable with the previous scenarios. However, now you get the choose between a fuel made out of plastic waste and gasoline. Plastic fuel is produced by melting plastic into oil. This oil has the same value as diesel or gasoline whereas this fuel can directly be used in the engine.

Scenario 1

Scenario 1: If you have to choose between one of these fuel types, which fuel would you choose? Fuel A or Fuel B?

Plastic			Gasoline		
Price	**Infrastructure**	**Emissions**	**Price**	**Infrastructure**	**Emissions**
€ 2,25	accessible at all gasstations	less CO2 emissions than your currently used fuel	€ 2,00	accessible at all gasstations	CO2 emissions equal to your currently used fuel

- Plastic
- Gasoline

Scenario 2

Scenario 2: If you have to choose between one of these fuel types, which fuel would you choose? Fuel A or Fuel B?

Plastic			Gasoline		
Price	**Infrastructure**	**Emissions**	**Price**	**Infrastructure**	**Emissions**
€ 0,75	accessible at 75% of the gasstations	more CO2 emissions than your currently used fuel	€ 2,00	accessible at all gasstations	CO2 emissions equal to your currently used fuel

- Plastic
- Gasoline

Scenario 3

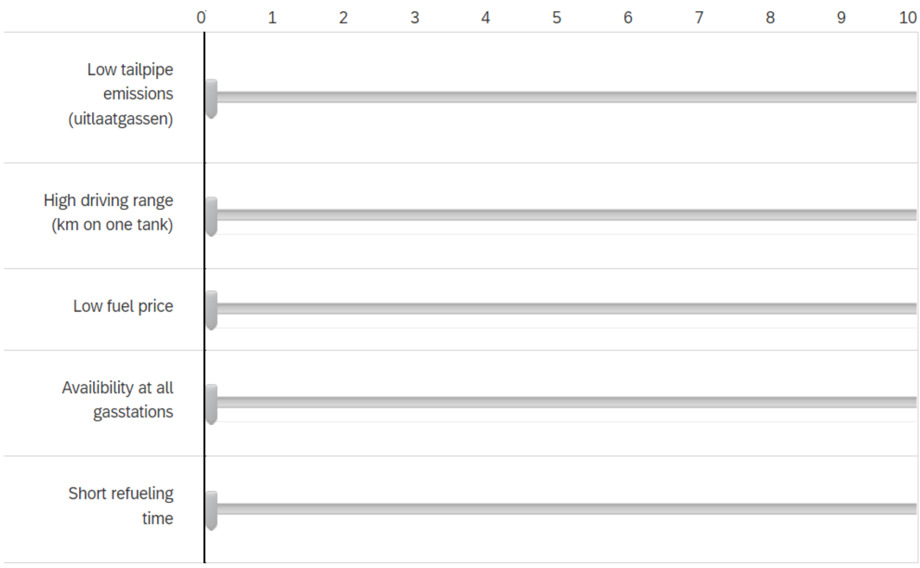
Scenario 3: If you have to choose between one of these fuel types, which fuel would you choose? Fuel A or Fuel B?

Plastic			Gasoline		
Price	**Infrastructure**	**Emissions**	**Price**	**Infrastructure**	**Emissions**
€ 1,50	accessible at 50% of the gasstations	CO2 emissions equal to your currently used fuel	€ 2,00	accessible at all gasstations	CO2 emissions equal to your currently used fuel

- Plastic
- Gasoline

Ranking

Please give a degree of importance to each variable that influences your decision the most when choosing a fuel (drag the slider to your importance level 0 = not important, 10 = very important)



To make a plastic-based fuel, plastic needs to be burnt to create an oil. This oil can directly be used in an engine. Would you be willing to transit to a plastic-based fuel?

- Yes
- No, because:
- Depends on:

To make a plastic-based fuel, plastic needs to be burnt to create an oil. This oil can directly be used in an engine. Considering that in the Netherlands 58% of our plastic waste is already burnt, would you be willing to use a plastic-based fuel?

- Yes
- No, because:
- Depends on:

End

We thank you for your time spent taking this survey.
Your response has been recorded.

D

Analytic methods for data handling

D.1. Conditional Logit

For a two-alternative DCE is frequently analysed using a limited dependant-variable model (Hauber et al. 2016). The basic method to apply is the conditional logit model. The conditional logit model represented by McFadden (1974) relates to the probability of a choice made among two or more alternatives with varying characteristics provided with attribute levels (Hauber et al. 2016). Thus, the conditional logit model determines the function of the characteristics of the alternatives rather than the characteristics of the individual (Hoffman and Duncan 1988). The attribute levels chosen by the respondent determine their choice profile. The model was consistent with the random utility theory referring to the probability of a respondent choosing an alternative based on individual characteristics and relative attractiveness (Zhong et al. 2022). This model also assumes that when an individual needs to make a choice, the individual will choose the alternative that maximizes his or her utility (Hauber et al. 2016). The conditional logit model is widely used in transportation demand studies (Hoffman and Duncan 1988).

There are two main limitations to the use of conditional logit. First, the conditional logit model assumes that the choice tasks measure utility equally well across all respondents. Secondly, the model does not take unobserved systematic differences in preferences into account (Hauber et al. 2016). Thus, with the conditional logit model, there exists scale heterogeneity and preference heterogeneity. Concerning scale heterogeneity, the scale is constant across respondents. This constant scale ignores the potential systemic variations in the model variance across choice tasks or groups which can result is a biased estimate of preference weights (Hauber et al. 2016). This same problem occurs for preference heterogeneity. The model assumes that all individuals have the same preferences that are represented in a single set of preference weights (Hauber et al. 2016).

D.2. Multinominal Logit (MNL)

The multinomial logit model is similar to the conditional logit model. Both models use the same statistical assumptions related to choice and variables used to choose. However, MNL relates choices to the characteristics of the individual making the choice (Hauber et al. 2016,Hoffman and Duncan 1988).

D.3. Random-Parameters Logit (RPL)

Random-parameter logit is a method that assumes the probability of selecting an alternative in a choice set, is a function of the attribute levels and a random error term that adjusts for individual-specific variations in preferences. In other words, the RPL is a combination of the conditional logit model and the MNL and therefore also known as the mixed-logit model (Hoffman and Duncan 1988). The RPL model assumes there exists a distribution of preference weights and reflects on the difference in preferences between individuals. The model estimates both a mean and a standard deviation effect (Hauber et al. 2016). A challenge of the RPL is that an individual's preference is not directly interpretable and therefore, it is difficult to determine the distributional characteristics of preferences (Hauber et al. 2016). The main limitation of RPL is that multiple simulations are necessary since the parameters of the simulation are not set to be the same across regression (Hauber et al. 2016).

D.4. Hierarchical Bayes (HB)

The hierarchical Bayes (HB) model generates preference estimates for each individual in the sample. The underlying choice-probability model is conditional logit. This model is however used to model each response per individual and not all responses at once. These individual responses are used to construct the distribution of preference weights access respondents. The mean and standard deviation are determined for each attribute level (Hauber et al. 2016). Considering conditional logit and RPL, the distribution of the mean preference weights is similar to the HB model. The large variety in the standard deviation means that respondents have different preferences for each attribute level. An advantage of the HB model compared to conditional logit and RPL is that the HB model requires no assumption of the common scale of the respondents (Hauber et al. 2016). A limitation of the HB model is that the procedure can be slower and is implemented in fewer software packages. The output of the HB model also requires some knowledge of sampling methods and Bayesian statistics (Hauber et al. 2016).

D.5. Latent-Class Finite-Mixture Model (LCM)

The LCM model assumes different groups and classes from the sample responses. This model assumes that each class had identical preference weights and that these weights are systematically different than other groups or classes (Hauber et al. 2016). This model also applies the conditional logit model.

E

Python code

E.1. Syntax for Biogeme: Generate parameters estimation for attributes from obtained data from unlabelled choice experiment

```
import pandas as pd
import biogeme.database as db
from biogeme.expressions import Variable
import biogeme.biogeme as bio
from biogeme import models
from biogeme.expressions import Beta

df = pd.read_csv ('Unlabelled_input_biogeme_csv.csv',  sep = ',')
database = db.Database ('Unlabelled_input_biogeme_csv', df )

Respondent = Variable('Respondent_ID')
Task = Variable('Choice_Task')
Price_A = Variable('Price_A')
Price_B = Variable('Price_B')
Infra_A = Variable('Infra_A')
Infra_B = Variable('Infra_B')
Emission_A = Variable('Emission_A')
Emission_B = Variable('Emission_B')
Choice = Variable('Choice')

#Define the basis of the beta's
ASC_fuel_A = Beta ( 'ASC_fuel_A' , 0, None , None , 1)
ASC_fuel_B = Beta ( 'ASC_fuel_B' , 0, None , None , 1)
Beta_Price_A = Beta ( 'Beta_Price_A' , 0, None , None , 0)
Beta_Price_B = Beta ( 'Beta_Price_B' , 0, None , None , 0)
Beta_Infra_A = Beta ( 'Beta_Infra_A' , 0, None , None , 0)
Beta_Infra_B = Beta ( 'Beta_Infra_B' , 0, None , None , 0)
Beta_Emission_A = Beta ( 'Beta_Emission_A' , 0, None , None , 0)
Beta_Emission_B = Beta ( 'Beta_Emission_B' , 0, None , None , 0)

```

```
#Define the utility function
V_fuelA = ASC_fuel_A + (Beta_Price_A * Price_A) + (Beta_Infra_A * Infra_A)
     + (Beta_Emission_A * Emission_A)
V_fuelB = ASC_fuel_B + (Beta_Price_B * Price_B) + (Beta_Infra_B * Infra_B)
     + (Beta_Emission_B * Emission_B)


#state the availability
av = None

#create dictionaries
V = {1: V_fuelA , 2: V_fuelB}

#Define Choice model
logprob = models.loglogit (V , av , Choice )

#Create Biogeme object
the_biogeme = bio . BIOGEME ( database , logprob )

#Rename Biogeme object
the_biogeme.modelName = 'Biogeme_thesis_Pascale_Six'

#Create results of the model
results = the_biogeme.estimate ()
#print(results)

pandas_results = results.getEstimatedParameters()
print ( pandas_results )
```

E.1.1. Python output from syntax

	Value	Rob. Std err	Rob. t-test	Rob. p-value
Beta_Emission_A	-1.063938	0.151794	-7.009092	2.398748e-12
Beta_Emission_B	-0.941324	0.144673	-6.506543	7.689960e-11
Beta_Infra_A	0.121918	0.154310	0.790087	4.294770e-01
Beta_Infra_B	0.508762	0.203114	2.504810	1.225173e-02
Beta_Price_A	-1.395476	0.180510	-7.730761	1.065814e-14
Beta_Price_B	-1.577249	0.149513	-10.549254	0.000000e+00

Figure E.1: Results from labelled choice experiment

E.2. Syntax for Biogeme: Generate parameters estimation for attributes from obtained data from labelled experiment

```
import pandas as pd
import biogeme.database as db
from biogeme.expressions import Variable
import biogeme.biogeme as bio
from biogeme import models
from biogeme.expressions import Beta
```

```

df = pd.read_csv ('Labelled_input_biogeme_CSV.csv',  sep = ',')
database = db.Database ('Labelled_input_biogeme_CSV', df )

Respondent = Variable('Respondent_ID')
Task = Variable('Choice_Task')
Price_Plastic = Variable('Price_Plastic')
Price_Gas = Variable('Price_Gas')
Infra_Plastic = Variable('Infra_Plastic')
Infra_Gas = Variable('Infra_Gas')
Emission_Plastic = Variable('Emission_Plastic')
Emission_Gas = Variable('Emission_Gas')
Choice = Variable('Choice')

#Define the basis of the beta's
ASC_fuel_Plastic = Beta ( 'ASC_fuel_Plastic' , 0, None , None , 0)
ASC_fuel_Gas = Beta ( 'ASC_fuel_Gas' , 0, None , None , 0)
Beta_Price_Plastic = Beta ( 'Beta_Price_Plastic' , 0, None , None , 0)
Beta_Price_Gas = Beta ( 'Beta_Price_Gas' , 0, None , None , 0)
Beta_Infra_Plastic = Beta ( 'Beta_Infra_Plastic' , 0, None , None , 0)
Beta_Infra_Gas = Beta ( 'Beta_Infra_Gas' , 0, None , None , 0)
Beta_Emission_Plastic = Beta ( 'Beta_Emission_Plastic' , 0, None , None ,
    0)
Beta_Emission_Gas = Beta ( 'Beta_Emission_Gas' , 0, None , None , 0)

#Define the utility function
V_fuel_Plastic = ASC_fuel_Plastic + (Beta_Price_Plastic * Price_Plastic) +
     (Beta_Infra_Plastic * Infra_Plastic) + (Beta_Emission_Plastic *
    Emission_Plastic)
V_fuel_Gas = ASC_fuel_Gas + (Beta_Price_Gas * Price_Gas) + (Beta_Infra_Gas
     * Infra_Gas) + (Beta_Emission_Gas * Emission_Gas)


#state the availability
av = None

#create dictionaries
V = {1: V_fuel_Plastic , 2: V_fuel_Gas}

#Define Choice model
logprob = models.loglogit (V , av , Choice )

#Create Biogeme object
the_biogeme = bio . BIOGEME ( database , logprob )

#Rename Biogeme object
the_biogeme.modelName = 'Labeled_Biogeme_thesis_Pascale_Six'

#Create results of the model
results = the_biogeme.estimate ()
#print(results)

pandas_results = results.getEstimatedParameters()
print ( pandas_results )
```

E.2.1. Python output from syntax

	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_fuel_Gas	0.000000	0.004965	0.000000	1.000000
ASC_fuel_Plastic	0.000000	0.004965	0.000000	1.000000
Beta_Emission_Gas	-0.027952	0.009930	-2.814768	0.004881
Beta_Emission_Plastic	0.010141	0.018229	0.556313	0.577997
Beta_Infra_Gas	-0.041928	0.014896	-2.814768	0.004881
Beta_Infra_Plastic	0.001976	0.184750	0.010693	0.991468
Beta_Price_Gas	-0.111807	0.039721	-2.814768	0.004881
Beta_Price_Plastic	0.030423	0.054687	0.556313	0.577997

Figure E.2: Results from unlabeled choice experiment

E.3. Syntax for Biogeme: Generate parameters estimation for attributes from obtained data from second survey

```
import pandas as pd
import biogeme.database as db
from biogeme.expressions import Variable
import biogeme.biogeme as bio
from biogeme import models
from biogeme.expressions import Beta

df = pd.read_csv ('Labelled_input2.0.csv',  sep = ',')
database = db.Database ('Labelled_input2.0', df )

Respondent = Variable('Respondent_ID')
Task = Variable('Choice_Task')
Price_Plastic = Variable('Price_Plastic')
Price_Gas = Variable('Price_Gas')
Infra_Plastic = Variable('Infra_Plastic')
Infra_Gas = Variable('Infra_Gas')
Emission_Plastic = Variable('Emission_Plastic')
Emission_Gas = Variable('Emission_Gas')
Choice = Variable('Choice')

#Define the basis of the beta's
ASC_fuel_Plastic = Beta ( 'ASC_fuel_Plastic' , 0, None , None , 0)
ASC_fuel_Gas = Beta ( 'ASC_fuel_Gas' , 0, None , None , 0)
Beta_Price_Plastic = Beta ( 'Beta_Price_Plastic' , 0, None , None , 0)
Beta_Price_Gas = Beta ( 'Beta_Price_Gas' , 0, None , None , 0)
Beta_Infra_Plastic = Beta ( 'Beta_Infra_Plastic' , 0, None , None , 0)
Beta_Infra_Gas = Beta ( 'Beta_Infra_Gas' , 0, None , None , 0)
Beta_Emission_Plastic = Beta ( 'Beta_Emission_Plastic' , 0, None , None ,
    0)
Beta_Emission_Gas = Beta ( 'Beta_Emission_Gas' , 0, None , None , 0)

#Define the utility function
V_fuel_Plastic = ASC_fuel_Plastic + (Beta_Price_Plastic * Price_Plastic) +
     (Beta_Infra_Plastic * Infra_Plastic) + (Beta_Emission_Plastic *
    Emission_Plastic)
```

```
V_fuel_Gas = ASC_fuel_Gas + (Beta_Price_Gas * Price_Gas) + (Beta_Infra_Gas * Infra_Gas) + (Beta_Emission_Gas * Emission_Gas)


#state the availability
av = None

#create dictionaries
V = {1: V_fuel_Plastic , 2: V_fuel_Gas}

#Define Choice model
logprob = models.loglogit (V , av , Choice )

#Create Biogeme object
the_biogeme = bio . BIOGEME ( database , logprob )

#Rename Biogeme object
the_biogeme.modelName = 'Labelled2_Biogeme_thesis_Pascale_Six'

#Create results of the model
results = the_biogeme.estimate ()
#print(results)

pandas_results = results.getEstimatedParameters()
print ( pandas_results )
```

E.3.1. Python output from syntax

	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_fuel_Gas	0.011804	0.004467	2.642411	0.008232
ASC_fuel_Plastic	-0.011804	0.004467	-2.642411	0.008232
Beta_Emission_Gas	-0.004343	0.008935	-0.486093	0.626901
Beta_Emission_Plastic	-1.500700	0.138516	10.834136	0.000000
Beta_Infra_Gas	-0.006515	0.013402	-0.486093	0.626901
Beta_Infra_Plastic	2.156082	0.217785	9.900050	0.000000
Beta_Price_Gas	-0.017372	0.035738	-0.486093	0.626901
Beta_Price_Plastic	-1.242247	0.076270	-16.287568	0.000000

Figure E.3: Results from unlabeled choice experiment