CARS ARE MORE THAN JUST THE FUEL THEY BURN. LIFE CYCLE ANALYSIS WITH COST BENEFIT ANALYSIS OF GREENER PERSONAL TRANSPORT POLICIES.

Integrating a Life Cycle Analysis into a Cost and benefit analysis of policies that aim to increase the adaption of the electrical vehicles. Using the Dutch Climate Agreement personal transport policies and the Dutch electrical vehicle market as casus.

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Master Thesis

Submitted in partial fulfillment of the requirement for the degree of the Master Industrial Ecology at the Leiden University and TU Delft

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Preface

Writing this master thesis became an educational experience where planning evolved from confirming data to extending beyond through analysis and cross-reference. Throughout the process I have received support, advice and guidance from a number of experts who generously gave their time and energy to help plan and produce this final draft.

Firstly, I would like to thank my two supervisors Dr. J.A. Annema and Dr. Ir. A. de Koning for their guidance and expertise. By using two different methods for my thesis, it was extremely helpful to have two supervisors who are expert in each of method. While Dr. J.A. Annema provided weekly guidance and expertise on the CBA method, Dr. Ir. A. de Koning could provide a different angle to look at my research and advise me with working with the LCA method.

Secondly, I would like to thank the researchers of the PBL and Revnext for helping me by providing the data and other salient details essential for my research focus. Their availability and ready assistance were of great help in the early construction and framing of this paper.

Lastly, I would like to thank my proof-readers without whom I could not have finished this report in this fashion. Their patience and eye for detail has helped to create the final result that you are reading here today.

Executive summary

After the Dutch government committed themselves to the Paris Climate Agreement, there has been some development in policies that have been introduced to limit the emissions of greenhouse gasses. These policies have been absorbed into the Dutch Climate Agreement. Some of these policies aim to stimulate the adoption rate of the battery electric vehicle into the personal vehicle market. Various Dutch research institutes undertook the task to measure the effects of these policies, while others used their published data to analyze the cost-efficiency of the policies. None however, seemed to integrate the emissions that occur during the full life cycle of the electric vehicle and the internal combustion vehicle. When only the tailpipe emissions are accounted for, the emissions of the BEV will always be (close to) zero. Adding the emissions of the full life cycle could potentially change the perception of policymakers on whether the electric vehicle stimulating policies are worthwhile or not. In addition, other emitted pollutants may be potentially harmful to the welfare of society at large beyond the dangers of CO_2 emissions. After considerable extensive research gap analysis, it is evident that there has been limited research focusing on the influence of integrating life cycle analysis into a cost-benefit one. This research aims to fill that gap by creating two CBAs (Cost Benefit Analysis). One conventional CBA, where only the tailpipe emissions are accounted for, and one where the full life cycle of both vehicles is considered. The Dutch climate agreement policies are used as a case-study. This research should provide an answer to the following question: What is the influence of incorporating a Life Cycle Analysis into a Cost Benefit Analysis of policies that aim to stimulate the battery electrical vehicle market? In addition, this thesis will also discuss the possible implication for researchers and policymakers.

A cost-benefit analysis is used in policy decision making to provide an insight in what the costs and benefits are of certain policies. A LCA (Life Cycle Analysis) measures all the environmental effects of the complete life cycle of the observed products or services that occurs during a certain function in their life cycle. By combining the two methods, the shortcomings of both methods can be limited. Using only the conventional CBA, does provide a clear view of the effects that the policies revealed on the adoption rate of the BEV, but does not give a wide enough image of the total environmental damage of the vehicles. A LCA does that, but does not provide the policymakers the necessary information on whether or not the policies that influence the adoption rate of the BEV are worthwhile from a welfare perspective. This research will also provide a bandwidth for a future scenario regarding a high and a low economy pathway. This is also applied in the terms of the environmental impact prices where there is a low, mid and a high price factor. This is done to account for the uncertainties that occur when predicting future scenarios.

The methodology of this research is partly derived from De Bruyn et al (2017) which provided guidelines for the methodology of a conventional CBA. After the problem, baseline and policy analysis comes the impact valuation. During this step, the effects and benefits of the policies are analyzed using data from research institutes and scientific papers. Firstly, The BEV adoption rate has to be known for the baseline and the policy scenario. Secondly, the environmental impact of one BEV and ICEV has to be analyzed using LCA's. After the effects on vehicle adaptation and the environmental impact of a BEV and ICEV were analyzed, the environmental impacts of these policies had to be calculated by combining the adaption rate with the environmental impacts of the vehicles. For the conventional CBA (CCBA), only the use-phase emissions were used, while for the cost-benefit life cycle analysis (CBLCA), all life stages were used. The effects were then monetized in order to compare the different

environmental impacts and put them all under the same unit. When the final results were provided, a balance of the costs and benefits were then illustrated in a table. The next step was to analyze the possible uncertainties and possibilities for future research. Lastly, the conclusion and recommendations for future research and policymakers are provided.

The effects of the policies on the electric vehicle adoption rate show an increase in sales compared to the baseline scenario during the time period that the policies are in place. From then on, the market sales quickly become equal to the baseline scenario. This means that the national costs and the environmental costs/benefits will also reveal a similar trend.
The environmental effects are measured by the mid-points of the ReCiPe method, which simply means that impact data are provided in a specific set of categories. When looking purely at the climate change indicators, it seems that the largest differences between the ICEV and the BEV lies in the environmental impact on the human toxicity, freshwater eco-toxicity and freshwater eutrophication. The BEV scores reasonably higher than the ICEV, often more than three times the amount. Most of these additional emissions come from the production of the powertrain, battery and electricity for the BEV. The BEV however scores lower than the ICEV on the climate change environmental impact. The progression of the BEV shows that the environmental impact in all environmental indicators declines, but some decline faster than the others. When multiplying these results with the environmental prices, it then becomes clear that the BEV has a higher total environmental cost than the ICEV. This is mostly due to the human toxicity indicator, where the impact difference is high and the environmental price is similarly high. This then reveals that the conventional CBA shows that the policies have a positive effect on the environment while the CBA (with the integrated LCA) shows a negative effect. This is shown in Table 1 and Table 2, where the environmental impacts of the CBLCA are negative numbers, which means they have a negative effect, while the environmental impact of the policies of the CCBA are positive.

Table 1: Environmental benefits CBA with the integration of the LCA

ENVIRONMENTAL IMPACTS CBLCA (MLN EUROS)

PRICES	Low			Average			High		
SCENARIO PATH	Low	Mid	High	Low	Mid	High	Low	Mid	High
2030	-88	-117	-160	-127	-170	-232	-206	-275	-376
2050	-97	-140	-169	-136	-192	-242	-222	-315	-394

Table 2: Environmental benefits CBA without the integration of the LCA

ENVIRONMENTAL IMPACTS CCBA (MLN EUROS)

PRICES	Low			Average			High		
SCENARIO PATH	Low	Mid	High	Low	Mid	High	Low	Mid	High
2030	22	29	40	62	82	113	77	102	141
2050	25	37	43	70	104	121	87	130	151

The final results of both CBA's provide a different perspective on the outcomes of the policies. The balance of both CBA’s are giving in Figure 1. The CBA without the integration of the LCA, show that the policies could be worthwhile under certain economic scenarios and environmental prices. However, when integrating the LCA, it becomes clear that the policies will have a negative effect on welfare under all circumstances. The quantitative difference between the two CBA's is large enough to suggest that the influence of integrating a LCA into a CBA is indeed significant. This is also true even when accounting for the uncertainties, which are partly reckoned with using the bandwidths of the future scenarios.

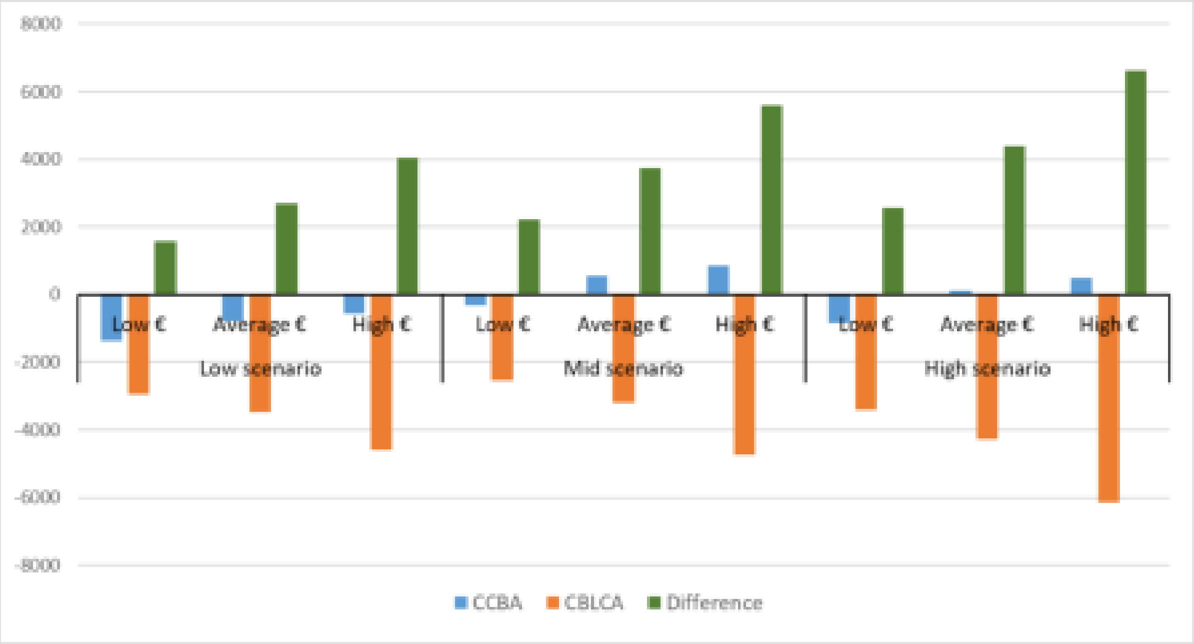

Figure 1: Balance (mln €) of the CCBA, the CBLCA and the difference between them

During the course of this research, a lot of assumptions have been made. Additional research is needed to check the validation of these assumptions and to improve the quality of the CBAs. This research listed several uncertainties that can be used for future research. These uncertainties can have a considerable effect on the results of this research and the difference between the CBA with the LCA and the CBA without the LCA. However, these uncertainties can impact the results in both ways, either increasing the difference or decreasing it; this suggests that they will even themselves out and/or stay within the economy bandwidths provided by this research. The only uncertainty that can potentially have a large impact on the results on its own, is the spatial difference of the emissions of the BEV. This means that the emissions of the vehicles during its life stages occur in different parts of the world. This can have considerable effect on the environmental price that is used in this research. However, also in this case that can work both ways and potentially even themselves out. Alternatively, this research provides an environmental price range to accommodate for this uncertainty. All this considered suggests that the bandwidths provided for this research are well enough to provide an answer to the research question. However, one should be careful to put too much emphasis on the exact results of both CBAs.

Despite the limitations of this study, it can be concluded that the influence of the LCA is significant enough to incorporate it into the CBA's. The consequences for policymakers will be that it would be advised to use LCA integrated CBA's for their decision making if their goal is to maximize the welfare of society. It is also advised for policymakers to use the results of CBLCA's to identify the key environmental problems of the goods or services that are influenced by the policies. In this case it would mean that the policymakers could focus on controlling the human toxicity levels that are polluting during the life cycle of the electrical vehicle. The advice to use LCA combined with CBA is not limited to policymakers. This study created an understanding on why it is important to use all life stages and multiple environmental impacts of a product or service when analyzing the costs and benefits. This means that future research focusing on these topics should incorporate the life cycle of the product or service. It also means that research on the type of uncertainties of this research are crucial. In particular the already mentioned spatial difference of the emissions during its life cycle. All the uncertainties and possibilities for future research are listed in Table 3. The table also identifies whether the uncertainties are of a general nature and can be used for studies of different kinds of products or services or are more specific to the case focus of this research.

Table 3: List of uncertainties and possible future research topics of this thesis research

UNCERTAINTY	GENERAL OR CASE SPECIFIC
BATTERY COMPOSITION CHANGE	Case specific
SPATIAL DIFFERENCE	General
TEMPORAL DIFFERENCE	General
WATERBED EFFECT, CO2 STANDARDS	Case specific
WATERBED EFFECT, ETS	General
EXTRA VEHICLE FLEET GROWTH	Case specific
MOBILITY CHANGE	Case specific
ELECTRICITY MIX	General
COST BEV	Case specific
DISRUPTION OF THE MARKET	General
EMERSION OF OTHER TECHNOLOGIES	General
FUTURE TREND	General

Abstract

After the Dutch government committed itself to the Paris Climate Agreement, there has been some development in policies that are introduced to limit the emissions of greenhouse gasses. These policies are introduced in the Dutch Climate Agreement. Some of these policies aim to stimulate the adoption rate of the battery electric vehicle into the personal vehicle market. While there have been studies undertaken to analyze the cost efficiency of these policies, they all use the tailpipe emissions and/or only use the greenhouse gas emissions to measure the environmental damage. Integrating a life cycle analysis to the research could potentially limit these shortcomings, which would provide a wider overview of the true impact these policies have on the welfare of society. This research integrated a life cycle analysis into a cost-benefit analysis to analyze its influence compared to a conventional cost-benefit analysis where only the tailpipe emissions are used. The results of this research suggested that there is a significant impact when the full life cycle of the vehicles is integrated. Even though there is plenty of additional research that can be done to improve the quantification of the costs and benefits, the bandwidths that are provided to cover the uncertainties provide for a plausible conclusion that policymakers can use in the future for decision making. This research suggests that policymakers would be better informed on their decision making if they would use cost-benefit analysis' where life cycle analyses are integrated. It also provides researchers un understanding into why it is important to incorporate the life cycle of the product or service into the research.

Content

1. Introduction

1.1. Problem definition

The transition to sustainable personal mobility remains a hot topic all over the world. The transport sector alone was responsible for 23% of all the emitted energy related GHG emissions in 2014 (Sims R, et al. 2014), meaning this sector greatly contributes to global warming. With both the energy consumption and the GHG emissions are still growing (Chapman, L. 2007), it seems a difficult sector to reduce GHG emissions in this increasingly globalized society.

The IPCC (Intergovernmental Panel on Climate Change) states that by 2050, the emitted GHG emissions from the total transport sector will double if no action is undertaken to tackle global warming (Sims R et al, 2014). To stay under the 1.5 C^o global warming, the IPCC also states that the GHG emissions need to gradually decline to net zero emissions in 2050 if the goals of 1.5 degrees Celsius globally are to be met. This means that large technological, societal, and/or cultural developments are needed over the course of roughly 30 years. Governments all over the world are discussing the possible policies that can steer these developments in a way that will lead to a zero-emissions transport sector.

After the Dutch government committed themselves to the Paris Climate agreement, several policies have been introduced to phase out fossil fuels by 2050. One of the plans that are introduced in the Netherlands own climate agreement is the phasing out of internal combustion engines (ICE) in the personal mobility sector. Several subsidies have been introduced to switch to driving the electric vehicle (EV). However, this also opened a storm of critique when the costs of these subsidies were a lot higher than predicted (Klein, P & Pauw, M. 2019). This has raised the question on what the actual costs and benefits are of the policies that were introduced by the Dutch government in the climate agreement of 2018 (Frederik, J. 2019). While the PBL (Planbureau voor de Leefomgeving; English: Netherlands Environmental Assessment Agency) and TNO (Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek; English: Netherlands Organisation for Applied Scientific Research) have conducted research into this topic (Nijland et al, 2019 & van Gilswijk et al, 2018), they only accounted for the CO_2 emissions during the *use* phase of both the combustion engine and electrical engine vehicles. However, these vehicles also pollute the environment through several other ways during their life cycle. This can change the whole perspective of the policies. When only the tailpipe emissions will be accounted for, the emissions of the BEV will always be (close to) zero. Adding the emissions of the full life cycle could potentially change the result of the CBA. In addition, other types of environmental pollution than just CO_2 emissions may occur that can potentially affect people's welfare. This still leaves the question on what the influence will be on the cost benefit analysis if the full life cycle, in appropriate impact categories, of both types of vehicle are taken into account. More details about the influence of LCA integrated into CBA's and previous research will be discussed in chapter 1.3.3.

This paper provides research into the influence of integrating the full life cycle analysis into the cost benefit analysis. The case that is used to analyze the influence are the policies proposed by the Dutch Climate Agreement that can be used to steer the personal vehicle transport sector to gradually reach zero GHG emissions. The goal of the research is to gain knowledge on the effect of incorporating Life Cycle Analysis into a Cost Benefit Analysis in this field area. This will be done by creating two Cost Benefit Analysis's (CBA). One where the effects of the proposed tax incentives are quantified using a literature review on Life Cycle Analysis' (LCA's) and one using the conventional method of using only the *use phase* emissions. With the implementation of LCA's, multiple environmental effects can be used to calculate the sense -or lack of such- within these policies proposed in the climate agreement. This analysis can be used for both researchers and governments. It creates an insight for analyst of the importance of integrating the life cycle of products and services into CBA, which could help future research. It also helps governments to make conscious decisions, which would help to limit possible discussions on proposed policies and speed up the process of the implementation of policies needed to achieve the goals in 2050 proposed by the IPCC.

1.2. Research questions

From the problem analysis, it can be concluded that there has is a need for a comprehensive research the analysis the effects of using Life Cycle Analysis in a Cost Benefit Analysis. This research will create two CBA's regarding the environmental effects of policies for stimulating the electrical vehicle market, where The Netherlands will serve as a casus. One CBA uses the conventional method - *the costs and effects of the PBL*- and the second CBA will use the *effects of the LCA's* that is provided after the literature research. The CBA's will both focus on the policies that are proposed by the Dutch government in the Dutch Climate Agreement. This means that the main research question for this thesis will be:

RQ$_1$: "What is the influence of incorporating a Life Cycle Analysis into a Cost Benefit Analysis of policies that aim to stimulate the battery electrical vehicle market?"

To answer this research question, the effect of the Dutch Climate Agreement policies to the Dutch electrical vehicle market regarding a time-scale from present to 2050 will be used as a case-study. The answer to this research question should provide two Net Present Values of the proposed policies that will be conducted in The Netherlands and can be compared to each other. A Net Present Value (NPV) is simply the difference between costs and benefits over a period of time, presented into the present value of cash. More details on the calculations of the NPV can be found in chapter 2.1.

The method to construct the Net Present Value of the policies is a Cost-Benefit Analysis (CBA). A CBA is an approach that estimates the costs and benefits of policy alternatives by measuring the gains and losses of individuals where money is used as the unit. Simply put, in this case it would mean measuring the cost to conduct the policies and to measure the benefits it has on society and evaluate it in monetary terms based on an individual's Willingness to Pay (WTP) for a good or service that increases their welfare or their Willingness to Accept (WTA) a loss in well-being for a monetary reward. When these costs and benefits are quantified the Net Present Value (NPV) can be calculated. More information on CBA can be found in chapter 2.1. Below are the sub-questions listed that are made to provide the information that is needed to answer the main research questions:

1. What are the effects of the proposed tax incentive of the Dutch Climate Agreement on the electrical vehicle market in The Netherlands and what are the costs?
2. What are the environmental and societal effects of the life cycle of an electrical vehicle and a combustion engine vehicle?
3. What are the effects of the proposed policies if only the tailpipe emissions are considered?
4. What are the environmental effects of the policies considering question 1 and 2?
5. What is the monetary value of these environmental effects?
6. What are the risks and uncertainties of the costs and benefits?

When these sub-questions have been answered, enough information will be provided to perform the CBA's and calculate the NPV's. The results are reported in this paper.

If the results of this study shows that there is an influence of incorporating a LCA into a CBA in this casus, another research question will follow which is:

RQ$_2$: "What are the potential implications for policy makers considering the outcomes of the research of incorporating Life Cycle Analysis into a Cost Benefit Analysis of policies that aim to stimulate the battery electrical vehicle market?"

This research question will be not be analyzed by utilizing formal methodology, but will appear based on the evaluation and discussion from results addressing the key research question. By addressing two main research questions, it is possible to analyze and interpret the results of this research so that two sectors may benefit from the research. The first research question is more focused on the influence of the methods and the combination of them and is likely to be more relevant for the scientific sector while the latter considers the societal impact of this research.

1.3. Literature review

This paragraph shows the current academic knowledge on costs and benefits of the EV while referencing governmental policies.

1.3.1. Literature methodology

The literature is reviewed to analyze the current state of literature on Cost-Benefit Analyses (CBA) in which LCA approaches are integrated, partly specified to electrical vehicles. Where the first step was to gain insight into the current state of knowledge of the Dutch Climate Agreement policies by reading the Dutch Climate Agreement and the analysis of the PBL (Planbureau voor de Leefomgeving; English: Netherlands Environmental Assessment Agency) and TNO (Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek; English: Netherlands Organisation for Applied Scientific Research).

The second step was to look at the limitations of these studies and find studies that considered these limitations. In this case, this was done by using the key words "CBA", "Cost-Benefit Analysis", "Electrical Vehicle" , "LCA" and/or "Life Cycle Analysis" in google scholar, the online registry of the Journal of Industrial Ecology as well the search engine Scopus. The studies that are provided by these search engines all have conducted their own research gap analysis. These analyses also provide useful information and studies used in this paper.

Lastly, the studies will be summarized in a table. This way, a research gap can be identified more easily.

1.3.2. EV policy research

Daniëls & Koelemeijer (2018) calculated the cost effectiveness of all the policies of the Dutch Climate Agreement. While van Gijlswijk et al. (2018) looked specifically into how the policies would affect the integration of the electrical vehicles into the personal vehicle market. Based on the plans of the Dutch Climate agreement and European policies, they analyzed how the EV would likely integrate into the passenger car market in the years up to 2030 using predictions on the influence of the policies and the price developments of batteries (Nykvist, 2019) and electrical vehicles. Nijland et al (2019) used this study to calculate the environmental effects of the Dutch climate agreement. Interestingly, only CO_2 production -based on vehicle usage- was considered rather than the whole life cycle. Since the production of both the electrical and the ICE vehicle share a considerably large part of the total emissions during the life cycle of a personal vehicle (Hawkins et al, 2014), omitting this equation could give a misleading result to the CBA. Also, other environmental effects closely related to the life cycle of the vehicles have been left out of the equation. Lastly, a cost effectiveness ranking still does not provide an answer to whether the policies of the Climate Agreement are actually an efficient investment.

These limitations found in Dutch research on governmental policies raises the question as to what the current status is of research conducted into *full life cycle* environmental effects of EVs and how these possible effects might be incorporated into recent CBA studies.

1.3.3. Cost/benefit analysis & life cycle analysis EV

Several studies analyzed the costs, benefits, and/or environmental effects of the electric vehicle integration. Table 4, shows the results of the research gap analysis on this subject. This table also highlights the various studies, their goals and methods and whether they used a CBA or an LCA (or similar) to analyze the effectiveness of the EV or its policies. It also illustrates what type of vehicles, which region and which type of pollution it is referring to; some studies do not focus on policies, but more on the environmental effects of BEVs in general. This is shown in the table as "vehicle orientated". Lastly, the table shows the scope of the research on whether it accounts for environmental damage of full life cycle or only the vehicle use phase.

The research analysis illustrates a variety of methods used to analyze the environmental impacts of BEVs and policies. Generally, CBA and cost-effectiveness studies tend to look more often at the effects on GHG emissions during the vehicle use-phase, while LCA's look at different kinds of pollution over a full life cycle. An exception is Mersky & Samaras (2019), which also takes SO_2 and NO_x emissions over the full life cycle of the vehicles into account. However, this study does not concentrate on the effects of policies, but rather on the effects of *electric vehicle integration* into the car market. It also concentrates solely on GHG, SO_2 and NO_x emissions. Finally, it concentrates on a specific region, Pittsburg (United States). This has major implications when considering results, since the electricity energy generation mix is quite different from the EU and The Netherlands. The US has a relatively large share of fossil fuel energy production compared to the EU (Mearns, 2016), which could partly explain why the environmental impacts of the BEV found in studies conducted in the US are often larger than the those conducted elsewhere.

CBA's that are more policy-related are more clearly depicted in the works from Holland et (2015), Massiani (2015) and Shafiei et al (2017). Massiani and Shafiei both look only at the environmental impact of GHG emissions during the use phase of the vehicle. Holland offers more scope in the variety of environmental effects, but also does not address the *full life cycle emissions* consideration.

Studies that provide a large quantity of different environmental effects are the LCA studies of Hawkins et al (2012) and Notter et al (2015). They present their results in different impact categories, however, both analyze largely the same environmental emissions, though use different tools to express their results. These studies are extensive, but unfortunately provide little insight into the effect of polices related to EV integration. Since they also do not monetize the environmental effects, these studies are also unable to provide politicians with a clear picture of the costs and benefits of EV integrating policies.

From Table 4 it could be concluded that there has been research conducted into the environmental effects of the BEV compared to the ICE, both for the use phase as well as the full life cycle. Also, the effects of the BEV supporting policies have been analyzed in various regions. However, there seems to be a missing link in providing an integrated picture where the effects of BEV stimulating policies, while integrating the full life cycle of the vehicle over a broad range of important environmental effects, has been considered. The aim of this research is to provide that missing link.

Table 4: Summary research gap analysis costs, benefits and/or life environmental effects analysis

STUDY	GOAL	METHOD	VEHICLES	POLICY OR VEHICLE ORIENTED	REGIONS	SCOPE	TYPE OF COSTS AND POLLUTION
ANAIR AND MAHMASSANI, 2012	Costs and environmental effects analysis of EV	Costs and effect analysis	BEV, PHEV, HV, ICE	Vehicle	US	Use Phase	Direct Private Costs, GHGs
ARCHSMITH ET AL, 2015	Full life cycle emission analysis of EV of multiple regions and energy mixes in US	LCA	BEV, ICE	Vehicle	US	Full Life Cycle	GHGs
DANIELS B. & R. KOELEMEIJER, 2016	Calculate cost-efficiency of Dutch climate policies	Cost-effectiveness study	BEV, ICE	Policy	The Netherlands	Use Phase	CO_2
FREIRE AND MARQUES, 2012	Analyze the private costs and GHG emissions of the EV over the full life cycle	Cost life cycle analysis	BEV, ICE	Vehicle	Portugal	Full Life Cycle	Direct Private Costs, GHGs
FUNK, K., & RABL, A, 1999	Calculate the (social) costs and benefits of an EV versus and ICE vehicle	CBA, LCA	BEV, ICE	Vehicle	France	Full life cycle	Direct private costs, GHG emissions
HADLEY AND TSVETKOVA, 2009	Analyze EV integration effects on US energy demand.	Scenario analysis	PHEV, ICE	Vehicle	US	Use phase	CO_2, SO_2, NO_x
HAWKINS ET AL, 2012	Provide an environmental comparison of an EV and an ICEV over their entire life cycle.	LCA	BEV, ICE	Vehicle	European Union	Full life cycle	GWP, TAP, PMFP, POFP, HTP, FETP, TETP, FEP, MDP, FDP*
HOLLAND ET AL, 2015	Analyze the gain or loss in welfare according to the emissions rate of EV vs ICE. Provide a normative policy approach.	Welfare analysis	BEV, ICE	Policy and vehicle	US	Use phase	Direct private costs, CO_2, SO_2, $PM_{2.5}$, NO_X
LUND AND KEMPTON, 2008	Analyze effects of V2G integration into the electricity market.	Scenario analysis	BEV, ICE	Vehicle	Denmark	Use phase	CO_2
MACPHERSON ET AL, 2012	Analyze appropriate environmental labelling of EVs by analyzing life cycle emissions under different grid mixes.	LCA	BEV, ICE	Vehicle	US	Full Life Cycle	GHGs
MASSIANI, J, 2015	Analyze the costs of the policies implemented in Germany and what the effects are based on extra sales on electrical vehicles and their environmental influence.	CBA	BEV, ICE	Policy	Germany	Use phase	Direct private costs, GHG emissions
MCCARTHY AND YANG, 2010	Analyze EV integration effects on US energy demand.	Effect analysis	BEV, PHEV, HFCV, ICE	Vehicle	US: California	Use phase	CO_2
MERSKY & SAMARAS, 2019	Compare the costs and benefits of the EV electrification and installation of PV systems on the City's	CBA, LCA	BEV, PHEV, HV, CV	Vehicle	US (Pittsburgh)	Full life cycle	Life Cycle Private and External Costs, GHGs, SO2, NOX

	public parking facilities using the full life cycle of the vehicles.						
MICHALEK ET AL, 2011	Asses the economic value of EV integration effects	LCA	BEV, PHEV, HEV, ICE	Vehicle	US	Full Life Cycle	CO2, NOx, PM, SO2, VOC, GHG, oil dependence and market effects
MORO & LONZA, 2018	Environmental effects of EV vs ICE on EU electricity grid	Environmental effect analysis	BEV, ICE	Vehicle	European Union	Use phase	GHGs
NEALER ET AL, 2015	Analysis of LCA studies concerning the EV.	LCA	BEV	Vehicle	US	Full life cycle	GHGs
NIJLAND, H., ET AL, 2019	Predicting the effects of the EV policies of the Dutch Climate agreement	Literature review	BEV, ICE	Policy	The Netherlands	Use phase	CO_2
NOTTER ET AL, 2015	Full life cycle analysis of FCEV, BEV and ICE	LCA	BEV, FCEV, ICE	Vehicle	US	Full life cycle	Factors according to the ReCiPe indicators.
PETERSON ET AL, 2011	Analyze EV integration and CO_2 tax effects on US energy demand and emissions.	Effect analysis	PHEV	Vehicle and policy	US	Use phase	CO_2, SO_2, NO_x
SAMARAS AND MEISTERLING, 2009	Analyze full life cycle environmental effects of PHEV and HEV integration.	LCA	PHEV, HEV, ICE	Vehicle	US	Full Life Cycle	CO_2, SO_2, NO_x
SHAFEL, E., ET AL. 2017	Analyze the effect of fiscal policy on Macro-economy and environment of Iceland.	CBA	ICE, HEV, PHEV, BEV	Policy	Iceland	Use phase	Private costs, GHG emissions
VILLAR, J. ET AL, 2013	Predict the (social) costs and benefits if the EV would have a certain market share in Spain	CBA	BEV, ICE	Vehicle	Spain	Use phase	Direct Private costs
THIS STUDY, 2020	Analyze costs and benefits of the Dutch policies to increase the adaption of the electrical vehicles using Life Cycle Analysis studies.	CBA, LCA	BEV, ICE	Policy	The Netherlands	Full life cycle	Direct private costs

* Terrestrial acidification (TAP), particulate matter formation (PMFP), photochemical oxidation formation (POFP), human toxicity (HTP), freshwater eco-toxicity (FETP), terrestrial eco-toxicity (TETP), freshwater eutrophication (FEP), mineral resource depletion (MDP), fossil resource depletion (FDP)

1.4. Case study

The case study for this thesis research is the climate agreement policies of The Netherlands regarding the stimulation of the electrical vehicle market. There are several reasons why this case is interesting for the topic of measuring the influence of the integration of the LCA into the CBA. Firstly, there is the *convenience issue* for this thesis research. Since the case study is the home country of the thesis research, communication with research institutes is therefore often easier and faster. Secondly, a lot of research into the effects of the policies of this particular case have already been done. This offers two benefits. Firstly, a lot of data is already available which means that more investigative man-hours can be freed-up for the actual topic of the research question and integration of the LCA. Secondly, the results of this research can be compared with the results of previous papers, which can strengthen the conclusion. For example, when the outcome of this investigation reveals considerable influence surrounding integration of the LCA, then this could create a different perspective on the conclusions of previous papers which can be of consequence for the decision making for policy makers.

1.5. Scientific and societal relevance

This research in this context aims to fulfill the knowledge gap that is explained in chapter 1.3. When taken out of this context, this analysis provides some scientific relevance to additional research into the influence of the combination of LCA within CBA. Even though this study looks specifically into the influence LCA and CBA has within the context of electric vehicle stimulation, it could provide a step-up for researchers to look into the effects in other regions. It could also provide a small step to a new way of thinking about environmental costs and benefits, where not only the use phase and greenhouse gasses are used as parameters to value policies, products and services.

The societal relevance of this research is aimed more directly at the context of this case. It could provide researches institutes with tools to enhance the quality of the CBA by including LCA, which provides policy makers the option to actually choose these CBAs. It also provides an insight for politicians to see the potential environmental problems concerning the different life phases and environmental impacts that occur during the life cycle. If, for example, the electrical vehicle proves to be high in environmental costs for the particular formation indicator during the end-phase of the life cycle, politicians could implement policies aimed directly to address this issue. In the end, this could ultimately improve the welfare of society, depending on the outcomes of this research.

1.6. Thesis outline

The structure of this master thesis is as following:

Chapter Two contains the literature analysis and theoretical framework -including highlights of key articles and datasets- informing the research. It will argue why these papers have been considered and what their strengths and benefits are. In addition, the theoretical framework of the *cost-benefit* and *life cycle* analysis will include an explanation of steps that need to be taken. From chapter three onwards the report will steer more closely towards the actual research content. Chapter three values the impact of policies analyzed. Firstly, the impact of policies on the electrical vehicle market is depicted. Secondly, the environmental and societal impacts of the full life cycle of an individual ICE and BEV vehicle are illustrated. Lastly, the national costs of these policies are presented. Chapter four reveals the final results when the data of chapter three has been combined. Chapter five analyses the assumptions made in this research and what future research into this topic could improve. It argues the assumptions that have been made and already begins to outline what might be improved through further research. Chapter six and seven will shape the concluding remarks for the research recommendations for future research and policymakers.

2. Theory and methodology

This chapter will provide the theoretical framework of the project. The first two paragraphs will handle the description and limitations of both the cost benefit analysis and the life cycle analysis. Afterwards, the methodology and structure of this paper will be explained. Finally, this chapter will focus on the main literature for this research and will include the reasoning which led to specific selection of base data material.

2.1. Theory of Cost-Benefit analysis

2.2.1. Theory

According to neoclassical economics, voluntary market exchanges between buyers and sellers, would result in both parties being better off. However, in practice these exchanges often results in *externalities*. Externalities are additional effects of market transactions that impact others outside the transaction (Harris & Roach, 2013). Refueling, servicing and generally maintaining vehicles creates external costs that are not accounted for between the buyer and seller. This is a situation where an unregulated market does not maximize welfare. This is called a market failure. To adjust this market failure, the government could implement policies. These policies are assessed by environmental economics and evaluated using cost benefit analyses'. A cost-benefit analysis is a tool that can be used to analyze policies in an attempt to monetize all the costs and benefits of a proposed policy in order to determine the net benefit of this policy. It can be used by policy makers to support the decision-making process. By mainly aiming to find the most efficient allocation for societies resources, it can provide a rational perspective for politicians (Hansjürgens, 2004).

A cost benefit analysis is carried out by identifying and evaluating the impacts of the policy that are to be analyzed. If a policy affects a resource that is needed to protect human health and the environment, it is considered an impact. Two important considerations are: is the impact *additional* and is it *merely displacing* the effect from one party to another? For example, if an action produces CO_2 but prevents another party from emitting the same amount of pollution, it can be considered non-additional (more information in chapter 5.3 on the waterbed effect). Also, a government subsidy cannot be seen as a cost for the government, since it is just simply a relocation of financial resources from one party to another, these costs should not be counted as an *impact* (the *behavior effects* of these subsidies however are important).

Impacts are identified as either creating a positive or negative effect on society at large. In which case, they can be monetized. This is done to measure all the effects using the same currency unit (in this case, Euros), since the impacts analyzed will likely have varying units when they are valued. Normally, monetary values are carried out by using market prices. This is of course more difficult for environmental and public goods where such prices do not always exist. The National Oceanic and Atmospheric Administration (NOAA) (1999) concluded that finding out the consumers' willingness-to-pay for goods or service is the most reliable way to determine the price of the impact that does not have an actual market price or monetary value.

Lastly, all the monetized costs and benefit flows have to be discounted. This is because the future costs and benefits have to expressed in present-day values. People have a time preference which is included in the CBA by discounting. Discounting is performed based on the discount rate, which can be a large contributor to the outcome found in a cost-benefit analysis, especially when the CBA considers impacts over large time periods. In the case of this study however, the discount rate is based on the papers of the PBL, which will be explained further in this chapter. When the costs and benefits are discounted, the results can be presented in the form of a Net Present Value, which gives the balance of the present costs and benefits, and thus should be positive in order to be a societally profitable investment.

Since the output of the CBA is based on data, estimations and assumptions, it is necessary to apply a sensitivity analysis to take into account the inclusion of uncertainty.

2.2. Life Cycle Analysis

A life Cycle Analysis (also known as a Life Cycle Assessment) is a tool to assess the environmental impacts of products and services used for fulfilling a certain function across their life cycle (Guineé et al, 2012). The method is standardized by ISO, so researchers using this tool follow more or less the same structure to structure their study. ISO 14040 (1997E) defines LCA as a "compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system throughout its life cycle". LCA's are used to compare products and services which have a shared function. For example, electrical vehicles and combustion engine vehicles share the same function, transporting humans from a to b. When these products are analyzed through an LCA, they should be compared to their shared functional unit which in this case would be: pollution per driven kilometer.

The structure of an LCA is provided by ISO (1997) and is given in Figure 2. The steps are as following: Goal and scope definition, inventory analysis, impact assessment and interpretation of the former three steps.

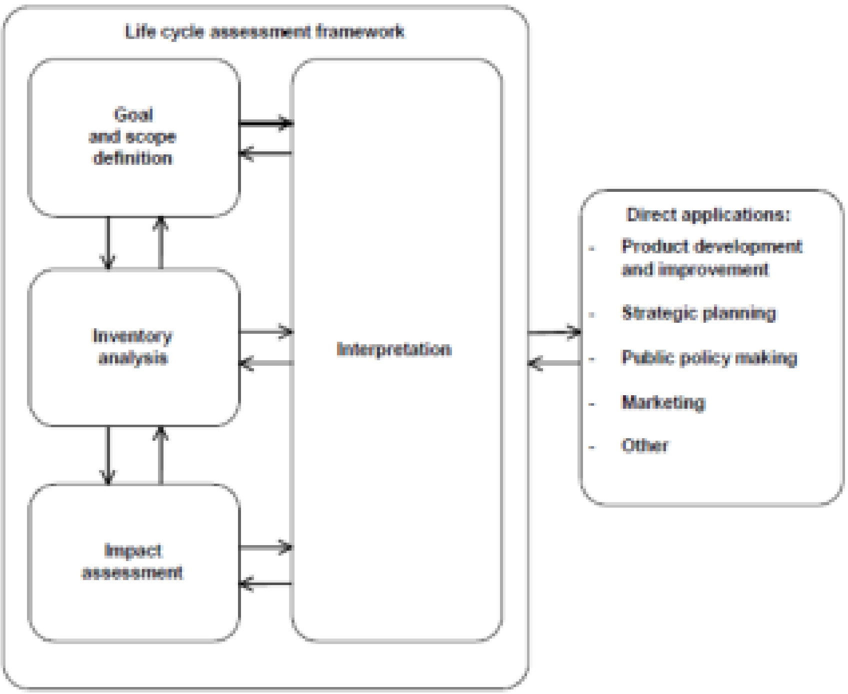

Figure 2: Methodology and phases of an LCA. (ISO, 1997)

2.2.2. Goal and scope definition

During this phase, the structure of the LCA is identified. The goal, objective of the research and the intended use, are defined. It is important that during this phase a clear boundary is stated in order to have clear scope regarding the temporal, geographical and technological coverage. This is also especially important for this study when looking into appropriate LCA data. The temporal and geographical coverage states the time period and geographical location from which the data is being sourced. At the same time, technological coverage means that the used state-of-the-art data matches the data of the temporal and spatial coverage. In the case of this study, the temporal, geographical and technological coverage of the data needs to correspond to the data that is used for the CBA. The next step in this phase is to define the functions, the functional unit, the alternatives and the reference flows. The functional unit is the quantified description that the product/service needs to perform to fulfil its function. The reference flows are the specific quantified amount of product(s) that are needed to deliver the performance that is described by the functional unit (Guinée et al, 2012).

2.2.3. Life Cycle Inventory (LCI)

During the Life Cycle Inventory (LCI) phase, the required data are collected to build up an inventory list. This will include materials, technologies, transportation, and power consumption. When these flows are identified and collected, the emissions are modelled and quantified. The LCI is a critical phase during the LCA and many data sources may be needed to complete the inventory list. One important aspect that needs to be recognized for this study is the method of allocation for the flows. Since most industrial processes are multifunctional, production processes can be dynamically interlinked with other processes. This creates the difficult task for LCA researchers to allocate which emissions belong to which specific production process. There are multiple methods to allocate these emissions, including allocation based on mass, economics, and energy.

2.2.4. Life Cycle Impact Assessment

The third phase uses the inventory that is created during the last phase and translates it into ‘understandable’ environmental impacts. ISO 14040 (1997E) describes this phase as “Phase of LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system”. There are five steps to this phase which are described below.

i. Selection of impact categories

During the first step of this phase, the impact categories are selected in which the data of the inventory is divided in. Also, the category indicators and evaluation models are created. Impact categories include impact on climate change, human toxicity, ecotoxicity, etc. The indicators are the characterization factors on which the impact category is measured against. For example, the indicator for the climate change category can be the Global Warming Potential (GWP). Which is the measure for Global Warming in terms of radiative forcing of a mass-unit. Several models that can be used concerning these impact categories are the CML-baseline, ReCiPe, etc. The model used for this research is the ReCiPe model and will be explained further in this chapter.

ii. Classification

During the classification phase, the flows of the inventory are allocated to the correct impact category.

iii. Characterization

When all the flows have been divided into the correct impact categories, they have to be levelled using a multiplier. For example, methane has a 25 times larger effect on global warming than carbon dioxide, which means that if the unit is kg CO_2 equivalent, then the multiplier for methane must be 25 in order to allow the aggregation into a single unit.

iv. Normalization

What follows are scores for every impact category. These scores all have different units and different scales. The next step is to normalize the results to a reference value to analyze the significance of the indicator results.

v. Aggregation and/or weighing

The final step or steps are used to aggregate the scores of the previous stage into a single or a low impact category. During this step the mid-point impact categories are aggregated into end-point categories. This makes them easier to understand and the results comparable. The results can also be multiplied by weighing factors if needed. These factors rely on the significance of the impact categories and on value choices.

2.2.5. Interpretation

The last phase of the LCA is the interpretation of the results within the confines of the aims and scope of this research. These results are then analyzed and used to inform the concluding remarks and recommendations. This phase provides the last checks for the completeness, sensitivity and consistency of the research.

2.3. Thesis methodology

2.3.1. LCA & CBA

This research will use a combination of the two methodologies, cost-benefit analysis and life cycle analysis. The combination of these methods enables a wider overview of the environmental impact of certain policies. It limits the shortcomings that occur for policymakers when using just one single method. Using only the conventional CBA does provide a clear view of the effects that the policies gave on the adoption rate of the BEV, but does not give a wide enough image of the total environmental damage of the vehicles. A LCA does that, but does not provide the policymakers the needed information on whether or not the policies that influence the adoption rate of the BEV are worthwhile. Combining these two methods limits the information gap, which could give policymakers the appropriate handles to make a conscious decision.

De Bruyn et al (2017) provided extensive guidelines in conducting a CBA. De Bruyn et al stated that the method of CBA consists of 8 steps. These steps are described below:

1. Problem analysis
2. Determine business as usual scenario
3. Define policy alternatives
4. Determine effects and benefits
5. Determine costs
6. Uncertainty- and risk analysis
7. Create overview costs and benefits
8. Present results

Since this thesis combines the CBA and LCA approaches and uses already existing data to integrate LCA into CBA, this research will use an altered version of the method described by De Bruyn et al. (2017).

The method of this thesis is explained below in paragraphs 2.3.2, 2.3.3, 2.3.5 and 2.3.6. The paragraph titles are the chapters that results of these steps are reported in.

2.3.2. Introduction, theory & methodology

The first three steps contain preparation for the research, whereas the determining of costs and benefits forms the core of the project. These steps will be explained in more detail below.

Problem analysis

The first step is the problem analysis. In this step, analysis will take place on what the current problems are in the current personal vehicle transport situation and what the policy goals are that transpire. This proposal, with the problem definition along with research gap analysis, can be defined as the *problem analysis*.

Determining the *business as usual* scenario

The second step is determining the most likely scenario that may occur should the Netherlands choose not to execute the policy based on current data. Its investigation will be carried out by conducting literature research on *recent scenario analysis*. The most important source of information will be the studies performed by the PBL (Nijland et al. 2019) on the possible mobility scenarios. The data was gathered from literature publicly provided by the PBL and the Rijksoverheid. When this proved to be inadequate, additional information needed to be gleaned via interviewing or simply contacting the research institute.

Determining policy alternatives

The third step is to determine the policy alternatives, that is, determine the policy that will be investigated. Normally this would require investigation into the technical, legal and economic feasibility. In this case, this would not be necessary since the policy comes directly from the Dutch Climate Agreement and should be considered valid. The policies are provided in the Appendix B.B.

2.3.3. Impact valuation

This chapter explains the effects the policies have on the electrical vehicle adoption rate and, consequently, the environmental benefits and national costs. During these steps were the LCA integrated into the CBA. The method to perform this is explained below by the steps of De Bruyn et al. (2017)

Determine effects and benefits

The fourth step of this thesis methodology is considering the effects of the policy - initially analyzing the consequences of electric vehicle adaptation. The source of this information is the same as in step 2 and broadly correlates to studies carried out by the PBL (Nijland et al. 2019). Since this study does not provide full data from 2020 until 2050, some data had to be extrapolated to create a scenario of which the CBA has been founded. Based on the electric vehicle adaption rate, other effects could be determined/calculated.

If the effects of the policies on the BEV adoption rate is known. The next step is to know the environmental impact of one BEV and ICEV. If these results are combined, the environmental impact of the policies can be calculated. The data of the LCA’s of the ICEV and the BEV were collected (see

Appendix B.D) to analyze the environmental effects of the life cycle of an electrical vehicle compared to a combustion engine. This has been done by using the key words “LCA”, “Life Cycle Analysis”, “Electrical Vehicle” and “EV” in google scholar, the online registry of the Journal of Industrial Ecology and the search engine Scopus. After these LCA’s were analyzed, the studies that were best suited to the context of this project were used to quantify the environmental effects of the two types of vehicles. The selected data are explained in chapter 3.3.1. The end-result of this section are the environmental effects quantified in their appropriate unit.

When the effects on vehicle adaptation and the environmental impact of a BEV and ICEV were known, the environmental impacts of these policies were then calculated. Both the CBA without the LCA (referred from now on as CCBA – Conventional Cost-Benefit Analysis) and the CBA with the integration of the LCA (referred from now on as CBLCA – Cost-Benefit Life Cycle Analysis) use the ReCiPe method (explained in chapter 2.4.3) and their indicators to account for the environmental impact of the policies. Since the papers of Nijland et al (2019) only accounts for the CO_2 emissions, the data of the LCA’s have to be used for both the CCBA and the CBLCA to analyze all appropriate effects of the policies. However, for the CCBA, only the use phase emissions have been considered. The formulas and data that were needed to make these calculations are provided in the appendix.

To monetize the effects, the Environmental Prices Handbook (de Bruyn et al, 2017) constructed by CE Delft will be used. According to de Bruyn et al, since it is unclear where in The Netherlands the pollution occurs, it is recommended to use key figures to monetize environmental effects. The Environmental Prices Handbook contains values for a wide range of environmental effects and is constructed using the ReCiPe method and is suitably compatible with LCA’s that use this method.

2.3.4. Uncertainties & Future research

Uncertainty- and risk analysis

With the prediction of environmental effects of policies comes uncertainty. It is important to take the risk and uncertainty into account with the CBA. This will be done by using the two scenarios (high and low) given by the PBL in the WLO (Toekomstverkenning Welvaart en Leefomgeving), and to use the lower and upper limit in the Environmental Prices Handbook when the environmental effects are monetized. The difference between the lower and upper limit scenarios are explained in the appendix B.C. This chapter also considers al the assumptions that have been made during this research and how future research should could improve on the research that has been made for this paper. Since this research differs from a conventional CBA, the more scientific layout is used where the uncertainty and future research analysis will come after the results chapter.

2.3.5. CBA results

This chapter contains the final results of the thesis research.

Creating an overview of costs and benefits

This step can be considered as the reporting of results found in this paper. The presentation of the results in the thesis must include the uncertainties and bandwidths of the environmental effects.

2.3.6. Discussion, conclusion & presentation

The final chapters include the discussion, recommendation and conclusion. The recommendation chapter includes the second main research question of this thesis, which revolves around the consequences/recommendation for policy makers considering the results of this paper.

Present results

This step can be considered the last presentation and defense for the thesis.

2.4. Data sources

In this paragraph, the key papers that are used for this research are explained as to what they actually researched and why these papers were chosen as base data.

2.4.1. Dataset policy effects

The dataset used to analyze the effects of the Dutch policies comes from Nijland et al. (2019) by the PBL. This dataset is used for the simple reason that the PBL is the national institute that has the task to perform research for the Dutch government in order to gain knowledge on certain policies concerning environment, nature and spatial planning.

The data of the effects of the policies on new sold EV's, emissions and costs until 2030 that comes from the PBL are calculated by the consultancy agency Revnext which uses the Carbon-tax model. The Carbon tax model is a model that calculates the consumer behavioral reactions based on price elasticity. The input parameter is the Total Cost of Ownership, but other variables that influence the consumer behavior are also taken into account for. The dataset by Revnext (2020) is provided to the student in the form of a spreadsheet after personal contact with the agency and thus does not come from a report or paper.

2.4.2. Dataset Life Cycle Analysis

The dataset for the life cycle analysis of electrical vehicles and combustion engine vehicles comes from the research of Hawkins et al. (2012). The reason this paper was chosen as a main dataset is because of the transparency of the paper, the accessibility and completeness of the available dataset of the study. The assumptions that were utilized for the calculating process were in line with the scenario envisaged and bore close relation to the thesis project's aims.

The dataset of Hawkins et al. provides a dataset that gives the absolute impact scores per km driven per type of vehicle for every stage of their life time. The impact scores are provided on mid-point level using the ReCiPe method, from the hierarchical perspective (explanation of hierarchical perspective in chapter 2.4.3). The functional unit is 1 kilometer driven under European average conditions. The driving cycles that are used for the calculations are according to the New European Driving Cycle and follow the UNECE 101 regulation (UNECE 2005). Electricity inputs for the electrical vehicles are also representative for the average European electricity mix in 2012. Vehicle and battery lifetime are assumed to be 150000 kilometers driven. This is, according to Hawkins et al., realistically aligned with typical lifetime assumptions for electrical vehicles. However, a sensitivity analysis has been made by Hawkins et al. for alternative lifetimes.

Carculator

Bauer et al. (2017) made an analysis of the future state of electrical vehicle production and technology and how this would affect the life cycle analysis of an electrical vehicle. In addition, they created an open source tool that could be used to calculate technological progress and its impact on environmental pollution. This tool is called *'carculator'* (Sacchi et al., in review) and is created by the Paul Scherrer Institute. This tool has been used during this thesis project, in addition to the LCA of Hawkins et al. to create a dataset for the timeframe 2020 to 2050. This means that the output of the LCA for 2050 can be vastly different to that of the initial LCA of Hawkins et al. To make sure only the technological progress of the vehicle is accounted for, assumptions such as the driving cycles are kept similar to that of the assumptions made by Hawkins et al. The technological changes that are used in this study involve those that improve the energy efficiency of the vehicle (Bauer et al., 2015). For example, weight reduction or battery specific energy. The only other factor that changes compared to the study of Hawkins et al. is the electricity production for the BEV. Bauer et al. uses the EU reference scenario 2016 for the electricity production (European Commission, 2016). The data that is used for this study is shown in Figure 3. It is noted however that it is very likely that some of these factors also change in the future depending on the policies The Netherlands and/or the EU decide to undertake. But since this is not within the scope of this thesis project, this is will be recommended for future research.

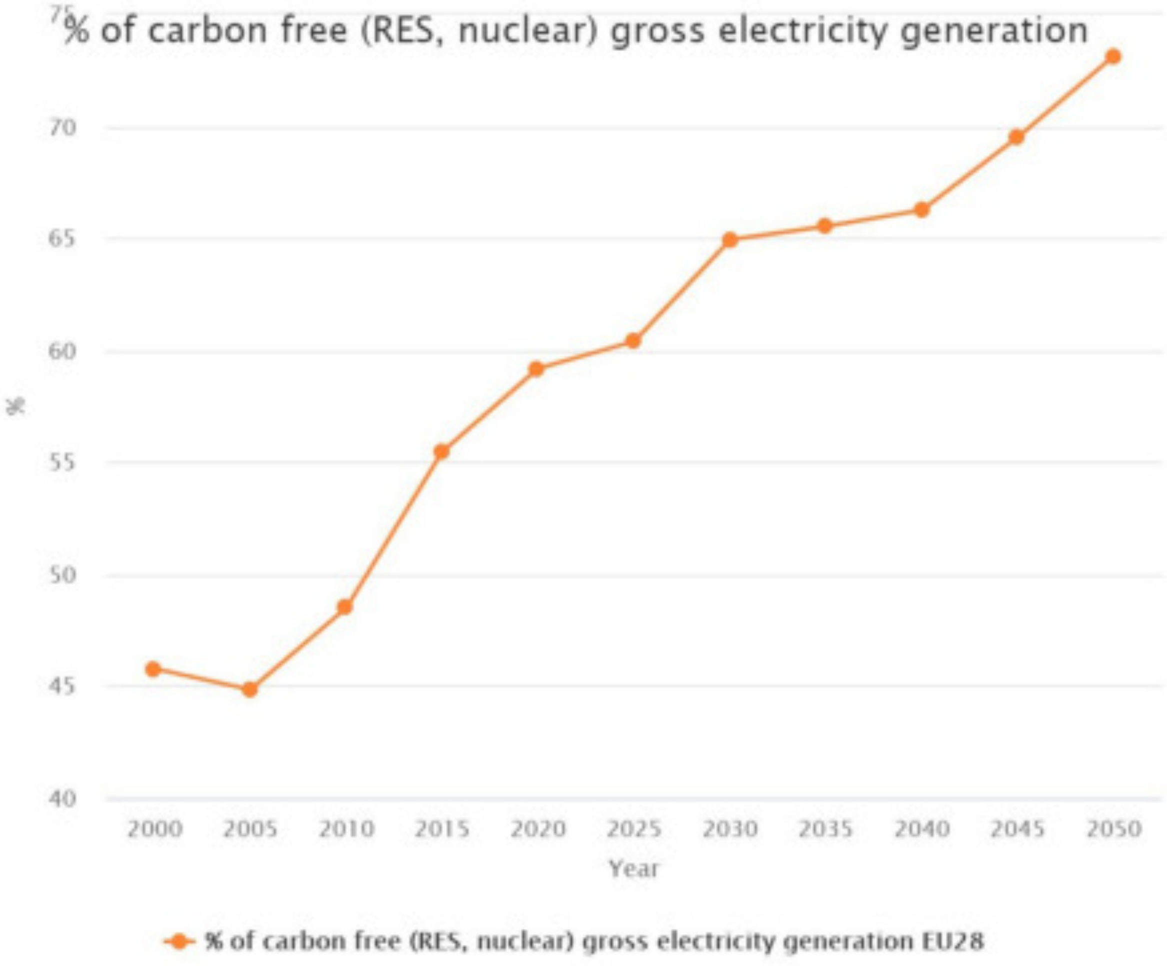

Figure 3: Reference scenario EU 2016 carbon free electricity production. Source: European Commision, 2016.

2.4.3. Environmental impacts prices

The third important dataset comes from De Bruyn et al (2017) by CE Delft. CE Delft made a handbook for environmental prices commissioned by the ministry of infrastructure and environment.

This handbook provides tools on how to use the correct environmental prices based on which type of study the researcher is performing. This handbook also explains and shows the results of the research that has been conducted to determine environmental prices on particle level, mid-point level and end-point level. The particle level is the lowest level on which emissions are quantified and are the flows of the inventory list in the LCI (for example emissions like CO_2 or CH_4). These are then converted into mid-point levels indicators, which focusses on a single environmental problem (for example CO_2 and NH_4 both account for the environmental problem ‘global warming’) . The end-point level indicators further aggregates the environmental impacts . Figure 4 shows the structure of the ReCiPe mid-point and end-point indicators. Particle levels are specific to the methodology of the handbook of De Bruyn et al (2017), which means it is not specified by the ReCiPe method and in Figure 4.

In the case of this study, the mid-point level environmental prices are used. This is because the LCA’s used for this research are based on the ReCiPe method, which means that the impact data are provided in a specific set of categories. These categories are in line with the mid-point levels provided by De Bruyn et al (2017). These indicators differ slightly from the original ReCiPe specific indicators, but are applicable with the LCA’s that are used for this study.

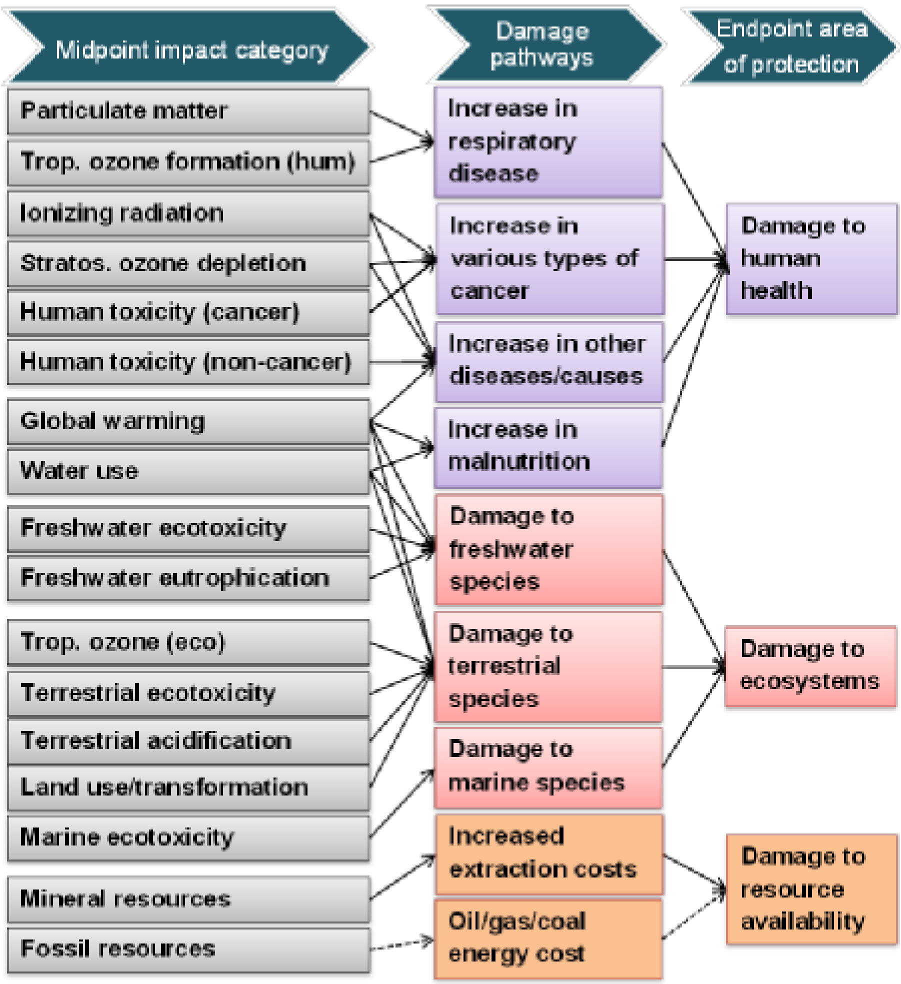

Figure 4. Overview of the structure of ReCiPe (2016) mid-point and end-point indicators. (Source: RIVM. 2018)

The prices provided by this handbook are based on the damage this type of environmental impact incurs on the welfare of society of The Netherlands. Based on this analysis, De Bruyn et al (2017) was able to determine the damage that one kilogram of extra emission would have on environmental welfare. There are multiple methods to determine the damage to society however. One of which used by De Bruyn et al, is the Willingness to Pay (WTP) and Willingness to Accept (WTA) mentioned earlier. Other methods include calculating the prevention costs for inhibiting the impact on the environment and reparation costs for repairing damage incurred. In Table 5 are the methods shown that are used to determine the environmental prices on end-point level.

Table 5: methods for determining end-point environmental prices (De Bruyn et al, 2017)

Endpoint	Methods
Human health Mortality	WTP & WTA (asked and tested based on historical preferences)
Human health Morbidity	WTP & WTA (asked and historical preferences)
Ecosystem services	WTP & WTA, reparation costs
Buildings and materials	Reparation costs
Resources	Damage costs, prevention costs, modelling
Climate change	Prevention costs
Nuisance	WTP & WTA, modelling concentration response function

The handbook presents different sets of environmental prices, based on the purpose of the research that the reader is conducting. Three of these sets are important for this study as they provide:

A+B): A high and low value of the prices based on economic principles. These values are based on an individualistic world view, which will be explained below. These values are normally used for CBAs, since they provide a range of uncertainty that is required to perform a CBA according to De Bruyn et al (2017).

C): A central value that is normally used for LCAs. These values are used as a weighing factor and are based on a hierarchical worldview.

Since this study integrates LCA with CBA, it is important to know the difference between the hierarchical and individualistic principle. This is to ensure the correct values are used for the research.

Hierarchical and individualistic principle

According to Huijbregts et al (2017), The ReCiPe methods impact indicators contain factors that follow three cultural perspectives: *individualistic, hierarchical* and *egalitarian*. These three perspectives represent a future worldview based on the choices humans may make when considering nature. The *individualistic* perspective is inherently short-term focused where optimism that technology can overcome many of the environmental hurdles is found; the *egalitarian* view however is longer term based where generally humans will be acting more cautious towards nature. The *hierarchical* view is a consensus model which is frequently used in scientific LCA models. How this would work in practice is best explained by an example. Considering the impact indicator of climate change, the differences between the three perspectives are illustrated in Table 6 which has been adopted from Huijbregts et al (2017) (p.20).

The reason why this is important is mainly due to the way specific emissions are calculated into the mid-point and end-point levels. When for example, while considering the mid-point indicator climate change and the greenhouse gasses carbon dioxide (CO_2) and methane (CH_4), the global warming potential (GWP) of these gasses will vary according to their perspective. This in fact indicates they are accounted for differently for the mid-point indicator Climate Change, per perspective. This is because gasses have a different life-cycle when emitted into the atmosphere in comparison to each other.

While CO_2 always has a GWP of 1 (which is considered the baseline), the GWP of methane changes from 84, to 34 to 4.8 (kg CO_2-eq/kg) depending on the individualistic, hierarchical and egalitarian perspective, respectively. Considering the differences in perspectives, the choice between individualistic and hierarchical worldviews could have a considerable effect on the outcome of this study.

For this thesis project, the individualistic worldview is chosen as the perspective for the environmental prices. However, this is not the same perspective that has been chosen by the authors of the LCA dataset that is used. The reason that a different perspective is used for the environmental prices is because of the uncertainty range that is provided (see Table 10), which fits the CBA requirement of having a uncertainty and risk bandwidth, and that the time horizon of the individualist perspective (20 years) is more in line with the scope of the thesis project (30 years).

Table 6: Value choices based on different ReCiPe perspectives (Huijbregts et al ,2017)

	INDIVIDUALIST	HIERARCHIST	EGALITARIAN
CLIMATE CHANGE			
TIME HORIZON	20 years	100 years	1000 years
CLIMATE-CARBON FEEDBACKS NON-CO2-GHGS	No	Yes	No
FUTURE SOCIO-ECONOMIC DEVELOPMENTS	Optimistic	Baseline	Pessimistic
ADAPTION POTENTIAL	Adaptive	Controlling	Comprehensive

2.5. Scope, assumptions & societal relevance

This research will, as is explained before, use already existing policy effect models and LCAs to create the two different CBAs. This means that no LCA will be performed and no models to calculate the effects of the policies will be created. However, in the case of the policy effect models, the data that is provided only accounts for the years from 2020 to 2030. In order to still receive valuable data and stay inside the scope of this research, certain assumptions have been made to make the calculations for the missing data. These assumptions are explained in Table 7, such as other assumptions that were needed to create the CBA.

Table 7: Assumptions made for the calculations of this research.

Assumptions subject	**Value**	**Needed for**	**Source**
TCO BEV	Linear trend from 2027-2030	Policy effects	Revnext (2020)
TCO BEV	Equal to TCO in 2020	National costs	Revnext (2020)
BEV & ICEV lifetime	12.5 years	National costs	Revnext (2020)
Policy effect on total fleet	None	Policy effects	None
Vehicle and battery lifetime	150.000 km	Environmental effects	Hawkins et al. (2013)
Growth market share after 2030	Linear trend from 2027-2030	Policy effects	Revnext (2020)
Percentage that leaves the total fleet (due to export/import and demolishing)	5.43%	Policy effects	CBS open database (2020)
Discount rate	3%	Costs and benefits	Nijland et al. (2020)

3. Impact valuation

This chapter will explore both the economic and non-economic costs and benefits of the alternative policy scenario compared to the baseline scenario. These effects will be explained by way of the data from which they were derived based on assumptions used to extrapolate the data into the correct time frame. This chapter first explains the BEV adoption rate and the associated national costs for the baseline and the policy scenario. Secondly, the LCA data and the environmental prices are analyzed. Afterwards, the effects on vehicle adaptation and the environmental impact of a BEV and ICEV were analyzed. Lastly the environmental impacts of the policies are explained in the final paragraph.

3.1. Impact on EV integration

3.1.1. EV market share

The impact of the policy alternatives (details about the policy alternatives can be found in appendix B.B on the electrical vehicle market from 2020 to 2030 has been analyzed by the PBL and Revnext. The results of the impact on new car sales can be found in Table 8. A few things can be observed from this table. When looking at the baseline columns of the table, which shows the BEV market share without the influence of the climate agreement policies, it can be seen that the BEV market share steadily rises in all paths. This is due to the expected rise of the economy and decline of the BEV price. The low, high and mid path have expected rates of economy growth and price decline, which results in differences in market share growth.

Another interesting feature is the effect of the alternative policies on the BEV market share. It shows a steep increase in the early years of the policy introduction indicating that there is an effect of the electric vehicle stimulating policies. Figure 5, shows the trend in BEV market share in a graph. From here, another noticeable trend is clearly visible. After 2025, the alternative policy shows a decline in market share. From there on, the alternative policy scenario follows the trend of the basis scenario in all paths. Interestingly enough, when looking at the climate agreement policy scenario from 2020 to 2030 (Table 8), the stimulation of the BEV market stops after 2025. This creates the suggestion that as soon as the government stops stimulating the BEV market, the market quickly responds and goes back to the baseline market trend. This indicates that the financial stimulation policies only affect the market in the years that they are active. These are then important observations when trying to predict the market share in the future.

Table 8: Market share of BEV in new sales (Revnext & De Bruyn et al. 2020)

	ALTERNATIVE			**BASELINE**		
	Mid path	**High path**	**Low path**	**Mid path**	**High path**	**Low path**
2020	9%	9%	9%	9%	9%	9%
2021	15%	16%	13%	1%	2%	1%
2022	14%	18%	11%	3%	5%	2%
2023	19%	25%	14%	5%	9%	2%
2024	25%	34%	17%	8%	15%	3%
2025	26%	41%	18%	12%	21%	5%
2026	19%	27%	10%	17%	24%	7%
2027	22%	34%	10%	21%	32%	9%
2028	25%	38%	12%	25%	37%	11%
2029	29%	45%	15%	29%	44%	14%
2030	34%	52%	18%	33%	51%	17%

To create the prediction of the BEV market share growth from 2030 to 2050, a trend has been charted using the growth of the years between 2027 and 2030. This creates a linear path of market share growth. At some point, there will be a 100% BEV market share (excluding the low path). It is clear however that using the trend of the years between 2027 and 2030, the growth of the policy alternative and the policy baseline will be almost completely identical.

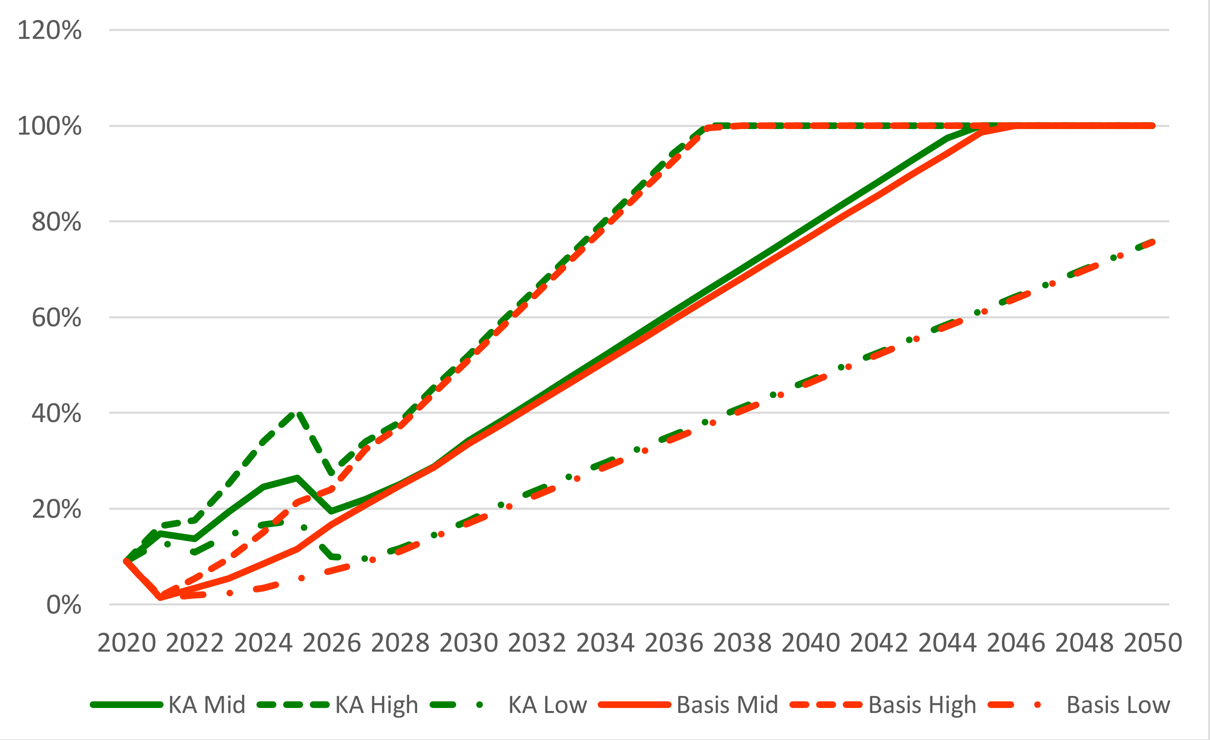

Figure 5: Market share BEV in new sales 2020-2050

3.2. National costs and benefits

3.2.1. 2020 to 2030

The effects of the policies on the national costs from 2020 to 2030 are calculated by the PBL and Revnext. Government costs, like subsidies and taxes are also calculated in, but are considered transactions. These factors will not be considered as national costs. Benefits to Dutch society of the policy scenario compared to the baseline scenario are indicated in Table 9 as negative numbers. The national costs include:

- Investment costs/savings vehicles and charging infrastructure
- Maintenance costs/savings
- Electricity costs
- Fuel savings

Table 9 shows the results of the cumulative national costs in million euros for the years 2030 and 2050 of the alternative policy scenario compared to the baseline policy scenario. Since the provided data only covers from 2020 to 2030, the years 2031 to 2050 needed to be calculated. Table 9 shows that the vehicle investment costs are the largest factor in the national costs, since the electrical vehicles are generally more expensive than conventional personal vehicles. However, the investment costs are almost nullified by the fuel savings the electrical vehicles provide. Of course, the vehicle which runs on electricity will also incur extra costs. The maintenance costs of an electrical vehicle are generally lower than conventional vehicles which means they are considered as a benefit in the alternative policy scenario. Since the costs and benefits are related to the amount of vehicles sold that year, it is not surprising that the low and high paths show different amounts than the mid path. In paragraph 3.1.1 we can see that in the low path scenario the growth of new EV car sales was lower than the mid path, while the high path scenario showed a higher growth. The costs and benefits in these scenario's show the same, where the low path has lower costs than mid and high path scenario's, while the high path has higher costs than the mid and low path scenario's.

Table 9: National costs (mln). Source: PBL & Revnext

MID PATH	INVESTMENT EVS	INVESTMENTS INFRASTRUCTURE	MAINTENANCE COSTS	ELECTRICITY COSTS	FUEL COSTS	TOTAL
2030	3595	300	-1571	985	-2708	601
2050	4605	384	-2012	1261	-3469	770
LOW PATH						
2030	3314	271	-1019	853	-2311	1109
2050	3773	309	-1160	972	-2631	1263
HIGH PATH						
2030	3758	308	-1156	968	-2620	1258
2050	4044	331	-1243	1041	-2820	1353

3.2.2. 2030 to 2050

Since the data from the PBL and Revnext only provides the time span between 2020 and 2030, the remaining years needed to be calculated. This was done by linking the national costs to the EV market sales. In this case it meant the extra car sales in 2021 would need to be calculated, which means the difference between the EV market sales from the reference policy scenario to the alternative policy scenario in 2021 is calculated. This is then divided by the national costs of the same year. This creates a costs per extra sold EV unit which can be used to calculate the national costs from 2021 to 2050 using the BEV market share in new sales from paragraph 3.1.1. The exact calculation method can be found in Appendix C.B. One very important assumption using this method of calculation is that the national costs of every extra EV sold would stay equal from 2021 up to 2050. This means that the costs of an electrical vehicle in 2050 is assumed to be the same from as the costs of an electrical vehicle of 2021. This was done to stay within the scope of the research project. How this assumption can affect the actual results of the research is explained in chapter 5.6.However, it is very likely that the (national) costs of an electrical vehicle will change over the years; this will be discussed in paragraph 5.6.

Again, we look at Table 9 to analyze the national costs trajectory. It is clear that the national costs between 2030 and 2050 will rise. However, there are differences in the amount it will rise between the scenario paths. The low and high path show almost no increase in costs & benefits in all categories, over a doubled time period. This slower rate of cost-growth is explained by the almost identical increase in EV market growth between the alternative and reference policy scenario. Only the mid path shows more increase in EV adaptation than the other scenarios.

3.3. Environmental impacts

3.3.1. Life cycle analysis

As mentioned in chapter 2, the data for the life cycle analysis is provided by Hawkins et al. (2012). The results of the life cycle analysis can be found in Table 23 in the Appendix. The results are categorized based on the impact category and the life cycle component. The impact is analyzed for the both the electric vehicle and the ICEV. The electric vehicle however is also divided between the electricity and their battery type, while the ICEV according to fuel use, diesel or gasoline type. More details about the different categories can be found in the Appendix (Appendix B.D).

For this thesis research, the comparison is made between the LI-NCM battery electric vehicle where the electricity for the EV is made by a European electricity mix grid and the gasoline ICEV. The Li-NCM battery is used, since this is more common in EVs than the Li-FePO4 batteries (Buchmann, 2001).

Table 23 shows the absolute impact scores per km driven per type of vehicle for every stage of life time. The results of Table 23 show that the impact valuation of the base vehicle (chassis, bodywork, etc.) is the same for every type of vehicle. This is true for every impact category. To make a fair comparison between the different types of vehicles (EV or ICEV), it is important that they are compared to each cars with the same function. For example, it is not fair to compare a small hatchback ICEV to a big luxury EV, since they do not share the same target audience and functionality. They are compared only for the characteristic differences between an EV and ICEV, which is the powertrain, battery, fuel/electricity, maintenance and end-of-life stage.

Figure 6 shows the normalized impacts of the life cycle of the EV and ICEV. From this figure, it is clear that for multiple impact categories, the *use phase* (fuel /electricity) has the largest environmental impact. Interestingly, it also shows that the electricity production for the use phase of the EV is of considerable importance. For the impact category *climate change* (which is GWP, global warming potential in Figure 6) the environmental impact of the *use phase* of the EV doubles when the electricity is produced by coal. Indicating that the role of the electricity grid mix is important when considering the future environmental impact of the EV.

GWP (Global warming potential)

As mentioned before, the environmental impact for the base vehicle is the same in both vehicle types. In the case of the GWP, the end-of-life phase also has the same environmental damage with both vehicle types. Overall, the ICEV has a higher impact on climate change than the BEV. The largest part of this occurs in the use phase as previously mentioned.

TAP (Terrestrial acidification)

Acidification of the soil is in both the ICEV and the BEV almost the same. With the BEV scoring slightly higher than the ICEV. Where the BEV has a slightly lower impact during the production phase of the powertrains, it has a considerable large impact during the production of the battery. Interestingly, the environmental impact of terrestrial acidification is equal not only during the base vehicle and the end-of-life phase, but also during the use phase of the fuel and electricity production. The paper of Hawkins et al. (2014) did not provide an explanation as to why this is and further research also could not give a possible explanation. Since the impact of the natural gas, coal and diesel vehicles are different. It is assumed in this paper that this is a coincidence, but further research may be required by future research.

PMFP (Particulate matter formation)

Particulate matter that pollutes the atmosphere is slightly more emitted by the BEV than the ICEV. The BEV scores particularly higher during the electricity production than the ICEV during its fuel usage. Comparing this to the outcome of the electricity production when it’s made by coal, it is likely that coal powerplants in the European electricity mix has a large influence on the PMFP output of the BEV.

POFP (Photochemical oxidation formation)

Photochemical oxidant formation is a pollution, where the pollutant reacts in certain atmospheric conditions, particularly under sunlight. This can cause human and materialistic harm (Baumann & Tillman, 2004). The ICEV emits almost 50% more than the BEV, which is mostly due to the fuel usage of the ICEV. The ICEV emits more than double the amount during the use phase than the BEV.

HTP (Human toxicity)

Emitted substances that are emitted in the environment that cause human harm (in certain doses) are expressed as the human toxicity potential (HTP). The human toxicity indicator is an interesting one, since this is an indicator where the difference between the ICEV and the BEV in quantitative pollution is quite large. The BEV pollutes more than three times as much as the ICEV. The BEV pollutes a lot more during both the production and the use-phase. The emissions during the production of the battery and powertrains together are more than half of the total amount of the emissions during the total life cycle.

FETP (Freshwater eco-toxicity)

Emissions that have a harmful impact on the fresh water ecosystems, as a result of toxic substances emitted in the air, water or soil, are expressed by the indicator freshwater eco-toxicity. The freshwater eco-toxicity of the BEV and the ICEV shows similar ratios as the HTP. Also here, the BEV scores three times the amount as the ICEV, which mostly occurs during the production of the batteries and powertrains and during the production of the electricity.

TETP (Terrestrial eco-toxicity)

Emissions that have a harmful impact on the terrestrial ecosystems, as a result of toxic substances emitted in the air, water or soil, are expressed by the indicator terrestrial eco-toxicity. The emissions during the life cycle of the ICEV and BEV show similar levels in both types of vehicles, in all phases of their lifetimes.

FEP (Freshwater eutrophication)

Pollution that impacts the nutrients level in the freshwater environment are expressed as freshwater eutrophication. . The freshwater eutrophication of the BEV and the ICEV shows similar ratios as the HTP. Also here, the BEV scores three times the amount as the ICEV, which mostly occurs during the production of the batteries and powertrains and during the production of the electricity.

MDP (Mineral resource) & FDP (Fossil resource depletion)

Since these indicators are not expressed in monetary terms in this research. These indicators will not be documented in this paper.

At last, it has to be mentioned that the environmental impacts of both vehicles occur during different time frames and at multiple locations. This can change the interpretation of the results of the LCA considerably, which will be further explained in chapter 5.2

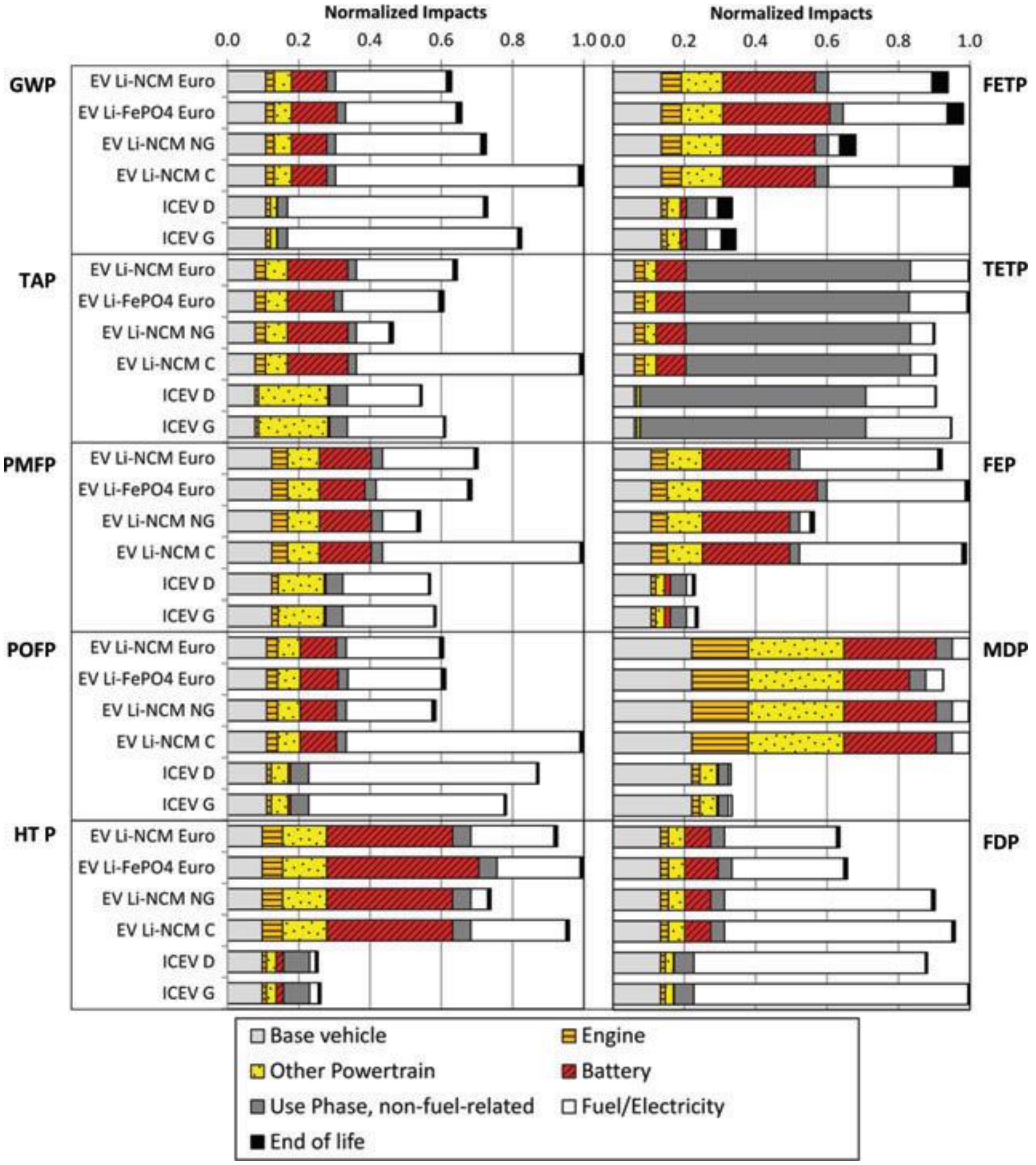

Figure 6: Normalized impacts of EV and ICEV life cycle. Results have been normalized to the largest total impact for each impact category. Abbreviations in appendix. Source: Hawkins et al. (2012)

3.3.2. Life cycle impact trajectory

Using the research and tool of '*carcurator*' a life cycle impact trajectory of the electrical vehicle could be made from 2012 to 2050. To create the trajectory, the *carculator* tool is used to estimate the environmental impacts of the years 2012, 2020, 2030 and 2050. Figure 7 shows the normalized trajectory of the environmental impact of the electric vehicle. It is clear that for most impact categories, the environmental impact of the BEV shows a downward trend. This is because of the more efficient use of materials and energy due to technological improvements. Also, it is estimated that the energy grid will have a slightly less fossil fuel reliant dependency, according to the EU reference scenario (Capros et al. 2016), which is used by Bauer et al.

Some impact indicators show a greater decline than others. For example, the freshwater eco-toxicity environmental impact of the BEV stays quite the same over the years, while the climate change environmental impact of the 2012 BEV is almost twice as high as the expected environmental impact of the 2050 BEV. How this will affect the final CBA, depends on the combination of the price of environmental impact and the quantity of the pollution. When an environmental impact lowers by half, but has a very slim impact on the total costs of the life cycle of the BEV, than the effect on the CBA is also less significant.

Using the normalized impact trajectory, the future environmental impacts could be calculated using the results of Bauer et al as a factor for the results of the original LCA of Hawkins et al. The total results of the life cycle analysis for the years 2012, 2020, 2030 and 2050 can be found in the Appendix (Appendix B.D).

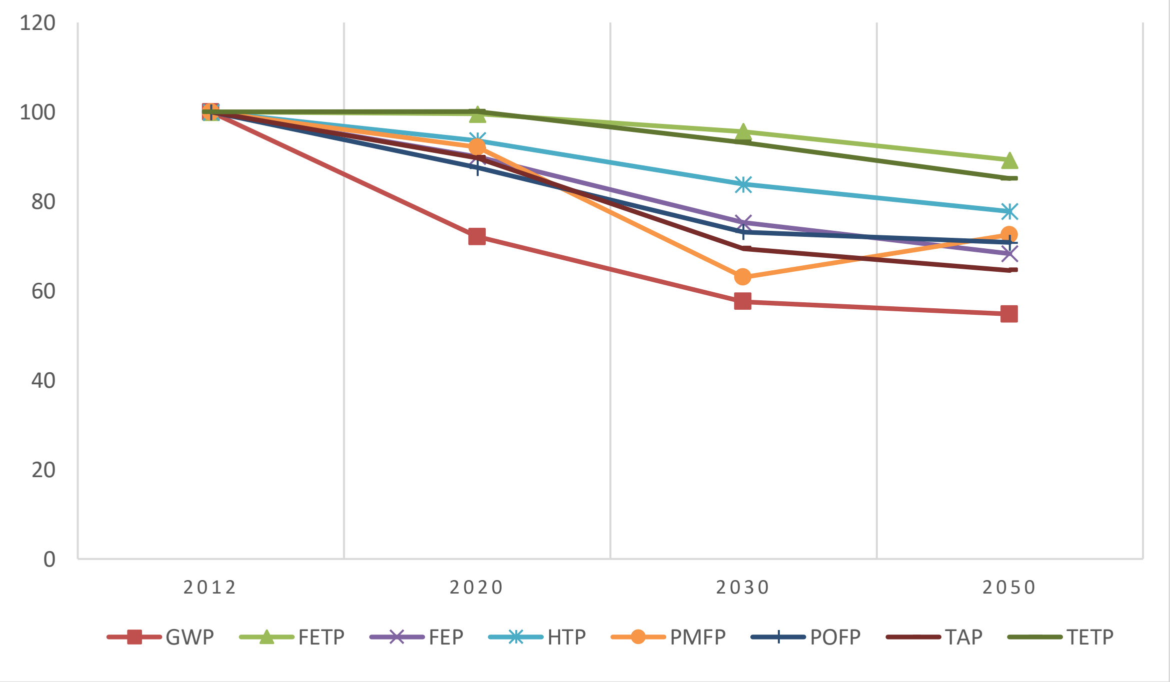

Figure 7: Life cycle impact trajectory 2012 to 2050 of electric vehicle. Source: Bauer et al. (In review).

3.3.3. Willingness to pay for environmental damage

The costs per impact category are provided in Table 10. The prices are given in a range from low, average to high. All these prices are used in order to stay into an *uncertainty range*. De Bruyn et al (2017) provides almost the same impact categories as do the findings of the LCA. Only the impact categories “metal and fossil depletion” are not being considered in the studies of De Bruyn et al (2017).

To monetize the environmental impacts, these prices are multiplied with the results of the LCA.

Table 10: Prices of environmental impacts. Source: De Bruyn et al (2017)

IMPACT CATEGORY	UNIT	LOW	AVERAGE	HIGH
CLIMATE CHANGE	€ / kg CO2 eq	0,01	0,06	0,06
OZONE DEPLETION	€ / kg CFC-11 eq	22,10	30,40	45,70
HUMAN TOXICITY	€ / kg 1.4-DCB eq	0,16	0,21	0,33
PHOTOCHEMICAL OXIDANT FORMATION	€ / kg NMVOC eq	1,61	2,10	3,14
PARTICULATE MATTER FORMATION	€ / kg PM10 eq	49,30	69,00	106,00
IONIZING RADIATION	€ / kg U235 eq	0,03	0,05	0,06
TERRESTRIAL ACIDIFICATION	€ / kg SO2 eq	1,19	5,40	10,70
FRESHWATER EUTROPHICATION	€ / kg P eq	0,47	1,90	3,71
MARINE EUTROPHICATION	€ / kg N eq	3,11	3,11	3,11
TERRESTRIAL ECOTOXICITY	€ / kg 1.4-DCB eq	2,21	8,89	17,30
FRESHWATER ECOTOXICITY	€ / kg 1.4-DCB eq	0,01	0,04	0,07
MARINE ECOTOXICITY	€ / kg 1.4-DCB eq	0,00	0,01	0,01
AGRICULTURAL LAND TRANSFORMATION	€ / m2a	0,01	0,03	0,05

3.3.4. Environmental costs and benefits

Table 11 and Table 12 show the final results of the environmental benefits when conducting a CBA *with* and *without* integrating the full life cycle of the EV and ICEV (from here, the CBA without integration of the LCA will be referred as CCBA, while the CBA integrating the LCA will be referred as CBLCA). In these tables, where the numbers are negative, it means the alternative policies occur as costs to social welfare compared to the reference policies. As can be seen from the tables below, there is a significant difference between the outcomes of the CBA with and without the integration of the LCA. This is because the CCBA considers the environmental impact of the EV to be zero. There was also the option to only account for the use-phase impacts of the EV (which would mean the environmental impact of the production of the electricity), but since Nijland et al. (2019) also choose to account for the CO_2 output of the EV as being *zero* (thus choosing to only account for tailpipe emissions), this method is considered as “the conventional” way to allocate the environmental impact. Since the goal of this research is to compare a conventional CBA to a LCA integrating CBA, the conventional method is used for the CCBA.

The detailed calculations for environmental costs and benefits (and the rest of the CBA) can be found in the appendix. These results are calculated by using all the previous data that are explained in this chapter. Using this data, a year by year environmental impact per kilometer driven is calculated, which is then monetized. Afterwards, the effects of the policies are calculated by using the environmental impact per kilometer driven and multiplying that with the effect of the policies on the EV and ICE market.

Results

The results of these calculations show that integrating the full life cycle of the EV changes the perception of the alternative policies. The results of the CCBA (Table 12) are all positive. This means that stimulating the BEV has a positive effect for the environment compared to when there are no policies. On the contrary, the results of the CBLCA (Table 11) are negative. The reason that the results of the CBLCA are negative is because the full life cycle of the EV itself has a more negative effect in welfare then the ICE (see appendix C.C). The combination of the difference of the vehicle environmental output and the price of the environmental indicator results in that the overall environmental impact of the BEV is greater than that of the ICEV. It seems that especially the combination of the impact on human toxicity and the price of the indicator has considerable effect on total environmental impact of the BEV. This will be further analyzed in chapter 5.2. This means that stimulating the electric vehicle market will reduce welfare when considering the full life cycle of the vehicle. The trajectory of the environmental benefits/costs are as expected. The benefits rise when the environmental prices are higher, while the costs grow larger when the prices do the same. The same goes for the scenario paths. The low scenario path has less benefits/costs then the mid and high scenario paths. This is because the adaptation of the EV in the lower scenarios is slower than the adaptation of the higher path scenarios.

Table 11: Environmental benefits CBA with the integration of the LCA

ENVIRONMENTAL BENEFITS CBLCA (MLN EUROS)

PRICES	Low			Average			High		
SCENARIO PATH	Low	Mid	High	Low	Mid	High	Low	Mid	High
2030	-88	-117	-160	-127	-170	-232	-206	-275	-376
2050	-97	-140	-169	-136	-192	-242	-222	-315	-394

Table 12: Environmental benefits CBA without the integration of the LCA

ENVIRONMENTAL BENEFITS CCBA (MLN EUROS)

PRICES	Low			Average			High		
SCENARIO PATH	Low	Mid	High	Low	Mid	High	Low	Mid	High
2030	22	29	40	62	82	113	77	102	141
2050	25	37	43	70	104	121	87	130	151

4. CBA results

This chapter shows the final results of the CBAs of both the one where LCA in not integrated and the one where LCA is integrated. It discusses the differences and what the consequences are for the policymakers in the future.

4.1. CBA without integrated LCA (CCBA)

Table 13 shows the final balance of the CBA without the integration of the LCA. This can be considered the conventional CBA, where it shows the costs and benefits of implementing the policy alternative.

The final results show that whether the policy alternative can be seen as worthwhile depends on the scenario path and how high the prices are. The higher the prices of the environmental impacts are, the higher the environmental benefits. This can be explained by the fact that the environmental impact of the BEV is counted as zero, since only the tailpipe emissions are accounted for. The higher the prices are, the higher the environmental benefit compared to the reference scenario. It is therefore no wonder that the average and high prices in the mid and high scenario, the balance of the CBA is positive. Which means that, in the circumstances of mid and high economy scenario with average and high environmental prices, the policies to deemed to be worthwhile to increase welfare.

Table 13: CBA without LCA 2020-2050 balance

CCBA 2020-2050 (MLN)

SCENARIO PATH	Low			Mid			High		
PRICES	Low	Average	High	Low	Average	High	Low	Average	High
ENVIRONMENTAL BENEFITS	324	912	1138	468	1318	1645	521	1469	1833
NATIONAL COSTS	1263	1263	1263	770	770	770	1353	1353	1353
BALANCE	-939	-351	-124	-302	548	875	-832	116	480

4.2. CBA with integrated LCA (CBLCA)

Table 14 shows the final balance of the CBA with the integration of the LCA. In contrary to the previous CBA, this analysis accounts for the full life cycle of both the ICEV and the BEV. As can be seen from the table, the higher the prices, the lower the environmental benefits. In this case the environmental benefits are negative which means that stimulation of the BEV causes additional environmental harm over its full life cycle. The balance is negative on quite a margin in all scenarios for all prices. This means that, should the policies be implemented, this would cause a reduction in welfare for The Netherlands. In this case, policy makers should be advised to not stimulate the BEV. However, as is explained in chapter 5, a lot of different factors come into play when interpreting these results. Since the goal of this research was to see the influence of the integration of LCA into CBA, policy makers should not consider the results of these tables as the final verdict on whether or not it is worthwhile to stimulate BEVs. However, this paper should give an insight on whether or not it is worthwhile to use CBAs which integrates LCAs for their decision making progress. Whether or not this is the case will be discussed in the following paragraphs.

Table 14: CBA with LCA integrated 2020-2050 balance

CBLCA 2020-2050 (MLN)									
SCENARIO PATH	Low			Mid			High		
PRICES	Low	Average	High	Low	Average	High	Low	Average	High
ENVIRONMENTAL BENEFITS	-1259	-1779	-2899	-1767	-2415	-3959	-2045	-2934	-4774
NATIONAL COSTS	1263	1263	1263	770	770	770	1353	1353	1353
BALANCE	-2522	-3042	-4162	-2537	-3185	-4729	-3398	-4288	-6127

4.3. Evaluation

Comparing Table 14 and Table 13, it shows that the integration of the LCA can have significant effect on the outcome of the CBA. Where in the conventional CBA, the benefits are (in some circumstances) able to outweigh the costs. While in the CBLCA, the environmental impact of the BEV compared to the ICEV results in a net loss. Figure 8 shows the absolute difference of the CCBA and the CBLCA between 2020 and 2050. The difference in national costs is zero, because the LCA does not affect the national costs. However, the difference between environmental benefits can be quite large. For example, in the case of the low scenario with the low prices, the difference between environmental benefits of the CCBA and the CBLCA (€1583 mln) is almost 5 times the total environmental benefits of the conventional CBA (€324 mln). The national costs however, stay equal between both CBAs. The scope of the national costs of this research are more focused at the costs during the use-phase of the consumer. It could be argued that it would be fair to incorporate the additional costs that producers, manufacturers and waste management's get when the policies are implemented into the CBLCA. Most of these extra costs are market distortion costs and are further explained in chapter 5.8.

As is mentioned in the “discussion & recommendations” chapter, policymakers should be careful and can't put too much emphasis on the exact numbers of the results. However, the results do show that the influence of the integration of the LCA on the CBA is quite significant under all scenarios and prices. This indicates that the life cycle of the vehicles should be considered for when decisions are being made by policy makers. However, this depends on the perception of the policymakers, which will be explained in the next paragraph.

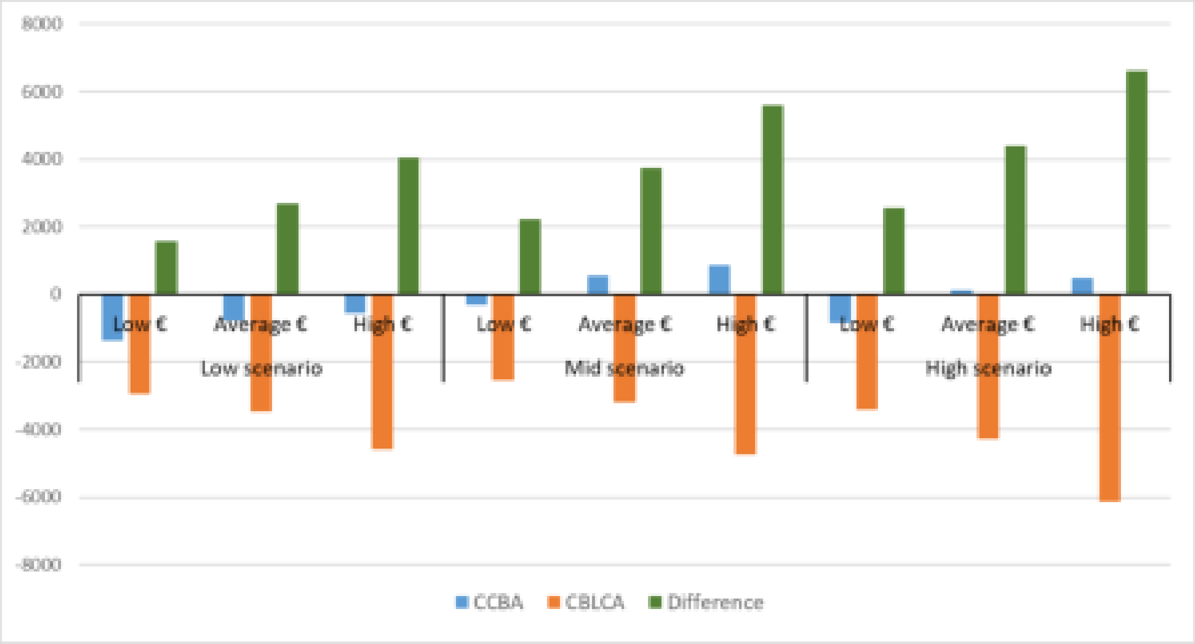

Figure 8: Balance (mln €) of the CCBA, the CBLCA and the difference between them.

5. Uncertainties & Future research

Conducting a cost-benefit analysis comes with facing uncertainties about the effects of the policies. These uncertainties rise when the effects of the policies play over a long period of time. Future scenarios have to be taken into account for, but are hard to predict. Future technologies, foreign policies and economic growth all have an effect on how strong the policies will affect the environment. Some of these uncertainties are already taken into account with in this paper using the low and high bandwidth of the (WLO) scenarios and using price ranges when monetizing the environmental effects. However, there are still uncertainties left that have to be analyzed and possibly taken into account for when conducting future research into this topic.

5.1. EV battery composition change

As mentioned in chapter 3.3.1, the battery that is used now for the LCA is the LI-NCM. However, looking at the results of Figure 6, the battery composition of the electric vehicle does significantly influence the environmental impact factor of this mode of transport. To further illustrate the significance of the battery, Peters et al. (2018) reviewed LCA studies to create a common base LCA for 5 different lithium-ion battery compositions used in EV's to analyze the difference in environmental impact of the batteries themselves. Figure 9 shows the normalized results of the (unified) LCI, provided per for 1 kg of battery mass or 1 kWh of storage capacity. First of all, looking at this figure, two interesting remarks can be identified. First of all, the impacts between batteries can change drastically depending on whether it is compared for storage capacity or weight. This is quite important in the case of batteries for electrical vehicles, since the extra weight of a battery can decrease the energy efficiency of the whole vehicle, while it increases the extra needed strength in the structure of the vehicle. Which, besides that it increases the total weight of the vehicle again, also increases the needed materials for the whole vehicle, thus increasing the environmental impact of the EV. Considering the context of the usage of the batteries, it is therefore important to look at the environmental impact of the batteries from both the storage capacity and weight perspective.

Secondly, according to Figure 9, the environmental impact between the 5 batteries can differ substantially. For example, the NCA battery scores almost 5 times as much as the LMO battery when looking at the acidification (AP) category per 1 kg of battery. This insight is significant for the life cycle impact of the electric vehicle, since the battery composition changes through the years or just per vehicle in general. The choice for the battery depends on a lot of factors (IEA, 2020). Safety, energy density, price and life time or just a few important factors. Personal vehicles can have different functions and requirements, which can alter the choice of the battery for a car manufacturer. This, combined with the fact that the environmental impact between the types of batteries is different, makes it even harder to create a LCA for a "general" electrical vehicle. Future research should therefore include the different battery types that are used in electrical vehicles and in the electrical vehicles of the future. It is also advised to model trends of the compositions change of the future battery types in the electrical vehicle fleet.

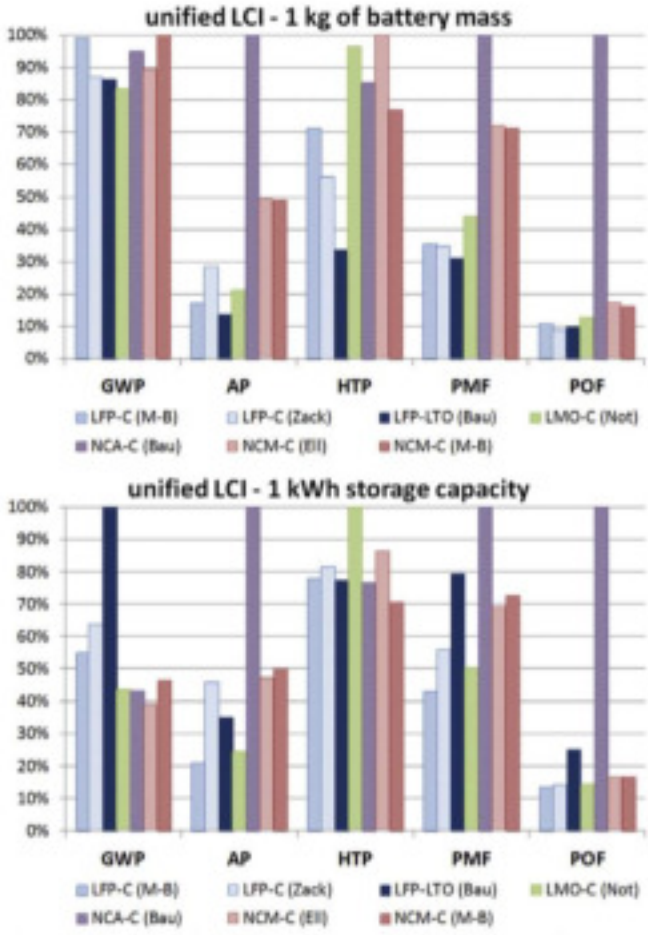

Figure 9: Normalized environmental impact of the 5 different batteries and studies per kg of battery and per kWh of storage capacity. The batteries are the LFP (Lithium-Iron-Phosphate with graphite anode), LTO (Lithium-Iron-Phosphate with lithium-titanate anode), NCM (Lithium-Nickel-Cobalt-Manganese-Oxide with graphite anode), NCA (Lithium-Nickel-Cobalt-Aluminum-Oxide with graphite anode) and the LMO (Lithium-Manganese-Oxide with graphite anode). Behind the battery type are the authors names of the research in short in brackets used by Peters et al., M-B = Majeau-Bettez et al., Zack = Zackrisson et al., Elling = Ellingsen et al., Not = Notter et al., Bau = Bauer et al. The categories are Global Warming Potential (GWP) acidification (AP), human toxicity potential (HTP), particulate matter formation (PMF), and photochemical ozone formation (POF). Source: Peters et al (2018).

5.2. Spatial and temporal difference environmental impacts

The life cycle analysis covers all the types of pollutions that occur during the life cycle of the vehicle. From the production of the batteries, the production of the chassis, the energy production needed for the vehicle, right through to the recycling of the various components. However, all these different processes happen in multiple countries at different times. While the batteries for example could be made in a factory in China, the recycling of those same batteries could be carried out elsewhere in Europe, for example, some 20 years down the road.

5.2.1. Spatial difference

The spatial difference of the environmental pollution could create major implications based on the actual prices of the environmental impacts. The environmental prices of this study are collected from the data and calculations of De Bruyn et al (2017). However, these are prices that are created for CBA's concerning The Netherlands. Even though the CBAs of the thesis research are focused on The Netherlands, integrating the full life cycle of the vehicle creates some implications. If only the *use phase* if the vehicle were to be accounted for, using these pricing indicators would be wholly legitimate due to the pollution occurring inside Dutch borders even though other phases of the life cycle of the vehicle could occur anywhere in the world. To illustrate the impact of the spatial differences on prices, Alberini et al. (2017) conducted a literature research on stated preferences studies for mitigating CO_2. Table 15 shows the WTP of different countries, which suggest that the time and place is of great importance for the willingness to pay for mitigating climate change. When considering the studies of Kompas et al. (2018), this is not that peculiar. Kompas et al. shows that the effects of climate change on GDP differ per country and changes over time (Figure 11). When the effects of an environmental impact may be for some greater than others, it is logical that the price of that type of pollution is then higher. To illustrate how this could affect the results of this research, Figure 10 shows the share of environmental costs of the life cycle of the BEV. Looking at this graph, it is clear that the environmental impact 'Human toxicity' contains almost half of all the costs of the electric vehicle. If these environmental problems occur in another country outside of The Netherlands which have a significantly lower or higher environmental costs for this indicator, than the results of the CBA could change dramatically. Considering all this, future research regarding the integration of LCAs into CBAs should take into account the spatial differences of the life cycle of the vehicles and their appropriate environmental prices.

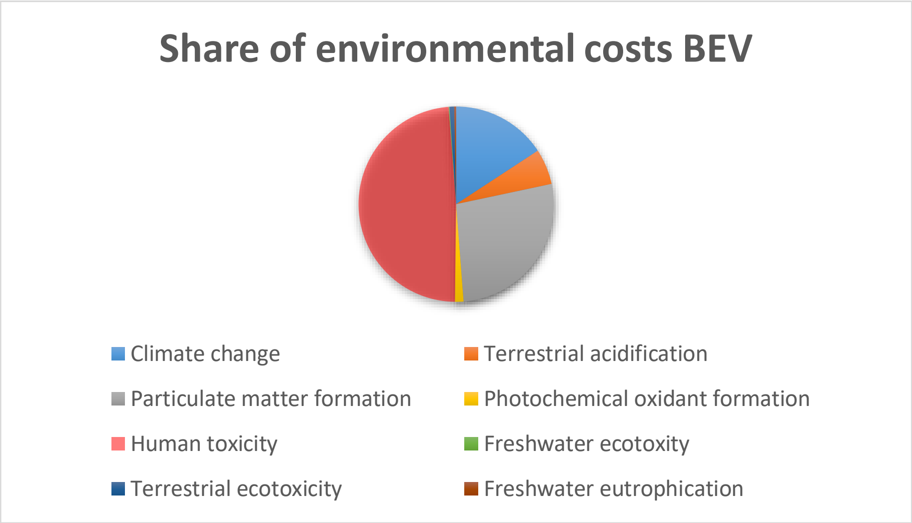

Figure 10: Share of the environmental costs of an BEV (average environmental prices).

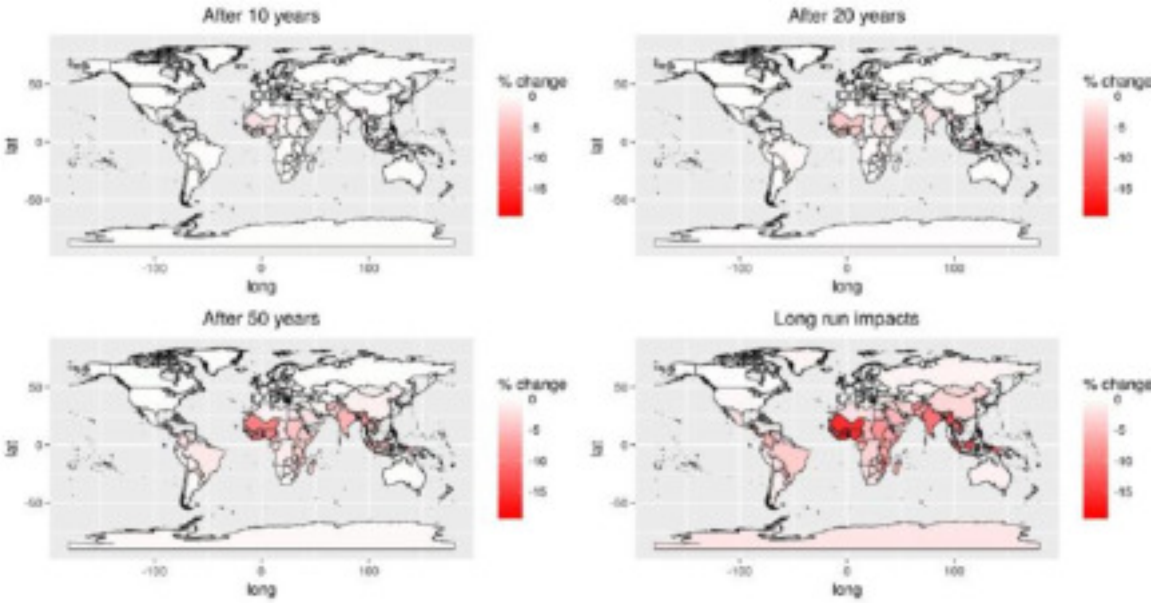

Figure 11: Effects of climate change on GDP per capita worldwide. Source: Kompas et al. (2018)

Table 15: Summary of stated preferences studies for mitigating CO2. Source: Alberini et al. (2017)

Study	**Country**	**WTP (euro per ton CO_2, 2014 exchange rate)**
Löschel et al. (2013)	Germany	13
MacKerron et al. (2009)	UK	36
Viscusi and Zeckhauser (2006)	USA	85
Longo et al. (2012)	Spain	62
Ščasný et al. (2017)	Czech Republic	18-70
Duan et al. (2014)	China	25

5.2.2. Temporal difference

As previously explained, the full life cycle of a vehicle could span several decades, which means the pollution it produces also covers several decades. For this thesis research, the assumption was made that the benefits/costs of a year are calculated by accounting every extra electric vehicle sold in that year and use the pollution that this vehicle produces over a full life cycle. However, the pollution of a vehicle does not all occur during that one year in which it was sold. The pollution from the recycling can occur 20 years later. This is especially of great importance when considering discounting. As mentioned in Chapter 2, discounting is done to express the future costs and benefits into present day values. Table 16 shows an example of the effect of a three percent discount rate on the results of this thesis research. Where the monetized environmental impacts are not discounted, the benefits would be substantially higher than if they were. It is therefore important that the environmental effects of the life cycle of the vehicles are accounted for at the time where they occur, and then correctly discounted for that time period.

Table 16: Example of the effect of discounting.

Avg. price, mid path	Not discounted	Discounted (3% rate)
Total benefits 2020-2050	133,98	104,45

5.3. Waterbed effect

The waterbed effect is the theory that when one problem is solved (or "pushed down") another one occurs at another time and/or space ("pops up"). In this particular case, it would mean that if the Dutch government would try to limit the environmental impact of the Dutch car fleet by stimulating the electric vehicle market, it could mean that the pollution that would otherwise be emitted in The Netherlands would then be emitted elsewhere, making the net savings (of the total environmental impact in the world) lower or even zero.

Waterbed effect EU CO_2 standards and targets

The Euro standards for passenger vehicles state that the average emissions of the car fleet of a manufacturer have to be below a certain threshold (depending on the weight of the car). Thus, the standards do not apply specifically to a country (Regulation (EU) 2019/631). Meaning that if a manufacturer sells low emission vehicles in The Netherlands, they can sell higher emissions vehicles in other countries (Nijland et al. (2019)).

Another regulation that could cause a waterbed effect with the Dutch EV policies, are the sales benchmarks that have been set to Zero and Low Emission Vehicles (ZLEV). Which are cars that have tailpipe emissions of less than 50 g/km. The regulations state that 15% of the car sales in 2025 have to be ZLEVs and 35% in 2030. Crucially, this is coupled with a bonus for carmakers that over achieve and sell more ZLEVs than the benchmark. Which can reduce their fleet wide average CO_2 emission target by up to 5% (Transport and Environment. (2019)). This, coupled with a multiplier formula for countries that sell less than 60% than the EU average, creates a loophole for manufactures to be able to sell more polluting vehicles when selling ZLEVs. The way this multiplier works is that if a BEV or fuel cell electric vehicle (FCEV) (having zero tailpipe emissions) is sold, it will be counted as 1.85 cars. Making it easy for manufacturers to exploit this loophole by registering these FCEVs or BEVs in countries that have these multipliers, while reselling it in other countries. This loophole is already abused by some carmakers to raise their target to 95 g/km in 2020/2021 (Transport and Environment. (2019)).

The exact effects of these waterbed effects have to be researched. These effects then have to be taken into account in the CBA to provide for a proper result.

Waterbed effect ETS

The waterbed effect can also influence the environmental impact of the EV in indirect ways. The EU has another system to limit the CO2 output of countries and manufacturers, the European Emission Trading System (EU-ETS). The EU-ETS is a cap on CO2 output of industries in the EU. To gain the right to pollute (emit CO2), certain rights have to be bought by companies/industries. The EU controls the amount of rights that can be sold, thus creating a cap on the amount of CO2 these industries can emit. This creates a market for CO2 rights. This whole system in itself creates a waterbed effect. When a company or industry decides to limit their CO2 output, it means that companies or industries elsewhere can buy these CO2 rights (or permits) that have been just been made available. This also works the other way around, when a company decides to increase their CO2 output and buy more permits. It would just simply increase the prices of the permits, making it unable for other companies to buy CO2 permits and pollute. Overall, the decision of one company to limit or increase their CO2 does not create a net benefit of total emissions with the EU-ETS system. It simply alters the prices of the CO2 permits.

How this affects the EV environmental impact is explained by Daniëls and Koelemeijer (2018). One important aspect of the EU-ETS is that it does not cover all companies or CO2 emitting entities. This is of great importance for the environmental impact of the EV compared to the ICEV. The EU-ETS does not cover the emissions of the tailpipe emissions of the ICEV. However, the power plants that are needed to create the energy to propel the EVs do fall under the EU-ETS. Introducing the EV into the market creates an extra load onto the energy system of the EU. However, the EU-ETS would automatically solve this with the waterbed effect by raising the prices of the permits in such a way that other industries cannot pollute as much anymore without making losses. This means that they have to lower their output or invest in greener technologies to make their company worthwhile. It could be argued that this creates a market distortion which also have welfare costs on its own, but that will be discussed in chapter 5.12.

In short, by shifting the environmental impact from a non-EU-ETS industry to an industry that does fall under the EU-ETS, the waterbed effect could create an effect in which the environmental impact of the EV could be significantly lower than is accounted for in this paper. How these effects are exactly influencing the environmental impacts of both the ICEV and EV, need to be researched and taken into account in the CBA.

5.4. Change in consumer behavior.

As can be seen in Table 27 and Table 28, The total fleet growth of the alternative policy scenario is equal to the total fleet growth of the baseline policy scenario. In this CBA, the assumption has been made that every electrical vehicle that has been sold thanks to the policies of the Climate Agreement, comes at the expense of the ICEV market. This means that someone would buy an electrical vehicle instead of an ICEV when he/she decides to purchase a car. However, research has to be made on whether this would actually happen. It is possible that when subsidizing electrical vehicles in a way that the total cost of ownership (TCO) decreases, extra EVs will be sold without interfering with the ICEV market. For example, the subsidies could be an incentive for people to buy an EV even if they would otherwise keep their old ICEV. Since this ICEV is probably still functional, it is likely that this vehicle will be sold through the secondhand market. It is possible that this could decrease the market value of second hand ICEVs, making it possible for people to own a car who previously wouldn’t buy one. This in the end, would increase the total car fleet.

Another example is if people with the means bought a second vehicle (which is an EV) for short distance rides while keeping the ICEV for longer distances like vacations thereby using both cars for different functionalities quite legitimately. Since EVs generally have a shorter range than ICEVs, this is not an unlikely scenario. This immediately brings another question to the table which is important for the calculations of the CBA; do EV owners drive the same amount of kilometers as ICEV users? In this paper, the total amount of kilometers driven in the policy scenario are equal to the baseline scenario. However, Verrips & Hilbers (2020) mentions that there is a possibility that electric vehicle owners are tended to drive more since the variable costs are much lower than that of an ICEV (lower energy costs and excises). This could lead to a higher automobility and also more congestion. Both higher automobility and congestion have an influence on the environmental impact of the electric vehicle and thus the policies that stimulate the electric vehicles. However, van Gijlswijk et al. (2018) recorded that BEVs generally have a lower annual mileage than ICEVs. They concluded that this occurs because only low milage ICEVs are replaced by BEVs. This can affect the environmental gain (or loss) of replacing the ICEVs with the BEVs. Future research should include the effects policies have on driving behavior, what the influence this is on the environmental impact and what this would mean for the CBA.

5.5. Electricity grid BEV

The electricity grid mix that is currently used for the LCA calculations is the reference scenario of the European Commission (2016). However, the European Commission states that this scenario is not designed as a forecast to what is likely to happen in the future, but more as a benchmark for other policies to compare to. Since the ambition of the EU is to be carbon neutral in 2050, it is likely that several policies will be implemented to reach this aim. Whether or not this is likely to actually fulfill. Likewise, since the electricity grid change also influences the environmental impact of the production of the BEV and the ICEV, the electricity grids of other countries are important as well for the LCA. It is therefore worth investigating what the actual forecast of the electricity mix could be for The Netherlands, the European Union and other countries that are involved in the life cycle of the personal vehicles.

5.6. Costs of electrical vehicle

This research assumes that the TCO (Total Cost of Ownership) of a BEV stays equal from 2021 onwards. Revnext (2020) does include the decline of TCO in electric vehicles in their national costs' predictions from 2020 to 2030, but since they the use annuity costs of the vehicle, which made it difficult to acquire the TCO of the BEV in 2030, the assumptions were made for this paper to use only the TCO of 2021. However, it is likely that the TCO of the BEV will decline. This is also supported by various literature (Nykvist & Nilsson, 2015 and van Velzen et al. 2019). There has been limited research on how much the TCO will decline after 2030, but since the TCO graph of the BEV shows a logarithmic decline (see Figure 12), it is likely that the TCO will stay more or less equal in the far future.

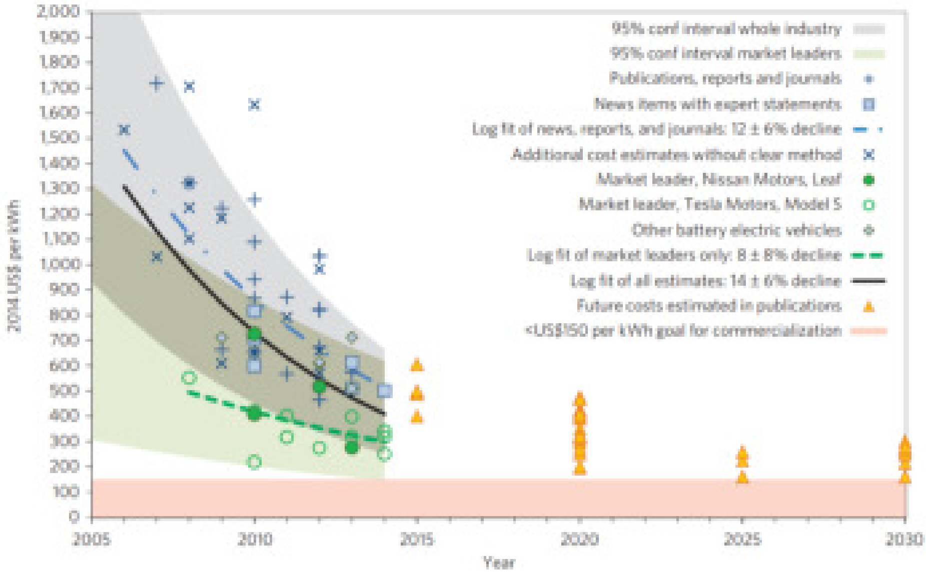

Figure 12: Predicted trajectory battery costs. Source: Nykvist & Nilsson (2015)

Additional research into the TCO of BEVs from 2030 onwards has to be made not only to calculate the national costs of the vehicle, but also to make a better future scenario for the BEV adaptation into the personal vehicle market (see chapter 5.10). The TCO does affect the consumers decision to buy an electric vehicle. Since this research uses the trend from 2027 to 2030 to predict the future vehicle adaptation from 2030 to 2050 (see Appendix C.A for the detailed explanation of the calculations), there is a mismatch in how the future scenario of the national costs is calculated versus how the future scenario of the vehicle adaptation is calculated. Since the trend of 2027 to 2030 when calculating the EV market share does consider a decline in TCO of the BEV, this will be extrapolated to 2050 when calculating the electric vehicle adaptation. However, the TCO of the BEV when calculating the national costs stays equal to 2021. This means that the TCO does decline when considering for the BEV market share, but not for the BEV national costs. Future research should estimate the TCO of the electric vehicle to 2050 and include this when estimating the future vehicle estimation as well when calculating the national costs of the BEV in future scenarios to prevent the mismatch that has been made in this research.

Another problem concerning the costs of the vehicle is the method the national costs of the electrical vehicle is calculated in this research. Revnext and PBL (2020) use the depreciation expense of the vehicles (using an estimated lifetime of 10 to 15 years) to calculate the national costs per year. Which means that the costs are annuity costs. However, this research used the TCO of the vehicles to account for the national costs of a specific. This would not make a difference in total costs over the time period (2020-2050), where it not for the necessity to discount the future. When using annuity costs, the national costs tend to be lower since the future depreciation costs are discounted. This is the same problem explained in chapter 5.2, where the future pollution of the vehicle is discounted for the year it was sold. In this case, the total amount of depreciation costs of the vehicle is discounted for the year it was sold. This is best explained by using a simple example that is presented in Table 17: Example of the discount effect on annuity costs method. Here, the first column is the method that was used for this research, the second column total costs when they are discounted, the third column the annuity method and the fourth when the annuity costs are properly discounted. The total costs after 5 years differ, which is greatly enhanced when the life time of the vehicle is longer. This means that using the annuity costs method lowers the total national costs of BEV.

Table 17: Example of the discount effect on annuity costs method.

DISCOUNT RATE: 0.03

YEAR	**Total costs**	**Discounted**	**Annuity costs**	**Discounted**
1	1500	1456	300	291
2	0	0	300	283
3	0	0	300	275
4	0	0	300	267
5	0	0	300	259
TOTAL	1500	1456	1500	1374

5.7. Electric vehicle driving distance

This paper assumes the total lifetime of both the ICEV and the BEV to be 150.000 km. This is the same amount of lifetime Hawkins et al. (2013) uses for the LCA. However, Hawkins et al. (2012) mentioned in their paper that the lifetime of both the ICEV and the BEV can range from 150.000 to 300.000 kilometers. Hawkins et al. Applied a sensitivity analysis for multiple driving ranges in their LCAs, but these are not taken into account for this research. The provide a representation on how and how much this would influence the LCAs of both vehicles. Increasing the lifetime of the vehicles to 250.000 kilometer instead of 150.000, decreases the GWP per kilometer of the BEV from 205 g CO2-eq/km to 165 g CO-eq/km. While the ICEV decreases only by 19 g CO2-eq/km (Hawkins et al, 2013). Selecting the correct lifetime is challenging since the lifetime of the vehicle can depend on many external factors like driving and charging behavior and climate conditions influence the degradation of the vehicles. An additional challenge comes when predicting the future lifetime of the vehicles, since technology can increase the lifetime considerable. As Zackrisson et al. (2010) showed that the lifetime of a typical Li-ion battery doubled in just 10 years. Additional research is required to choose the correct lifetime for current and future vehicles.

5.8. Disruption of the market

According to Harris & Roach (2013), subsidies that stimulate environmentally friendly products are a way of correcting the market in such a way that the social costs of environmental pollution are internalized. The same applies for taxing products that cause environmental damage. By internalizing the external costs and/or benefits, the market would work more efficiently and produce more welfare (Harris & Roach. 2013). However, in this case, multiple markets are getting infected by the subsidies of the Climate Agreement. Subsidizing the EV market will also have an effect on the electricity market (De Bruyn et al, 2017). More electrical vehicles will put a higher strain on the power generation network. There are two incidents that occur and are of importance for the CBA integrating the LCA. Firstly, Putting a higher strain on the electricity market will raise the prices of electricity. Sun and wind power producers (which generally are first in order to deliver electricity) will receive a higher income because of this higher price (providing that there is wind and/or sun to produce electricity). This change in electricity prices is called *profile effects* (De Bruyn et al. 2017) and these have to be integrated into the CBA according the de Bruyn et al. (2017). Research has been made by Hanemann & Bruckner (2018) to what the possible effect could be. The concluded that the peak price could increase, but possible V2G (vehicle to grid) technologies could level this out or even reduce the price.

However, a downside to this extra strain on the electricity market is that there will be extra power generators needed. When there is a higher peak demand, usually the more controllable power generators (like oil, coal and gas) are used to fill up the electricity shortage. Since these are often not environmental friendly power producers, this will often cause more pollution which has to be integrated into the CBA and LCA of the research.

In chapter 4.3, it was mentioned that the national costs between the CBLCA and the CCBCA are equal, which may not be fair since these whole life cycle of the CBLCA should be accounted for in both the national costs and the environmental impacts. Potential costs that could influence the CBLCA are explained by Alberini (2020). In this case, a market shift between the EV and ICEV market would occur. This could include, for example, shifts of resources to other markets and transaction costs. Job opportunities will arise, but at the same time will cause unemployment and firms closing, which would result in retraining of employees. What the exact costs are of these market shifts needs to be analyzed and accounted for in a CBA where the life cycle of the product or the service is integrated.

5.9. Emersion of other technologies

This research looked specifically into the adoption rate of the battery electric vehicle. According to this study and the trend that is used for the period after 2030, the BEV market share (of newly sold vehicles) should be 100% at some point in the future. Of course, a truly 100% market share is unlikely since there will always be early adopters or even conservative vehicle consumers. Especially for the late future, new technologies can play a big role in the personal vehicle market. For example, Fuel Cell Electric Vehicles (FCEV) and solar powered vehicles may not be able to penetrate the current market, but this may be the case in 2050. Research that includes the possible integration of new technologies that may be able to compete with the BEV market have to be analyzed to see whether they have an influence on the personal vehicle market or not. It is important to note that it is unlikely that the emersion of other technologies will have a large impact on the results of this particular CBA, since the results (see chapter 3.1) show that the effect of the policies rapidly decreases after 2026. However, when looking at the whole context of this research, future research should include this topic. Especially when the policies are projected to have a lasting influence.

5.10. Future trend analysis

The future scenarios of the electrical vehicle adoption rate of this thesis research from 2020 to 2030 are calculated by Revnext and PBL (2020). These scenarios are based on the assumptions and analysis that have been made which are explained in Appendix B.C. However, the years 2030 to 2050 are calculated using a linear trend of 2027 to 2030 and extrapolate it to 2050. Looking at the trend of 2020 to 2030, using a linear trend would not be that unrealistic. However, analysis has to be made on what the factors are for this linear growth and whether it is likely that this would stay the same in the future. It is possible that there will be a diminishing effect due to particular consumer behavior (for example, having an aversion for electrical vehicles or love for a certain type of ICEV vehicle, etc.). Research has to be made to create an as realistic as possible future trend scenario for the mid, low and high economy scenarios. Similar to the uncertainty of chapter 5.9, it is unlikely that the a better future trend analysis will have a large impact on the results of this particular CBA, but still need to be included in future research on similar topics.

5.11. Other external costs

The scope of this CBA focused only on the environmental impact of the policies. However, when considering the effect the policies have on welfare, other external costs also have to be considered. Verrips & Hilbers (2020) mention that 40% of the external costs of a personal vehicle are the traffic accidents. Since this is a rather large portion of the total external cost of personal vehicles, policies that have effect on road safety can have a significant effect on the results of the CBA. O'Malley et al. (2015) for example conducted a research on the crashworthiness of electrical vehicles compared to conventional vehicles. They concluded that the likelihood of passengers getting injured in electric vehicles is slightly lower. However, the overall costs of repairs and replacements of electrical vehicles are on average far higher than the ICEVs.

Other examples of external costs involve congestion and noise disturbance. Congestion has already been mentioned in chapter 5.4. The impact of these policies on noise disturbance are actually quite interesting since one the most notable features of electrical vehicles are that they produce much less sound.

The impact that these policies have on the external costs and thus the results of the CBA have to be analyzed to create a better comparison of the welfare difference between the policy scenario and the baseline scenario.

5.12. Individual and hierarchical perspective

As is explained in chapter 2.4.3, the choice for this research has been made to use the individual perspective for the environmental prices, and the hierarchical perspective for the LCA. In order to keep the consistency in the research, it could be argued that it is preferable to use only one perspective for both the prices and the LCA. It should be noted that there is no right or wrong answer in this case on what perspective to choose. However, as has been mentioned in chapter 2.4.3, the choice could potentially have considerable effect on the outcome of the LCA, since the effects in some cases can change in multiple orders of magnitude.

The choice of perspective does not change the quality of the CBA. However, to enhance the transparency of the research, it is advised to add the difference of the three perspectives in the uncertainty ranges or sensitivity analysis.

5.13. Conclusion chapter 5

After listing all the uncertainties and possible additional research to further enhance the quality of this research topic, it leaves the question on what this all means for the results of this paper. Therefore, it is important to gain a general overview on all the uncertainties and topic for future research and what their possible effect would be on the final results of both CBAs. For example, some uncertainties will likely change the environmental output of the policies when they are accounted for in the CBAs. This can have both an increasing or decreasing effect. When the battery composition of the future BEV fleet will change, it will likely lower the environmental output of the BEV (see chapter 5.1). On the other hand, if the policies increase the total personal vehicle fleet, it will raise the environmental output of the policies. Table 18 shows a short summary of the potential effects of the uncertainties that are discussed on the results of this research. It shows on what part of the CBA it has an effect, if it has a decreasing or increasing (or both) effect on the costs of the policies, if it has an effect on the difference between the CCBA and the CBLCA and the potential magnitude of the effect. These potential effects are all estimated guesses based on the literature that is found and explained in the paragraph where these uncertainties are discussed.

Based on the outcome of this table. It suggested that most of the uncertainties will have an impact on the outcome of this research, but there is a high chance that they will even themselves out or will fall within the bandwidths of the economy scenarios that are provided within this paper. The only uncertainty that can potentially have a large effect on the outcome of this research, is the spatial difference of the emissions of the vehicle which can change the price of the environmental indicators. This could change the results considerably, but it is still unknown if it would increase or decrease the difference between the two CBAs. As mentioned in chapter 3, the BEV has a higher emission rate in some environmental indicators, and lower in others. Even though this is an important uncertainty, this is partly taken into account for by using three different environmental prices that are provided by De Bruyn et al (2017).

In short, it seems that the bandwidths that are provided for this research are sufficient enough to provide an answer to the research question. However, one should be careful not to put too much emphasis on the exact results of either CBAs.

Table 18: General overview of the uncertainties and their potential effect.

UNCERTAINTY	EFFECT	CHANGE COSTS OF POLICIES	CHANGE IN DIFFERENCE CCBA & CBLCA	POTENTIAL MAGNITUDE EFFECT
BATTERY COMPOSITION CHANGE	BEV environmental impact	Decreasing	Yes	Medium
SPATIAL DIFFERENCE	Price of environmental indicator	Both	Yes	Large
TEMPORAL DIFFERENCE	Output environmental costs	Decreasing	Yes	Medium
WATERBED EFFECT, CO2 STANDARDS	Environmental costs policies	Increasing	Yes	Small
WATERBED EFFECT, ETS	Environmental costs policies	Decreasing	Yes	Small
EXTRA VEHICLE FLEET GROWTH	Costs policies	Increasing	Yes	Medium
MOBILITY CHANGE	Costs policies	Both	Yes	Small
ELECTRICITY MIX	BEV environmental impact	Both	Yes	Medium
COST BEV	National costs BEV	Decreasing	No	Small
DISRUPTION OF THE MARKET	Costs policies	Both	Yes	Small
EMERSION OF OTHER TECHNOLOGIES	BEV adoption rate	None	No	None
FUTURE TREND	BEV adoption rate	Both	No	None
OTHER EXTERNALITIES	BEV & ICEV environmental impact	Both	Yes	Medium

6. Discussion & recommendations

This chapter will provide a final insight on how to interpret the results, what the recommendation is for future research based on the chapter "uncertainties & future research" and what the final recommendations are for policymakers.

The results of this CBA show a quantitative comparison between a conventional CBA and a LCA integrated CBA. The problem with exact numbers is that they can give the perception there is just one final truth, and no discussion is possible on the outcome of the research. The policies are either worthwhile (CBA shows a positive balance), or they are not (CBA shows a negative balance). As with almost all scientific research, this is not the case. To overcome perceptions like these, a bandwidth is provided. In this case as a low, mid and high economy scenario and a low, mid and high price range. But even using these bandwidths, it is not advised to immediately raise to any fast conclusions based on the numbers of this research. Chapter 5 shows a list of propositions that can be made to enhance the quality of this research. Some of these propositions can be made with relative ease, and would have been made possible to include in this thesis research would there be more time available. However, some of the propositions require large additional research into a different field. For example, the research on the influence of the consumer behavior in electrical vehicles is a whole different topic of enquiry, which could be nevertheless important. Also, big international events can have a large influence on the outcomes. During the research of this thesis, the COVID-19 pandemic hit the world which showed a such events can have extensive effects on the economy, politics, welfare, etc. These events are of course partly considered for in the low economy scenario bandwidth, but since there are great uncertainties to the extent of the effects of the Corona virus, only the future will tell how this would influence the outcome of the policies.

Now it is also important to see how this research *should* be interpreted. The difference between the results of both CBA’s is significant in all economic scenarios and all price ranges. The fact that when even using the bandwidths of the CBA’s, the outcomes are still vastly different, suggests that the influence of the LCA integrated into the CBA is evident. In short, the results of this paper should be used by policymakers and researchers as an insight into whether or not to use CBA’s that have integrated LCA’s into their research. This research should not be used as an insight on the exact quantity the welfare of The Netherlands will gain or lose by implementing the policies that are used for this case study.

6.1. Recommendation future research

The results of this research show the impact of adding LCA to CBA for electrical vehicle stimulating policies. Which proves the importance of the combination of the two methods. However, the uncertainties that are explained in chapter 5 do show that there is still a large scientific gap and possibilities for future research. Researches could aim to analyze the effect of really specific details of the uncertainties that are listed below. For example, analyzing the effect of the waterbed EU-ETS uncertainty of the integration of electrical vehicles. Other researchers could potentially use this knowledge to provide realistic CBA's integrated with LCA's that could be of help for policymakers.

This, of course, is not limited to this particular case of electrical vehicle policies. All CBA's that analyze policies that affect all sorts of goods or service flows can be used to integrate LCA and CBA. Which, like this research, shows new knowledge gaps that need to be addressed and provides better insights for policymakers. This means that future research focusing on these topics should incorporate the life cycle of the product or service. It also means that research on the type of uncertainties of this research are crucial. In particular the already mentioned spatial difference of the emissions during its life cycle. All the uncertainties and possibilities for future research that are discussed in this thesis are linted in Table 19. The table also identifies if the uncertainties are of a general nature and can be used for studies of different kinds of products or services or are more specific to the case of this research.

Table 19: List of recommendations for future research.

UNCERTAINTY	GENERAL OR CASE SPECIFIC
BATTERY COMPOSITION CHANGE	Case specific
SPATIAL DIFFERENCE EMISSIONS	General
TEMPORAL DIFFERENCE EMISSIONS	General
WATERBED EFFECT, CO2 STANDARDS	Case specific
WATERBED EFFECT, ETS	General
EXTRA VEHICLE FLEET GROWTH	Case specific
MOBILITY CHANGE	Case specific
ELECTRICITY MIX	General
COST BEV	Case specific
DISRUPTION OF THE MARKET	General
EMERSION OF OTHER TECHNOLOGIES	General
FUTURE TREND	General

6.2. Recommendation policy makers

The results of this research have been analyzed and evaluated by the uncertainty analysis. Now the second main research question has to be answered as to what the consequences are for policymakers. The results of this chapter indicate that focusing on the full life cycle of the vehicle can change the perception on whether the policies on electric vehicles can be worthwhile or not. However, whether the policies are worthwhile also depends on the perception of the policymakers themselves. This will be further outlined in this paragraph.

2030 ambition

According to the climate agreement, the ambition of The Netherlands for 2030 is to have a 100% market share of electric vehicles in new sales. Which, according to this study and those of the PBL and Revnext (2020), is unlikely. However, when focused solely on this ambition alone, of course it can worthwhile to stimulate the electric vehicle market. In that sense the CBA depends on the WTP of the ambition to have a 100% EV market share and not of the environmental impacts. Of course, this is a simplistic way of viewing at this perception. Since this ambition comes from the greater goal of The Netherlands to reduce its impact on climate change. The underlying goal is to reduce the greenhouse gas emissions by 49% in 2030 compared to the emissions of The Netherlands in 1990 ("Wat is het doel van het Klimaatakkoord?", 2020), which corresponds to a reduction of 49 MTon CO2 equivalent. Also this changes the perception on the CBA. Since this solely looks at the climate change indicator and only looks to reduce emissions within their own border. Since most of the time only the use phase of the vehicle shows emissions directly in The Netherlands, this can change the need for a LCA approach within the CBA.

The consequences for the policy makers when looking at the perception of the 2030 climate agreement ambition, is that at first, they have to decide what the actual goal is. Have a 100% market share of EVs or reduce emissions by 49%? Even so, from the LCA results (Table 23) it is clear that, when you look only at the climate change indicator, the BEV scores better than the ICEV, although the difference is a lot less when considering the full life cycle of both vehicles. To summarize, when policy makers want to make an informed decision on their policies of stimulating BEVs to reach the climate agreement goals, a CBA which integrates the full life cycle of the vehicle is not partiality necessary. However, when the goal of policymakers is to reduce the greenhouse gasses in The Netherlands, it is advised to use the use phase emissions instead of the tailpipe emissions. Since most of the electricity comes from Dutch powerplants.

2050 EU goals

The 2050 EU goals is to be climate neutral, which means that no country in the EU will produce any greenhouse gas emissions ("2050 long-term strategy", 2018). The Netherlands are committed to this goal since they are an EU member. Looking at this perception, the conventional CBA (without the integration of the LCA) showed that replacing the ICEV with the BEV is a great way to make the personal vehicle market climate neutral. After all, the conventional CBA only accounts for the tailpipe emissions (which is zero for the BEV). However, when considering the LCA (Table 23), it is clear that the BEV does produce a significant amount of greenhouse gasses during its life cycle. The problem is that these emissions are emitted elsewhere. This can be from the power plants in the EU, or from production facilities in Asia. The point being that emissions from the ICEV are being partly shifted to be emitted elsewhere. Some of these places are aiming to be 100% emission neutral to (power-plants in Europe), while other countries do not (currently) have the exact goals (production facilities in United States). This can be significant for policy makers when considering stimulating the BEV, since they also have to account for the burden shifting to other countries. This can result in extra costs which are not directly related to the TCO of electric vehicles (extra wind turbines or solar panels needed for "green" energy). This changes the results of the CBA.

When policymakers have the perception of only accounting for greenhouse gas emissions for their own citizens (so burden shifting is not deemed to be a relevant problem), then using a conventional CBA with the addition of the greenhouse gas emissions of the electricity production of the BEV is appropriate. However, when looking at a broader perspective where burden shifting is not acceptable, then a LCA integrated into a CBA is strongly advised, where foreign emissions are being accounted for too.

Maximizing welfare

CBA's are used to measure the difference in welfare between policies. Ideally, if policymakers are to use CBA's in their decision making, their aim should be to maximize welfare. This is a different perception than the ones previous mentioned, because welfare is measured by more than just the national costs and the external costs of the greenhouse gas emissions. The CBA in this research was measured by the environmental impacts of the full life cycle of the vehicle. Even this is not a perfect rendition of the welfare change of the policies, which is explained in chapter 5. In short, if the policymakers aim to maximize welfare, they are advised to lead their decision making by a CBA with the integration of LCA's that covers all the external costs of the ICEV and the BEV and the other remarks mentioned in chapter 5.

Broader scope of policy implication

One of the most interesting insights of this research is that results show that environmental costs of an electrical vehicle can be considerable during *all* phases of the life cycle (depending on the environmental impact). Besides, the greatest costs to welfare are not necessarily the effects on climate change (see Table 43). This insight could well prove to be a guide for policymakers to focus on the specific environmental impacts during specific phases of the vehicle. This is not limited to electrical vehicles. All sorts of goods and services can be used for LCA. Policymakers could create policies that tackle the phases and environmental impacts that have the largest effect on welfare. Which ultimately would improve the total environmental impact of the product or service which increase welfare.

7. Conclusion

In this final chapter, the final results and the remarks are discussed based on the research questions that are provided in the first chapter. Firstly, the sub-questions will be answered which would lead to the conclusion of the main research questions. The final part of this conclusion consists of the generalization of the discussion and the future research recommendation.

7.1. Sub research questions

SQ1. What are the effects of the proposed tax incentive of the Dutch Climate Agreement on the electrical vehicle market in The Netherlands and what are the costs?

The effects of the climate agreement policies are limited to the years they are implemented. From the years 2021 to 2025 there is a considerable growth of the BEV adaptation rate compared to the reference scenario. From then on, the adoption rate quickly falls into almost the same growth levels as what the reference scenario shows. This means that the national costs of the policies also quickly decrease from 2025 onwards. This is the same in the low, mid and high scenario. When a trend is made of the BEV sales from 2030 onwards, then both in the mid and high scenario will the personal vehicle market be of 100% BEVs. However, this would be the case in both the reference as the policy scenario. The low scenario reaches a maximum of 76% market share in 2050.

SQ2. What are the environmental effects of the life cycle of an electrical vehicle and a combustion engine vehicle?

The environmental effects are measured by the mid-points of the ReCiPe method. The detailed results can be found in the appendix Table 23. When looking purely at the climate change indicators, it seems that the largest differences between the ICEV and the BEV lies in the environmental impact on the human toxicity, freshwater eco-toxicity and freshwater eutrophication. The BEV scores reasonably higher than the ICEV, often more than three times the amount. Most of these additional emissions come from the production of the powertrain, battery and electricity for the BEV. The BEV however scores lower than the ICEV on the climate change environmental impact. The progression of the BEV shows that the environmental impact in all environmental indicators declines, but some decline faster than the others. How large the influence is of these differences and progressions on the final result of the CBA depends on the prices of the indicators.

SQ3. What are the effects of the proposed policies if only the tailpipe emissions are considered?

Since the BEV does not have any tailpipe emissions, the effects of the policies create a large difference in environmental impact between the BEV and the ICEV. The effects are especially large between the years of 2021 and 2025, where the policies are still active and the influence of these policies are most noticeable.

SQ4. What are the environmental effects of the policies considering question 1 and 2?

When the prices are multiplied by the quantity of the environmental impact of the full life cycle of both the ICEV and BEV, then the BEV has a higher overall environmental impact than the ICEV. Consequently, since the policies stimulate the adoption of the BEV, this would result in a higher environmental impact than if the policies would not be implemented.

SQ5. What is the monetary value of these environmental effects?

The monetary values are provided by de Bruyn et al. (2017) and are served within three categories to create a price range. A high and low value for the upper and lower boundary and a mid-range that is the most likely value.

SQ6. What are the risks and uncertainties of the costs and benefits?

The uncertainties that are discussed in this research can have a considerable effect on the results of this research and the difference between the CBA with the LCA and the CBA without the LCA. However, these uncertainties can impact the results in both ways, either increasing the difference or decreasing it, which suggests that they will even themselves out and/or stay within the economy bandwidths and the price ranges that are provided by this research. After evaluating all the uncertainties that have been mentioned, it is concluded that the bandwidths that are provided for this research are well enough to provide an answer to the research question. However, one should be careful to put too much emphasis on the exact results of both CBAs.

7.2. Main research questions

The results show that the influence of integrating the environmental impact of the full life cycle of ICEV and the BEV can change the perspective of the CBA considerably. The conventional CBA shows that under some economic circumstances, the policies can be worthwhile in terms of adding welfare to society. However, when the LCA is integrated, it shows that the stimulation of the BEV has a negative impact on welfare, in all economic circumstances. There are two factors that come into play that contribute to these large differences.

Firstly, the production of the components of the BEV and the electricity to propel the vehicle has a large effect on the total environmental impact of the vehicle. This can be higher than the ICEV, which is why the total amount of emissions during the life cycle of the BEV is often higher in some environmental indicators than the ICEV. When this is compared to the conventional CBA, where only the tailpipe emissions are accounted for (which is zero for the BEV), the difference in the two CBA's can be substantial.

Secondly, the impact of additional environmental indicators, compared to when previous research only accounted for the CO2 emissions or the greenhouse gasses, have a substantial impact on the final results of the CBA. In this research, both CBA's use the same indicators, since the total welfare change is measured. The results of the CBLCA show that the human toxicity indicator has a large influence on the total environmental impact of the BEV. Almost half of all the costs that occur during the full life cycle of the BEV comes from the impact it has on human toxicity. Since the emissions of the BEV that influence this indicator is more than three times as high as the emissions of the ICEV. It shows that the addition of environmental impacts has a substantial influence on the final outcomes of the CBA.

The consequences of the results of this research for policymakers and researchers can be considerable. In the case of the policymakers, this can depend on the goals and perspective of the policymakers themselves. As previously mentioned, the influence of the environmental indicators other than climate change on the total environmental impact of the BEV are substantial. Should the policymakers choose not to care for these indicators, whether that is because of the CO2 reduction goals they have for The Netherlands or the EU or other political reasons, than the influence of the integration of the LCA into the CBA is less significant. However, if the policymakers aim to increase the total welfare of Dutch society, using CBA's that integrate LCA into the research would be strongly advised. Additionally, the two significant contributing factors that contribute to the difference between the CCBA and the CBLCA show that policymakers are also advised to aim their policies at the life cycle phases and environmental impacts that contribute the largest to the costs to welfare.

This study created an understanding on why it is important to use all life stages and multiple environmental impacts of a product or service when analyzing the costs and benefits. This means that future research focusing on these topics are advised to incorporate the life cycle of the product or service. It also means that research on the type of uncertainties of this research are crucial. In particular the spatial difference of the emissions during its life cycle.

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B. Input data CBA

A. Reference scenario

The reference scenario uses only the source policies of the European Union. These policies have to make sure that newly sold personal vehicles in 2030 produce 37.5 percent less CO2 than in 2021. Nijland et al assumes that this means that 30 percent of the newly sold vehicles in 2030 will be EV's. TNO (Van Gilswijk et al., 2018) analysed the effect if only the European source policy will be implemented. In the most favorable case, these policies will stimulate the EV market in such a way that 65 percent of the new cars sold will be EV's, but in the least favorable case the integration of the EV in the personal vehicle market will completely come to a halt in 2030. Since Van Gilswijk et al shows great uncertainties in their end results, this CBA will use a *base, low* and *high* scenario factoring.

In the reference scenario, all the current fiscal policies for *tailpipe emission free vehicles* will be cancelled as of the first of January 2021. This means that:

- The discount to the mrb will come to a halt. Which means that EVs and PHEVs will be taxed the same way as ICEVs. Since the mrb is based on the weight of the vehicles and EVs and PHEVs are generally heavier than ICEVs, this means that EVs and PHEVs will receive on average a higher tariff than ICEVs.
- 22 percent addition to business vehicles for all types of cars.
- MIA cap to zero.
- EV's will receive a standard bpm tariff of 350 euro.

B. Policy alternatives

The policy alternatives that are analyzed are proposed in the Climate Agreement Klimaat Akkoord (KA). The KA mentions several fiscal policies that are used to stimulate the electrical vehicle integration:

- From 2021 onwards, new tailpipe emission free personal vehicles will be subsidized with 4000 euro, while gradually declining to 2550 euro in 2025. The subsidy can be used for cars with a price lower than 60.000 euro. The subsidy declines linearly from 40.000 to 60.000.
- Electric vehicles are exempt from bpm (belasting personenauto's and motorrijwielen, English: tax for personal vehicles and motorcycles) and mrb (motorrijtuigenbelasting, English: motor vehicle tax) until 2025. Afterwards, consumers pay 360 euro to bpm and a percentage of the mrb that nonelectric vehicles buyers pay (see Table 20)
- Electric business vehicles that are cheaper than 45.000 euro receive a lowered tax addition when the car is used for private use. This maximum will lower in 2021 to 45.000 euro. The lowered tax addition is 8% in 2020 and steadily rises to 22% in 2026.
- Excise on vans will be raised by 1 cent in 2020 and another cent in 2023.
- Petrol and diesel vehicles will pay an increase in the mrb and an innovation fee of 87.50 euro in 2021 steadily increasing to 350 euro in 2030.
- From 2020 to 2030, 1.4 million charging station for electrical vehicles need to be build. Which comes to a total estimated cost of 1.4 billion euros.

Table 20: Fiscal policies OKA. Source Nijland et al (2019)

Tax incentive arrangement	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
BPM	0	0	0	0	0	360	360	360	360	360	360
MRB (FC)EV	0	0	0	0	0	25	100	100	100	100	100
Tax addition business vehicle and CAp	8	12	16	16	16	17	22	22	22	22	22
	45000	40000	40000	40000	40000	40000	N/A	N/A	N/A	N/A	N/A
Private subsidy	4000	4000	3700	3350	2950	2550	0	0	0	0	0
	40-60k	40-60k	40-60k	40-60k	40-60k	40-60k	0	0	0	0	0

Table 21: Financing plan climate agreement.

Financing plan	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Excise fuels	0	1	1	2	2	2	2	2	2	2	2
MRB vans	0	24	48	72	96	72	72	72	72	72	72

C. Low, base & high economy scenarios

The scenario analysis is based on the analysis that is made by the PBL (Nijland et al. 2019). Which in turn is based on the WLO economic scenarios and the analysis made by van Gijlswijk et al. (2018) regarding the insights in future electric mobility. These papers formed the assumptions and starting points for the analysis made by Nijland et al. (2020) and Revnext (2020). The assumptions and starting points can be found below in Table 22.

Table 22: Assumptions and starting points policy effects. Source: Nijland et al. 2020

Parameter	**High scenario**	**Mid scenario**	**Low scenario**
Source policy EU in combination with price strategy car manufacturers. Considered as car supply EU	Max. 40% EV, ICEV supply is 5 g/km less efficient, PHEV max 10%, avg. 55 g/km in 2030	Max 35% EV, ICEV supply ca. 90 g/km, PHEV max 10%, avg. 55 g/km in 2030	Max 25% EV, ICEV supply 5 g/km more efficient, PHEV max 15%, avg. 55 g/km in 2030
Pass-through EU source policy to The Netherlands (characteristics ca supply for The Netherlands)	37% EV in 2030, ICEV in The Netherlands to avg. 90 gm/km NEDC, 2% PHEV, gem. 55 g/km in 2030	34% EV in 2030, ICEV in The Netherlands to avg. 85 g/km NEDC. PHEV max 3%, avg. 55 g/km in 2030	25% EV in 2030, ICEV in The Netherlands to avg. 80 gm/km NEDC, slightly higher ICEV prices, 11% PHEV, gem. 55 g/km in 2030
Available supply (production car manufacturers)	A strong increase in supply for the EU market. In total +5% compared to mid scenario	An increase in EV supply. Towards 35% in 2030. No 2030 supply restrictions for the Dutch market in 2030.	A lower availability of EVs for the EU market. Car manufacturers focus on PHEV and ICEV CO2 reduction. In total –10% reduction compared to mid scenario
Residual value and depreciation EV	Towards 2030 an EV has 3%-point higher residual value than an ICEV	Towards 2030 an EV has similar residual value compared to an ICEV (compared to its new price)	Towards 2030 an EV has 3%-point lower residual value than an ICEV
Battery price, battery size, energy efficiency and density	Decrease of €140/kWh in 2019 to €72/kWh in 2025 and €47/kWh in 2030 (price reduction of 1,7% per year). Battery size, energy efficiency, radius and density equal to mid scenario.	Decrease of €140/kWh in 2019 to €77/kWh in 2025 and €55/kWh in 2030 (price reduction of 1,5% per year). Increase of: battery size (avg. 6 kWh), energy density (to 225 Wh/kg), efficiency (till 2025 by 1.7% per year and till 2030 by 1.4% per year) and radius (avg. +100 km).	Decrease of €140/kWh in 2019 to €93/kWh in 2025 and €64/kWh in 2030 (price reduction of 1,3% per year). Battery size, energy efficiency, radius and density equal to mid scenario.
EV developing costs storage	20% reduction in 2025, 50% reduction in 2030 (approximately 0.6% extra price reduction per year).	10% reduction in 2025, 25% reduction in 2030 (approximately 0.3% extra price reduction per year).	Zero price reduction in both 2025 and 2030.
TCO sight years consumers	TCO private purchase based on 4 years (less short sighted, larger 'earn back' awareness).	TCO private purchase based on 3 years.	TCO private purchase based on 3 years.
Costs ROB (Reparatie, onderhoud & banden; English: Reparation, maintenance & tires) BEVs	50% lower than ICEV	40% lower than ICEV.	30% lower than ICEV.

D. Life cycle analysis

Table 23 shows the LCA presented by Hawkins et al. (2012). The table shows the absolute impact scores per kilometer driven for each type of vehicle in 3 stages of their life cycle.
Production phase:

- Base vehicle: the production of the chassis and shell of the vehicle.
- Engine: the production of the IC engine or electrical engine.
- Other powertrain: the production of the other components that are needed for propelling the vehicle (hardware, gearbox, etc.)
- Battery: The production of the battery pack electric vehicles (the batteries for the ICEV are under the category 'other powertrain')

Use-phase:

- Use-phase, non-fuel related:
- Fuel/electricity: The environmental pollution that occurs during the production of the electricity of the EV or the combustion of the fuel of the ICEV.

End-of-life phase: Environmental pollution during the recycling or waste management of the vehicles.

The LCA provides results based on 10 environmental impact categories:

1. Climate change: Pollution that increases the earths greenhouse effect. Measured in CO2 equivalent.
2. Terrestrial acidification: Terrestrial acidification is the change in soil chemistry that comes from the deposition of nutrients in acidifying forms (Azevedo et al. 2014). This decreases the soil fertility and affects the ecosystem quality. Measured in SO2 (sulfur dioxide) equivalent.
3. Particulate matter formation: Fine particulate matter pollutes the atmosphere and can cause health problems when it is inhaled and reaches the upper part of the lungs and airways. Measured in PM10 (coarse particles with a diameter of 10 micrometers or less (US EPA, 2016)) equivalent.
4. Photochemical oxidant formation: Photochemical oxidant formation is a pollution, where the pollutant reacts in certain atmospheric conditions, particularly under sunlight. This can cause human and materialistic harm (Baumann & Tillman, 2004). Measured in NMVOC (Non-methane volatile organic compounds) equivalent.
5. Human toxicity: Emitted substances that are emitted in the environment that cause human harm (in certain doses) are expressed as the human toxicity potential (HTP) (Goedkoop et al. 2013). Measured in 1.4-DCB (1,4 dichlorobenzene) equivalent.
6. Freshwater ecotoxicity: Emissions that have a harmful impact on the fresh water ecosystems, as a result of toxic substances emitted in the air, water or soil, are expressed by the indicator freshwater eco-toxicity (Goedkoop et al. 2013). Measured in 1.4-DCB (1,4 dichlorobenzene) equivalent.
7. Terrestrial ecotoxicity: Emissions that have a harmful impact on the terrestrial ecosystems, as a result of toxic substances emitted in the air, water or soil, are expressed by the indicator

terrestrial eco-toxicity (Goedkoop et al. 2013). Measured in 1.4-DCB (1,4 dichlorobenzene) equivalent.

8. Freshwater eutrophication: Pollution that impacts the nutrients level in the freshwater environment are expressed as freshwater eutrophication. (Goedkoop et al. 2013). Measured in P (phosphorus) equivalent
9. Metal depletion: Minerals that are extracted (mined) from a deposit and are because of that contributing to the depletion of that deposit are called metal depletion (Goedkoop et al. 2013). Measured in Fe (iron) equivalent.
10. Fossil depletion: Fossil fuels are characterized as a group of resources that contain hydrocarbons (Goedkoop et al. 2013). The depletion of these fossil fuels is called fossil depletion. Measured in Oil equivalent.

Table 24 shows the relative change of the environmental impact of the BEV. The relative change is provided of every individual impact category, but is the average relative difference of the phases of the vehicle.

Table 23: Absolute impact scores per km driven per type of vehicle for every stage of life time. Source: Hawkins et al. 2012

Absolute impact scores per km driven per type of vehicle for every stage of life time (Hawkins et al 2012)								
		Electric vehicle				ICEV		
	Electricity/fuel type	European mix		Natural gas	Coal	Diesel	Gasoline	
	Battery	LI-NCM	LiFePO4	Li-NCM	Li-NCM			
Impact	**Life cycle component**							
Climate change	Base vehicle	34,4223	34,4223	34,4223	34,4223	34,4223	34,4223	
	Engine	6,2586	6,2586	6,2586	6,2586	3,1293	3,1293	
	Other powertrain	15,6465	15,6465	15,6465	15,6465	6,2586	6,2586	
	Battery	31,293	40,6809	31,293	31,293	0	0	
	Use phase, non fuel related	6,2586	6,2586	6,2586	6,2586	9,3879	9,3879	
	Fuel/Electricity	97,0083	97,0083	128,3013	212,7924	172,1115	203,4045	
	End of life	3,1293	6,2586	3,1293	3,1293	3,1293	3,1293	
	Total	**196,79**	**205,81**	**227,22**	**312,93**	**228,38**	**258,32**	**g CO2 eq**
Terrestrial acidification	Base vehicle	0,1168	0,1168	0,1168	0,1168	0,1168	0,1168	
	Engine	0,0438	0,0438	0,0438	0,0438	0,0146	0,0146	
	Other powertrain	0,0876	0,0876	0,0876	0,0876	0,292	0,292	
	Battery	0,2482	0,1898	0,2482	0,2482	0	0	
	Use phase, non fuel related	0,0292	0,0292	0,0292	0,0292	0,073	0,073	
	Fuel/Electricity	0,3942	0,3942	0,1314	0,9198	0,292	0,3942	
	End of life	0,0146	0,0146	0,0146	0,0146	0,0146	0,0146	
	Total	**0,94**	**0,88**	**0,68**	**1,46**	**0,79**	**0,89**	**g SO2 eq**
Particulate matter formation	Base vehicle	0,06	0,06	0,06	0,06	0,06	0,06	
	Engine	0,02	0,02	0,02	0,02	0,01	0,01	
	Other powertrain	0,045	0,045	0,045	0,045	0,065	0,065	
	Battery	0,075	0,065	0,075	0,075	0	0	
	Use phase, non fuel related	0,015	0,015	0,015	0,015	0,025	0,025	
	Fuel/Electricity	0,13	0,13	0,05	0,275	0,12	0,03	
	End of life	0,005	0,005	0,005	0,005	0	0	
	Total	**0,35**	**0,34**	**0,27**	**0,5**	**0,28**	**0,29**	**g PM10 eq**
Photochemical oxidant formation	Base vehicle	0,0858	0,0858	0,0858	0,0858	0,0858	0,0858	
	Engine	0,0234	0,0234	0,0234	0,0234	0,0078	0,0078	
	Other powertrain	0,0468	0,0468	0,0468	0,0468	0,039	0,039	
	Battery	0,078	0,0858	0,078	0,078	0,0078	0,0078	
	Use phase, non fuel related	0,0234	0,0234	0,0234	0,0234	0,039	0,039	
	Fuel/Electricity	0,2028	0,2028	0,1872	0,5148	0,4992	0,429	
	End of life	0,0078	0,0078	0,0078	0,0078	0,0078	0,0078	
	Total	**0,47**	**0,48**	**0,46**	**0,78**	**0,68**	**0,61**	**g NMVOC eq**
Human toxicity	Base vehicle	28,32	28,32	28,32	28,32	28,32	28,32	
	Engine	16,992	16,992	16,992	16,992	2,832	2,832	
	Other powertrain	33,984	33,984	33,984	33,984	8,496	8,496	
	Battery	99,12	121,776	99,12	99,12	5,664	5,664	
	Use phase, non fuel related	14,16	14,16	14,16	14,16	19,824	19,824	
	Fuel/Electricity	65,136	65,136	14,16	76,464	5,664	5,664	
	End of life	2,832	2,832	2,832	2,832	2,832	2,832	
	Total	**262,19**	**283,2**	**209,41**	**271,65**	**71,98**	**74,09**	**g 1.4-DCB eq**
Freshwater ecotoxity	Base vehicle	0,6118	0,6118	0,6118	0,6118	0,6118	0,6118	
	Engine	0,2622	0,2622	0,2622	0,2622	0,0874	0,0874	
	Other powertrain	0,5244	0,5244	0,5244	0,5244	0,1748	0,1748	
	Battery	1,1362	1,311	1,1362	1,1362	0,0874	0,0874	
	Use phase, non fuel related	0,1748	0,1748	0,1748	0,1748	0,2622	0,2622	
	Fuel/Electricity	1,2673	1,2673	0,1311	1,5295	0,1311	0,1748	
	End of life	0,1748	0,2185	0,1748	0,1748	0,1748	0,1748	
	Total	**4,11**	**4,29**	**2,98**	**4,37**	**1,46**	**1,51**	**g 1.4-DCB eq**
Terrestrial ecotoxicity	Base vehicle	0,0048	0,0048	0,0048	0,0048	0,0048	0,0048	
	Engine	0,0024	0,0024	0,0024	0,0024	0,0008	0,0008	
	Other powertrain	0,0024	0,0024	0,0024	0,0024	0,0008	0,0008	
	Battery	0,0064	0,0064	0,0064	0,0064	0	0	
	Use phase, non fuel related	0,0504	0,0504	0,0504	0,0504	0,0504	0,0504	
	Fuel/Electricity	0,0128	0,0128	0,0048	0,0056	0,0152	0,0192	
	End of life	0	0	0	0	0	0	
	Total	**0,08**	**0,08**	**0,07**	**0,07**	**0,07**	**0,08**	**g 1.4-DCB eq**
Freshwater eutrophication	Base vehicle	0,0242	0,0242	0,0242	0,0242	0,0242	0,0242	
	Engine	0,0088	0,0088	0,0088	0,0088	0,0022	0,0022	
	Other powertrain	0,022	0,022	0,022	0,022	0,0066	0,0066	
	Battery	0,0528	0,0704	0,0528	0,0528	0,0044	0,0044	
	Use phase, non fuel related	0,0066	0,0066	0,0066	0,0066	0,011	0,011	
	Fuel/Electricity	0,0858	0,0858	0,0066	0,1012	0,0044	0,0066	
	End of life	0,0022	0,0022	0,0022	0,0022	0,0022	0,0022	
	Total	**0,21**	**0,22**	**0,13**	**0,22**	**0,05**	**0,05**	**g P eq**
Metal depletion	Base vehicle	19,8814	19,8814	19,8814	19,8814	19,8814	19,8814	
	Engine	14,4592	14,4592	14,4592	14,4592	1,8074	1,8074	
	Other powertrain	24,3999	24,3999	24,3999	24,3999	4,5185	4,5185	
	Battery	23,4962	16,2666	23,4962	23,4962	0	0	
	Use phase, non fuel related	4,5185	4,5185	4,5185	4,5185	2,7111	2,7111	
	Fuel/Electricity	4,5185	4,5185	4,5185	4,5185	0,9037	0,9037	
	End of life	0	0	0	0	0	0	
	Total	**90,37**	**83,65**	**90,17**	**90,35**	**29,9**	**30,16**	**g FE eq**
Fossil depletion	Base vehicle	11,752	11,752	11,752	11,752	11,752	11,752	
	Engine	1,808	1,808	1,808	1,808	0,904	0,904	
	Other powertrain	4,52	4,52	4,52	4,52	1,808	1,808	
	Battery	6,328	8,136	6,328	6,328	0	0	
	Use phase, non fuel related	3,616	3,616	3,616	3,616	4,52	4,52	
	Fuel/Electricity	28,024	28,024	52,432	57,856	58,76	69,608	
	End of life	0,904	0,904	0,904	0,904	0,904	0,904	
	Total	**57,47**	**59,42**	**81,58**	**86,7**	**79,64**	**90,4**	**g oil eq**

Table 24: Relative change of environmental impact BEV. Source: Sacchi et al, In review.

Impact	*2012*	*2020*	*2030*	*2050*
GWP	100	72	58	55
FETP	100	100	96	89
FEP	100	90	75	68
HTP	100	94	84	78
PMFP	100	92	63	73
POFP	100	88	73	71
TAP	100	90	69	65
TETP	100	100	93	85

E. Environmental impact prices

Table 25 gives the environmental prices that are provided by De Bruyn et al (2017). The prices are given in a range of low, average and high. According to De Bruyn et al, the average (or central as they call it) value should be seen as the most likely environmental price. While the low and high values are the lower and upper boundary that provide for an uncertainty scenario.

Table 25: Environmental impact prices. Source: De Bruyn et al. (2017)

Impact category	Unit	Price Low	Average	High
Climate change	*€ / kg CO2 eq*	0,014	0,057	0,057
Ozone depletion	*€ / kg CFC-11 eq*	22,1	30,4	45,7
Human toxicity	*€ / kg 1.4-DCB eq*	0,157	0,214	0,331
Photochemical oxidant formation	*€ / kg NMVOC eq*	1,61	2,1	3,14
Particulate matter formation	*€ / kg PM10 eq*	49,3	69	106
Ionizing radiation	*€ / kg U235 eq*	0,0305	0,0473	0,061
Terrestrial acidification	*€ / kg SO2 eq*	1,19	5,4	10,7
Freshwater eutrophication	*€ / kg P eq*	0,473	1,9	3,71
Marine eutrophication	*€ / kg N eq*	3,11	3,11	3,11
Terrestrial ecotoxicity	*€ / kg 1.4-DCB eq*	2,21	8,89	17,3
Freshwater ecotoxicity	*€ / kg 1.4-DCB eq*	0,00917	0,0369	0,072
Marine ecotoxicity	*€ / kg 1.4-DCB eq*	0,00188	0,00756	0,015
Agricultural land transformation	*€ / m2a*	0,00647	0,0261	0,051

C. Output data

A. EV car market share

Table 27 to Table 37 show the composition of the personal vehicle fleet and how it changes each year. The columns are explained in Table 26.

Table 26: Abbreviations of EV market share tables

COLUMN TITLE	MEANING
%	Market share of new battery electrical vehicles (%).
% CUM	Market share of battery electrical vehicles of total fleet (%).
# CUM	Total amount of electrical vehicles in The Netherlands (mln).
FLEET	Total amount of personal vehicles in The Netherlands (mln).
BEV NEW	Amount of battery electrical vehicles sold in that year (mln).
NBEV NEW	Amount of non- battery electrical vehicles sold in that year (mln).
$\%V_{TOT}$	Amount of vehicles sold that year (mln)
%DEM	Average percentage that is demolished every year (%)
%IE	Average percentage of the import and export difference every year (%)
%OOF	Average percentage that leaves the vehicle fleet every year (%)

The new vehicle market share and the total fleet market share of the policy scenario (KA: climate agreement scenario) from 2020 to 2030 are provided by Revnext (2020) and the PBL (Nijland et al. 2019), just as the market share of new BEVs of the baseline scenario. The rest needed to be calculated and will be explained below.

%

The market share of new BEVs between 2021 and 2030 is provided by Revnext (2020). The years from 2030 to 2050 are calculated by creating a linear trend from the years 2027 to 2030.

% cum

The market share of BEV in the total fleet composition of the policy alternative is provided by Revnext (2020). The baseline scenario is calculated by using the market share of new BEVs and the total fleet market share of the policy alternative. The formula below is used for this calculation.

$$\%cum_{Bnew} = \frac{\Delta\%cum_{CA}}{\%_{CA}} * \%_{Bnew} + \%cum_{Bold}$$

 # cum

Total amount of battery electrical vehicles in The Netherlands is calculated by multiplying the total fleet with the share of BEV in that year.

Fleet

Total amount of personal vehicles in The Netherlands in 2020 and 2030 is provided by the WLO (CPB/PBL, 2015). This paper assumes a linear trend between 2020 and 2050 in electric vehicle growth. This means that the following years after 2030 are calculated by using a linear trend between 2020 and 2050.

BEV new

The amount of BEVs sold in that year is calculated by using multiplying the total amount of vehicles sold with the market share of new BEVs that year.

nBEV new

The amount of non-BEVs sold in that year is calculated by using multiplying the total amount of vehicles sold with the market share of new non-BEVs that year.

$\%V_{tot}$

The total amount of vehicles sold in that year is calculated by first using the average percentage that leaves the vehicle fleet and multiplying that with the total fleet of previous year. That is then added to the difference in total fleet composition.

%Dem, %IE & %OOF

The average percentage of demolished and import and export difference is calculated by using the percentage of demolished vehicles and import and export difference during the time period of 200-2020 and 2006-2014 respectively. The average percentage that leaves the vehicle fleet every year is calculated by adding %Dem and %IE. The data that is used can be found in Table 36 and comes from the open database of the Centraal Planbureau voor Statistiek (2020).

Mid scenario path

Table 27: Baseline, mid economy scenario

	BASELINE					
YEAR	**%**	**% cum.**	**# cum.**	**Fleet**	**BEV new**	**nBEV new**
2020	9	1,24	0,1	8,7	0,05	0,56
2021	1	1,37	0,1	8,8	0,01	0,57
2022	3	1,49	0,1	8,9	0,02	0,56
2023	5	1,71	0,2	9,0	0,03	0,55
2024	8	2,06	0,2	9,1	0,05	0,54
2025	12	2,52	0,2	9,2	0,07	0,53
2026	17	3,03	0,3	9,3	0,10	0,50
2027	21	3,66	0,3	9,4	0,13	0,48
2028	25	4,40	0,4	9,5	0,15	0,46
2029	29	5,26	0,5	9,6	0,18	0,44
2030	33	6,28	0,6	9,7	0,21	0,41
2031	38	7,18	0,7	9,8	0,24	0,39
2032	42	8,11	0,8	9,9	0,27	0,37
2033	46	9,04	0,9	10,0	0,30	0,34
2034	51	9,97	1,0	10,1	0,33	0,32
2035	55	10,90	1,1	10,2	0,36	0,29
2036	59	11,82	1,2	10,3	0,39	0,27
2037	64	12,75	1,3	10,4	0,42	0,24
2038	68	13,67	1,4	10,5	0,46	0,21
2039	72	14,60	1,6	10,6	0,49	0,19
2040	77	15,52	1,7	10,7	0,52	0,16
2041	81	16,45	1,8	10,8	0,56	0,13
2042	86	17,37	1,9	10,9	0,59	0,10
2043	90	18,29	2,0	11,0	0,63	0,07
2044	94	19,21	2,1	11,1	0,66	0,04
2045	99	20,15	2,3	11,2	0,70	0,01
2046	100	21,11	2,4	11,3	0,71	0,00
2047	100	22,06	2,5	11,4	0,72	0,00
2048	100	23,01	2,7	11,5	0,72	0,00
2049	100	23,96	2,8	11,6	0,73	0,00
2050	100	24,92	2,9	11,7	0,73	0,00

Table 28: Policy alternative, mid economy scenario

	KA					
YEAR	**%**	**% cum.**	**# cum.**	**Fleet**	**BEV new**	**nBEV new**
2020	9	1,24	0,1	8,7	0,055	0,556
2021	15	2,58	0,2	8,8	0,084	0,489
2022	14	3,05	0,3	8,9	0,079	0,500
2023	19	3,85	0,3	9,0	0,113	0,471
2024	25	4,85	0,4	9,1	0,145	0,445
2025	26	5,91	0,5	9,2	0,157	0,438
2026	19	6,51	0,6	9,3	0,117	0,484
2027	22	7,17	0,7	9,4	0,133	0,473
2028	25	7,92	0,8	9,5	0,154	0,458
2029	29	8,78	0,8	9,6	0,178	0,440
2030	34	9,83	1,0	9,7	0,213	0,410
2031	38	10,75	1,1	9,8	0,242	0,387
2032	43	11,70	1,2	9,9	0,273	0,362
2033	48	12,65	1,3	10,0	0,304	0,336
2034	52	13,61	1,4	10,1	0,336	0,309
2035	57	14,56	1,5	10,2	0,368	0,283
2036	61	15,51	1,6	10,3	0,401	0,255
2037	66	16,46	1,7	10,4	0,435	0,227
2038	70	17,42	1,8	10,5	0,469	0,199
2039	75	18,37	2,0	10,6	0,503	0,170
2040	79	19,32	2,1	10,7	0,538	0,141
2041	84	20,28	2,2	10,8	0,573	0,111
2042	88	21,23	2,3	10,9	0,609	0,081
2043	93	22,18	2,4	11,0	0,646	0,050
2044	97	23,13	2,6	11,1	0,683	0,018
2045	100	24,09	2,7	11,2	0,707	0,000
2046	100	25,04	2,8	11,3	0,712	0,000
2047	100	25,99	3,0	11,4	0,718	0,000
2048	100	26,94	3,1	11,5	0,723	0,000
2049	100	27,90	3,2	11,6	0,729	0,000
2050	100	28,85	3,4	11,7	0,734	0,000

Table 29: Difference market share and total fleet, mid economy scenario

YEAR	%	# V_{TOT}
2020	0	0,6
2021	13	0,6
2022	10	0,6
2023	14	0,6
2024	16	0,6
2025	15	0,6
2026	3	0,6
2027	1	0,6
2028	0	0,6
2029	0	0,6
2030	1	0,6
2031	1	0,6
2032	1	0,6
2033	1	0,6
2034	1	0,6
2035	1	0,7
2036	2	0,7
2037	2	0,7
2038	2	0,7
2039	2	0,7
2040	2	0,7
2041	3	0,7
2042	3	0,7
2043	3	0,7
2044	3	0,7
2045	1	0,7
2046	0	0,7
2047	0	0,7
2048	0	0,7
2049	0	0,7
2050	0	0,7

Low scenario path

Table 30: Baseline, low economy scenario

	BASELINE					
YEAR	**%**	**% cum.**	**# cum.**	**Fleet**	**BEV new**	**nBEV new**
2020	9	1,24	0,1	8,7	0,055	0,556
2021	1	1,36	0,1	8,7	0,007	0,515
2022	2	1,42	0,1	8,8	0,010	0,514
2023	2	1,50	0,1	8,8	0,012	0,515
2024	3	1,62	0,1	8,9	0,018	0,512
2025	5	1,81	0,2	8,9	0,028	0,504
2026	7	1,94	0,2	9,0	0,038	0,497
2027	9	2,06	0,2	9,0	0,048	0,490
2028	11	2,25	0,2	9,1	0,059	0,481
2029	14	2,53	0,2	9,1	0,077	0,466
2030	17	2,91	0,3	9,2	0,092	0,454
2031	20	3,21	0,3	9,3	0,113	0,456
2032	23	3,54	0,3	9,3	0,131	0,442
2033	26	3,86	0,4	9,4	0,148	0,428
2034	29	4,19	0,4	9,5	0,166	0,414
2035	32	4,52	0,4	9,5	0,185	0,399
2036	35	4,86	0,5	9,6	0,203	0,385
2037	37	5,19	0,5	9,7	0,222	0,370
2038	40	5,52	0,5	9,7	0,241	0,355
2039	43	5,86	0,6	9,8	0,260	0,340
2040	46	6,19	0,6	9,9	0,279	0,324
2041	49	6,53	0,7	10,0	0,299	0,308
2042	52	6,87	0,7	10,0	0,319	0,292
2043	55	7,20	0,7	10,1	0,339	0,276
2044	58	7,54	0,8	10,2	0,359	0,260
2045	61	7,88	0,8	10,2	0,379	0,243
2046	64	8,22	0,8	10,3	0,400	0,226
2047	67	8,56	0,9	10,4	0,421	0,209
2048	70	8,90	0,9	10,4	0,442	0,192
2049	73	9,24	1,0	10,5	0,464	0,174
2050	76	9,58	1,0	10,6	0,485	0,156

Table 31: Policy alternative, low economy scenario

	KA					
YEAR	**%**	**% cum.**	**# cum.**	**Fleet**	**BEV new**	**nBEV new**
2020	9	1,24	0,1	8,7	0,055	0,556
2021	13	2,45	0,2	8,7	0,068	0,454
2022	11	2,79	0,2	8,8	0,057	0,467
2023	14	3,32	0,3	8,8	0,076	0,451
2024	17	3,92	0,3	8,9	0,088	0,441
2025	18	4,53	0,4	8,9	0,093	0,439
2026	10	4,71	0,4	9,0	0,053	0,482
2027	10	4,85	0,4	9,0	0,051	0,486
2028	12	5,04	0,5	9,1	0,063	0,477
2029	15	5,33	0,5	9,1	0,079	0,464
2030	18	5,72	0,5	9,2	0,096	0,450
2031	21	6,05	0,6	9,3	0,119	0,449
2032	24	6,39	0,6	9,3	0,137	0,436
2033	27	6,73	0,6	9,4	0,154	0,422
2034	30	7,07	0,7	9,5	0,172	0,408
2035	33	7,41	0,7	9,5	0,190	0,394
2036	35	7,75	0,7	9,6	0,208	0,380
2037	38	8,09	0,8	9,7	0,226	0,365
2038	41	8,43	0,8	9,7	0,245	0,351
2039	44	8,77	0,9	9,8	0,264	0,336
2040	47	9,11	0,9	9,9	0,283	0,320
2041	50	9,45	0,9	10,0	0,302	0,305
2042	53	9,79	1,0	10,0	0,322	0,289
2043	56	10,13	1,0	10,1	0,342	0,273
2044	58	10,47	1,1	10,2	0,361	0,257
2045	61	10,81	1,1	10,2	0,382	0,241
2046	64	11,15	1,1	10,3	0,402	0,224
2047	67	11,49	1,2	10,4	0,423	0,207
2048	70	11,83	1,2	10,4	0,443	0,190
2049	73	12,17	1,3	10,5	0,464	0,173
2050	76	12,51	1,3	10,6	0,486	0,156

Table 32: Difference market share and total fleet, low economy scenario

YEAR	%	# V_{TOT}
2020	0	0,6
2021	12	0,5
2022	9	0,5
2023	12	0,5
2024	13	0,5
2025	12	0,5
2026	3	0,5
2027	1	0,5
2028	1	0,5
2029	0	0,5
2030	0,6	0,5
2031	1,1	0,6
2032	1,1	0,6
2033	1,0	0,6
2034	0,9	0,6
2035	0,9	0,6
2036	0,8	0,6
2037	0,8	0,6
2038	0,7	0,6
2039	0,7	0,6
2040	0,6	0,6
2041	0,6	0,6
2042	0,5	0,6
2043	0,5	0,6
2044	0,4	0,6
2045	0,3	0,6
2046	0,3	0,6
2047	67	8,56
2048	70	8,90
2049	73	9,24
2050	76	9,58

High scenario path

Table 33: Baseline, high economy scenario

	BASELINE					
YEAR	**%**	**% cum.**	**# cum.**	**Fleet**	**BEV new**	**nBEV new**
2020	9	1,24	0,1	8,7	0,055	0,556
2021	2	1,39	0,1	8,8	0,011	0,615
2022	5	1,60	0,1	9,0	0,034	0,599
2023	9	2,02	0,2	9,1	0,061	0,581
2024	15	2,69	0,3	9,3	0,098	0,553
2025	21	3,64	0,3	9,4	0,141	0,518
2026	24	4,51	0,4	9,6	0,160	0,507
2027	32	5,71	0,6	9,8	0,219	0,456
2028	37	7,05	0,7	9,9	0,254	0,430
2029	44	8,66	0,9	10,1	0,306	0,387
2030	51	10,51	1,1	10,2	0,357	0,344
2031	58	12,21	1,3	10,4	0,399	0,290
2032	65	13,95	1,5	10,5	0,452	0,244
2033	72	15,69	1,7	10,6	0,505	0,198
2034	79	17,44	1,9	10,8	0,560	0,151
2035	86	19,18	2,1	10,9	0,615	0,103
2036	93	20,93	2,3	11,0	0,672	0,053
2037	100	22,69	2,5	11,2	0,730	0,003
2038	100	24,47	2,8	11,3	0,740	0,000
2039	100	26,24	3,0	11,4	0,747	0,000
2040	100	28,02	3,2	11,6	0,754	0,000
2041	100	29,79	3,5	11,7	0,762	0,000
2042	100	31,56	3,7	11,8	0,769	0,000
2043	100	33,34	4,0	12,0	0,776	0,000
2044	100	35,11	4,2	12,1	0,783	0,000
2045	100	36,88	4,5	12,2	0,791	0,000
2046	100	38,66	4,8	12,4	0,798	0,000
2047	100	40,43	5,1	12,5	0,805	0,000
2048	100	42,20	5,3	12,6	0,813	0,000
2049	100	43,98	5,6	12,8	0,820	0,000
2050	100	45,75	5,9	12,9	0,827	0,000

Table 34: policy alternative, high economy scenario

	KA					
YEAR	**%**	**% cum.**	**# cum.**	**Fleet**	**BEV new**	**nBEV new**
2020	9	1,24	0,1	8,7	0,055	0,556
2021	16	2,71	0,2	8,8	0,103	0,523
2022	18	3,38	0,3	9,0	0,111	0,523
2023	25	4,51	0,4	9,1	0,162	0,480
2024	34	6,03	0,6	9,3	0,221	0,429
2025	41	7,83	0,7	9,4	0,267	0,392
2026	27	8,83	0,8	9,6	0,183	0,484
2027	34	10,08	1,0	9,8	0,230	0,446
2028	38	11,45	1,1	9,9	0,260	0,424
2029	45	13,10	1,3	10,1	0,314	0,378
2030	52	15,00	1,5	10,2	0,364	0,336
2031	59	16,73	1,7	10,4	0,407	0,282
2032	66	18,51	1,9	10,5	0,460	0,236
2033	73	20,28	2,2	10,6	0,514	0,189
2034	80	22,05	2,4	10,8	0,569	0,141
2035	87	23,83	2,6	10,9	0,626	0,092
2036	94	25,60	2,8	11,0	0,683	0,042
2037	100	27,37	3,1	11,2	0,733	0,000
2038	100	29,15	3,3	11,3	0,740	0,000
2039	100	30,92	3,5	11,4	0,747	0,000
2040	100	32,69	3,8	11,6	0,754	0,000
2041	100	34,47	4,0	11,7	0,762	0,000
2042	100	36,24	4,3	11,8	0,769	0,000
2043	100	38,01	4,5	12,0	0,776	0,000
2044	100	39,79	4,8	12,1	0,783	0,000
2045	100	41,56	5,1	12,2	0,791	0,000
2046	100	43,33	5,4	12,4	0,798	0,000
2047	100	45,11	5,6	12,5	0,805	0,000
2048	100	46,88	5,9	12,6	0,813	0,000
2049	100	48,66	6,2	12,8	0,820	0,000
2050	100	50,43	6,5	12,9	0,827	0,000

Table 35: Difference market share and total fleet, high economy scenario

YEAR	%	# V_{TOT}
2020	0	0,6
2021	15	0,6
2022	12	0,6
2023	16	0,6
2024	19	0,7
2025	19	0,7
2026	4	0,7
2027	2	0,7
2028	1	0,7
2029	1	0,7
2030	1,0	0,7
2031	1,2	0,7
2032	1,2	0,7
2033	1,3	0,7
2034	1,4	0,7
2035	1,4	0,7
2036	1,5	0,7
2037	0,4	0,7
2038	0	0,7
2039	0	0,7
2040	0	0,8
2041	0	0,8
2042	0	0,8
2043	0	0,8
2044	0	0,8
2045	0	0,8
2046	0	0,8
2047	0	0,8
2048	0	0,8
2049	0	0,8
2050	0	0,8

Table 36: Fleet composition, demolitions and import export ratio 2000 to 2020. Source: CPB (2020)

	Total number of vehicles			**demolition**			**Δ import/export**		
Year	**# BEV**	**# Non-BEV**	**Tot fleet**	**ICE**	**BEV**	**% dem/fleet**	**Import**	**Export**	**Total**
2000	0	6343164	6343164	327709	0	5,2			-126351
2001	0	6539040	6539040	322523	0	4,9			-130253
2002	0	6710595	6710595	313309	0	4,7			-133670
2003	0	6854947	6854947	309811	0	4,5			-136546
2004	0	6908890	6908890	292864	0	4,2			-137620
2005	0	6991974	6991974	251464	0	3,6			-139275
2006	0	7092293	7092293	241018	0	3,4	56.219	179.901	-123682
2007	0	7230178	7230178	213149	0	2,9	70.515	209.446	-138931
2008	0	7391903	7391903	210476	0	2,8	71.989	205.455	-133466
2009	0	7542331	7542331	262610	0	3,5	73.064	181.928	-108864
2010	266	7622087	7622353	245838	0	3,2	92.553	193.131	-100578
2011	2157	7733390	7735547	251010	0	3,2	84.680	273.938	-189258
2012	2709	7856003	7858712	238092	0	3,0	74.945	324.590	-249645
2013	3.505	7912108	7915613	233765	0	3,0	94.110	278.770	-184660
2014	4.621	7927669	7932290	227039	0	2,9	115.361	247.188	-131827
2015	7.416	7971667	7979083	201644	0	2,5			-158938
2016	9.962	8090902	8100864	206393	0	2,6			-161364
2017	13.709	8209265	8222974	226700	0	2,8			-163796
2018	21.842	8351402	8373244	242238	0	2,9			-166789
2019	44.678	8485906	8530584	229734	0	2,7			-169923
2020	107536	8570375	8677911	310323	0	3,6			-172858

Table 37: %IE, %Dem and %OOF.

Percentage of total fleet Δimport-export per year (%IE)	**Percentage demolished average (%Dem)**	**Percentage out of fleet (%OOF)**
-1,99	3,4	5,43

B. National costs

The national costs are calculated by using the national costs that are provided by Revnext (2020). The costs that are provided are annuity costs which means that costs of one vehicle that is sold in one year is spread out over multiple years. According to Revnext, the depreciation costs follow a term of 10 to 15 years. For the simplicity of the calculations of this research, 12,5 years is assumed as the total depreciation time period. By using this, the total costs of one vehicle can be calculated per sector (EV investment, charging infrastructure, electricity, etc.). This is provided in Table 42. This means that the formula for the total vehicle costs (TVc) is as following:

$$Vc_x = \frac{AVc_x * 12.5}{BEVnew_{CA} - BEVnew_B}$$

Where AVc is the annuity vehicle costs provided by Revnext in Table 41 and x is the sector that is calculated. The total national costs are then calculated by using the total costs of the vehicle and multiplying it by the difference between the sold vehicles in the policy alternative and the baseline. The formula is as following:

$$TC_x = TVc_x * (BEVnew_{CA} - BEVnew_B)$$

The national costs are of course discounted which uses the following formula (Harris & Roach, 2011):

$$PV(TC_x) = \frac{TC_x}{(1 + r)^n}$$

Where PV is the present value of the total cost, r is the discount rate (0.03) and n is the number of years in the future. This formula is also used to calculate the present value of the environmental benefits.

Table 38: Mid scenario path national costs. 2020-2050

INVESTMENTS	**EV'S**	**CHARGING INFRASTRUCTURE**	**MAINTENANCE**	**ELECTRICITY**	**FUEL**	**TOTAL**
2020	0	0	0	0	0	0
2021	682,3	57,0	-298,1	186,8	-513,9	114
2022	512,0	42,7	-223,7	140,2	-385,6	86
2023	688,0	57,4	-300,6	188,4	-518,2	115
2024	774,9	64,7	-338,6	212,2	-583,6	130
2025	699,5	58,4	-305,6	191,6	-526,9	117
2026	130,4	10,9	-57,0	35,7	-98,3	22
2027	53,3	4,4	-23,3	14,6	-40,1	9
2028	14,9	1,2	-6,5	4,1	-11,2	2
2029	10,2	0,9	-4,5	2,8	-7,7	2
2030	29,6	2,5	-12,9	8,1	-22,3	5
2031	32,6	2,7	-14,3	8,9	-24,6	5
2032	39,3	3,3	-17,2	10,8	-29,6	7
2033	45,7	3,8	-20,0	12,5	-34,5	8
2034	51,9	4,3	-22,7	14,2	-39,1	9
2035	57,7	4,8	-25,2	15,8	-43,5	10
2036	63,3	5,3	-27,6	17,3	-47,6	11
2037	68,6	5,7	-30,0	18,8	-51,6	11
2038	73,6	6,1	-32,2	20,2	-55,5	12
2039	78,4	6,5	-34,3	21,5	-59,1	13
2040	83,0	6,9	-36,3	22,7	-62,5	14
2041	87,3	7,3	-38,2	23,9	-65,8	15
2042	91,4	7,6	-39,9	25,0	-68,9	15
2043	95,3	8,0	-41,6	26,1	-71,8	16
2044	99,0	8,3	-43,2	27,1	-74,5	17
2045	42,9	3,6	-18,8	11,8	-32,3	7
2046	0,0	0,0	0,0	0,0	0,0	0
2047	0,0	0,0	0,0	0,0	0,0	0
2048	0,0	0,0	0,0	0,0	0,0	0
2049	0,0	0,0	0,0	0,0	0,0	0
2050	0,0	0,0	0,0	0,0	0,0	0
TOTAL 2030	3595	300	-1571	985	-2708	601
TOTAL 2050	4605	384	-2012	1261	-3469	770

Table 39: Low scenario path national costs. 2020-2050

INVESTMENTS	EV'S	CHARGING INFRASTRUCTURE	MAINTENANCE	ELECTRICITY	FUEL	TOTAL
2020	0	0	0	0	0	0
2021	647,0	53,0	-198,9	166,6	-451,1	217
2022	484,2	39,7	-148,9	124,7	-337,6	162
2023	639,2	52,4	-196,5	164,6	-445,7	214
2024	679,2	55,6	-208,8	174,9	-473,6	227
2025	612,7	50,2	-188,4	157,8		632
2026	139,5	11,4	-42,9	35,9	-97,2	47
2027	31,8	2,6	-9,8	8,2	-22,2	11
2028	34,8	2,8	-10,7	9,0	-24,3	12
2029	17,2	1,4	-5,3	4,4	-12,0	6
2030	28,2	2,3	-8,7	7,3	-19,7	9
2031	50,0	4,1	-15,4	12,9	-34,8	17
2032	46,4	3,8	-14,3	11,9	-32,4	16
2033	43,0	3,5	-13,2	11,1	-30,0	14
2034	39,7	3,3	-12,2	10,2	-27,7	13
2035	36,6	3,0	-11,2	9,4	-25,5	12
2036	33,5	2,7	-10,3	8,6	-23,4	11
2037	30,6	2,5	-9,4	7,9	-21,3	10
2038	27,8	2,3	-8,5	7,2	-19,4	9
2039	25,1	2,1	-7,7	6,5	-17,5	8
2040	22,5	1,8	-6,9	5,8	-15,7	8
2041	20,0	1,6	-6,2	5,2	-14,0	7
2042	17,7	1,4	-5,4	4,5	-12,3	6
2043	15,4	1,3	-4,7	4,0	-10,7	5
2044	13,2	1,1	-4,1	3,4	-9,2	4
2045	11,1	0,9	-3,4	2,9	-7,7	4
2046	9,1	0,7	-2,8	2,3	-6,3	3
2047	7,2	0,6	-2,2	1,8	-5,0	2
2048	5,3	0,4	-1,6	1,4	-3,7	2
2049	3,6	0,3	-1,1	0,9	-2,5	1
2050	1,9	0,2	-0,6	0,5	-1,3	1
TOTAL 2030	3314	271	-1019	853	-1883	1536
TOTAL 2050	3773	309	-1160	972	-2204	1690

Table 40: High scenario path national costs. 2020-2050

INVESTMENTS	**EV'S**	**CHARGING INFRASTRUCTURE**	**MAINTENANCE**	**ELECTRICITY**	**FUEL**	**TOTAL**
2020	0	0	0	0	0	0
2021	647,0	53,0	-198,9	166,6	-451,1	217
2022	525,8	43,1	-161,7	135,4	-366,6	176
2023	671,0	55,0	-206,3	172,8	-467,8	225
2024	797,8	65,3	-245,3	205,4	-556,2	267
2025	790,8	64,8	-243,1	203,6	-551,4	265
2026	143,9	11,8	-44,2	37,0	-100,3	48
2027	62,5	5,1	-19,2	16,1	-43,6	21
2028	35,6	2,9	-10,9	9,2	-24,8	12
2029	44,9	3,7	-13,8	11,6	-31,3	15
2030	39,2	3,2	-12,1	10,1	-27,3	13
2031	42,0	3,4	-12,9	10,8	-29,3	14
2032	43,5	3,6	-13,4	11,2	-30,3	15
2033	44,9	3,7	-13,8	11,6	-31,3	15
2034	46,2	3,8	-14,2	11,9	-32,2	15
2035	47,5	3,9	-14,6	12,2	-33,1	16
2036	48,6	4,0	-15,0	12,5	-33,9	16
2037	12,8	1,0	-3,9	3,3	-8,9	4
2038	0,0	0,0	0,0	0,0	0,0	0
2039	0,0	0,0	0,0	0,0	0,0	0
2040	0,0	0,0	0,0	0,0	0,0	0
2041	0,0	0,0	0,0	0,0	0,0	0
2042	0,0	0,0	0,0	0,0	0,0	0
2043	0,0	0,0	0,0	0,0	0,0	0
2044	0,0	0,0	0,0	0,0	0,0	0
2045	0,0	0,0	0,0	0,0	0,0	0
2046	0,0	0,0	0,0	0,0	0,0	0
2047	0,0	0,0	0,0	0,0	0,0	0
2048	0,0	0,0	0,0	0,0	0,0	0
2049	0,0	0,0	0,0	0,0	0,0	0
2050	0,0	0,0	0,0	0,0	0,0	0
TOTAL 2030	3758	308	-1156	968	-2620	1258
TOTAL 2050	4044	331	-1243	1041	-2820	1353

Table 41: National costs of the year 2020 (annuity costs method) (AVc) (mln euros). Source: Revnext (2020)

SCENARIO	INVESTMENT	YEAR 2020
MID ECONOMY	EV's	54,6
	Charging infrastructure	4,6
	Maintenance	-23,8
	Electricity	14,9
	Fuel	-41,1
	Total	9,1
LOW ECONOMY	EV's	51,8
	Charging infrastructure	4,2
	Maintenance	-15,9
	Electricity	13,3
	Fuel	-36,1
	Total	17,3
HIGH ECONOMY	EV's	63,0
	Charging infrastructure	5,0
	Maintenance	-33,3
	Electricity	16,7
	Fuel	-45,7
	Total	5,7

Table 42: Costs per vehicle.

	COSTS PER VEHICLE (MLN EUROS) (TVC)		
	Low economy	Mid economy	High economy
EV'S	10583	8937	7043
CHARGING INFRASTRUCTURE	867	746	577
MAINTENANCE	-3254	-3905	-2165
ELECTRICITY	2725	2447	1813
FUEL	-7379	-6731	-4911

C. Monetarized Life Cycle Analysis

Table 43:Monetarized LCA BEV & ICEV 2012

Monetarized impact scores per km driven per type of vehicle for every stage of life time (Low prices)								
		Electric vehicle				ICEV		
	Electricity/fuel type	European mix		Natural gas	Coal	Diesel	Gasoline	
	Battery	LI-NCM	LiFePO4	Li-NCM	Li-NCM			
Impact	**Life cycle component**							
Climate change	Base vehicle	4,82E-04	4,82E-04	4,82E-04	4,82E-04	4,82E-04	4,82E-04	
	Engine	8,76E-05	8,76E-05	8,76E-05	8,76E-05	4,38E-05	4,38E-05	
	Other powertrain	2,19E-04	2,19E-04	2,19E-04	2,19E-04	8,76E-05	8,76E-05	
	Battery	4,38E-04	5,70E-04	4,38E-04	4,38E-04	0,00E+00	0,00E+00	
	Use phase, non fuel related	8,76E-05	8,76E-05	8,76E-05	8,76E-05	1,31E-04	1,31E-04	
	Fuel/Electricity	1,36E-03	1,36E-03	1,80E-03	2,98E-03	2,41E-03	2,85E-03	
	End of life	4,38E-05	8,76E-05	4,38E-05	4,38E-05	4,38E-05	4,38E-05	
	Total	2,76E-03	2,88E-03	3,18E-03	4,38E-03	3,20E-03	3,62E-03	**Euro/km**
Terrestrial acidification	Base vehicle	1,39E-04	1,39E-04	1,39E-04	1,39E-04	1,39E-04	1,39E-04	
	Engine	5,21E-05	5,21E-05	5,21E-05	5,21E-05	1,74E-05	1,74E-05	
	Other powertrain	1,04E-04	1,04E-04	1,04E-04	1,04E-04	3,47E-04	3,47E-04	
	Battery	2,95E-04	2,26E-04	2,95E-04	2,95E-04	0,00E+00	0,00E+00	
	Use phase, non fuel related	3,47E-05	3,47E-05	3,47E-05	3,47E-05	8,69E-05	8,69E-05	
	Fuel/Electricity	4,69E-04	4,69E-04	1,56E-04	1,09E-03	3,47E-04	4,69E-04	
	End of life	1,74E-05	1,74E-05	1,74E-05	1,74E-05	1,74E-05	1,74E-05	
	Total	1,12E-03	1,05E-03	8,09E-04	1,74E-03	9,40E-04	1,06E-03	**Euro/km**
Particulate matter formation	Base vehicle	2,96E-03	2,96E-03	2,96E-03	2,96E-03	2,96E-03	2,96E-03	
	Engine	9,86E-04	9,86E-04	9,86E-04	9,86E-04	4,93E-04	4,93E-04	
	Other powertrain	2,22E-03	2,22E-03	2,22E-03	2,22E-03	3,20E-03	3,20E-03	
	Battery	3,70E-03	3,20E-03	3,70E-03	3,70E-03	0,00E+00	0,00E+00	
	Use phase, non fuel related	7,40E-04	7,40E-04	7,40E-04	7,40E-04	1,23E-03	1,23E-03	
	Fuel/Electricity	6,41E-03	6,41E-03	2,47E-03	1,36E-02	5,92E-03	1,48E-03	
	End of life	2,47E-04	2,47E-04	2,47E-04	2,47E-04	0,00E+00	0,00E+00	
	Total	1,73E-02	1,68E-02	1,33E-02	2,47E-02	1,38E-02	1,43E-02	**Euro/km**
Photochemical oxidant formation	Base vehicle	1,38E-04	1,38E-04	1,38E-04	1,38E-04	1,38E-04	1,38E-04	
	Engine	3,77E-05	3,77E-05	3,77E-05	3,77E-05	1,26E-05	1,26E-05	
	Other powertrain	7,53E-05	7,53E-05	7,53E-05	7,53E-05	6,28E-05	6,28E-05	
	Battery	1,26E-04	1,38E-04	1,26E-04	1,26E-04	1,26E-05	1,26E-05	
	Use phase, non fuel related	3,77E-05	3,77E-05	3,77E-05	3,77E-05	6,28E-05	6,28E-05	
	Fuel/Electricity	3,27E-04	3,27E-04	3,01E-04	8,29E-04	8,04E-04	6,91E-04	
	End of life	1,26E-05	1,26E-05	1,26E-05	1,26E-05	1,26E-05	1,26E-05	
	Total	7,57E-04	7,73E-04	7,41E-04	1,26E-03	1,09E-03	9,82E-04	**Euro/km**
Human toxicity	Base vehicle	4,45E-03	4,45E-03	4,45E-03	4,45E-03	4,45E-03	4,45E-03	
	Engine	2,67E-03	2,67E-03	2,67E-03	2,67E-03	4,45E-04	4,45E-04	
	Other powertrain	5,34E-03	5,34E-03	5,34E-03	5,34E-03	1,33E-03	1,33E-03	
	Battery	1,56E-02	1,91E-02	1,56E-02	1,56E-02	8,89E-04	8,89E-04	
	Use phase, non fuel related	2,22E-03	2,22E-03	2,22E-03	2,22E-03	3,11E-03	3,11E-03	
	Fuel/Electricity	1,02E-02	1,02E-02	2,22E-03	1,20E-02	8,89E-04	8,89E-04	
	End of life	4,45E-04	4,45E-04	4,45E-04	4,45E-04	4,45E-04	4,45E-04	
	Total	4,12E-02	4,45E-02	3,29E-02	4,26E-02	1,13E-02	1,16E-02	**Euro/km**
Freshwater ecotoxity	Base vehicle	5,61E-06	5,61E-06	5,61E-06	5,61E-06	5,61E-06	5,61E-06	
	Engine	2,40E-06	2,40E-06	2,40E-06	2,40E-06	8,01E-07	8,01E-07	
	Other powertrain	4,81E-06	4,81E-06	4,81E-06	4,81E-06	1,60E-06	1,60E-06	
	Battery	1,04E-05	1,20E-05	1,04E-05	1,04E-05	8,01E-07	8,01E-07	
	Use phase, non fuel related	1,60E-06	1,60E-06	1,60E-06	1,60E-06	2,40E-06	2,40E-06	
	Fuel/Electricity	1,16E-05	1,16E-05	1,20E-06	1,40E-05	1,20E-06	1,60E-06	
	End of life	1,60E-06	2,00E-06	1,60E-06	1,60E-06	1,60E-06	1,60E-06	
	Total	3,77E-05	3,93E-05	2,73E-05	4,01E-05	1,34E-05	1,38E-05	**Euro/km**
Terrestrial ecotoxicity	Base vehicle	1,06E-05	1,06E-05	1,06E-05	1,06E-05	1,06E-05	1,06E-05	
	Engine	5,30E-06	5,30E-06	5,30E-06	5,30E-06	1,77E-06	1,77E-06	
	Other powertrain	5,30E-06	5,30E-06	5,30E-06	5,30E-06	1,77E-06	1,77E-06	
	Battery	1,41E-05	1,41E-05	1,41E-05	1,41E-05	0,00E+00	0,00E+00	
	Use phase, non fuel related	1,11E-04	1,11E-04	1,11E-04	1,11E-04	1,11E-04	1,11E-04	
	Fuel/Electricity	2,83E-05	2,83E-05	1,06E-05	1,24E-05	3,36E-05	4,24E-05	
	End of life	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
	Total	1,77E-04	1,77E-04	1,55E-04	1,55E-04	1,55E-04	1,77E-04	**Euro/km**
Freshwater eutrophication	Base vehicle	1,14E-05	1,14E-05	1,14E-05	1,14E-05	1,14E-05	1,14E-05	
	Engine	4,16E-06	4,16E-06	4,16E-06	4,16E-06	1,04E-06	1,04E-06	
	Other powertrain	1,04E-05	1,04E-05	1,04E-05	1,04E-05	3,12E-06	3,12E-06	
	Battery	2,50E-05	3,33E-05	2,50E-05	2,50E-05	2,08E-06	2,08E-06	
	Use phase, non fuel related	3,12E-06	3,12E-06	3,12E-06	3,12E-06	5,20E-06	5,20E-06	
	Fuel/Electricity	4,06E-05	4,06E-05	3,12E-06	4,79E-05	2,08E-06	3,12E-06	
	End of life	1,04E-06	1,04E-06	1,04E-06	1,04E-06	1,04E-06	1,04E-06	
	Total	9,93E-05	1,04E-04	6,15E-05	1,04E-04	2,37E-05	2,37E-05	**Euro/km**

D. CBLCA effects

The effects of both the CBLCA and the CCBA are calculated by using the monetarized LCA and multiplying that with the amount of BEVs sold of either the baseline or the policy alternative. This is then multiplied with the amount of kilometers a BEV drives (which is assumed to be 150.000 km, which is derived from the assumption that is made by the LCA of Hawkins et al. (2015)). The ICEV uses only the use phase of the LCA, while the BEV uses the every phase, and uses the monetarized yearly LCA.

Table 44: Monetarized environmental effects CBLCA low prices.

Prices Low

	Mid economy (mln)			Low economy (mln)			High economy (mln)		
	Basis	KA	Δ Discounted	Basis	KA	Δ Discounted	Basis	KA	Δ Discounted
2020	3152	3152	0	3152	3152	0	3152	3152	0
2021	2769	3092	-304	2515	2773	-243	3028	3416	-366
2022	2843	3083	-220	2541	2733	-176	3163	3476	-287
2023	2912	3232	-285	2561	2813	-224	3302	3699	-353
2024	3003	3361	-309	2595	2860	-229	3471	3939	-403
2025	3092	3412	-268	2641	2878	-198	3653	4112	-384
2026	3215	3274	-48	2684	2737	-43	3739	3821	-67
2027	3314	3338	-19	2724	2736	-9	3952	3988	-28
2028	3403	3410	-5	2767	2780	-10	4069	4089	-15
2029	3483	3488	-3	2824	2831	-5	4230	4254	-18
2030	3576	3588	-9	2870	2880	-7	4372	4393	-15
2031	3681	3695	-10	3039	3057	-13	4433	4457	-16
2032	3790	3808	-12	3106	3124	-12	4615	4639	-17
2033	3900	3921	-14	3174	3191	-11	4798	4824	-17
2034	4011	4036	-16	3242	3258	-10	4984	5011	-18
2035	4123	4151	-17	3311	3325	-9	5171	5200	-18
2036	4236	4267	-19	3379	3393	-8	5360	5390	-18
2037	4349	4384	-20	3448	3461	-8	5550	5559	-5
2038	4463	4501	-22	3518	3530	-7	5607	5607	0
2039	4578	4620	-23	3587	3598	-6	5655	5655	0
2040	4694	4739	-24	3657	3667	-6	5703	5703	0
2041	4810	4859	-26	3727	3737	-5	5751	5751	0
2042	4927	4979	-27	3797	3806	-4	5798	5798	0
2043	5044	5101	-28	3868	3876	-4	5846	5846	0
2044	5163	5223	-29	3939	3946	-3	5893	5893	0
2045	5282	5308	-12	4010	4016	-3	5941	5941	0
2046	5343	5343	0	4081	4086	-2	5988	5988	0
2047	5378	5378	0	4153	4157	-2	6035	6035	0
2048	5413	5413	0	4224	4227	-1	6082	6082	0
2049	5448	5448	0	4296	4298	-1	6128	6128	0
2050	5482	5482	0	4369	4370	0	6175	6175	0
Total 2030			-1469			-1144			-1936
Total 2050			-1767			-1259			-2045

Table 45: Monetarized environmental effects CBLCA average prices.

Prices average

	Mid economy (mln)			Low economy (mln)			High economy (mln)		
	Basis	KA	Δ Discounted	Basis	KA	Δ Discounted	Basis	KA	Δ Discounted
2020	5609	5609	0	5609	5609	0	5609	5609	0
2021	4997	5457	-433	4540	4907	-347	5462	6014	-521
2022	5113	5458	-315	4582	4858	-252	5670	6119	-411
2023	5223	5686	-411	4616	4979	-322	5887	6459	-509
2024	5366	5886	-449	4670	5055	-332	6150	6829	-586
2025	5508	5976	-392	4744	5090	-290	6434	7105	-562
2026	5701	5788	-71	4813	4891	-64	6579	6701	-99
2027	5862	5897	-28	4878	4896	-14	6918	6971	-42
2028	6011	6020	-8	4949	4969	-15	7117	7146	-23
2029	6137	6144	-5	5039	5048	-7	7368	7405	-27
2030	6283	6301	-14	5110	5125	-11	7591	7623	-23
2031	6397	6417	-14	5372	5398	-18	7579	7612	-23
2032	6505	6528	-16	5447	5471	-16	7752	7785	-22
2033	6600	6627	-18	5514	5535	-14	7904	7937	-22
2034	6684	6713	-19	5574	5593	-12	8035	8068	-21
2035	6754	6785	-19	5626	5643	-10	8144	8176	-20
2036	6812	6844	-20	5671	5685	-9	8230	8262	-19
2037	6856	6889	-20	5707	5720	-7	8293	8301	-5
2038	6886	6920	-19	5735	5746	-6	8211	8211	0
2039	7010	7046	-20	5812	5822	-5	8282	8282	0
2040	7133	7173	-21	5889	5898	-5	8353	8353	0
2041	7257	7300	-22	5966	5974	-4	8424	8424	0
2042	7381	7427	-23	6043	6051	-4	8494	8494	0
2043	7505	7554	-24	6120	6127	-3	8564	8564	0
2044	7630	7682	-25	6197	6203	-3	8634	8634	0
2045	7755	7778	-11	6274	6279	-2	8704	8704	0
2046	7830	7830	0	6351	6355	-2	8774	8774	0
2047	7881	7881	0	6428	6432	-2	8843	8843	0
2048	7933	7933	0	6505	6508	-1	8913	8913	0
2049	7984	7984	0	6582	6584	-1	8982	8982	0
2050	8035	8035	0	6659	6660	0	9051	9051	0
Total 2030			-2124			-1653			-2802
Total 2050			-2415			-1779			-2934

Table 46: Monetarized environmental effects CBLCA high prices.

Prices high

	Mid economy (mln)			Low economy (mln)			High economy (mln)		
	Basis	KA	Δ Discounted	Basis	KA	Δ Discounted	Basis	KA	Δ Discounted
2020	8154	8154	0	8154	8154	0	8154	8154	0
2021	7226	7963	-695	6563	7154	-556	7899	8786	-836
2022	7405	7960	-508	6628	7072	-406	8222	8946	-662
2023	7575	8324	-665	6679	7267	-522	8563	9490	-823
2024	7800	8646	-730	6763	7389	-540	8979	10084	-953
2025	8025	8790	-641	6880	7446	-474	9434	10532	-919
2026	8336	8479	-116	6990	7119	-105	9665	9865	-163
2027	8596	8655	-46	7095	7124	-23	10218	10305	-69
2028	8839	8855	-12	7210	7243	-25	10542	10592	-38
2029	9045	9056	-8	7356	7372	-12	10955	11016	-46
2030	9284	9316	-23	7474	7499	-18	11323	11376	-38
2031	9474	9508	-24	7872	7915	-31	11342	11397	-39
2032	9655	9695	-27	7995	8034	-27	11636	11692	-38
2033	9817	9862	-30	8107	8142	-24	11900	11956	-37
2034	9961	10011	-32	8207	8240	-21	12132	12188	-36
2035	10086	10140	-33	8297	8325	-18	12331	12387	-35
2036	10192	10249	-34	8375	8400	-15	12496	12552	-33
2037	10278	10337	-35	8440	8463	-13	12627	12640	-8
2038	10343	10404	-34	8494	8513	-11	12506	12506	0
2039	10550	10616	-37	8621	8639	-10	12614	12614	0
2040	10757	10828	-39	8749	8765	-9	12721	12721	0
2041	10964	11042	-40	8877	8892	-8	12829	12829	0
2042	11173	11256	-42	9005	9018	-7	12936	12936	0
2043	11382	11471	-44	9133	9145	-6	13043	13043	0
2044	11592	11686	-45	9261	9272	-5	13149	13149	0
2045	11803	11845	-19	9390	9399	-4	13255	13255	0
2046	11923	11923	0	9519	9526	-3	13361	13361	0
2047	12002	12002	0	9647	9654	-3	13467	13467	0
2048	12080	12080	0	9776	9781	-2	13572	13572	0
2049	12158	12158	0	9905	9908	-1	13677	13677	0
2050	12236	12236	0	10034	10036	-1	13782	13782	0
Total 2030			-3444			-2681			-4547
Total 2050			-3959			-2899			-4774

E. CCBA effects

Similar to the calculation method of the CBLCA effects, the monetarized LCA is used and multiplied with the amount of BEVs sold of either the baseline or the policy alternative. In the case of the CCBA, only the tailpipe emissions are used which means that the ICEV uses only the use phase of the vehicle while the BEV emissions are set to zero.

Table 47: Monetarized environmental effects CCBA low prices.

Prices low

	Mid economy (mln)			Low economy (mln)			High economy (mln)		
	Basis	KA	Δ Discounted	Basis	KA	Δ Discounted	Basis	KA	Δ Discounted
2020	535	535	0	535	535	0	535	535	0
2021	545	471	69	496	437	56	592	504	83
2022	539	482	52	495	450	42	578	503	68
2023	533	454	70	496	434	55	560	462	87
2024	520	429	79	493	425	58	533	413	103
2025	507	422	71	486	423	53	499	377	102
2026	483	467	13	479	464	12	489	466	19
2027	463	456	5	472	469	3	440	430	8
2028	444	442	2	463	460	3	415	409	5
2029	425	423	1	449	447	1	372	365	6
2030	399	395	3	437	434	2	331	324	5
2031	378	373	3	439	433	4	279	271	5
2032	354	348	4	426	420	4	235	227	6
2033	331	324	5	412	407	4	191	182	6
2034	306	298	5	399	393	3	145	136	6
2035	282	272	6	385	380	3	99	89	6
2036	257	246	6	371	366	3	51	41	6
2037	231	219	7	356	352	3	3	0	2
2038	205	192	7	342	338	2	0	0	0
2039	178	164	8	327	323	2	0	0	0
2040	151	136	8	312	309	2	0	0	0
2041	124	107	9	297	294	2	0	0	0
2042	96	78	9	282	279	2	0	0	0
2043	68	48	10	266	263	1	0	0	0
2044	39	18	10	250	248	1	0	0	0
2045	9	0	4	234	232	1	0	0	0
2046	0	0	0	218	216	1	0	0	0
2047	0	0	0	201	200	1	0	0	0
2048	0	0	0	185	183	0	0	0	0
2049	0	0	0	168	167	0	0	0	0
2050	0	0	0	151	150	0	0	0	0
Total 2030			365			284			485
Total 2050			468			324			521

Table 48: Monetarized environmental effects CCBA average prices.

Prices average

	Mid economy (mln)			Low economy (mln)			High economy (mln)		
	Basis	KA	Δ Discounted	Basis	KA	Δ Discounted	Basis	KA	Δ Discounted
2020	1508	1508	0	1508	1508	0	1508	1508	0
2021	1534	1327	195	1397	1231	156	1668	1419	235
2022	1517	1357	147	1395	1267	117	1627	1418	191
2023	1501	1279	197	1397	1223	155	1577	1303	244
2024	1466	1209	222	1388	1198	164	1501	1165	290
2025	1429	1190	200	1369	1192	148	1406	1063	287
2026	1361	1315	37	1349	1308	34	1377	1313	52
2027	1304	1285	15	1330	1320	8	1239	1210	23
2028	1250	1244	4	1306	1295	8	1168	1151	13
2029	1197	1193	3	1266	1260	4	1049	1027	16
2030	1125	1113	8	1232	1223	7	933	913	14
2031	1064	1051	9	1237	1220	12	786	765	15
2032	998	982	11	1200	1183	11	663	640	16
2033	931	912	13	1162	1146	10	538	513	16
2034	863	840	15	1124	1109	10	409	383	17
2035	794	767	17	1084	1070	9	278	251	17
2036	723	693	18	1045	1031	8	144	115	18
2037	651	617	20	1004	992	7	8	0	5
2038	577	540	21	963	951	7	0	0	0
2039	503	462	22	922	911	6	0	0	0
2040	426	382	24	879	869	5	0	0	0
2041	349	301	25	837	827	5	0	0	0
2042	270	219	26	793	785	4	0	0	0
2043	190	135	27	749	742	4	0	0	0
2044	109	50	28	705	698	3	0	0	0
2045	26	0	12	659	654	3	0	0	0
2046	0	0	0	614	609	2	0	0	0
2047	0	0	0	567	563	2	0	0	0
2048	0	0	0	520	517	1	0	0	0
2049	0	0	0	472	470	1	0	0	0
2050	0	0	0	424	423	0	0	0	0
Total 2030			1029			801			1365
Total 2050			1318			912			1469

Table 49: Monetarized environmental effects CCBA high prices.

Prices high

	Mid economy (mln)			Low economy (mln)			High economy (mln)		
	Basis	KA	Δ Discounted	Basis	KA	Δ Discounted	Basis	KA	Δ Discounted
2020	1882	1882	0	1882	1882	0	1882	1882	0
2021	1915	1656	244	1744	1537	195	2082	1771	293
2022	1893	1694	183	1741	1582	146	2031	1770	238
2023	1873	1596	246	1744	1527	193	1969	1626	304
2024	1830	1509	277	1733	1495	205	1873	1454	362
2025	1783	1485	250	1708	1487	185	1755	1327	359
2026	1698	1641	47	1684	1632	42	1719	1639	65
2027	1628	1604	19	1660	1648	10	1546	1510	28
2028	1560	1553	5	1630	1616	10	1458	1437	16
2029	1494	1489	4	1580	1573	5	1309	1282	20
2030	1404	1390	11	1538	1526	9	1164	1140	18
2031	1328	1311	12	1544	1523	15	981	954	19
2032	1246	1225	14	1498	1477	14	828	799	20
2033	1162	1138	16	1450	1431	13	671	640	20
2034	1077	1048	19	1402	1383	12	511	478	21
2035	991	957	21	1353	1336	11	347	313	22
2036	902	865	23	1304	1287	10	180	144	22
2037	812	770	24	1253	1238	9	10	0	6
2038	720	674	26	1202	1187	8	0	0	0
2039	627	577	28	1150	1137	8	0	0	0
2040	532	477	30	1098	1085	7	0	0	0
2041	436	376	31	1044	1033	6	0	0	0
2042	337	273	33	990	979	5	0	0	0
2043	238	168	34	935	926	5	0	0	0
2044	136	62	35	879	871	4	0	0	0
2045	33	0	15	823	816	3	0	0	0
2046	0	0	0	766	760	3	0	0	0
2047	0	0	0	708	703	2	0	0	0
2048	0	0	0	649	645	2	0	0	0
2049	0	0	0	589	587	1	0	0	0
2050	0	0	0	529	528	1	0	0	0
Total 2030			1284			1000			1704
Total 2050			1645			1138			1833

D. List of tables

E. List of figures

F. List of abbreviations

Table 50: List of abbreviations

1.4-DCB	1,4 dichlorobenzene
AVC	Average vehicle costs
BEV	Battery Electric Vehicle
BPM	Belasting personenauto's and motorrijwielen, English: tax for personal vehicles and motorcycles
C	Coal
CBA	Cost-Benefit Analysis
CBLCA	Cost-Benefit Life Cycle Analysis
CCBA	Conventional Cost-Benefit Analysis
CH_4	Methane
CO_2	Carbon dioxide
EU	European Union
EU-ETS	European Emission Trading System
Euro	European electricity mix
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
FDP	Fossil resource depletion
Fe	Iron
FEP	Freshwater eutrophication
FETP	Freshwater eco-toxicity
GHG	Greenhouse Gas
GWP	Global warming potential
HTP	Human toxicity
ICEV	Internal combustion engine vehicle
LCA	Life Cycle Analysis
LFP	Lithium-Iron-Phosphate with graphite anode
$LiFePO_4$	Lithium iron phosphate
Li-NCM	Lithium nickel cobalt manganese
LMO	Lithium-Manganese-Oxide with graphite anode
LTO	Lithium-Iron-Phosphate with lithium-titanate anode
MDP	Mineral resource
Mln	million
MRB	Motorrijtuigenbelasting, English: motor vehicle tax
NCA	Lithium-Nickel-Cobalt-Aluminum-Oxide with graphite anode
NCM	Lithium-Nickel-Cobalt-Manganese-Oxide with graphite anode
NG	Natural gas
NiMH	Nickel Metal Hydride battery
NMVOC	Non-methane volatile organic compounds
P	Phosphorus
PHEV	Plug-in Electric Vehicle
PM10	Coarse particles with a diameter of 10 micrometers or less
PMFP	Particulate matter formation
POFP	Photochemical oxidation formation
SO_2	Sulfur dioxide
SO_2	Sulphur Dioxide
TAP	Terrestrial acidification
TCO	Total Cost of Ownership

TETP	Terrestrial eco-toxicity
VC	Vehicle costs
WTA	Willingness To Accept
WTP	Willingness To Pay
ZLEV	Zero and Low Emission Vehicles