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An assessment of the cost-effectiveness of the Norwegian EV policy between 2010-2019

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Kunnskap for en bedre verden

Preface

I would like to thank my supervisor, professor Anders Skonhoft for coming up with the idea for the topic of this thesis, and for guidance throughout the process.

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Abstract

In Norway there is a goal that all new passenger vehicles will be zero emission vehicles (ZEVs) by 2025. The argument behind this goal is that a transition towards ZEVs will help reduce greenhouse gas emissions. To be able to meet this goal, extensive electric vehicle (EV) benefits are in place to induce EV sales. VAT exemption on the purchase of new vehicles, and reduced payment in road tolls are examples of some of these benefits. Thereby, a successful EV policy will lead to decreasing revenue from taxes related to purchase and ownership of vehicles.

To assess the cost-effectiveness of the Norwegian EV policy, revenue loss for the different EV benefits has been quantified for the years 2010-2019. The data used is mostly based on calculations by the Ministry of Finance and the Norwegian Public Roads Administration, while original calculations were performed for some of the benefits. Results from life cycle analyses of EVs and conventional vehicles (ICEVs) were used to find annual emission reductions when replacing an ICEV with an EV in Norway. The cost of the policy was then set up against emission reductions as a result of the number of EVs. Given that 80 percent of kilometres driven by an EV replaces kilometres taken by an ICEV, the cost of the EV policy is found to constitute 26 708 NOK per tonne CO_2 reduced in 2019. For the same year, emission reductions as a result of the number of EV was 220 223 tonne CO_2, while each EV owner did on average receive 22 563 NOK in indirect subsidies. Overall this made up almost 5.9 billion NOK in revenue loss for the government in 2019. In 2010, the corresponding number was 48.3 million NOK.

Sammendrag

I Norge er det et mål at alle nye personbiler skal være nullutslippskjøretøy innen 2025. Argumentet bak dette målet er at en overgang til nullutslippsbiler vil bidra til å redusere klimagassutslipp. For å oppnå dette målet eksisterer det omfattende økonomiske fordeler ved kjøp og bruk av elbiler. Merverdiavgiftsfritak ved kjøp og redusert betaling i bompenger er eksempler på noen av disse fordelene. Dermed vil en vellykket elbilpolitikk føre til synkende inntekter fra skatter relatert til kjøp og eierskap av personbiler.

For å vurdere kostnadseffektiviteten til den norske elbilpolitikken er inntektstapet for de forskjellige elbilfordelene beregnet for årene 2010-2019. Utregningene er hovedsakelig basert på tall fra Finansdepartementet og Statens vegvesen, mens originale beregninger ble utført for noen av fordelene. Resultater fra livssyklusanalyser av elbiler og konvensjonelle biler ble brukt for å finne årlige utslippsreduksjoner når en elbil erstatter en konvensjonell bil i Norge. Kostnadene ved politikken ble deretter satt opp mot utslippsreduksjoner som følge av antall elbiler. Gitt at 80 prosent av kilometer kjørt av en elbil erstatter kilometer kjørt av en konvensjonell bil, utgjør kostnadene ved elbilpolitikken 26 708 kroner per tonn CO_2 redusert i 2019. For samme år var utslippsreduksjonene som et resultat av antall elbiler 220 223 tonn CO_2, mens hver elbileier i gjennomsnitt mottok 22 563 kroner i indirekte subsidier. Totalt utgjorde dette nesten 5.9 milliarder kroner i statlig inntektstap i 2019. I 2010 var tilsvarende tall 48.3 millioner kroner.

Contents

1. Introduction

The Norwegian electric vehicle (EV) policy is deemed a success in terms of EVs purchased (Figenbaum 2018, 12; Aasness and Odeck 2015, 6). Norway is the country in the world with most EVs per capita (Departementene 2019, 15). At the end of 2010, only 2 068 EV passenger cars were registered in Norway (SSB 2020a). By 31 Dec 2019, 9.3 percent of the passenger car fleet consisted of EVs, with over 260 000 vehicles (SSB 2020a). At the same time EVs made up 42.4 percent of the sale of new passenger vehicles (Bergskaug 2020). The success of EVs in Norway is a result of extensive EV benefits, such as tax exemptions, and use related benefits, including free parking and exemption from road toll payments, combined with heavy taxes on purchase and use of conventional gasoline and diesel vehicles (ICEVs) (Bjertnæs 2013, 5; Birkeli et al. 2016, 1-2; Aasness and Odeck 2015; Figenbaum 2018, 12). The first EV benefit, exemption of purchase tax, was introduced as early as 1990 (Norsk Elbilforening 2019). However, it was not until Nissan Leaf became available on the Norwegian market in 2011, that EV sales started to increase substantially. The first Tesla came in 2013, and in 2015 Volkswagen's e-golf was the most sold car in Norway (Birkeli et al. 2016, 1-2).

The motivation behind the EV benefits is to induce EV sales as a measure to reduce greenhouse gas emissions (GHG emissions) from the transport sector (Royal Ministry of Finance 2017, 2; Holtsmark and Skonhoft 2014, 161). EVs are deemed a more environmental friendly option due to zero tailpipe emissions. Emissions from the transport sector made up about 30 percent of emissions in Norway in 2018. Over half of emissions within transport come from road transportation (SSB 2019b). Life cycle analyses show that EVs can emit less carbon dioxide (CO_2) during their lifetime compared to ICEVs. However, the result is sensitive to the energy mix of the electricity the EV runs on (Woo, Choi, and Ahn 2017, 2,13; Del Pero, Delogu, and Pierini 2018, 533).

EVs do not represent a perfect substitute for ICEVs, due to higher purchase prices and limited driving range. This represents a disadvantage for the user and can therefore lead to limited demand for EVs. According to the Norwegian government, economic incentives are therefore necessary to promote the diffusion of EVs in Norway (Royal Ministry of Finance 2017, 2-3). According to Figenbaum (2017), EVs have had a price advantage over ICEVs in Norway since 2013 due to zero value added tax (VAT) and purchase tax (32). Calculations show that, given today's EV benefits, vehicle lifetime costs are lower for EVs than for comparable ICEVs (Figenbaum et al. 2019, 101,155; Figenbaum 2018, 16).

Aside from extensive EV benefits, other factors facilitate EV adoption in Norway. High purchasing power is one of these factors (Figenbaum et al. 2019, 65,72). It is not uncommon for Norwegian households to have more than one car. In 2018, 22 percent of families had at least two cars (Fjørtoft and Pilskog 2019). Research shows that early EV adopters were mainly multivehicle households (Figenbaum 2018, 34). It has been possible for many families to have one EV for nearby travels and one ICEV for longer travels. EV adoption has therefore been possible in Norway in the early phase, with limited driving range for EVs. In Norway, 75 percent of households can park a car on their own property. This facilitates home charging, and 94 percent of Norwegian EV owners charge their vehicle at home (47). In addition, the cost of electricity in Norway is among the cheapest in Europe (14).

Although EVs emit less GHG emissions over their lifetime compared to an ICEV, not all trips taken by an EV will replace trips by an ICEV. When substantial use related benefit, such as free road toll and free parking are in place, consumers will in some degree substitute away from using alternative transport such as public transport towards the use of EVs. In this way, EV benefits will lead to increased private car use (Holtsmark 2012, 10). Research show that negative external effects related to the use of EVs are almost as high as for ICEVs. EVs have lower negative external effects regarding GHG emissions and local pollution, but when it comes to noise, congestion, accidents etc, there is no difference between these types of vehicles (Fridstrøm 2019a, 32; Finansdepartementet 2015, 71).

An issue with the EV policy is that tax revenue related to ownership of vehicles is decreasing (Fridstrøm 2019a, 15). There seems to be a general agreement that today's EV policy is not sustainable in the long run. The OECD have recently criticised the Norwegian EV benefit regime. In their report "Economic Survey of Norway" they state that the subsidies will mainly benefit the wealthier households. In addition, the policy leads to loss of government revenue and is therefore deemed inefficient (OECD 2019, 54). Several Norwegian economists have voiced their concern with the high cost of the policy (Bjertnæs 2016; Holtsmark and Skonhoft 2014; Skonhoft and Skarstein 2019). The Green Tax Commission set down by the Ministry of Finance in 2014, was given the task to assess how green taxes could contribute to better utilisation of resources and to meet the stated climate goals. The commission recommended ending several of the EV benefits such as the VAT exemption and exemption of the purchase tax. They did, however, open up to EV purchase subsidies listed as expenditures in the budget, but with a stated plan to scale down the subsidies (Finansdepartementet 2015, 93).

In 2012, a majority in the Norwegian Parliament decided that the EV benefits would last until at least 2017, or when number the of EVs in Norway reached 50 000. This number was reached already in 2015. However, it was decided to extend the period for the EV benefits (NTB 2015). The VAT, exemption that needs EFTA approval, is valid until the end of 2020. The current government has promised to keep the EV benefits in their present form until the end of 2021 (Norsk Elbilforening 2019). Elections for Parliament are held in 2021.

1.1 Research question

The aim of this thesis is to assess the effectiveness of the Norwegian EV policy. There are different ways to measure effectiveness. One way is to look at goal effectiveness. Goal effectiveness means whether the objective of the policy is reached (Aurland-Bredesen 2016, 4). If the goal of the EV policy is increased EV sales, there is no question that the policy has been effective (Figenbaum 2018, 12; Aasness and Odeck 2015, 6). Also, if the objective is reduced CO_2 emissions, the policy can be deemed goal effective as EVs have lower life cycle emissions than comparable ICEVs in Norway (Aurland-Bredesen 2016, 4). Cost-effectiveness differs from goals effectiveness. Cost-effectiveness has been achieved if the goal has been reached at least cost possible (Perman et al. 2011, 178). This thesis will aim at finding the cost-effectiveness of the EV policy, represented as Norwegian kroner (NOK) spent per tonne CO_2 reduced annually, for the years 2010-2019. Costs will in this case mean loss of government revenue due to tax exemptions and direct government spending, such as subsidies to deployment of charging stations. The scenario analysed will be the hypothetical situation where EVs are taxed according to the same rules as ICEVs. Calculations will be based on numbers of registered EVs during the last ten years. The high demand for EVs in Norway is a result of low prices due to the extensive EV benefits. In the hypothetical situation where these benefits are removed, one could therefore expect a lower share of EVs. One can argue that most of these EVs would have been replaced by an ICEV. It is however likely that for some of the EVs purchased, an ICEV would not have been an option to the consumer. Thereby the cost of the policy will in some extent be overestimated. It is assumed that the goal of the EV policy is reduced CO_2 emissions. Reduced CO_2 emissions as a result of the number of EVs will be calculated by comparing life cycle emissions of EVs and ICEVs.

The cost of the EV policy has repeatedly been debated in Norway the last years. Researchers do not agree whether the EV benefits constitute a cheap or expensive environmental policy (see for example Fridstrøm 2015 and Bjertnæs 2019). Some superficial calculations have been performed where loss of government revenue has been included as a cost (Holtsmark and Skonhoft 2014; Skonhoft and Skarstein 2019; Holtsmark 2012; Akerbæk 2018), but a thorough analysis has yet to be performed. As

Norwegian politicians are increasingly open to change the EV subsidy regime (NTB 2018; Gilbrant 2020), knowledge about the costs and benefits could help make a decision for the future of the policy.

In 2019, the households within the 10 percent with highest income, bought 37 percent of new EVs, while household within the 50 percent with the lowest income bought only 10 percent of new EVs (Fjørtoft and Pilskog 2020). The fact that richer households are the ones that in a large degree reap the benefits of the subsidies, serves as an argument for the importance of assessing the cost-effectiveness of the policy. When revenue from taxes related to ownership of vehicles decreases, other taxes will have to increase in order to maintain the level of the total tax revenue. One of three stated main goals of the Norwegian tax system is to influence the distribution of income and wealth between people. The other two are securing revenue for the state and correcting for market failure (Det Kongelige Finansdepartement 2015a, 26). Given this, one could argue that it is important to look at how the EV policy affects both distribution and the tax revenue, not only whether it corrects a market failure, here being CO_2 emissions, when assessing the policy. Looking at distributional effects is outside of the scope of this thesis. But the research question presented ensures that the effect the policy has on tax revenue will be included as a cost in the analysis of how effective the EV policy is.

1.2 Definitions

The analysis will focus on one type of zero emission vehicles (ZEVs), battery electric vehicles (BEVs). Throughout the thesis the term EV will be used for BEVs. Table 1.1 displays an explanation of abbreviations used for vehicles that run on different fuel. Although being a ZEV, hydrogen fuel cell electric vehicles are excluded from the analysis as they make up a small share of the Norwegian passenger car fleet, with only 146 registered passenger vehicles in 2019 (SSB 2020b). They share the same benefits as BEVs (Fridstrøm 2019b, 2). Plug in hybrid electric vehicles, although containing a rechargeable battery, are not included as they also run on traditional fuel (Figenbaum 2017, 15). They are however popular in Norway, with 116 000 registered passenger cars in 2019 (SSB 2020b). They are not covered by same benefits as EVs and would therefore complicate the analysis if included (Fridstrøm 2019b, 2). Conventional cars that run on gasoline or diesel are called internal combustion engine vehicles (ICEVs). Only passenger vehicles are included to simplify the analysis. Such a simplification can be justified as most electric vehicles in Norway are passenger cars (SSB 2020b).

Most of the EV benefits in place are not subsidies strictly speaking, as they do not represent a direct transfer from the government to the consumer listed as an expenditure in the budget. Still, EV benefits leading to loss of tax revenue will be called subsidies throughout this thesis. This approach can be justified as tax exemptions can be regarded as indirect subsidies (van Beers et al. 2007, 2466). Benefits, subsidies or tax exemptions, are terminology that can describe the Norwegian EV policy. These terms will be used interchangeably throughout the thesis.

Table 1.1: Abbreviations and explanations for different types of vehicles

ZEV	Zero emission vehicles, vehicles with no tailpipe emissions. Include battery electric vehicles and hydrogen fuel cell electric vehicles
BEV	Battery electric vehicle, only powered by electricity (subcategory of ZEV)
FCEV	Hydrogen fuel cell electric vehicle, uses a fuel cell instead of a battery, or in combination with a battery or supercapacitor, to power its on-board electric motor (subcategory of ZEV)
ICEV	Internal combustion engine vehicle, includes vehicles that run on gasoline and diesel
HEV	Hybrid electric vehicle, combine the drive powers of an internal combustion engine and an electrical machine
PEV	Plug-in electric vehicle, includes both BEVs and PHEVs
PHEV	Plug-in hybrid electric vehicle, powered by electricity recharged from the grid and ICEVs fuelled by diesel or gasoline, and alternatively, an ICEV running as a generator producing electricity used in the motor

Sources: Figenbaum 2017, 15; Royal Ministry of Finance 2017, 9; Singh, Bansal, and Singh 2019, 77; Fridstrøm 2019b, 2.

Greenhouse gasses (GHG) are gasses that contribute to global warming and climate change. Data on GHG emissions is reported in CO_2 equivalents. Other GHG emissions apart from CO_2 such as methane (CH_4) and nitrous oxide (N_2O), are then included. Based on the global warming potential relative to CO_2, these gasses are converted into units of CO_2. If not otherwise specified CO_2 emissions will mean CO_2-equivalents. GHG emissions, or just emissions will also be used as terms describing CO_2 equivalents throughout the thesis. Local pollution such as NO_x is not a GHG, and therefore not included when talking about CO_2 equivalents (The Guardian 2011; Eurostat 2016).

1.3 Literature review

The field of Economics provide several methods to quantify the costs and benefits of the EV policy. This section will go through some of the relevant research done by both government agencies and economists in Norway. Examples of relevant international literature will also be provided. Lastly, the research conducted in this thesis will be positioned within the field of already existing research.

Bjertnæs (2016) calculated the welfare effects of the EV policy by looking at the deadweight loss created by the tax exemptions. In the presence of EV subsidies, consumers who would otherwise have preferred an ICEV will buy an EV as long as the total amount of lifetime EV subsidies exceeds what they would need in monetary compensation to purchase an EV instead of an ICEV. This compensation is then a measure of the utility loss when the consumer buys an EV instead of an ICEV (62). The fact that consumers alter behaviour due to the price change created by the subsidy, is what generates the deadweight loss.[1] Bjertnæs uses the theory of the deadweight loss to calculate the societal cost of the EV policy. He finds the total amount of taxes for an ICEV during its lifetime and compares it to EV lifetime taxes. The difference between the taxes, the tax wedge, is found to be 280 000 NOK. The tax wedge represents the marginal cost for society of one more EV. To find the CO_2 reduced, he assumes than an EV drives 13 264 kilometre (km) a year and an EV lifetime of 18.5 years. He further assumes that an ICEV emits 203 grams of CO_2 per km and that all trips by an EV replaces trips taken by an ICEV. Bjertnæs only includes emissions from combustion of fuel in the vehicle. He finds that an EV will give total CO_2 reductions of 50 tonne over its lifetime. On the margin, meaning one more EV, the tax revenue loss equals 5 600 NOK per tonne CO_2 reduced. This is a measure of the welfare loss of one more EV and equals the increase in the deadweight loss (63). Bjertnæs refers to Hawkins et al. (2012), which found life cycle emissions of EVs to be 10-30 percent lower than for ICEVs. If these estimates are included in the analysis, Bjertnæs finds that the marginal cost of the EV policy increases to 18 600-56 000 NOK per tonne CO_2 reduced (64). He concludes that the cost of the EV policy is high, and that it is more costly than the measures presented in the report “Klimakur 2020” by the Norwegian Environment Agency (67).

The Norwegian Environment Agency have calculated the societal cost of phasing in EVs from 2016-2030 (Birkeli et al. 2016). Loss of tax revenue as a cost is therefore not included, as this represents a redistribution of resources between actors (1). They find the cost of EVs by quantifying the disadvantages and advantages of EVs compared to ICEVs. The net of this represents the societal cost of phasing in EVs (3). For EVs, advantages included are less maintenance and energy costs, as well as health benefits due to absence of local pollution (2). Disadvantages include EVs being more expensive, cost of charging, and limited driving range (32-33). Disadvantages due to limited driving range is assumed to reduce over the time period, and disappear completely in 2024, as a result of expected technological improvements (32). When estimating reduced CO_2 emissions, they exclude emissions

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[1] See Mankiw and Taylor 2011, 251 for an explanation of the deadweight loss.

from production of the vehicles, and assume zero emissions in the electricity production (Birkeli et al. 2016, 1). In the period analysed they assume that an average EV will have the same yearly mileage as an ICEV. In a questionnaire developed by the Norwegian EV Association (NEVA), members of this association reported in what degree trips taken by their EV replaces trips taken by an ICEV. The average self-reported number was 83 percent. Based on this, the Agency then assumes that 80 percent of kilometres driven by an EV replaces kilometres driven by an ICEV. This number is assumed to be 100 per cent in 2022 (23-24). They look at four different scenarios for the speed of phasing in EVs towards 2030, and find the costs to lie between 600 to 1 100 NOK per tonne CO_2 reduced (38).

The Institute of Transport Economics have calculated the societal cost of EVs for different segments in the vehicle market. They look at passenger vehicles in five segments: small, compact, medium, large and luxury. They compare the societal costs of EVs with comparable ICEVs in 2019 and in 2025 (Figenbaum et al. 2019, 109-110). The cost of tax exemptions is not included. However, 20 percent of the VAT exemption is included as a cost to capture the cost of distortions in the market, as a result of increasing other taxes to make up for the loss of tax revenue (109, 122). This is in accordance with what the Norwegian Ministry of Finance recommend to use when calculating the societal cost of tax collection (Det Kongelige Finansdepartement 2014a, 6). Among other costs included are fast charging costs, as well as the cost of the time spent on fast charging. This is meant to capture the disadvantage of limited driving range (Figenbaum et al. 2019, 12, 110). Energy costs and vehicle depreciation is also included. The cost of emitting CO_2 is set to 508 NOK per tonne CO_2 in 2019 and is linearly increasing towards 2030. They find EVs to have higher societal costs than comparable ICEVs in 2019 for all vehicle segments. The result is very sensitive to the cost of fast charging, both financial cost and cost of time spent. If assuming that users only charge at home, EVs have the same societal costs as ICEVs already between 2020-2021. The calculations show that EVs will have higher societal costs than ICEVs in 2025, but the difference has decreased substantially (109-110).

Skonhoft and Skarstein (2019) provided an assessment of the EV policy by calculating NOK per tonne CO_2 reduced in 2018. Their calculations are based on estimated revenue loss of the different EV benefits provided by the Ministry of Finance for 2017. As their analysis include the financial costs of the policy, it is not merely an analysis of societal costs. According to the Ministry of Finance, exemption of purchase tax and VAT led to a revenue loss of 3.9 billion NOK in 2017. To find yearly costs, Skonhoft and Skarstein assume an EV lifetime of 10 years. This will amount to 390 million NOK of lost revenue a year. Revenue loss for reduced annual tax, reduced tax for private use of EV company cars, and loss of road toll and ferry fare payments were also calculated by the Ministry of

Finance. The Ministry did not provide calculations for loss of road use tax. Skonhoft and Skarstein calculate this to be 434 million NOK in 2018. The cost of subsidies to charging stations is not included. They find total loss of revenue to be around 2.1 billion NOK in 2018. To find the environmental benefit of EVs, they assume average yearly mileage of EVs to be 12 000 km in 2018, and that 60 percent of these km driven replace km driven by an ICEV. Thereby, an EV will on average reduce driving of an ICEV with 7 200 km. They further assume that an ICEV emits 160 gram CO_2 per km. With an average of 170 000 EVs in 2018, this gives total CO_2 reductions of about 200 000 tonnes. They find the cost of the policy to be around 10 000 NOK per tonne CO_2 reduced. As they did not include emissions from production of vehicles, they note that if considered, the cost per tonne may be even higher.

Thorne and Hughes (2019) have conducted research on the cost-effectiveness of a proposed EV purchase tax exemption in Canada. In 2019, the government of Canada proposed a new federal purchase incentive of up to $5 000 CAD for EVs with a retail price of less than $45 000 CAD. They use data for the different Canadian provinces to evaluate the EV subsidies in terms of cost per tonne of removed CO_2, to see how much the cost-effectiveness varies between provinces. Some Canadian provinces such as Quebec and British Columbia relies almost exclusively on renewable energy in electricity production, while others rely mostly on fossil fuels (520). To find the climate potential of EVs compared to ICEVs, they look at emissions from one ICEV and one EV, a Honda Civic and Hyundai Ioniq EV, respectively. They use average annual passenger distances in 2018 together with electricity consumption emissions intensity (gram CO_2 per kWh) for the different provinces (520-521). They assume a vehicle lifetime of 8 years (523). For ICEVs, only tailpipe emissions are included, while emissions from production of the vehicle are excluded for both vehicles (521). They find that given a tax rebate of $5 000 CAD, the cost of the policy varies between around $200 CAD per tonne CO_2 reduced in Newfoundland and Labrador to around $2 300 CAD per tonne CO_2 reduced in Alberta (524). Given currency rates as of 9 June 2020, this constitutes almost 1 400 NOK and 16 000 NOK, respectively. They conclude that there exist more cost-effective measures to reduce emissions in Canada, and that an EV purchase subsidy is an ineffective tool (526).

Shafiei et al. (2018) analyse the economic consequences of introducing policies aimed at promoting EVs in Iceland, through a dynamic simulation-based analysis. The model used enables them to simulate interactions between fuel supply, market dynamics, and consumer behaviour. The objective is to compare the macroeconomic costs of different incentives to promote EVs. This includes looking at how different measures affect government revenue, as well as the level of GHG emissions and consumer benefit. They claim that many studies have focused on the impact EV incentives have on consumer behaviour and vehicle costs, but that implications on government revenue have been less explored (432). Six scenarios aimed at promoting EVs are assessed. These scenarios are based on different taxes and subsidies on fuels and vehicles. The business as usual (BAU) scenario reflects the fiscal policies currently in place in Iceland. In this scenario, there already exists a VAT exemption on purchase of EVs as well as taxes for the use of ICEVs. The different measures assessed are "BAU + tax", "subsidy + tax", "subsidy", "feebate", and "feebate + tax". The "feebate" option means a purchase fee for ICEVs equivalent to 20 percent of the price of the ICEV, in combination with a price subsidy for EVs equivalent to 20 percent of the ICEV price. The "tax" option means a higher carbon tax, while the "subsidy" measure means direct subsidies of 20 percent of the EV purchase price, in addition to the incentives that already exist (435). They calculate the cost-effectiveness of GHG emission reductions and find the measures "BAU + tax" and "subsidy + tax" to be the most cost-effective, with a cost of \$-16 USD and \$188 USD per tonne CO_2 reduced, respectively. The "subsidy" scenario is found to be the least cost-effective option with a cost of \$478 USD per tonne CO_2 reduced (440).

To conclude, research on the societal cost of the Norwegian EV policy have been provided by several actors. Calculations that include loss of tax revenue as a cost are scarce and superficial. The aim of this thesis is to provide a more comprehensive analysis where the cost of the revenue loss is included. The method will be based on the approach in Skonhoft and Skarstein (2019). The analysis in this thesis will be more thorough as calculations will be done for the years 2010-2019. Some of the costs lacking in the analysis by Skonhoft and Skarstein (2019) will be included. Emissions from production of EVs and ICEVs will be included when assessing the climate potential of EVs.

The aim is that the analysis in this thesis will work as a supplement to the already existing research on societal costs of the EV policy. Such an analysis may give a better foundation for making decisions on policy changes regarding the EV benefits. An analysis which includes financial costs can be beneficial as analyses on societal costs underestimate the actual cost of the policy, and can therefore give the impression that a certain policy is more effective than it really is.

1.4 Structure

The structure of the thesis will be the following. First, background information regarding Norway's emission goals as well as a historic overview of the EV policy will be provided. The theoretical foundation for EV subsidies will be discussed before going through the data used. Then follows a presentation of the results as well as a discussion. Lastly, concluding remarks will be given.

2. Context

This chapter will provide background information regarding Norway's EV benefit regime. First, relevant Norwegian environmental policy will be explained. Then a historical overview of Norway's EV policy will be provided. Lastly, the theoretical foundation for EV subsidies will be discussed.

2.1 Norway's commitments regarding CO_2 emissions

Norway has both nationally decided goals and international commitments regarding climate policy and emission cuts. This section will elaborate on the main structure of these goals and agreements, as well as mentioning some targets regarding the road transportation sector specifically.

In February 2020, Norway sent updated goals to the United Nations regarding emission cuts in accordance with the Paris agreement[1] from 2015. Norway is now committed to cutting 50-55 percent of emissions compared to 1990 by 2030. This must pass through the Norwegian Parliament (Falnes 2020).

Norway takes part in the European Union's (EU) system for climate cooperation between 2021-2030. While Norway has taken part in the EU Emission Trading System (EU ETS) since 2008 as part of the EEA-agreement, Norway joined the Effort Sharing Decision (ESD) in 2019 (Regjeringen 2019).

EU ETS is a 'cap and trade' system[2] (European Commission 2020b). Given that member states emit no more than their quotas allow, and that distributed quotas are reduced over time, emissions covered by the quota system will be cut. In this manner, Norway will contribute to emission cuts, even if emissions are not necessarily reduced in Norway. According to economic theory, cuts will happen where abatement costs are lowest, thereby ensuring cost-effectiveness (Perman et al. 2011, 202-203, 206-207). According to the European Commission, emissions in sectors covered by ETS will be reduced by 43 percent in 2030 compared to 2005 (European Commission 2020b). About 50 percent of Norwegian emissions are covered by the EU ETS sector, with oil production and industry being the main sectors. Energy production is also covered by the EU ETS (Regjeringen 2019; Naturvernforbundet 2020).

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[1] The overall goal of the Paris agreement is to limit global warming to no more than an increase of 2 degrees compared to pre-industrial times. In addition, countries shall strive to limit the temperature increase to 1.5 degrees (Regjeringen 2019).

[2] See Perman et al. 2011, 202-203, for an explanation of a 'cap and trade' system.

Norway's motivation for joining the ESD is to be part of the EUs framework for fulfilment of the Paris agreement. Through the ESD, Norway is committed to cutting 40 percent in the ESD sectors by 2030 compared to 2005 (Regjeringen 2019). Sectors covered by the ESD are transport, agriculture, heating of buildings, industry and waste (European Commission 2020a). Member countries have been given a budget for emissions each year, meaning that countries cannot maintain their emission level until 2029, and then reach the stated target by reducing emissions in 2030 alone. Some flexibility is allowed, as it is possible to transfer parts of the emission cut from one year to another. The ESD agreement is legally binding, and member states can be penalised if they violate their obligations (Regjeringen 2019).

In Norway, road transportation is the largest emitting ESD sector (Miljødirektoratet 2020d, 5). In 2018, emissions from this sector was 9.1 million tonne CO_2, making up 17.5 percent of the total emissions of 52 million tonne CO_2, stemming from both ETS and ESD sectors (SSB 2019c). In the recently published report "Klimakur 2030", different government agencies examined the possibilities of reducing emissions in ESD-sectors of 50 percent in 2030 compared to 2005. They found that road transportation was the sector with the most potential for reducing emissions, with 11.8 million tonne CO_2 over the years 2021-2030, making up almost 30 percent of the examined cut potential (Miljødirektoratet 2020d, 6, 12).

In addition to goals through international agreements, Norway has set national climate targets. Like the EU, Norway has a goal to be a low carbon society in 2050, meaning an emission cut of 80-95 percent compared to 1990 (Det Kongelige Finansdepartement 2017a, 11).

Norway has set several environmental motivated goals for the transport sector. In 2017, the government set a target of a 35 percent reduction in emissions from the transport sector by 2030 compared to 2005. In 2018, emissions from this sector was at 2005-level (SSB 2019b).

A target stated in the "National Transport Plan" for 2018-2029, is that in 2025 all new passenger vehicles and light vans will be zero emission vehicles. Goals regarding shares of zero emission busses, lorries and heavy vans were also set (Royal Ministry of Finance 2017, 11-12).

Another goal stemming for the "National Transport Plan" (2014-2023 and 2018-2029) is a goal of zero growth in passenger travels by car. This target concerns transport around cities, meaning that the growth in travels are to be done by public transport, or by walking or cycling (Regjeringen 2020).

2.2 History of EV benefits

The Norwegian EV policy has gradually been developed over the years. The first fiscal measure was introduced in 1990, which was exemption of the purchase tax. The last one was introduced in 2018, which was exemption of the re-registration tax (Norsk Elbilforening 2019, Royal Ministry of Finance 2017, 6). This section will provide an overview of the EV benefits that have been in place since 1990.

The exemption of the VAT (value added tax), which constitutes 25 percent of the price of the vehicle, was introduced in 2001. This was extended to also apply to leasing of cars in 2015 (Norsk Elbilforening 2019).

In 2018, exemption from re-registration tax was introduced for second-hand purchases of EVs. The re-registration tax is a fiscal tax, meant to substitute the VAT for second-hand motor vehicles (Royal Ministry of Finance 2017, 1,6).

The purchase tax is a one-time tax levied on vehicles imported to Norway. The size of the tax depends on the weight of the vehicle as well as the GHG emissions and NOx pollution (Det Kongelige Finansdepartement 2019, 127). In the first half of 2017, the average purchase tax for new vehicles was around 90 000 NOK. If levied in accordance with the current rules, the average purchase tax for EV would have been considerably lower than the average for ICEVs (Norsk Elbilforening 2019; Akerbæk 2018).

From 2018, EVs have been exempt of annual tax (Royal Ministry of Finance 2017, 1). From 1996 to 2017, EVs were levied a reduced annual tax (Akerbæk 2018). In 2019, the annual tax for an ICEV under 7 500 kg, that were registered the whole year, constituted 2 910 NOK (Skatteetaten 2019).

Reduced tax for private use of EV company cars has been in place since 2000. Users have been able to subtract 50 percent of the listing price of the EV when calculating the tax base. This was reduced to 40 percent in 2018 (Akerbæk 2018).

From 1997 and until 2018, EVs were exempt from payment in all road tolls in Norway (Figenbaum et al. 2019, 5). From 2018, EVs can be charged up until 50 percent of what an ICEV would be charged for road toll (Norsk Elbilforening 2019). From 1 June 2019, EVs pay a reduced fee in and around Oslo (Fjellinjen 2020). The EV fees in Oslo were doubled from March 1st 2020 (NTB 2020). According to Figenbaum et al. (2019) full exemption for EVs are still in place in most road tolls (6).

EV users do not pay road use tax or CO_2 tax. Together these taxes make up the fuel tax, which is included in the gasoline and diesel prices. In 2019, The road use tax rates were 5.25 NOK per litre for gasoline, and 3.81 NOK per litre for diesel (Det Kongelige Finansdepartement 2019, 34). EV owners, on the other hand, pay a tax on the use of electricity (Akerbæk 2018).

EVs have been allowed in bus lanes by law since 2005 (Norsk Elbilforening 2019). However, there are deviations from this law. On the road westwards towards Oslo, E18, rules regarding minimum number of passengers and restrictions in the rush hour, have been in place since 2015. Restrictions were introduced as a response to overcrowding in the bus lanes, making the buses unable to meet their time schedule (Skogstad 2019).

From 1999 until 2017, EVs could park for free at municipal parking spaces by regulation. From 1 Jan 2017, municipalities can charge EVs up until 50 percent of the price paid by ICEVs (Norsk Elbilforening 2019).

Free charging of EVs has been in place in some locations in Norway since 1999. This benefit has mainly been offered in combination with free parking (Figenbaum et al. 2019, 6). From 4 Mar 2019, the municipality of Oslo introduced fees for charging. The motivation to end the free charging scheme was mainly due to extended use of charging spots as free parking. Bergen, Trondheim and Stavanger all have different systems for subsidising charging of EVs (Valle 2018; NTB 2019).

EVs could enjoy free boarding on classified national road ferries and most county ferries from 2009-2017. From 2018, EVs get minimum a 50 percent discount on ferries (Figenbaum et al. 2019, 6).

Since 2018, when buying a zero emission van, the buyer has received fiscal compensation when scrapping the fossil van the zero emission van is meant to substitute (Norsk Elbilforening 2019).

Since 2019, drivers with license class B (passenger car, etc.) have been allowed to drive electric vans class C1 (light lorries), that are up to 4 250 kg (Norsk Elbilforening 2019).

In Norway, there have been different types of initiatives to give financial support to the installation of charging stations. Transnova administered subsidies to deployment of charging stations from 2011 until 2015, when they merged with state-owned enterprise Enova. Since then, Enova have subsidised projects aimed at fast charging among main roads and in municipalities without fast charging (Figenbaum et al. 2019, 6).

2.3 Theory: The rationale for and against EV benefits

This section will discuss arguments regarding EV subsidies based on economic theory. Economic theory does not give a consistent answer to whether EV subsidies should be put in place, as there are both arguments for and against subsidies.

2.3.1 Externalities, taxes and subsidies

In welfare economics, given several theoretical assumptions,[3] the market equilibrium is efficient.[4] When one or more of these assumptions fail, we have what is called market failure[5] (Perman et al. 2011, 8). One of these market failures is the presence of externalities (123). ”An external effect, or an externality, is said to occur when the production or consumption decisions of one agent have an impact on the utility or profit of another agent in an unintended way, and when no compensation/payment is made by the generator of the impact to the affected party” (121). Said in other words, externalities create a divergence between the individual actor’s private marginal cost and benefits and society’s marginal costs and benefits (Begg et al. 2014, 303). As a result, negative externalities lead to overproduction or overconsumption of goods, whereas there will be undersupply in the presence of positive externalities (Perman et al. 2011, 123).

There are several negative externalities related to the use of vehicles. Among these are CO_2 emissions, noise, congestion, accidents, road wear and local pollution (Rødseth et al. 2019, 5). Researchers from the Institute of Transport Economics (Fridstrøm 2019a) have quantified the negative externalities mentioned above for different types of vehicles, in different geographic situations: rural, town with a population of 15 000 to 100 000, or a city defined as population over 100 000. They calculated the marginal cost as NOK per kilometre as an average over the day. The results are shown in Figure 2.1. EVs differ from ICEVs when it comes to CO_2 and local pollution, but are very similar to ICEVs when it comes to the other externalities mentioned. They find that EVs only have substantially lower marginal external costs in cities with a population over 100 000. It should also be commented that the calculated external cost of CO_2 emissions constitute a small share of the overall negative external effects of vehicle use (32).

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[3] See Perman et al. 2011, 103 for a list of these assumptions.

[4] “An allocation of resources that maximises the sum of consumer and producer surplus is said to be efficient” (Mankiw and Taylor 2011, 156).

[5] Market failure is “the inability of some unregulated markets to allocate resources efficiently” (155).

Figure 2.1: Marginal external costs for passenger vehicles running on different fuel, NOK per km, average over the day

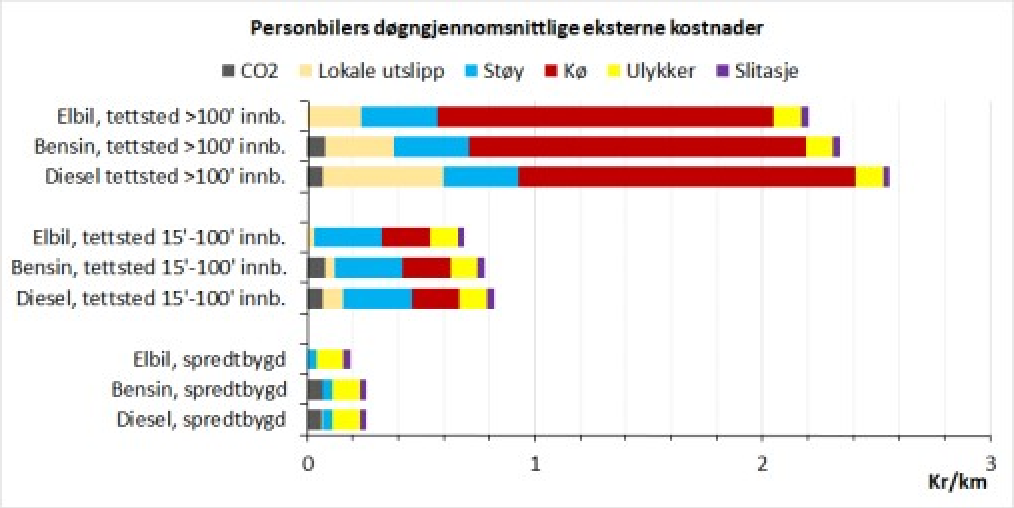

Fig. 3.17 Marginale eksterne kostnader ved personbilbruk, i gjennomsnitt over døgnet, etter kostnadstype, bosettingstetthet og energiteknologi. Kilde: Rødseth m. fl. (2019).

Source: Fridstrøm 2019a, 32.

A similar calculation has been performed in the report "Environmental Pricing", conducted by the Green Tax Commission (Finansdepartementet 2015, 71). Results are shown in Figure 2.2. Unlike in the calculations done by the Institute of Transport Economics, CO_2 emissions are excluded. It is evident that EVs differ from ICEVs only when it comes to local pollution. Again, this effect is only visible in cities with a population of more than 100 000.

According to economic theory, taxes create distortions due to the wedge between marginal benefit and marginal cost (Begg et al. 2014, 329). However, in the 'first-best world'[6] and in the presence of a negative externality, the efficient market equilibrium can be restored by levying a tax (Perman et al. 2011, 165). Such a tax is called a Pigovian tax, and is based on the polluter pays principle (Thune-Larsen et al. 2014, 2; Bjertnæs 2016, 63). If the tax is set correctly, the actor will internalise the externality, meaning that the socially optimal amount of the good will be provided or consumed (Thune-Larsen et al. 2014, 1-2).

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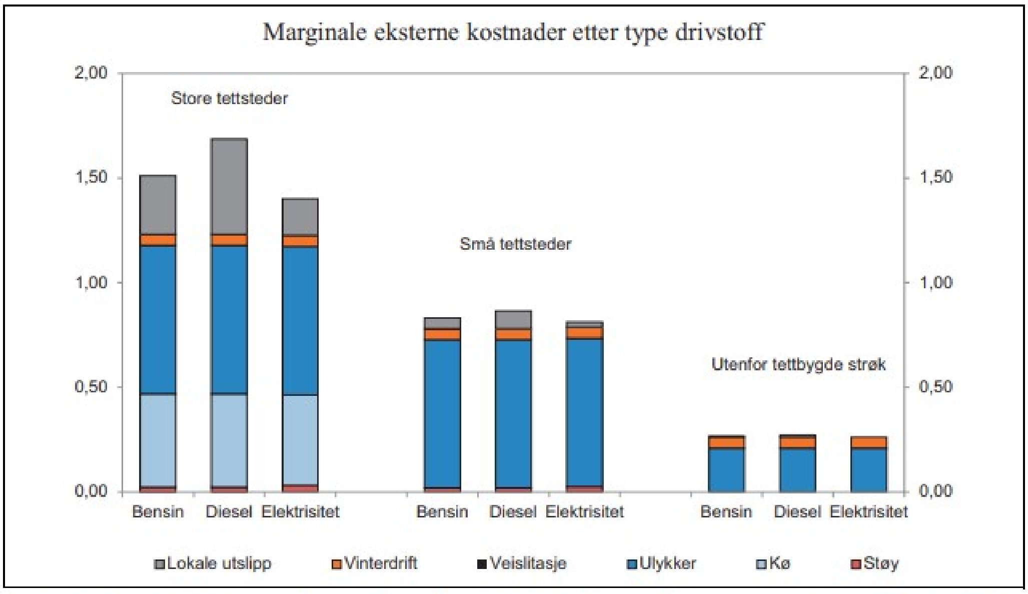
[6] A world "in which there would be a complete competitive equilibrium other than for the presence of one single market distortion" (Perman et al. 2011, 165).

Figure 2.2: Marginal external costs for vehicles running on different fuel, NOK per km in 2014-kroner



Figur 6.7 Marginale eksterne kostnader ved veitrafikk i ulike områder etter type drivstoff.[1] Personbiler. Kroner per kilometer i 2014-priser

[1] Store tettsteder: Over 100 000 innbyggere. Små tettsteder: Under 100 000 innbyggere. Utenfor tettbygde strøk: Under 200 innbyggere.

Kilder: Transportøkonomisk institutt og Statistisk sentralbyrå.

Source: Finansdepartementet 2015, 71.

A second argument for levying taxes in cases of negative externalities, is the double dividend hypothesis. The double dividend hypothesis states that the introduction of environmental motivated taxes, intended to decrease harmful activity, will enable the government to decrease taxes that create distortions in other parts of the economy. Thereby, the overall efficiency of the tax system will increase (Perman et al. 2011, 165).

In Figure 2.3, external costs during rush hour are compared to the fuel tax. The purpose of the fuel tax, which consists of the CO_2 tax and the road use tax, is to correct for the external costs of road use. Since EVs do not use traditional fuel, it is exempt of this tax. The fuel tax is insufficient to correct for negative externalities during rush hour, except for ICEVs driving in rural places (Fridstrøm 2019c, 4).

According to economic theory, the use of EVs should be taxed consistent with the marginal external cost associated with the use of the vehicle (Rødseth et al. 2019, 6). This is due to the divergence between the private cost and society's cost of the use of the vehicle. The amount of travels undertaken will be larger than what is optimal, and taxes could be set to achieve the optimal amount (5). Today, as EVs are exempt of the fuel tax, this external effect is not internalised.

Figure 2.3: Fuel tax and marginal external cost during rush hour

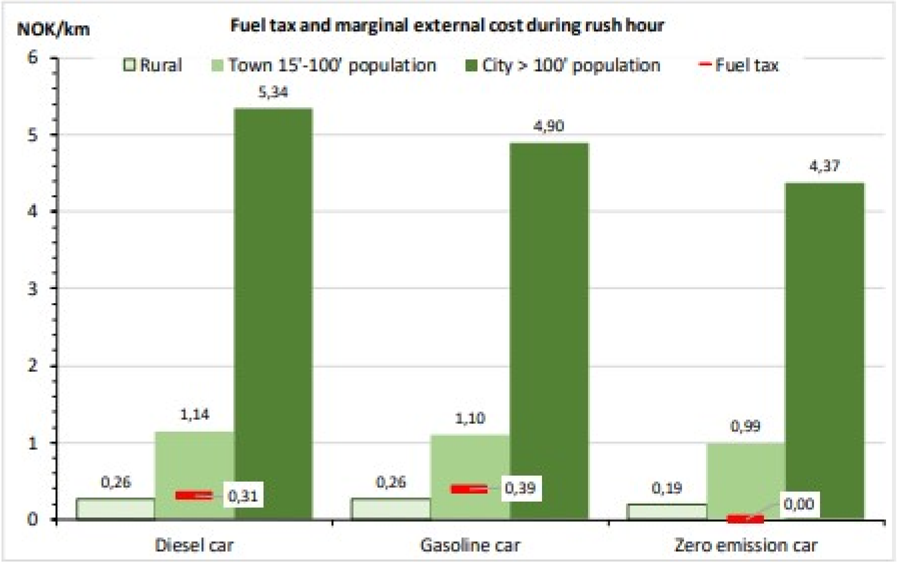


Fig. E.4 Marginal external costs of automobile use during rush hour, compared to fuel tax charged, by population density and vehicle's energy technology.

Source: Fridstrøm 2019c, 4.

The Green Tax Commission have recommended that use related taxes for EVs should be set according to the marginal external cost. As the marginal external costs of the use of EVs are lower than for ICEVs, these use related taxes should be lower for EVs than for ICEVs (Finansdepartementet 2015, 19).

Despite the argument for taxation of EVs based on economic theory, there exist extensive EV subsidies in Norway today. The use of subsidies is a controversial tool, as it will have to be financed by taxes, thereby creating distortions and welfare loss in the economy. Subsidies can also incentivise firms to overproduce certain goods (WTO 2006, 30; Mankiw and Taylor 2011, 133). Holtsmark (2012) argues that EV subsidies is an ineffective tool for reduced emissions in the transport sector. It is better to introduce policy directly aimed at the problem, which is the use of fossil energy. The use of subsidies will lead to unintended effects, and can be counterproductive (9). Skonhoft and Skarstein (2019) points to one of these unintended effects being increased use of private cars. They argue that it would be more efficient to increase the cost of fossil fuels, when the goal is reduced CO_2 emissions.

To conclude, the use of an EV generates negative externalities, thereby creating a rationale for taxation. Today subsidies are in place to insentivise the purchase and use of EVs instead of ICEVs, as the negative externalities related to the use of EVs are lower than for ICEVs. However, according to economic theory, it is more efficient to tax the unwanted activity, than to subsidise cleaner alternatives, as subsidies are costly and can have to unintended effects.

In the following analysis, CO_2 emissions related to the life cycle of vehicles is the only externality that will be included. As shown above, CO_2 emissions is the externality where EVs differ considerably from ICEVs in all geographic situations and is therefore of interest in the scope of this thesis.

2.3.2 Indirect network effects

Indirect network effects can be defined as a situation where “the benefit of adoption/investment on one side of the market increases with the network size of the other size of the market” (Li et al. 2017, 90). This contrasts with direct network effects, where a user’s benefit of consuming a product or service increases with an increasing user base (Swann 2002, 417). A standard example is a social network platform, such as Facebook.

In the case of EVs, indirect network effects are present if an increased number of charging stations will lead to higher sales of EVs, and vice versa, increased EV sales leads to the installation of more charging stations. This feedback loop is a result of consumers being reluctant towards purchasing EVs if there are few charging stations installed, and companies lacking incentive to build charging stations when the EV fleet is of limited size (Li et al. 2017, 90). This indirect network effect can be viewed as a market failure as a result of positive external effects. Consumers of EVs and investors of charging stations will not take into account this positive externality in their decision to consume or invest, but only consider their private benefit. When this market failure is not corrected for, there will be under-consumption of EVs as well as underproduction of charging stations (Liebowitz and Margolis. 1995, Church, Neil, and Krause 2008, cited in Li et al. 2017, 97). The presence of indirect network effects can then be used as an argument for government intervention in the market in question. In the case of EVs, the government can either subsidise EV purchase/use or charging stations installations, or do a combination of the two measures (Li et al. 2017, 91).

Research on indirect network effects in the EV market suggests that this effect is present (Springel 2016; Li et al. 2017). Li et al. (2017) use data from the US to assess the strength of the effect, and to determine on which side of the market the indirect effect is strongest. They look at the market in the US from 2011 to 2013, in the hypothetical situation were charging stations and EV purchases were subsidised equally. They find that subsidising charging stations was the most cost-effective instrument

(Li et al. 2017, 124). This could give the idea that governments should focus on subsidising the supply of charging stations instead of the purchase of EVs if the goal is to increase the number of EVs. However, the authors stress that this result is partly due to early adopters being price insensitive, and as EV buyers could become more price sensitive when the market matures, combined with a likely increase in driving range, this effect may no longer be the strongest. Still, their research indicate that deployment of charging stations is an effective way to increase EV sales in the early market stage (127).

Greåker and Midttømme (2016) have a different approach when studying the presence of network effects in the EV market. They look at the distribution of a clean good as a substitute for a dirty good when network effects are present. Their research question is whether failing to account for network effects will lead to excess inertia. In the presence of network effects, excess inertia occurs when the best technology or the best solution is not the one that is adopted (Farrell and Saloner 1986, cited in Greåker and Midttømme 2016, 27). Greåker and Midttømme assess whether setting a Pigovian tax on the dirty good is a sufficient incentive for the diffusion of the cleaner alternative. Governments might not want to subsidise a cleaner alternative as it is not necessarily obvious which clean technology among many is the best substitute. For this reason, governments might rely solely on taxing the dirty good (27). To investigate this, they set up a theoretical model and later apply it on the Norwegian EV market in the Oslo area, using data from 2008 onwards (32,33). They look at a situation where the cost and quality of an EV is equal to that of an ICEV (35). They find that a Pigovian tax, which does not take the network effect into account, is not sufficient for a successful diffusion of EVs. They also compare the Pigovian tax with the current tax and the optimal tax. They find that the current tax, which is above the Pigovian tax, will lead to a market development that is too slow, while a Pigovian tax would lead to excess inertia. The optimal tax is initially higher than the current tax, and will lead to a faster diffusion of EVs (32,33).

The Norwegian government have acknowledged the existence of network effects, and how this can create problems in an early phase. Network effects have thus been served as an argument for government support of charging infrastructure, specifically through state-owned enterprise Enova (Departementene 2019, 69). At the same time, the government has stated that further deployment of charging infrastructure should be based on commercial initiatives in a free market. Still, they recognise that commercial initiatives will not be profitable in some areas, for example in the northernmost region Troms and Finnmark, and that government support through Enova is necessary in this region (89).

Research on network effects in the EV market suggest that subsidies are necessary for this technology to “take off”. However, whether EVs are the best clean substitute for ICEVs has not been addressed here. How long it is optimal for the government to provide EV subsidies is also uncertain. If the presence of network effects causes a market failure, subsidising this market should eventually lead to the market having matured, making subsidies unnecessary for further adoption of EVs. The Green Tax Commission argued in 2015 that the market share for EVs was of such a size that EV benefits aimed at correcting for network effects could be reduced (Finansdepartementet 2015, 19).

2.3.3 Subsidies, technology development and global prices

New and more environmental friendly technology can be expensive to develop. Although it may be a cost-effective investment for society, it may not be for private investors. This serves as a rationale for government policies aimed at promoting green technology in an early phase. These policies can be put in two different categories, subsidies given directly to the technology producer meant for research and development (R&D), and policies meant to increase the demand of these products in an effort to create a market for the green technology (Nemet and Baker 2009, 49-50; Olson 2015, 5-6; Greaker, Golombek, and Hoel 2019). The Norwegian EV policy with subsidies meant to increase EV adoption are demand subsidies and can therefore be placed in the second category.

Two arguments regarding the effects of these subsidies have been presented in the Norwegian EV debate. The first one is that Norwegian subsidies have led to technological improvements of EVs, specifically improved battery capacity. The second is that EV purchases in Norway have induced lower EV prices worldwide. The assumption behind this argument is that economies of scale[7] makes it possible for producers to lower the prices with increasing sales (Fridstrøm and Østli 2014, 22; Greaker, Golombek, and Hoel 2019, 19-20). Better battery capacity and lower prices have in turn led to higher global sales which will result in lower emissions globally. This section will briefly discuss these arguments.

Skonhoft and Holtsmark (2014) discuss and discard the validity of the argument that EV subsidies will provide EV manufacturers with an incentive to develop better battery technology. As batteries are not exclusively used in EVs, improved battery technology will also benefit manufacturers of for example laptops and mobile phones. They argue that there already exist enough incentives for research on

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[7] Economies of scale is “the property whereby long-run average total cost falls as the quantity of output increases” (Mankiw and Taylor 2011, 279).

battery technology, and they question whether EV subsidies have any additional effect on technology development of batteries (62).

Bjertnæs (2016) discards the argument that Norwegian EV subsidies will help create a global market for EVs, that in the long run can lead to reduced GHG emissions worldwide. He argues that EV sales were marginal in Norway up until 2010, as it was in the rest of the world. He claims that since 2010, the Norwegian EV market has grown at the same speed as in other countries (65).

Researchers from the Institute of Transport Economics, on the other hand, argue that the development of a Norwegian EV market has helped create a global market for EVs. The fact that sales of EV models such as Nissan Leaf, Volkswagen e-Golf as well as Tesla Model S and X in Norway make up a two-digit percentage of global sales, is meant to underline this argument (Figenbaum et al. 2019, 7). From 2010-2018, Norway was the European country with most EV-sales in absolute number, before Germany surpassed Norway in 2019 (Feratovic 2019).

Whether Norwegian EV subsidies have had an effect on technological development and global EV prices is difficult to assess. Views on this matter differ, and it is outside the scope of this thesis to conclude on this question. Potential global emission cuts due to the Norwegian EV policy will not be included in the following analysis.

3. Life cycle analysis

A life cycle assessment (LCA) is an analysis where total emissions through the life cycle of the vehicle are quantified. This involves emissions from production, operation of the vehicle including emissions from production of fuel, emissions from maintenance, and lastly end-of-life emissions when disposing the vehicle (Del Pero, Delogu, and Pierini 2018, 521). The goal of the LCA is to compare lifetime emissions for EVs and ICEVs, and thereby assess the potential climate benefit of EVs relative to ICEVs.

To be able to perform a LCA assumptions need to be made on vehicle lifetime (in km), yearly mileage (in km), and fuel economy (litre per km or kWh per km). This needs to be done to be able to quantify the emissions as grams of CO_2 per km driven. Thereby emissions from production and end-of-life are distributed through the lifetime of the vehicle.

In the LCA literature it is common to refer to emissions related to the use phase of the vehicle as Well-to-Wheel (WTW) emissions. A WTW analysis considers the entire supply chain of the power source for the relevant vehicle technologies. WTW is divided between Well-to-Tank (WTT) emissions and Tank-to-Wheel (TTW) emissions. WTT represent emissions related to extraction, production and transportation of the fuel, while TTW emissions are emissions from driving the car using the stored energy in the vehicle (Woo, Choi, and Ahn 2017, 6-7). EVs emit no CO_2 in the operation of the vehicle, and thus TTW emissions are zero. There are however WTT emissions from electricity production.

Quantifying emissions in a LCA is a challenging task. Therefore an EVs potential to reduce CO_2 emissions varies drastically in the LCA literature. General LCAs are challenging to perform as the result is sensitive to the electricity mix of the country in question (Hausfather 2019; Woo, Choi, and Ahn 2017; Del Pero, Delogu, and Pierini 2018). EVs emit less during their lifetime compared to ICEVs in countries where the electricity is based on renewable energy, however this may not be the case if the electricity is mostly based on coal (Del Pero, Delogu, and Pierini 2018; Woo, Choi, and Ahn 2017). As the production of the EV battery is energy intensive, where the battery is produced has implications for EV lifetime emissions (Hausfather 2019). Assumptions on vehicle segment is a determinant factor for life cycle emissions, both when it comes to emissions from production, and in the use phase (Woo, Choi, and Ahn 2017, 2). Assumed driving pattern, as well as climate, is relevant for the fuel economy of the vehicle, which has implications for WTW emissions (Hausfather 2019).

Several assumptions need to be made to be able to perform a LCA, and the result is sensitive to these assumptions (Hausfather 2019). In the following sections necessary simplifications and assumptions will be made to be able to assess the climate potential of EVs compared to ICEVs in Norway.

3.1 Simplifications

In the LCA, the vehicles assessed will be within the compact segment, meaning a vehicle of around 1 500 kg. Basing the analysis on a compact vehicle is in line with Dyngen (2016), which used the compact vehicle Volkswagen e-golf in his analysis for optimal taxation of EVs, arguing that it works as a representative of an average EV (57). This simplification has been done as it has proven difficult to find data on the composition of the Norwegian vehicle market when it comes to the different vehicle segments. In the first years, most EVs available were in the subcompact category (Figenbaum et al. 2019, 26). However, over the years, EVs have become available in all the different categories. In 2019, 31 percent of EVs available in Norway were in the subcompact segment, 43 percent were in the compact segment, and 26 percent were categorised as medium large or large (27).

As a simplification, emissions from maintenance and end-of-life treatment will not be included in the analysis. Emissions from these phases represent a small share of life cycle emissions and can be excluded without much implications. It should be noted that there are higher emissions related to end-of-life treatment of EVs than for ICEVs due to the disposal of the battery (Del Pero, Delogu, and Pierini 2018, 523; Ellingsen, Singh, and Strømman 2016, 4,5).

The Norwegian electricity generation is based on renewable energy, mostly hydropower. Thereby, the resulting emissions are small. The emission intensity of the Norwegian electricity mix has been estimated to be 30 gram CO_2 per kWh in 2012. The emission intensity varies between years depending on how much electricity is exported vs imported, as electricity production in Norway is sensitive to the rainfall (Fridstrøm and Alfsen 2014, 14). Woo, Choi, and Ahn (2017) have estimated the emission intensity to be around 2 gram CO_2 per km, for cars in the compact class given fuel economy of 0.13 kWh per km. This was based on Norwegian electricity production consisting of 94 percent hydropower (344-345,349). As a simplification it will be assumed that emissions from electricity production in Norway (WTT emissions) are zero. As these emissions are small, excluding it will have no major implications for the analysis. Excluding emissions from electricity production is common when assessing the climate potential of EVs in Norway (Skonhoft and Skarstein 2019; Bjertnæs 2016, 63; Birkeli et al. 2016, 1)

3.2 Emissions from production

Ellingsen, Singh, and Strømman (2016) analyse the implications of vehicle size on emissions from the production of the vehicle. They look at the following segments: A (mini car), C (medium car) D (large car) and F (luxury car). The C-segment (medium car), is equivalent to the compact segment, which is the vehicle segment the analysis in this thesis will be based on (2-4).

Ellingsen, Singh, and Strømman base the estimates on emissions from production of EVs on data from Hawkins et al. (2012) and Ellingsen et al. (2014). While emissions from production of ICEVs are based on data from reports published by Daimler and Volkswagen. Their analysis is limited to models produced from 2010 and onward (Ellingsen, Singh, and Strømman 2016, 3).

Ellingsen, Singh, and Strømman find emissions from production to vary between 6.3–7.1 kg CO_2 per kg of car for EVs, while for the ICEVs the results indicated emissions of 3.9–5.7 kg CO_2 per kg of car. The difference in emissions related to production of EVs and ICEVs, was mainly due to the battery production, which constituted 31–46 percent of the total EV production emissions (Ellingsen, Singh, and Strømman 2016, 5). Their results indicate that smaller vehicles are associated with lower CO_2 emission in the production phase. According to their results, when looking at a vehicle of 1 500 kg, emissions from the production of an EV can be expected to lie between 9.45-10.65 tonne CO_2. The corresponding value for an ICEV of equal weight can be expected to lie between 5.85-8.55 tonne CO_2.

In a report from 2019 by Agora Verkehrwende, a German tink tank concerned with questions related to sustainable transport systems, emissions related to production of EVs and ICEVs are assessed. They find emissions from production of an EV in the compact class to make up 5.1 tonne CO_2 for the battery alone, and 12.1 tonne CO_2 in total. For a corresponding ICEV the emissions from the production phase constitute 6.7 tonne CO_2 (Helms et al. 2019 cited in Thompson 2020, 8).[1]

The estimates for EVs by Agora Verkehrwende are higher than the estimates presented in Ellingsen, Singh, and Strømman (2016), while the estimates for the ICEV lies within the range for a corresponding vehicle in Ellingsen, Singh, and Strømman (2016). In the analysis the lower estimates from Ellingsen, Singh, and Strømman (2016) will be used. This constitute emissions of 9.45 tonne CO_2 in the production phase for an EV, and 5.85 tonne for an ICEV for a typical vehicle of 1 500 kg in the compact class.

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[1] The original report is in German, and has therefore not been utilised.

3.3 Well-to-Wheel emissions

As EVs have no TTW emissions (tailpipe emissions), together with the assumption of zero emissions in the production of Norwegian electricity, only WTW emissions for ICEVs will be estimated.

Finding an estimate for WTW emissions from ICEVs during the years 2010-2019 is a challenging task. Fuel economy, type of vehicle, and type of fuel, are some of the factors that affect the level of WTW emissions. Several of these factors can be assumed to have changed during the last ten years. For example, emissions related to the combustion of fuel in ICEVs (emissions per km) have decreased in Norway during the last years (Figenbaum 2018, 24). Increased use of biofuel[2] in Norway can partly explain the decrease in these emissions (SSB 2019b). Despite the trend of decreasing emissions, within the scope of this thesis, it is a necessary simplification to assume one estimate for WTW emissions for the entire time period.

The numbers necessary to perform the analysis in this thesis are WTT and TTW emissions presented as grams of CO_2 per km for an ICEV in the compact segment. Assumptions regarding fuel economy of an ICEVs also need to be made to be able to calculate loss of revenue due to EVs not paying road use tax.

As mentioned, there exist literature on life cycle emissions of ICEVs and EVs. A problem with this literature is that it is not common to specify the assumptions made regarding WTW emissions. For example Hawkins et al. (2012), conclude that EVs powered by the European electricity mix lead to a 10-24 percent decrease in GHG emissions relative to a diesel or gasoline ICEV assuming a lifetime of 150 000 km (53). However, they do not provide the actual emissions calculated for the different phases. Therefore, it has proven challenging to find a satisfactory estimate on WTW emissions for ICEVs within already existing research. However, there are some exceptions. Woo, Choi, and Ahn (2017) and Del Pero, Delogu, and Pierini (2018) present their findings in a way that makes it possible to extract their assumptions on fuel economy and WTW emissions. Del Pero, Delogu, and Pierini (2018) assess life cycle emissions of light duty vehicles, while Woo, Choi, and Ahn (2017) look at passenger cars within the following vehicle segments: subcompact, compact, full size luxury and SUV.

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[2] In Norway there has been a requirement to blend in biofuel with traditional fuel (diesel and gasoline) since 2009. (Finansdepartementet 2015, 74). CO_2 emissions from combustion of biofuel is counted as zero in national data on emissions (Miljødirektoratet 2020a).

As the analysis will be based on vehicles within the compact class, the research done by Woo, Choi, and Ahn (2017) on compact vehicles will be utilised. Their analysis is based on actual vehicles in the market. BMWi3 and Volkswagen e-golf are the representatives for compact EVs (349). These two vehicles made up around 25 percent of EVs in Norway in 2017 (Frydenlund 2017). BMW 3 series, Hyundai i30 and Volkswagen golf make up the ICEVs that are meant to be comparable to the compact EVs. These are presented both as gasoline and diesel vehicles (Woo, Choi, and Ahn 2017, 349).

When calculating WTW emissions Woo, Choi, and Ahn used JEC's WTW CO_2 data (Edwards et al. 2014, cited in Woo, Choi, and Ahn 2017, 342-343), which they state was the newest and most reliable source available at that time. The resulting WTW emissions for a compact diesel and gasoline vehicle, can be seen in Table 3.1. As several vehicle models have been assessed, they have taken the average of the vehicles within each segment to find one value representing a compact diesel ICEV and one value for a gasoline ICEV. The average WTW emissions for a compact gasoline car is found to be 119.7 CO_2 per km, while the corresponding estimate for a diesel vehicle is 96.1 grams CO_2 per km (344).

Table 3.1: WTW emissions for compact ICEVs, grams CO_2/km

	Well-to-Tank	Tank-to-Wheel	Well-to-Wheel
Gasoline	20.0	99.7	119.7
Diesel	16.7	79.4	96.1

Source: Woo, Choi, and Ahn 2017, 344.

If these estimates are compared to the estimates on the other segments presented in Woo, Choi, and Ahn (2017), it is evident that the result differs between vehicle types. For vehicles in the subcompact class the estimated WTW emissions are 101.4 and 89.8 grams CO_2 per km for gasoline and diesel, respectively. For full size luxury vehicles, the corresponding estimates were 187.5 (gasoline) and 143.1 (diesel). Lastly, for SUVs estimated WTW emission are 210.1 grams for gasoline and 165.6 grams for diesel vehicles (344). According to the research by Woo, Choi, and Ahn (2017), the bigger the vehicle, the higher the estimated WTW emissions.

The estimates from Woo, Choi, and Ahn (2017) can be compared to estimates used in the literature on the costs and benefits of the EV policy in Norway. Bjertnæs (2016) assumed that an ICEV emits 203 grams of CO_2 per km (63). Skonhoft and Skarstein (2019) on the other hand assumed emissions of 160 gram CO_2 per km for ICEVs. Holtsmark and Skonhoft (2014) compared a Nissan Leaf with a

Toyota Prius, which was assumed to emit 110 grams CO_2 per km (164).

The research referred to above only look at TTW emissions, while Woo, Choi, and Ahn (2017) look at both WTT and TTW emissions. Still the estimates from Woo, Choi, and Ahn (2017) are lower. A reason for the difference can be that the estimates in Woo, Choi, and Ahn (2017) are based on emissions from new vehicles, while Bjertnæs (2016) and Skonhoft and Skarstein (2019) may have based their estimations on emissions from the existing vehicle park. Holtsmark and Skonhoft (2014), on the other hand used calculated emissions from an actual vehicle. If one assumes that EVs are purchased instead of a new ICEV, which is a reasonable assumption, the method in Woo, Choi, and Ahn (2017) will better incorporate the actual CO_2 reductions related to an increasing number of EVs.

Average WTW emissions assumed by Woo, Choi, and Ahn (2017) for gasoline and diesel ICEVs will therefore be used. Rounded to the closest whole number this gives WTT emissions of 18 grams CO_2 per km and TTW emissions of 90 grams CO_2 per km, making up WTW emissions of 108 grams CO_2 per km in total.

Assumptions regarding fuel economy for ICEVs also need to be made. The assumptions by Woo, Choi, and Ahn (2017) regarding fuel economy for the different compact ICEVs can be seen in Table 3.2 (349). The fuel economy data used is taken from the Vehicle Certification Agency (VCA), which is an executive government agency of the United Kingdom Department for Transport (342).

Table 3.2: Fuel economy for compact ICEVs, litre/km

	Gasoline	Diesel
BMW 3 series	0.045	0.031
Hyundai i30	0.049	0.03
Volkswagen golf	0.035	0.028

Source: Woo, Choi, and Ahn 2017, 349.

To ensure consistency, an average of the estimates from Woo, Choi, and Ahn (2017), will be used by giving the diesel and gasoline ICEVs the same weight. Rounded to three decimals this will give a fuel economy of 0.036 litre per km. This is lower than Del Pero, Delogu, and Pierini (2018), which assumed fuel economy of 0.058 litre per km for a light duty vehicle that runs on gasoline (526). The Norwegian Environment Agency on the other hand assumed fuel economy for smaller ICEVs to be 0.067 litre per km, in the time period 2016-2030. (Birkeli et al. 2016, 57).

3.4 Yearly number of EVs

Data on the number of registered EVs in Norway is necessary to be able to calculate the overall yearly emission reductions as a result of the EV policy.

Statistics Norway have published data on registered EVs at the end of the year (31 Dec) up until 2019 (SSB 2020a). The data from 2010-2019 can be seen in Table 3.3. Using these numbers directly will lead to overestimating the climate effects of the Norwegian EV policy, as vehicles registered at the end of the year will be treated the same as vehicles that have been registered the whole year. Still, these values will be used as estimates on the yearly number of EVs. This is to ensure consistency with the analysis on the cost of the policy, where overall costs are divided on the number of vehicles registered, when finding revenue loss per vehicle.

Table 3.3: Data on number of EVs registered

	2010	**2011**	**2012**	**2013**	**2014**
EVs registered at end of year	2 068	3 909	8 031	17 770	38 652
	2015	**2016**	**2017**	**2018**	**2019**
EVs registered at end of year	69 134	97 532	138 983	195 351	260 692

Source: SSB 2020a.

3.5 Estimated yearly mileage for EVs

Data on yearly mileage for different vehicle types is available from Statistics Norway (SSB 2020c). As can be seen in Table 3.4, estimated average yearly mileage for EVs has increased substantially, from 6 806 km in 2010 to 12 631 km in 2019.

Table 3.4: Average yearly mileage in Norway for different vehicle technologies, km per vehicle

	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Gasoline	11 106	10 729	10 365	9990	9 695	9 502	9 309	9 210	9 034	8 809
Diesel	17 335	16 626	16 691	16 229	15 741	15 494	15 059	14 829	14 527	13 936
Electric	6 806	6 427	7 612	5 692	7 729	11 380	11 788	11 818	12 171	12 631

Source: SSB 2020c.

Assumptions made on yearly mileage varies in the literature. Holtsmark (2012) assumed yearly mileage of 7 500 km, which are in line with the data from Statistics Norway for 2012 (7). Bjertnæs (2016) on the other hand, assumed that an EV drives 13 264 km a year. He claims this was the average for Norwegian passenger vehicles in 2014, according to Statistics Norway (63). This is an optimistic estimate if compared to data from Statistics Norway on EVs from 2014. Skonhoft and Skarstein (2019) referred to Statistics Norway when assuming yearly mileage of EVs of 12 000 km in 2018.

As a simplification, one estimate will be used to represent the whole time period. This is to ensure consistency with the assumptions made on vehicle lifetime in kilometres, which is used when distributing emissions from the production phase over the lifetime of the vehicle. The estimate will be based on the data on average yearly mileage from Statistics Norway. Simply taking the average over the years would lead to an average yearly mileage just over 8 200 km. However, this is not a good estimate for the time period. As a majority of the EV park was acquired the last couple of years (see Table 3.3), more more weight should be put on the number for yearly mileage the last years. A weighted average for yearly mileage, where the average number of EVs each year is accounted for, yields an average of just under 11 800 km. 12 000 km has therefore been chosen as an estimate for the entire time period. This estimate will lead to overestimation of the reduced CO_2 emissions for the first years in the time period analysed, and the climate potential will be underestimated for the years 2018-2019, when yearly mileage was slightly above 12 000 km. Overall when multiplied with the average number of EVs for each year, it will give a number close to the reality of total kilometres driven by EVs from 2010-2019.

3.6 EV and battery lifetime

Vehicle lifetime can be presented in both total kilometres and in years. This section will present relevant literature where EV lifetime has been assumed or calculated.

Hawkins et al. (2012) assume an EV lifetime of 150 000 km, and claim that this is in line with lifetime assumed by the automobile industry. Further on, they state that EV lifetime found in the literature ranges between 150 000 and 300 000 km (56). When performing a LCA, Del Pero, Delogu, and Pierini (2018) assume an EV lifetime of 150 000 km. However, they refer to Lombardi et al. (2017) which assumed lifetime of 200 000 km, and Samaras and Meisterling (2008) and Bauer et al. (2015) which assumed an EV lifetime of 240 000 km (Del Pero, Delogu, and Pierini 2018, 530).

The Norwegian Environment Agency have previously assumed the same lifetime for EVs as for passenger vehicles in general, which is about 18 years. However, the period studied was from 2016-2047 (Birkeli et al. 2016, 11). The Institute of Transport Economics have also assumed same lifetime for EVs and ICEVs of 17 years (Figenbaum et al. 2019, 13).

Bjertnæs (2016) assumed yearly EV mileage of 13 264 km a year and an EV lifetime of 18.5 years, based on average for passenger vehicles (63). This constitutes about 245 000 km over the lifetime of the EV. This is a high estimate and is a result of basing the assumptions on data for passenger vehicles in general and not for EVs specifically. Skonhoft and Skarstein (2019), assumed yearly mileage of 12 000 km. Combined with a lifetime of 10 years this makes up a total of 120 000 km.

According to car producer Nissan, their EV model Nissan Leaf has had an average lifetime of 10 years. This is based on analysing 400 000 vehicles since 2011 (E24 2019).

Assumed lifetime varies in the literature. It is also likely that average EV lifetime has increased during the relevant time period from 2010-2019. As EVs constitute a rather new technology, it is reasonable that the vehicles have improved in this area since 2010. In the analysis, an EV lifetime of 180 000 km will be assumed. With already assumed yearly mileage of 12 000 km, this leads to an EV lifetime of 15 years. The chosen estimate lies between the estimates on EV lifetime presented in this section.

Assumptions regarding battery lifetime must also be made. Figenbaum et al. (2019) argue that there are no indications that the battery will last shorter than the EV, although the capacity of the battery will be reduced over time leading to decreased driving range. The fact that Li-ion batteries represent a rather new technology means that the batteries are not old enough to be able to properly investigate the lifetime of the batteries (17). As mentioned above, car producer Nissan analysed 400 000 models of Nissan Leaf to assess the lifetime of the vehicle. At the same time, they researched battery lifetime, and found it to be 22 years (E24 2019). Hawkins et al. (2012) also assumed the battery to last at least as long as the EV, with an assumed lifetime of 150 000 km (56). In line with existing research, it will be assumed that the battery of the EV will not need to be changed during the lifetime of the vehicle.

To sum up, in the analysis it is assumed that the battery lasts at least as long as the EV. Further on, yearly mileage of 12 000 km is assumed. Together with a lifetime of 15 years, this constitute 180 000 driven km during the lifetime of the vehicle. To ensure consistency a total lifetime of 15 years is also assumed in the analysis on the cost of the EV policy.

3.7 The waterbed argument

As Norway is connected to the electrical grid of continental Europe (Fridstrøm and Østli 2014, 22), one could argue that the alternative use of Norwegian electricity should be analysed. The electricity used to power EVs could be exported to other countries. If Norwegian electricity replaces electricity based on a carbon intensive energy source, the alternative use of Norwegian electricity could lead to reduced global emissions (Krogvold et al. 2019, 7-8; Fridstrøm and Østli 2014, 22).

However, as Norway is part of the EU ETS quota system, this argument does not apply. Use of EVs will not lead to increased total emissions, but to a higher quota price (Holtsmark 2012, 5). The quota regime is further explained in chapter 2.1. To explain why the alternative use of Norwegian electricity is not relevant, economists use the waterbed argument (Holtsmark and Skonhoft 2014, 164; Amundsen 2020, 16; Bjertnæs 2016, 63). The waterbed argument goes as follows: as electricity production is covered by the EU ETS, reduced emissions as a result of reducing the electricity production in one country will be offset by increased emissions somewhere else. Reduced emissions lead to less demand for emission quotas which will decrease the price of these. The determining factor for emissions within sectors covered by the EU ETS is the emission cap. This cap being reduced over time is what ensures emission cuts. Thereby, Norwegian export of electricity to Europe, and possible reductions of electricity produced based on fossil fuels in other countries, will not lead to reduced global emissions (Amundsen 2020, 18; Holtsmark and Skonhoft 2014, 164).

However, there are some mechanisms with the quota market that indicate that the waterbed argument may not hold 100 percent in the third phase of the EU ETS (2013-2020). To ensure stability in the market, it is has been allowed to buy quotas and save them for future use, so called “banking”. After the financial crisis the economic activity in Europe decreased, which induced a surplus of quotas and therefore low quota prices. This led to “banking”, where quotas were acquired for future use. An increasing surplus of quotas led to the fear of a collapse of the quota market. Therefore, the member states agreed in 2014 to take quotas away from the market. These quotas would be returned at a later time when the market was more stable (Amundsen 2020, 17).

Amundsen (2020) argues that the rules for the third phase ensures the validity of the waterbed argument. Reduced demand for emission quotas in one country will not affect total emissions within the EU ETS sector. The quota cap is set and binding, but he further argues that due to the quota surplus, and the withdrawal of quotas, this only applies in the long run. He therefore argues that the time horizon decides whether one can assume that the waterbed argument holds 100 percent or not. If the time horizon for example is the level of emissions in 2025, one country's emissions cuts within the EU ETS will in some extent affect the level of total emissions within the EU ETS (18). Calculations performed have indicated that the quota surplus will not disappear until after 2050 (De Økonomiske Råd 2018, cited in Amundsen 2020, 18).

One can argue that as long as there is a surplus of emission quotas in the EU ETS, a shift to more EVs in Norway will in some extent give increased emissions from electricity production in the EU (Fridstrøm and Østli 2014, 22). The potential emission cuts in the case of export of Norwegian electricity should thereby be analysed when calculating the climate potential of EVs. However, 1 kWh of export will not necessarily lead to an equivalent decrease of production in the receiving countries (22).

In a report published by The Norwegian Water Resources and Energy Directorate (NVE), they assess the influence Norwegian land-based wind power can have on GHG emissions from electricity generation in Europe (Krogvold et al. 2019, 4). Here, they assume that the waterbed argument does not hold, and that reduced emissions therefore will lead to an equivalent reduction of the emission cap in the EU ETS (Skonhoft 2019; Krogvold et al. 2019, 8). Their calculations are for 2025 where it is assumed a generation of 18 TWh land-based wind power in Norway. The effect of an additional 10 TWh of wind power is then simulated. The aim is to see how these 10 TWh affect the export of electricity, electricity production based on fossil fuels, and eventually the level of CO_2 emissions in Europe (7). According to the model, 9.5 of these 10 Twh will be exported. 0.5 TWh of this again will be lost during transportation. According to the simulation, gas power generation, coal power generation and heat and electricity generation based on fossil fuels will in total be reduced by 9 Twh each year. In the model, Norwegian wind power's replacement of electricity based on fossil fuels will then represent a reduction in GHG emissions in the power generation sector in Europe by around 5 million tonnes of CO_2 per year (8). In the simulation, it is assumed that the exchange cables connecting the Norwegian grid to England and Germany are operational by 2025. A significant increase in Europe's grid capacity from 2018-2025 is also assumed (9).

To sum up, there are uncertainties as to whether the waterbed argument holds 100 percent in the relevant time period analysed. Still, in the main analysis of this thesis, it will be assumed that the waterbed argument applies. The alternative use of Norwegian electricity will therefore not be assessed.

4. The degree of substitution

The degree of substitution between EVs and ICEVs shows the extent to which an EV replaces driving by an ICEV. A degree of substitution of 50 percent means that half of km driven by an EV replaces km driven by an ICEV. 50 per cent of the driving then comes in addition, for example by replacing other modes of transportation. The fact that 2/3 of families with an EV own at least one ICEV, can indicate that many families own an EV for nearby travels, and an ICEV for longer trips (Fjørtoft and Pilskog 2019). Thereby, EVs may not work as a substitute for the ICEV, but rather as a supplement.

When substantial use related benefits, such as free toll roads and free parking are in place, consumers may substitute away from using alternative transport, such as public transportation or walking and cycling, towards the use of EVs. Trips that formerly were not realised, may be realised after the acquisition of an EV (Nygaard 2015, 2). In addition to extensive use related benefits, there are low use cost of EVs compared to ICEVs, due to low electricity prices in Norway (Figenbaum 2018, 14). According to basic economic theory, lower marginal costs (cost per trip) will lead to increased consumption of a good. In the case for EVs, this will lead to more trips realised by cars (Stræde and Ulven 2017, 65). In this way, EV benefits will lead to more private vehicle use, which is not the intention of the policy.

The degree of substitution will depend on the price elasticity of demand[1] for travels by vehicle. If consumers are price insensitive (low elasticity) lower prices will not substantially increase the use of the good. This points towards a higher degree of substitution. If consumers are price sensitive (high elasticity) lower prices will substantially increase the use of the good. This points to a lower degree of substitution.

The long-term price elasticity of operating cost of an owned vehicle has been estimated to be -0.52 (Finansdepartementet 2007, 110). This estimate can be used in a simple and informal calculation to explain the implications of the low use related cost for EVs. For this calculation, it is assumed that operating costs per km for EVs is half of that for ICEVs. This is a careful estimate, as the combination of low electricity prices, and high taxes on the use of ICEVs are likley to lead to a larger difference between use related costs of the two vehicles. Given an elasticity of -0.5, operating costs of 50 percent and assuming constant elasticity of demand, kilometres driven would increase by 25 percent after replacing an ICEV with an EV. The example is a simple calculation to illustrate the implications of

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[1] Price elasticity of demand is the percentage change in the quantity demanded when the price increases by one percent (Sydsæter, Hammond, and Strom 2014).

lower costs on total driving, and should be interpreted accordingly. Still, it shows the importance of taking the degree of substitution into account when analysing the effect the EV policy has on reduced emissions. If not accounted for, the positive effects of EVs will be overestimated.

There exists little research on the degree of substitution between EVs and ICEVs in Norway. Still, some research that has attempted to quantify this degree will be presented.

The Norwegian Environment Agency have previously used 80 percent as the degree of substitution when assessing the climate benefits of EVs. This number was based on a questionnaire of self-reported driving patterns by the members of the Norwegian EV Association (NEVA) in 2016. Here, EV owners on average reported that 83 percent of km driven by their EV replaced km by an ICEV. The Agency assumed that due to increased driving range and more EV models being available, every km driven by an EV would fully substitute km taken by an ICEV in 2022 (Birkeli et al. 2016, 23-24). As members of NEVA do not represent a random sample of EV owners, in addition to their self interest in the subject, it is difficult to trust the validity of the results from the questionnaire.

Kolbenstvedt (2013) found that EV owners changed their travel pattern after buying an EV. Between 65 to 80 percent of the EV use replaced the use of an ICEV. At the same time, the EV replaced use of public transport and walking or cycling, estimated to be about 5-20 percent and 10 percent, respectively. These findings indicate a degree of substitution of 65-80 percent between EVs and ICEVs (96,115).

In his master thesis, Nygaard (2015) finds that owning an EV reduces annual travels taken by an ICEV of about 40 percent (41). He further finds the effects of acquiring an EV on the use of public transportation to be small, and only significant in the case of commuting (43). However, Nygaard has based his estimations on a small, and not random sample, which weakens the validity of the results. The analysis is based on a questionnaire mainly distributed among employees at the Norwegian University of Life Sciences (12-13,44).

In their master thesis, Stræde and Ulven (2017) conclude that a degree of substitution between 30-50 percent is a reasonable estimate (58). Their analysis was based on a questionnaire sent to employees at the Norwegian University of Science and Technology (21). As their analysis is not based on a random sample, the results may not apply to the overall population. However, their main analysis was supplemented with actual travel count data from toll roads in the Trondheim area (51). If crossings of ICEVs reduces at about the same rate as crossings of EVs increases, this would indicate a high degree of substitution. For 2016, they find a small decrease in crossings by ICEVs. Thereby their findings are in line with the analysis based on the questionnaire. EVs substitute ICEVs in some degree, but this number is lower than anticipated (53).

The research presented varies in their estimated degree of substitution. It is also likely that the degree of substitution has increased during the years 2010-2019. With increased driving range as well as increased availability of charging stations across roads, EVs have become a better substitute for ICEVs. Some statistics that support this assumption will be provided.

In 2016, 79 percent of EVs were owned by multivehicle households. This was reduced to 73 percent in 2018. This indicates that EVs are increasingly becoming an actual option to an ICEVs, and not just an extra vehicle in a multivehicle households (Figenbaum and Nordbakke 2019, 12). According to the Institute of Transport Economics, the use of EVs on longer trips has also increased, due to increased driving range and available charging infrastructure, which facilitates the use of EVs on longer trips. In 2018, 31 percent of EV owners stated that they used their vehicle on trips over 300 km, compared to 52 percent among ICEV owners, which shows that ICEVs are still the preferred option for longer trips (Figenbaum et al. 2019, 137).

Average yearly mileage for EVs has increased drastically between 2010-2019, from 6 806 km in 2010 to 12 631 km in 2019. This indicates that the degree of substitution has increased during these years. However, it could also point to increased use of private vehicles. Yearly mileage for ICEVs has decreased during the same period, which strengthens the argument that this indicates an increased degree of substitution. For gasoline vehicles yearly mileage has decreased from 11 106 km in 2010, to 8 809 km in 2019. The corresponding numbers for diesel vehicles are 17 335 and 13 936 (SSB 2020c).

Research intended to estimate the degree of substitution in Norway diverges substantially. At the same time, it is likely that the degree of substitution has changed through the ten years studied in this thesis. As a careful estimate, 80 percent degree of substitution will be used when presenting the results. It should be noted that in line with the discussion above, this is a high estimate for the relevant time period. A sensitivity analysis with degrees of substitution of 100, 60 and 40 percent for the year 2019 will therefore be provided. A sensitivity analysis will be performed as it is interesting to see how sensitive the results, cost per tonne CO_2 reduced, is to the chosen estimate on the degree of substitution.

5. Data on the cost of the EV policy

This chapter will go through the EV benefits, and how much loss of government revenue the different subsidies and tax exemptions have induced from 2010 to 2019. Some of the benefits have been excluded, and explanations to why will be provided. Most of the data used is from the Ministry of Finance, which since 2011 have provided yearly estimates on loss of government revenue from the VAT exemption. Since 2013, they have added several of the other tax exemptions in their calculations. A weakness with the data from the Ministry of Finance is that they do not distinguish between passenger vehicles and other vehicles in their estimations. As this thesis only looks at passenger vehicles, using this data will mean overestimating the cost of the policy. Using this data regardless can be defended by the fact that most EVs registered are passenger vehicles (SSB 2020b; Figenbaum et al. 2019, 5). The calculated costs have been converted to 2019-kroner based on the consumer price index from Statistics Norway, which is a common measure for inflation (SSB 2020d). It is necessary to correct for inflation to be able to compare the cost of the policy through the years studied.

Table 5.1: Number of EVs in Norway

	2010	**2011**	**2012**	**2013**	**2014**
EVs registered at end of year	2 068	3 909	8 031	17 770	38 652
Yearly newly registered EVs	292	1 841	4 122	9 739	20 882
	2015	**2016**	**2017**	**2018**	**2019**
EVs registered at end of year	69 134	97 532	138 983	195 351	260 692
Yearly newly registered EVs	30 482	28 398	41 451	56 368	65 341

Source: SSB 2020a.

As mentioned above, values on loss of government revenue lack for certain years in the calculations provided by the Ministry of Finance. In such cases, a value for the missing year has been estimated. These estimations have been based on data from Statistics Norway on EVs registered from 2010-2019, as can be seen in Table 5.1 (SSB 2020a). The difference between EVs registered at the end of a certain year and the year before has been used as an estimate for newly registered passenger EVs. This solution was chosen as it has proven difficult to find data on EV sales for the years 2010-2019. The estimate explained will not give a complete picture of vehicles sold in a certain year, as cars that are disposed of will affect the number of cars registered. However, as most EVs are rather new, numbers of EVs scrapped between 2010-2019 can be expected to be small, and will therefore not have serious implications for the analysis.[1] The estimates on revenue loss presented, will in general be rounded to the closest hundred thousand.

5.1 Value added tax

The Ministry of Finance have provided calculations for value of the loss of VAT for the years 2011-2019 (Det Kongelige Finansdepartement 2011, 265; Det Kongelige Finansdepartement 2012, 288; Det Kongelige Finansdepartement 2013, 382; Det Kongelige Finansdepartement 2014b, 300; Det Kongelige Finansdepartement 2015b, 353; Det Kongelige Finansdepartement 2016, 328; Det Kongelige Finansdepartement 2017b, 360; Det Kongelige Finansdepartement 2018b, 434; Det Kongelige Finansdepartement 2019, 314).

A value for 2010 thereby had to be estimated. The estimate for yearly newly registered vehicles in 2011 was used to calculate the loss of revenue per new vehicle registered in 2011. This number was then multiplied with the estimate for new cars sold in 2010, which then represents the total loss of government revenue due to the VAT exemption for EVs in 2010. A weakness with this method, is that it is assumed that the value of the VAT exemption per newly registered vehicle was equal in 2010 and 2011. The calculations from the Ministry of Finance as well as the result of the estimation for 2010 can be found in Table 5.2.

Table 5.2: Revenue loss due to the VAT exemption, in million NOK

	2010	**2011**	**2012**	**2013**	**2014**
Revenue loss	11.1	70	200	500	1 500
Revenue loss in 2019-kroner	13.4	83.2	236	577.5	1 698
	2015	**2016**	**2017**	**2018**	**2019**
Revenue loss	2 000	2 300	4 000	5 400	7 700
Revenue loss in 2019-kroner	2 216	2 458,7	4 200	5 518,8	7 700

Source: see main text above.

As discussed in chapter 3, when assessing the relative climate potential of EVs, vehicle lifetime emissions are calculated. Thereby, emissions from production of the vehicle are distributed through the expected lifetime of the vehicle when finding yearly emissions. Therefore, the same needs to be done

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[1] Only 630 EVs were scrapped in 2019, which made up 0.5 percent of vehicles scrapped that year (Opplysningsrådet for veitrafikken 2020).

with the EV benefits that lead to a one-time revenue loss, when the aim is to compare costs (yearly loss of revenue) to benefits (yearly reduced CO_2 emissions).

The VAT exemption leads to a one-time revenue loss. This cost will therefore be distributed through the lifetime of the vehicle, assumed to be 15 years.

The following method was used: first the estimated yearly loss of VAT provided by the Ministry of Finance was converted to 2019-kroner. Yearly loss for 2010-2019 was then added together to find total revenue loss during the ten-year period. This was then divided on the total of newly registered vehicles during the same period, to find an estimate for the average loss of VAT per newly registered EV between 2010-2019. This was found to be 95 404 NOK in 2019-kroner. To find annual loss per vehicle this amount needed to be distributed through the lifetime of the vehicle. In this process it was necessary to account for the alternative revenue of the reduced tax income. The discount rate is the alternative cost of bound capital and thereby reflects the returns of the capital if invested in the best alternative (Direktoratet for økonomistyring 2018, 121). For projects with a time interval of up to 40 years the Ministry of Finance recommend using a discount rate of 4 percent (Det Kongelige Finansdepartement 2014a, 5). A discount rate of 4 percent was therefore used when calculating the annuity, meaning annual payment over 15 years, given equal payment each year. This was found to be 8 581 NOK per year per vehicle. To find total yearly revenue loss this estimate of 8 581 was multiplied by the number of EVs registered each year. The result of this calculation can be seen in Table 5.3.

The method outlined may seem like an unnecessary complicated way to perform the calculations. One alternative could be to compare lifetime costs (revenue loss) with lifetime benefits (CO_2 reductions). However, this would not be possible as it is uncertain how long the different EV subsidies will be in place. Therefore, the solution is to look at yearly benefits and costs in the chosen timeline (2010-2019) based on benefits and costs during the lifetime of the vehicle.

Table 5.3: Annual revenue loss due to the VAT exemption, million NOK in 2019-kroner

	2010	**2011**	**2012**	**2013**	**2014**
Annual revenue loss	17.7	33.5	68.9	152.5	331.7
	2015	**2016**	**2017**	**2018**	**2019**
Annual revenue loss	593.2	836.9	1 192.6	1 676.2	2 236.9

Source: see main text above.

5.2 Purchase tax

The Ministry of Finance have provided calculations for the value of the loss of purchase tax for the years 2013-2019 (Det Kongelige Finansdepartement 2014b, 300; Det Kongelige Finansdepartement 2015b, 353; Det Kongelige Finansdepartement 2016, 328; Det Kongelige Finansdepartement 2017b, 360; Det Kongelige Finansdepartement 2018b, 434; Det Kongelige Finansdepartement 2019, 314).

Estimations for 2010-2012 have been based on estimated loss of purchase tax per newly registered EV for the year 2013. A weakness with this calculation is that it is assumed that the composition of types of EVs sold was constant between 2010-2013. As vehicle weight is significant for the value of the purchase tax, vehicle type will affect the estimated revenue loss (127). It is also assumed that the rules for calculating the purchase tax have been constant from 2010-2013, which has not been the case (Det Kongelige Finansdepartement 2013, 162). The calculations done by the Ministry of Finance and the estimates for 2010-2013 can be seen in Table 5.4.

Table 5.4: Revenue loss due to the purchase tax exemption, in million NOK

	2010	**2011**	**2012**	**2013**	**2014**
Revenue loss	24	151.2	338.6	800	1 750
Revenue loss in 2019-kroner	28.9	179.7	399.5	924	1 981
	2015	**2016**	**2017**	**2018**	**2019**
Revenue loss	1 750	1 000	1 400	1 500	3 600
Revenue loss in 2019-kroner	1 939	1 069	1 470	1 533	3 600

Source: see main text above.

The method used for distributing the loss of the VAT over the lifetime of the vehicle is also used for the purchase tax, and will therefore not be repeated here. The method outlined yields an average loss of purchase tax per vehicle of 50 688 NOK in 2019-kroner. Taking the annuity over 15 years gives annual loss per vehicle of around 4 559 NOK in 2019-kroner. The total estimated annual loss due to the purchase tax exemption, where the cost has been distributed through the lifetime of the vehicle can be seen in Table 5.5.

Table 5.5: Annual revenue loss due to the purchase tax exemption, million NOK in 2019-kroner

	2010	**2011**	**2012**	**2013**	**2014**
Annual revenue loss	9.4	17.8	36.6	81	176.2
	2015	**2016**	**2017**	**2018**	**2019**
Annual revenue loss	315.2	444.6	633.6	890.6	1 188.5

Source: see main text above.

5.3 Annual tax

Original calculations for the loss of annual tax for the years 2010-2019 have been performed for this thesis. At the same time the Ministry of Finance have provided calculations for the years 2013-2019 (Det Kongelige Finansdepartement 2014b, 300; Det Kongelige Finansdepartement 2015b, 353; Det Kongelige Finansdepartement 2016, 328; Det Kongelige Finansdepartement 2017b, 360; Det Kongelige Finansdepartement 2018b, 434; Det Kongelige Finansdepartement 2019, 314).

In Table 5.6, both the Ministry's calculations and the original calculations for this thesis are provided. The estimates found in this thesis are similar to the calculations done by the Ministry, which strengthens the reliability of the estimations done by the Ministry of Finance. In the following analysis the original calculations from this thesis will be used.

Table 5.6: Revenue loss due to reduced annual tax (2010-2017) and tax exemption (2018-2019), in million NOK

	2010	**2011**	**2012**	**2013**	**2014**
Calculations by the Ministry of Finance	-	-	-	40	90
Original calculations for this thesis	4.8	8.4	17.4	38.7	85,9
	2015	**2016**	**2017**	**2018**	**2019**
Calculations by the Ministry of Finance	160	250	300	500	700
Original calculations for this thesis	161.5	243.3	304.2	501.7	680.2

Source: see main text.

To calculate the revenue loss, data from Statistics Norway on number of EVs registered at the end of the year was used (see Table 5.1) (SSB 2020a), as well as data on the rate of the annual tax for EVs and ICEVs for the years 2010-2019 (Toll-og Avgiftsdirektoratet 2010, 3; Toll-og Avgiftsdirektoratet 2011, 3; Toll-og Avgiftsdirektoratet 2012, 3; Skatteetaten 2017; Skatteetaten 2019).

From 2018, EVs have been fully exempt of the annual tax. Therefore, two calculations have been performed, one for the years 2010-2017 and one for the years 2018-2019. The annual tax rate differs for vehicles over and under 7 500 kg. Passenger EVs will be in the category under 7 500 kg (Statens Vegvesen 2020b).

For the years 2010-2017, EVs payed an annual tax rate lower than that for ICEVs (see Table 5.7 for the yearly rates). To calculate the loss of government revenue the tax rate for EVs has been subtracted from the rate for ICEV. The difference between the two rates was then multiplied with the number of EVs registered at the end of the previous year. Loss of revenue from newly registered cars needed to be calculated as well. Vehicles that were registered in the second half of the year payed half the annual tax rate (Toll-og Avgiftsdirektoratet 2012, 4). It was assumed that 50 percent of newly registered EVs were registered in the first half, and 50 percent in the second half of the year. Based on these assumptions, yearly loss of government revenue due to reduced annual tax for the years 2010-2017 were calculated. The results can be found in Table 5.6.

Table 5.7: Annual tax rate in NOK

	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Rate for vehicles under 7 500 kg	2 790	2 840	2 885	2 940	2 995	3 060	3 135	2 820
Rate for EVs	395	400	405	415	425	435	445	455
Difference in rate	2 395	2 440	2 480	2 525	2 570	2 625	2 690	2 365

Sources: Toll-og Avgiftsdirektoratet 2010, 3; Toll-og Avgiftsdirektoratet 2011, 3; Toll-og Avgiftsdirektoratet 2012, 3; Skatteetaten 2017.

Table 5.8: Annual tax from 2018-2019, daily rate in NOK

	01.01.18-28.02.18	**01.03.18-28.02.19**	**01.03.19-31.12.19**	**Weighted average**
Rate for vehicles under 7 500 kg	7.73	7.85	7.97	7.89

Souce: Skatteetaten 2019

In 2018, the annual rate was replaced with a daily rate. Thereby the overall annual tax payment was based on how many days of the year the vehicle had been registered. During the two years from 2018-2020, three different rates were in place, which can be seen in Table 5.8. In the last column, a weighted average of the three different rates has been calculated. This was based on how many months the rates were in force, and was done to simplify the calculations.

Assumptions on what time of the year the new vehicles had been registered needed to be made. The newly registered vehicles were divided into four segments and it was assumed that 25 percent was registered on 1 Jan, 25 percent on 1 Apr, 25 percent on 1 Jul and the remaining 25 percent on 1 Oct. The result of the calculations can be seen in Table 5.6. As mentioned above, they are similar to the calculations done by the Ministry of Finance, which gives validation to the assumptions and simplifications made when calculating revenue loss in this thesis. Yearly loss of annual tax converted to 2019-kroner can be found in Table 5.9.

Table 5.9: Revenue loss due to reduced annual tax (2010-2017) and tax exemption (2018-2019), NOK in 2019-kroner

	2010	**2011**	**2012**	**2013**	**2014**
Revenue loss in million NOK	5.7	10	20.5	44.7	97.3
	2015	**2016**	**2017**	**2018**	**2019**
Revenue loss in million NOK	178.9	260	319.4	512.7	680.2

Sources: see main text above.

5.4 Re-registration tax

This benefit has only been in place since 2018. According to the Ministry of Finance it made up 135 million NOK in 2018 (138 million in 2019-kroner) and 185 million NOK in 2019 (Det Kongelige Finansdepartement 2018b, 434; Det Kongelige Finansdepartement 2019, 314).

5.5 Reduced tax for private use of EV company cars

The Ministry of Finance have provided calculations for the years 2014-2019 (Det Kongelige Finansdepartement 2015b, 353; Det Kongelige Finansdepartement 2016, 328; Det Kongelige Finansdepartement 2017b, 360; Det Kongelige Finansdepartement 2018b, 434; Det Kongelige Finansdepartement 2019, 314).

Estimated loss of government revenue due to reduced tax for private use of EV company cars for 2010-2013 have been calculated based on an average of the revenue loss per EV registered for 2014-2017. The calculations are based on the years 2014-2017 as the rules for this tax scheme changed in 2018 (Akerbæk 2018). A weakness with this estimation is that it has been assumed that both the share of EVs as company cars, and the private use of these, has constituted a constant share of the number of

EVs registered between 2010-2017. As the yearly estimated loss is small, this simplification will not have serious implications for the overall analysis. The calculations done by the Ministry of Finance as well as the estimates for 2010-2013 can be found in Table 5.10.

Table 5.10: Revenue loss due reduced tax for private use of EV company cars, in million NOK

	2010	**2011**	**2012**	**2013**	**2014**
Revenue loss	3.6	6.8	13.9	30.8	110
Revenue loss in 2019-kroner	4.3	8.1	16.4	35.6	124.5
	2015	**2016**	**2017**	**2018**	**2019**
Revenue loss	85	125	220	150	200
Revenue loss in 2019-kroner	94.2	133.6	231	153.3	200

Sources: see main text above.

5.6 Road use tax

The Ministry of Finance have not provided calculations for loss of road use tax. EV owners do not pay this tax as it is levied through the purchase price of conventional fuel (Akerbæk 2018). The rate of the road use tax (NOK per litre) depends on the fuel type, as diesel and gasoline are taxed with different rates (Det Kongelige Finansdepartement 2010, 32; Det Kongelige Finansdepartement 2011, 36; Det Kongelige Finansdepartement 2012, 35; Det Kongelige Finansdepartement 2013, 38; Det Kongelige Finansdepartement 2014b, 37; Det Kongelige Finansdepartement 2015b, 38; Det Kongelige Finansdepartement 2016, 37; Det Kongelige Finansdepartement 2017b, 37; Det Kongelige Finansdepartement 2018b, 38; Det Kongelige Finansdepartement 2019, 34).

The fact that biofuel also has been taxed, and the frequent changes of the tax scheme, makes it challenging to find an estimate for the tax rate. In Table 5.11, the tax rates for gasoline, diesel and biofuel (bioethanol and biodiesel) are provided for the years 2015-2018. It was decided to base the estimate on the tax scheme during these four years, due to the complex and rapid changes in the rules prior to 2015. From 2015-2018, biofuel[2] was taxed equal as gasoline and diesel. Table 5.11 displays the average road use tax rate given equal use of gasoline/bioethanol and diesel/biodiesel. In the last row this is converted to 2019-kroner. The estimated rate for all years are close to 4.5 NOK, which is the rate chosen as an estimate for the years 2010-2019.

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[2] In Norway there has been a requirement to blend in biofuel with traditional fuel (diesel and gasoline) since 2009. (Finansdepartementet 2015, 74). The tax rate applies to fuel within this required share.

Table 5.11: Road use tax rate, NOK per litre from 2015-2018

	2015	**2016**	**2017**	**2018**
Gasoline/bioethanol	4.87	4.99	5.19	5.17
Diesel/biodiesel	3.36	3.44	3.8	3.75
Average (equal share of diesel and gasoline)	4.12	4.22	4.50	4.46
Average in 2019-kroner	4.56	4.51	4.72	4.56

Sources: Det Kongelige Finansdepartement 2015b, 38; Det Kongelige Finansdepartement 2016, 37; Det Kongelige Finansdepartement 2017b, 37; Det Kongelige Finansdepartement 2018b, 38.

To calculate the revenue loss, assumptions needed to be made on fuel economy (litre per km driven) as well as yearly mileage for EVs. These assumptions have already been discussed in chapter 3.3 and 3.5. Therefore fuel economy of 0.036 litre per kilometre and yearly mileage of 12 000 km per EV were assumed. This results in a yearly revenue loss of 1 944 NOK, in 2019-kroner, per EV. Numbers of EVs registered each year are displayed in Table 5.1. Multiplied with the estimated loss per EV of 1 944 NOK this gives total yearly loss, which can be found in Table 5.12.

Table 5.12: Revenue loss due to EVs being exempt of road use tax, in million NOK (2019-kroner)

	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Loss of road use tax	4	7.6	15.6	34.5	75.1	134.4	189.6	270.2	379.8	506.8

Sources: see main text above.

5.7 Road toll

Loss of revenue due to road toll exemption is based on calculations from the Norwegian Public Roads Administration for the years 2011-2018 (Statens Vegvesen 2020a, 14-15). They have calculated the loss of revenue based on an assumption that most crossings of EVs would have occurred without the exemptions in place. It is likely that this number would have been lower, at least in the bigger cities where public transport is an option. They therefore acknowledge that the method used might overestimate the revenue loss. Further on, they use average revenue per crossing in the different toll road projects to calculate the value of the EV crossings (15). A weakness with the data from the Norwegian Public Roads Administration is that they do not distinguish between passenger vehicles and other vehicles in their estimations. As this thesis only looks at passenger vehicles, using this data could lead to overestimating the cost of the policy.

The value on revenue loss for 2010 is missing in the cited report. Estimated annual loss per EV registered has steadily increased from 2011 to 2018. Therefore, loss of revenue per vehicle in 2011, and not the average over the years, was used when estimating the loss in 2010.

Table 5.13: Numbers on EVs an road toll

	2010	**2011**	**2012**	**2013**	**2014**
Number of EV crossings in million	-	0.4	1.4	3.6	11
Loss of revenue per EV crossing in NOK	-	25	21	22	18
	2015	**2016**	**2017**	**2018**	**2019**
Number of EV crossings in million	22.4	34.9	47.5	66.4	88.6
Loss of revenue per EV crossing in NOK	17	16	17	18	18

Sources: see main text and Statens Vegvesen 2020a, 14-15.

The Norwegian Public Roads Administration have not yet published numbers for 2019. Several toll roads started charging EVs in 2019 (Statens Vegvesen 2020a, 5). EVs cannot be charged more than 50 percent of what a comparable ICEV would pay in road toll (Norges Automobil-Forbund 2018). The Norwegian Public Roads Administration have provided the number of EVs passing through toll roads for the years 2011-2018 (see Table 5.13) (Statens Vegvesen 2020a, 14). This has been used to calculate loss of revenue per EV crossing. The estimate for 2019 is based on the assumption that loss per EV crossing would be half of that in 2018. In 2018, this number was approximately 18 NOK (see Table 5.13, where the amount has been rounded to the closest whole NOK). This assumption is likely to lead to a smaller estimate than what is correct as far from all toll roads started charging EVs in 2019 (Norges Automobil-Forbund 2018). Data for numbers of EVs registered at the end of the year was used. Further it was assumed that crossings per car registered was the same in 2019 as in 2018, which is estimated to be almost 340 crossings per vehicle. This assumption, all else equal, is likely to lead to a larger estimate than what is correct, as it is likely that crossings per EV fell with the introduction of toll road payments, as some might have substituted towards public transportation or realised fewer travels with an EV. The data from the Norwegian Public Roads Administration as well as the calculations for 2010 and 2019 can be seen in Table 5.14.

Table 5.14: Revenue loss due to road toll exemption, in million NOK

	2010	**2011**	**2012**	**2013**	**2014**
Revenue loss	5.3	10	30	80	200
Revenue loss in 2019-kroner	6.4	11.9	35.4	92.4	226.4
	2015	**2016**	**2017**	**2018**	**2019**
Revenue loss	370	550	790	1 200	800.7
Revenue loss in 2019-kroner	410	588	829.5	1 226.4	800.7

Sources: see main text and Statens Vegvesen 2020a, 14-15.

5.8 Free boarding on ferries

Calculations on loss of ferry fare for EVs for the years 2014-2017 and for 2019 have been provided by the Norwegian Public Roads Administration, and have been referred to by the Ministry of Transport (Det Kongelige Samferdselsdepartement 2015, 214; Det Kongelige Samferdselsdepartement 2016, 234; Det Kongelige Samferdselsdepartement 2017, 215; Det Kongelige Samferdselsdepartement 2019, 217).

Estimates for 2010-2013 and 2018 have been calculated based on the revenue loss for the other years. The revenue loss for the years 2010-2013 is estimated based on average yearly loss per EV registered between 2014-2017. As the rules changed in 2018, when ferries could charge EVs up to 50 percent of a comparable ICEV, the estimation for 2018 is based on loss per registered EV in 2019. The estimates together with the values from the Norwegian Public Roads Administration can be found in Table 5.15. It is uncertain how the Norwegian Public Roads Administration calculated loss of revenue due to free boarding on ferries, but it is likely that the effects of reduced demand due to higher prices, as explained for toll roads, also applies in this case. If this is not accounted for, the numbers can be overestimated.

Table 5.15: Revenue loss due to free boarding on ferries, in million NOK

	2010	**2011**	**2012**	**2013**	**2014**
Revenue loss	0.3	0.6	1.3	2.8	6
Revenue loss in 2019-kroner	0.4	0.7	1.5	3.2	6.8
	2015	**2016**	**2017**	**2018**	**2019**
Revenue loss	12	15	20.9	33.7	45
Revenue loss in 2019-kroner	13.3	16	21.9	34.5	45

Sources: see main text above.

5.9 Subsidies to charging stations

As mentioned in chapter 2.2, Enova and previously Transnova, have been in charge of giving out subsidies to charging infrastructure projects since 2011 (Figenbaum et al. 2019, 6). Data on the amount of subsidies given out by Transnova before becoming part of Enova in 2015 has not been found. The fact that the company does not longer exist has made this challenging. The overall value from grants to fast charging stations from Enova for the years 2015-2019 has been included. Enova have had two different subsidy schemes in the relevant time period, a competition-based from 2015-2016 and a rights-based from 2017 to 2019 (Enova 2020a; Enova 2020b; Departementene 2019, 73-74).

Data for a project administered by the Norwegian Environment Agency called ”Klimasats”, for the years 2016-2019 has also been included (Miljødirektoratet 2020c). The Agency have given out subsidies to municipalities that applied for grants to charging infrastructure projects from 2016 (Departementene 2019, 38). As the search engine on their page does not allow to search specifically for subsidies to EV charging stations, the numbers presented may not represent a complete list of relevant projects, and a few irrelevant projects may be included.[3]

Table 5.16: Grants to charging infrastructure projects, in million NOK (2019-kroner)

Subsidy scheme	**Value of grants**
Enova competition-based, 2015-2016	54.4
Enova rights-based, 2017-201	20.3
Klimasats, 2016-2019	49.5
In total	124.2

Sources: Enova 2020a; Enova 2020b; Miljødirektoratet 2020c.

The list presented do not represent a complete list of subsidies to deployment of charging stations between 2010-2019. Aside from missing data from Transnova, there exist other subsidy schemes which have been excluded. One example are subsidies administered by regions or municipalities, for example for deployment of normal chargers in housing cooperatives (Figenbaum et al. 2019, 6). Although not being an exhaustive list, the grants identified will be included in the following analysis. The amount given out through the programs outlined are shown in Table 5.16. If the total amount of subsidies to charging stations is distributed through the ten years studied, the annual subsidy per EV

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[3] Projects categorised as “lade tjeneste” are the ones included. Projects that have been labelled as cancelled have been excluded.

registered is found to be 149 NOK.

5.10 Other EV benefits

The Institute of Transport Economics performed an anaylysis on the cost of free parking on municipal parking spaces for EVs in 2014 (Fearnley 2014). Here, loss of revenue is estimated to around 100-120 million NOK in 2014. This amount is assumed to increase substantially with an increasing number of EVs (9). At the time of the report there were 30 000 EVs registered (3). The Ministry of Transport referred to the research done by the Institute of Transport Economics in 2018, and stated that given the same assumptions, and with the number of EVs as of June 2017 (118 600 vehicles), the estimated revenue loss would be 400 to 470 million NOK a year. However, they acknowledged the uncertainties with the original estimations and that the underlying assumptions had changed since 2014 (Det Kongelige Samferdselsdepartement 2018, 16). Based on there only being available calculations for one year, the costs of this benefit will not be included in the analysis.

Calculations on the cost of free charging of EVs have not been found. It appears common to exclude free charging in research on the cost and benefits of the EV policy. For example, the Norwegian Environment Agency did not include this as a benefit when calculating the value of different use related incentives (Birkeli et al. 2016, 53). The cost of free charging will therefore be excluded. This can be done with little implications, as it is expected to constitute a rather small amount.

The benefit of getting access to bus lanes will be excluded for two reasons. It is difficult to estimate what this benefit is worth, and it does not lead to loss of revenue, and is thus not a financial cost for the government. The cost of giving access to the bus lane is rather distributed along those using public transport who experience increased travel time due to congestion in the bus lane. Access to the bus lane is, however, still an economic benefit as it leads to time saved for the users, which is equivalent to money (Aasness and Odeck 2015, 4).

Since 2019, drivers with license class B (passenger car, etc.) have been allowed to also drive electric vans class C1, that are up to 4 250 kg (Norsk Elbilforening 2019). As for access to bus lane, this is a benefit that does not induce a loss of government revenue. It is therefore excluded from the analysis.

Since 2018, when buying a zero emission van, the buyer has received fiscal compensation when scrapping the fossil van the zero emission van is meant to substitute (Norsk Elbilforening 2019). This cost will not be included as only passenger vehicles are analysed in this thesis.

6. Results

This chapter will present the results of the calculations on lifetime emissions discussed in chapter 3, as well as the estimations performed in chapter 5 on annual revenue loss as a result of the EV policy. These results, will then be put together to find an estimate on the cost-effectiveness of the policy, presented as NOK per tonne CO_2 reduced.

6.1 Benefit: CO_2 reductions

It has been found that an EV emits 9.45 tonne CO_2 in the production phase, while corresponding emissions for the ICEV are 5.85 tonne CO_2. If these emissions are distributed over the lifetime of the vehicle of 180 000 kilometres, it is found that the production phase leads to CO_2 emissions of 52.5 grams per km for the EV, and 32.5 grams per km for the ICEV. When adding WTW emissions of 108 grams CO_2 per km, total emissions for the ICEV will be 140.5 grams CO_2 per km. The difference between the two vehicles is then 88 grams CO_2 per km. This difference represents emissions reduced per kilometre driven by an EV, when the degree of substitution between EVs and ICEVs is not accounted for.

To find yearly emission reductions per EV, this estimate needs to be multiplied by kilometres driven per year. Given 80 percent degree of substitution and yearly mileage of 12 000 km, this amounts to 9 600 kilometres per EV per year. Given these assumptions, an EV will on average be responsible for a reduction of 0.8448 tonne CO_2 each year. This amount multiplied by the number of EVs registered each year, gives total yearly emission reduction as a result of EVs. These estimates can be found in Table 6.1, where the values have been rounded to the closest whole tonne.

Table 6.1: Yearly emission reductions as a result of the number of EVs, in tonne CO_2 reduced

	2010	**2011**	**2012**	**2013**	**2014**
Yearly CO_2 reductions	1 747	3 302	6 785	15 012	32 653
	2015	**2016**	**2017**	**2018**	**2019**
Yearly CO_2 reductions	58 404	82 395	117 413	165 033	220 233

For the year 2019, CO_2 reductions as a result of the number of EVs constituted 220 233 tonne. For the entire time period, the EV park has led to CO_2 reductions of a total of 702 977 tonne.

6.2 Cost: loss of government revenue

Table 6.2 displays annual cost of the EV policy, in 2019-kroner, resulting from the different tax exemptions, as well as subsidies to charging stations. The estimated annual cost of the policy has increased from 48.3 million NOK in 2010, to 5 882 million, or almost 5.9 billion NOK in 2019.

Table 6.2: Total yearly value of the different EV benefits, in million NOK (2019-kroner)

	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
VAT	17.7	33.5	68.9	152.5	331.7	593.2	836.9	1 192.6	1 676.2	2 236.9
Purchase tax	9.4	17.8	36.6	81	176.2	315.2	444.6	633.6	890.6	1 188.5
Annual tax	5.7	10	20.5	44.7	97.3	178.9	260	319.4	512.7	680.2
Re-registration tax	-	-	-	-	-	-	-	-	138	185
Tax on private use of company cars	4.3	8.1	16.4	35.6	124.5	94.2	133.6	231	153.3	200
Road use tax	4	7.6	15.6	34.5	75.1	134.4	189.6	270.2	379.8	506.8
Road toll	6.4	11.9	35.4	92.4	226.4	410	588	829.5	1 226.4	800.7
Free boarding on ferries	0.4	0.7	1.5	3.2	6.8	13.3	16	21.9	34.5	45
Subsidies to charging infrastructure	0.3	0.6	1.2	2.7	5.8	10.3	14.6	20.7	29.2	38.9
In total	48.3	90.2	196.2	446.7	1 043.8	1 749.5	2 483.4	3 519	5 040.6	5 882

Table 6.3 shows annual cost per vehicle. This is a result of dividing the values from Table 6.2 on yearly number of EVs registered (see Table 5.1). Due to the method of calculation, the estimated loss per vehicle is equal through the years for the VAT and purchase tax exemptions, as well as for loss of road use tax, and subsidies to charging stations. The results show that cost per EV has stayed rather stable through the years, ranging from 22 563 NOK in 2019 to 27 004 NOK in 2014. This stability will in part be a result of the method of estimation for the VAT and purchase tax exemptions, which make up a large share of revenue loss per vehicle. Therefore, if the aim is to compare the cost of the policy through the years, not too much attention should be put on the evolution of cost per vehicle, but rather the change in overall costs, as can be seen in Table 6.2.

It is no surprise that the exemption of VAT and purchase tax constitute the largest share of the value of the EV benefits. Together they made up 13 140 NOK of the value of benefits per EV in 2019, making up 58 percent of the total subsidies. Use related benefits, here being reduced tax on private use of company cars, road use tax, road toll and free boarding on ferries, equal 5 955 NOK in 2019. Among these, road toll is the biggest contributor with 3 071 NOK. The drop from 2018, where this is estimated to 6 278 NOK per vehicle, is a result of the method of estimation, as data for 2019 has not yet been provided by the Norwegian Public Roads Administration. As several road tolls started charging EVs

50 percent of what an ICEV would pay in 2019, it was assumed that loss per EV crossing in 2019 were half of what it had been in 2018. This is a careful estimate likely to lead to underestimation of this cost, as not all road tolls introduced payment for EVs in 2019. Annual tax is also a large contributor to the size of the overall benefits with 2 609 NOK per EV in 2019.

Table 6.3: Yearly value of the different EV benefits per EV registered, NOK in 2019-kroner

	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
VAT	8 581	8 581	8 581	8 581	8 581	8 581	8 581	8 581	8 581	8 581
Purchase tax	4 559	4 559	4 559	4 559	4 559	4 559	4 559	4 559	4 559	4 559
Annual tax	2 779	2 557	2 551	2 517	2 516	2 588	2 666	2 298	2 625	2 609
Re-registration tax	-	-	-	-	-	-	-	-	706	710
Tax on private use of company cars	2 087	2 061	2 047	2 004	3 222	1 362	1 370	1 662	785	767
Road use tax	1 944	1 944	1 944	1 944	1 944	1 944	1 944	1 944	1 944	1 944
Road toll	3 078	3 039	4 408	5 200	5 857	5 930	6 028	5 968	6 278	3 071
Free boarding on ferries	190	188	187	183	176	192	164	158	176	173
Subsidies to charging infrastructure	149	149	149	149	149	149	149	149	149	149
Total per EV registered	23 367	23 079	24 426	25 136	27 004	25 305	25 462	25 319	25 803	22 563

6.3 Cost vs benefit

The aim of this thesis is to assess the cost-effectiveness of the EV policy, by finding an estimate on NOK per tonne CO_2 reduced. This is found by dividing annual costs on annual emission reductions. In 2019, cost per EV was 22 563 NOK. Divided on estimated CO_2 reductions of 0.8448 tonne per vehicle, this gives a cost of 26 708 NOK per tonne CO_2 reduced. The result for all years can be found in Table 6.4. The cost-effectiveness varies between 26 708 NOK per tonne CO_2 reduced in 2019, to 31 965 NOK per tonne CO_2 reduced in 2014. The average cost-effectiveness, when giving all years equal weight is 29 293 NOK per tonne CO_2 reduced.

Table 6.4: Cost-effectiveness of the EV policy represented as NOK per tonne CO_2 reduced, in 2019-kroner

	2010	**2011**	**2012**	**2013**	**2014**
NOK per tonne CO_2 reduced	27 660	27 318	28 913	29 754	31 965
	2015	**2016**	**2017**	**2018**	**2019**
NOK per tonne CO_2 reduced	29 954	30 140	29 971	30 543	26 708

6.3.1 Sensitivity analysis

As the cost-effectiveness of the EV policy will vary with the chosen estimate on the degree of substitution between EVs and ICEVs, results for different estimates will be provided. Results given a degree of substitution of 100, 80, 60 and 40 percent are shown in Table 6.5 for the year 2019. Cost per tonne CO_2 reduced in 2019 varies between 53 416 to 23 826 NOK, for a degree of substitution between 40 and 100 percent.

Table 6.5: Cost-effectiveness of the EV policy in 2019, for different estimates on the degree of substitution

Degree of substitution in percent	**100**	**80**	**60**	**40**
Yearly mileage in km per EV	12 000	9 600	7 200	4 800
Tonne CO_2 reduced per EV	1.056	0.8448	0.6336	0.4224
NOK per tonne CO_2 reduced	23 826	26 708	35 611	53 416

7. Discussion

To be able to discuss the results presented in the previous chapter, they need to put in a context. For example, results on emission reductions due to the number of EVs will be compared to the level of emissions from road transportation. The cost of the policy will be compared to the tax revenue related to purchase and ownership of vehicles. The cost-effectiveness will be compared to both the cost of emitting as well as cost on other environmental policy.

This chapter will also provide a discussion of elements with the EV policy that have not been the main topic in this thesis. A discussion of the implications of the waterbed argument not holding will be given. Limitations regarding the method used will also be discussed. The last section will provide policy recommendations based on the results presented.

7.1 Emissions reduced as a result of the EV policy

In 2018, emissions from road transportation were 9.1 million tonne CO_2. This made up 17.5 percent of total emissions in Norway of 52 million tonne CO_2. Emissions from passenger vehicles were 4.68 million tonne CO_2, making up 52 percent of emissions from road transportation (Miljødirektoratet 2019).

In this thesis emission reductions as a result of the number of EVs were found to be 165 033 tonne CO_2 in 2018. As a share of total emissions from passenger vehicles, this makes up 3.53 percent. As a share of emissions from road transportation the number is 1.81 percent. As a share of the total emissions of 52 million tonne CO_2, the emissions reduced made up almost 0.32 percent.

In 2017, the government set a goal of a 35 percent reduction in emissions from the transport sector by 2030 compared to 2005. In 2018, emissions from this sector was at 2005-level, which was around 16.4 million tonne CO_2 (SSB 2019b). Thereby emissions need to be 5.7 million tonne lower in the transport sector in 2030 to achieve this goal.

The results presented in this thesis can be used to assess whether a continuation of the EV policy will contribute towards reaching this goal. In 2019, 42.4 percent of new sold passenger vehicles were EVs. Overall, 142 381 new passenger vehicles were sold in 2019. The sale of new passenger vehicles has stayed rather stable the last ten years. The yearly average of new passenger vehicles the last ten years is approximately 144 000 vehicles (Hovland 2020).

Two examples will be provided to assess in what degree the EV policy can help reach the goal for 2030. The first is a situation where EV sales constitute 50 percent of new sold vehicles for the years 2020-2025. With a yearly total sale of 140 000 passenger vehicles, new EVs will constitute 70 000 vehicles annually. This gives 420 000 new EVs over the six-year period. The second is a higher estimate, in accordance with the goal of 100 percent of new passenger vehicles being EVs in 2025 (Regjeringen 2020). It is assumed that 50 percent of new vehicles are EVs in 2020, and that this share will increase by 10 percentage points each year and reach 100 percent in 2025. A yearly sale of 140 000 new passenger vehicles is still assumed. This will lead to 630 000 new EVs by the end of 2025. Given an EV park at the end of 2019 of 260 000 vehicles, the lower estimate gives 680 000 EVs at the end of 2025, while the higher estimate gives 890 000 EVs at the end of 2025. Given yearly CO_2 reductions of 0,8448 tonne per EV, the lower estimate will lead to 574 464 tonne CO_2 reduced in 2025, compared to a situation with no EVs, whereas the higher estimate gives CO_2 reductions of 751 872 tonne in 2025. These estimates are for 2025, five years away from 2030. If the EV park keeps increasing from 2025, the estimated CO_2 reductions will be even higher in 2030. Given the results in this thesis, and the assumptions on annual sales made above, a continuation of the EV policy will help contribute towards achieving the goal for CO_2 reductions in the transport sector by 2030. However, this section has not discussed at what cost. It should also be noted that the analysis look at vehicle lifetime emissions, which means that some of the emissions estimated will happen outside of Norway. Thereby emissions reduced as a result of the number of EVs is not directly comparable to the level of emissions in the Norwegian transport sector.

7.2 The cost of the EV policy

For 2019, the cost of the EV policy is found to constitute almost 5.9 billion NOK. This estimate can be compared to the level of revenue from taxes related to purchase and ownership of vehicles (motor vehicle taxes). In 2007, this was estimated to give revenue of 72 billion NOK. The revenue decreased after the financial crisis, but later increased and constituted 60 billion NOK in 2013. After 2013, the revenue has fallen again, with an annual decrease of around 2.2 billion NOK. Revenue from motor vehicle taxes was estimated to 47 billion NOK in the government's budget proposal for 2019, excluding VAT, which is a general tax. The estimate includes purchase tax, annual tax, re-registration tax and road use tax (Det Kongelige Finansdepartement 2018b, 204, 206). According to the result in this thesis, EV exemption of these taxes constitute almost 2.6 billion in revenue loss in 2019. As a share of the revenue from motor vehicle taxes they make up 5.53 percent.

To get an understanding of the size of the EV benefits, the revenue loss can also be compared the size of the National budget. For 2019, total revenue in the National budget was estimated to 1 430 billion NOK (Det Kongelige Finansdepartement 2018a). 5.9 billion NOK make up 0,41 percent of the size of the National budget, which is not an insignificant amount.

The calculation in the previous section on reduced CO_2 emissions in 2025, can be used to find a value of the revenue loss in 2025, given that the EV benefits are unchanged. The lower estimate outlined would give 680 000 EVs at the end of 2025. With yearly revenue loss of 22 563 NOK per EV in 2019 assumed to also apply in 2025, this will give total annual revenue loss of over 15 billion NOK (in 2019-kroner). The higher estimate, with 890 000 EVs at the end of 2025, will mean a total annual revenue loss of just above 20 billion NOK (in 2019-kroner) in 2025.

7.3 The cost-effectiveness of the EV policy

In this thesis, the cost of the EV policy was found to be 26 708 NOK per tonne CO_2 reduced in 2019. As mentioned in chapter 1.3, there exist research on the cost of EV policy both in Norway, and in other countries. It can therefore be interesting to compare the result in this thesis with estimations conducted by others.

Bjertnæs (2016) found the societal cost of the EV policy to be 5 600 NOK per tonne CO_2 reduced. When also including emissions from production of the vehicles, this estimate increased to between 18 600-56 000 NOK per tonne CO_2 reduced.

The Norwegian Environment Agency calculated the societal cost of phasing in EVs from 2016-2030 (Birkeli et al. 2016). They looked at four different scenarios for the speed of phasing in EVs towards 2030, and found the costs to lie between 600 to 1 100 NOK per tonne CO_2 reduced. Only emissions from combustion of fuel was included.

Skonhoft and Skarstein (2019) found the cost of the policy to be around 10 000 NOK per tonne CO_2 reduced in 2018. Here, government revenue loss due to tax exemptions were included in the analysis. Only TTW emissions from ICEVs were assessed.

Thorne and Hughes (2019) used data from different Canadian provinces to evaluate EV subsidies in terms of cost per tonne of removed CO_2 emissions, to see how much the cost-effectiveness varied between provinces. They found that given a tax rebate of \$5 000 CAD, the cost-effectiveness varied between around \$200-\$2 300 CAD per tonne CO_2 reduced. Given currency rates as of 9 June 2020, this constitutes almost 1 400 NOK and 16 000 NOK, respectively.

Shafiei et al. (2018) analysed the economic consequences of introducing policies aimed at promoting EVs in Iceland, through a dynamic simulation-based analysis. They calculated the cost-effectiveness of emission reductions and found the measures “BAU + tax” and “subsidy + tax” to be the most cost-effective at reducing CO_2, with a cost of \$-16 USD and \$188 USD per tonne CO_2 reduced respectively. The “subsidy” scenario was found to be the least cost-effective option with a cost of \$478 USD per tonne CO_2 reduced. Given currency rates as of 9 June 2020, this constitutes almost 4 500 NOK.

The research conducted in this thesis is not directly comparable to research done on the societal cost of the policy. In such analyses tax exemptions are excluded as a cost. As this represents a monetary transfer between actors, it is not regarded as a cost for the society. In that sense, it is no surprise that the estimate in this thesis is higher than the estimate presented by The Norwegian Environment Agency.

The estimates in this thesis lie over the estimate found by Skonhoft and Skarstein (2019). The analysis in this thesis is more comprehensive, where also emissions from production of the vehicle and the fuel is included. The estimates in this thesis also lie over the estimated cost-effectiveness for EV subsidies in Canada and Iceland, conducted by Thorne and Hughes (2019) and Shafiei et al. (2018), respectively.

The result can also be compared to the cost of other environmental policies. As mentioned in chapter 2.1, different government agencies examined the possibilities of emission reductions in ESD-sectors of 50 percent in 2030 compared to 2005 in the report ”Klimakur 2030” (Miljødirektoratet 2020d). In the report, they put different measures for CO_2 reductions in three cost categories depending on the societal cost of the measure. The cost categories are $<$ 500, 500 - 1 500 and $>$ 1500 NOK per tonne CO_2 reduced.

The measures identified are calculated in relation to a baseline scenario. The baseline scenario represents what would happen with today’s instruments in place, as well as taking factors such as population development and economic growth into consideration (Miljødirektoratet2020d, 6).

Regarding EVs, the baseline scenario is that 62.5 percent of new passenger vehicles sold will be EVs in 2025 (Miljødirektoratet 2020b, 581). The measure assessed in the report is the goal of all new sold passenger vehicles being electric by the end of 2025. The costs and emission reductions identified will thereby be in addition to those assumed according to the baseline scenario (580). They find this measure to lie in the middle cost category of 500 - 1 500 NOK per tonne CO_2 reduced. The potential emissions reductions between 2021-2030 are found to be 2.54 million tonne CO_2 (Miljødirektoratet 2020b, 54).

For comparison, measures aimed at reaching the target of zero growth in passenger car traffic (see chapter 2.1) are put in the middle cost category as well, with a cut potential of 0.76 million tonne CO_2 reduced for the years 2021-2030 (54).

Increased use of advanced biofuel, also called second generation biofuel, is the measure analysed for road transportation with the largest cut potential of 2.55 million tonne CO_2 reduced between 2021-2030. This measure lies in the upper cost category (54).

The estimated cost-effectiveness of the EV policy in this thesis is higher than the cost of the measures outlined in "Klimakur 2030". The result in this thesis is however not directly comparable to the costs presented in "Klimakur 2030" as financial costs are not included. It is therefore difficult to assess whether the EV policy is an expensive measure to reduce emissions, when comparing it to other climate policies.

The cost of the EV policy, as NOK per tonne CO_2 reduced, can also be compared to the cost of emitting CO_2. EV benefits can be regarded as an abatement subsidy. If a tax is levied on CO_2, producers will reduce emissions as long as the abatement cost is lower than the tax. Adjustment will therefore happen where the marginal cost of abatement is equal to the tax (Perman et al. 2011, 197). According to economic theory, cost efficiency requires that the marginal abatement cost is equal for all polluters (198). Therefore, it is interesting to see how the abatement cost for CO_2 reductions as a result of the EV policy, compares to the cost of abatement for other measures.

The cost of the Norwegian EV policy is high compared to the quota price in the EU ETS. At the end of May 2020, the quota price was 21.4 EUR per tonne CO_2 emitted (Energi og Klima 2020). According to the exchange rate as of 3 June 2020, this constitutes almost 228 NOK. In Norway there is a tax on emitting CO_2. In 2019, the CO_2 tax per litre gasoline was 1.18 NOK. According to the Ministry of Finance, the tax on gasoline constituted a tax of 500 NOK per tonne CO_2 in 2019 (Det Kongelige Finansdepartement 2019, 56). This is above the quota price in the EU ETS, but far below the cost for CO_2 reductions through the EV policy. The cost of the EV subsidies were 26 708 NOK per tonne CO_2 reduced in 2019. If gasoline was taxed accordingly, this would constitute a tax per litre of approximately 63 NOK in 2019.

7.4 Implications of the waterbed argument on the results

The waterbed argument was discussed in chapter 3.7. The validity of this argument decides whether it is relevant to look at the alternative use of Norwegian electricity when assessing the climate potential of EVs. To underline the importance of the EU ETS system in the debate on EVs, an example for 2019 will be provided where electricity used to power EVs where rather exported to European countries. Here, it is assumed that the waterbed argument does not apply. Calculations by the Norwegian Water Resources and Energy Directorate (NVE) explained in chapter 3.7 will therefore be used, where they found that in 2025, 9.5 TWh export of Norwegian electricity would lead to a total of 5 million tonne CO_2 reduced in Europe annually (Krogvold et al. 2019, 8). Given fuel economy of 0.13 kWh per km (Woo, Choi, and Ahn 2017, 349) and yearly mileage of 12 000 km, an EV uses on average 1 560 kWh a year. Given EVs registered of 260 692 at the end of 2019, this gives total electricity use of around 0.4 TWh. Given the estimates from NVE, the exportation of 0.4 TWh to Europe will lead to emission reductions of 214 042 tonne CO_2 annually. This is slightly below the estimated emission reductions of 220 223 tonne CO_2 as a result of the number of EVs in Norway in 2019. In this example, the alternative use of Norwegian electricity is an equally good environmental policy, given that it is irrelevant where the emission reductions occur. As simulations for the year 2025 is used on the year 2019, the calculation presented here should be interpreted as an informal calculation, meant as a simple illustrations to show implications of the waterbed argument not holding.

7.5 Other implications of the EV policy

Distributional effects of the EV benefits have not been addressed in the analysis in this thesis. As mentioned in chapter 1, the wealthier households have in a large degree been the recipients of the EV subsidies (Fjørtoft and Pilskog 2020). The results in this thesis indicate that every EV owner has received around 25 000 NOK (in 2019-kroner) on average in indirect subsidies each year the last ten years. One of three stated main goals of the Norwegian tax system is to influence the distribution of income and wealth between people (Det Kongelige Finansdepartement 2015a, 26). The EV subsidies is then directly in conflict with the principle of distribution of wealth, when this amount mainly goes to wealthier households. On the other hand, Statistics Norway mention that as more EVs end up in the second-hand market, the tax exemptions will indirectly benefit households without a high income, as the price on second-hand vehicles is influenced by tax exemptions on the purchase of new vehicles. Thereby, introducing VAT for new EVs, would likely lead to an increase in the price of EVs on the second-hand market (Fjørtoft and Pilskog 2019). Second-hand owners will experience the same use related benefits, as well as exemption of annual tax. In this manner, a second-hand market for EVs will lead to the EV policy also benefiting the not so rich households.

In the analysis, only the climate potential of EVs regarding CO_2 emissions has been assessed. The use of an EV does not lead to local pollution. According to the Institute of Transport Economics, marginal external costs of local pollution due to the use of ICEVs constitute a significant amount in cities with a population of over 100 000. However, this constitute a small cost in rural places or in towns with up until 100 000 inhabitants (Fridstrøm 2019a, 32). EVs thereby have a positive effect for the local environment in cities. As this benefit is not included in the analysis on the cost-effectiveness of the EV policy, the overall benefits of EVs compared to ICEVs will be underestimated. On the other hand, as the low use related costs of EVs leads to increased use of private passenger vehicles, other negative external effects of vehicle use, such as congestion and accidents will increase with an increasing number of EVs. These effects have neither been included in the analysis.

7.6 Limitations with the research conducted in this thesis

There are some limitations regarding the method used in this thesis, that will have implications for the presented results. Some examples will be mentioned here.

To find the revenue loss of the EV policy, the scenario looked at has been the hypothetical situation where EVs were taxed according to the rules for ICEVs. If EVs were taxed, the number of EVs would have been considerably lower than it is today. One can argue that most of these EVs would have been replaced by an ICEV. It is however likely that for some of the EVs purchased, an ICEV would not have been an option to the consumer. Thereby the revenue loss will in some extent be overestimated.

The assumptions and simplifications from the life cycle analysis have implications for the estimated climate potential of EVs. Among these are the assumptions that yearly mileage for EVs, as well as the degree of substitution between EVs and ICEVs, have been constant through the period studied. These simplifications make comparison of the cost-effectiveness between years less interesting.

To asses the climate potential of EVs, lifetime emissions for a compact vehicle have been quantified, as a representative of an average EV. It would have been interesting to look at the composition of the EV park over the years regarding the different segments. Research done by Woo, Choi, and Ahn (2017) indicate that WTW emissions from ICEVs vary with vehicle segment, and in general the bigger the vehicle, the larger the emissions. Ellingsen, Singh, and Strømman (2016) found that emissions from the production phase of EVs increases with the size of the vehicle. Based on this, Tesla vehicles, that are quite heavy, will all else equal, lead to higher emissions in the production phase than the compact vehicle of around 1 500 kg which has been the representative of an average EV in this thesis.

Number of EVs registered at the end of the year has been used an estimate for vehicles during the whole year. This assumption will lead to overestimating the CO_2 reductions related to EVs. It also leads to overestimation of the loss of road use tax, as this depends on total kilometres driven by EVs.

The calculations on the revenue loss have mostly been based on estimates provided by the Ministry of Finance and the Norwegian Public Roads Administration. It is uncertain how detailed these estimations are. The original calculations for loss of annual tax performed in this thesis, which are based on the tax rate and vehicles registered, are very similar to the calculations by the Ministry of Finance. This indicates that the estimates from the Ministry of Finance are quite detailed.

A weakness with the data from the Ministry of Finance and the Norwegian Public Roads Administration is that they do not distinguish between passenger EVs and other vehicles. Still, passenger vehicles make up a large share of EVs in the Norwegian market (SSB 2020b). The original calculations for loss of annual tax were similar to the estimates from the Ministry of Finance, which is a sign that the simplification of only looking at passenger EVs did not have much implications for the cost analysis.

Estimates on the cost of the policy lack for some of the EV benefits. For example, the list presented on subsidies to charging infrastructure during the ten years studied is not complete. For some of the EV benefits, calculations lack for certain years. The loss of revenue for the years missing has been estimated based on the calculations for the other years. It would have been preferable to have calculations for all years. Especially for loss of road toll, it would have been beneficial to have an estimate provided by the Norwegian Public Roads Administration for 2019, as this make up a large share of the value of the EV benefits.

7.7 Policy recommendations

The current government has promised to keep the EV benefits in their present form until the end of 2021 (Norsk Elbilforening 2019). What happens after 2021 is therefore uncertain, but Norwegian politicians are increasingly open to change the EV subsidy regime (NTB 2018; Gilbrant 2020).

A goal from the “National Transport Plan” (2014-2023 and 2018-2029) is zero growth in passenger travels by car. This goal concerns transport around cities, meaning that the growth in travels are to be done by public transport, or by walking or cycling (Regjeringen 2020). The EV policy, which induces increased use of cars, is then in conflict with this goal.

The analysis in chapter 6.3.1 shows the importance of the degree of substitution on the cost-effectiveness of the policy. Cost per tonne CO_2 reduced in 2019 varies between 53 416 to 23 826 NOK, for a degree of substitution between 40 and 100 percent. One could argue that policy aimed at increasing the degree of substitution should be implemented. The policy should be designed in a way so that EVs become an actual substitute for ICEVs, rather than a substitute for public transportation, cycling or lead to the realisation of travels that would not have occurred in the absence of EVs. A way to ensure this, is to increase the cost on the use of EVs. Today, these costs are practically zero. Given basic economic theory, lower prices will lead to increased use of a good. It should therefore not come as a surprise that private car use increases when consumers go from ICEVs to EVs (Stræde and Ulven 2017, 57).

The argument of increasing the use related costs is in line with what has been suggested by the Green Tax Commission, which recommended that use related taxes for EVs should be set according to the marginal external cost. As the marginal external costs of the use of EVs are lower than for ICEVs, these use related taxes should be lower for EVs than for ICEVs (Finansdepartementet 2015, 19).

Use related costs for EVs have increased the last years. Some road tolls, especially in the Oslo area have started charging EVs. Free parking and charging have been removed several places (Norsk Elbilforening 2019). Still, EVs are exempt of the road use tax as this is part of the fuel tax. The road use tax is meant to correct for external costs of vehicle use, such as accidents and road wear (Fridstrøm 2019c, 4). As it is part of the fuel tax, changes in the tax regime will have to be implemented for EVs to be levied this tax. One idea could be to include road use tax when collecting insurance payment, which has already been done with the annual tax. The tax payments would thereby be based on kilometres driven stated in the car insurance (SSB 2019a).

A way to ensure that vehicles pay for the external costs they inflict, is so-called marginal cost road pricing (MCRP). With a global satellite navigation system (GNSS), the technological barriers to implement a system close to MCRP is removed (Fridstrøm 2019c, 9). Still, there are some issues regarding privacy and the possible manipulation of the system, which can make implementation of such a system challenging (Oslo Economics 2019, 35; Fridstrøm 2019a, 67). The feasibility of such a system will not be further discussed, but recommended reading is Fridstrøm (2019) if this is a subject of interest.

8. Conclusion

This thesis has assessed the cost-effectiveness of the Norwegian EV policy, by finding an estimate on NOK per tonne CO_2 reduced for the years 2010-2019. Revenue loss for the different EV benefits has been quantified, mostly based on calculations by the Ministry of Finance and the Norwegian Public Roads Administration. Original calculations were performed for revenue loss of annual tax and road use tax. Results from life cycle analyses of EVs and ICEVs were used to find annual emission reductions when replacing an ICEV with an EV. This was based on vehicles in the compact segment, which worked as a representative of an average passenger vehicle.

The cost of the policy was then set up against emission reductions as a result of the number of EVs. Given that 80 percent of kilometres driven by an EV replaces kilometres taken by an ICEV, the cost of the EV policy is found to constitute 26 708 NOK per tonne CO_2 reduced in 2019. The estimate on the cost-effectiveness is sensitive to the chosen degree of substitution between EVs and ICEVs. For 2019, cost per tonne CO_2 reduced varies between 53 416 to 23 826 NOK, for a degree of substitution between 40 and 100 percent.

Compared to the quota price in the EU ETS, of almost 228 NOK per tonne CO_2 as of May 2020, the cost of reducing emissions through the EV policy is high. The Norwegian CO_2 tax on gasoline constituted 500 kroner per tonne CO_2 in 2019. This is above the quota price in the EU ETS, but far below the cost for CO_2 reductions through EV subsidies.

In Norway, EVs emit less CO_2 than comparable ICEVs over the vehicle lifetime. However, regarding other negative externalities related to vehicle use, such as congestion and accidents, EVs perform no better than ICEVs. With extensive EV benefits in place, the EV policy will lead to increased use of passenger vehicles. As EVs are exempt of most taxes, the negative externalities of vehicle use are not internalised with today's policies. Changes in the EV policy, which increases the use related costs of EVs, should therefore be implemented.

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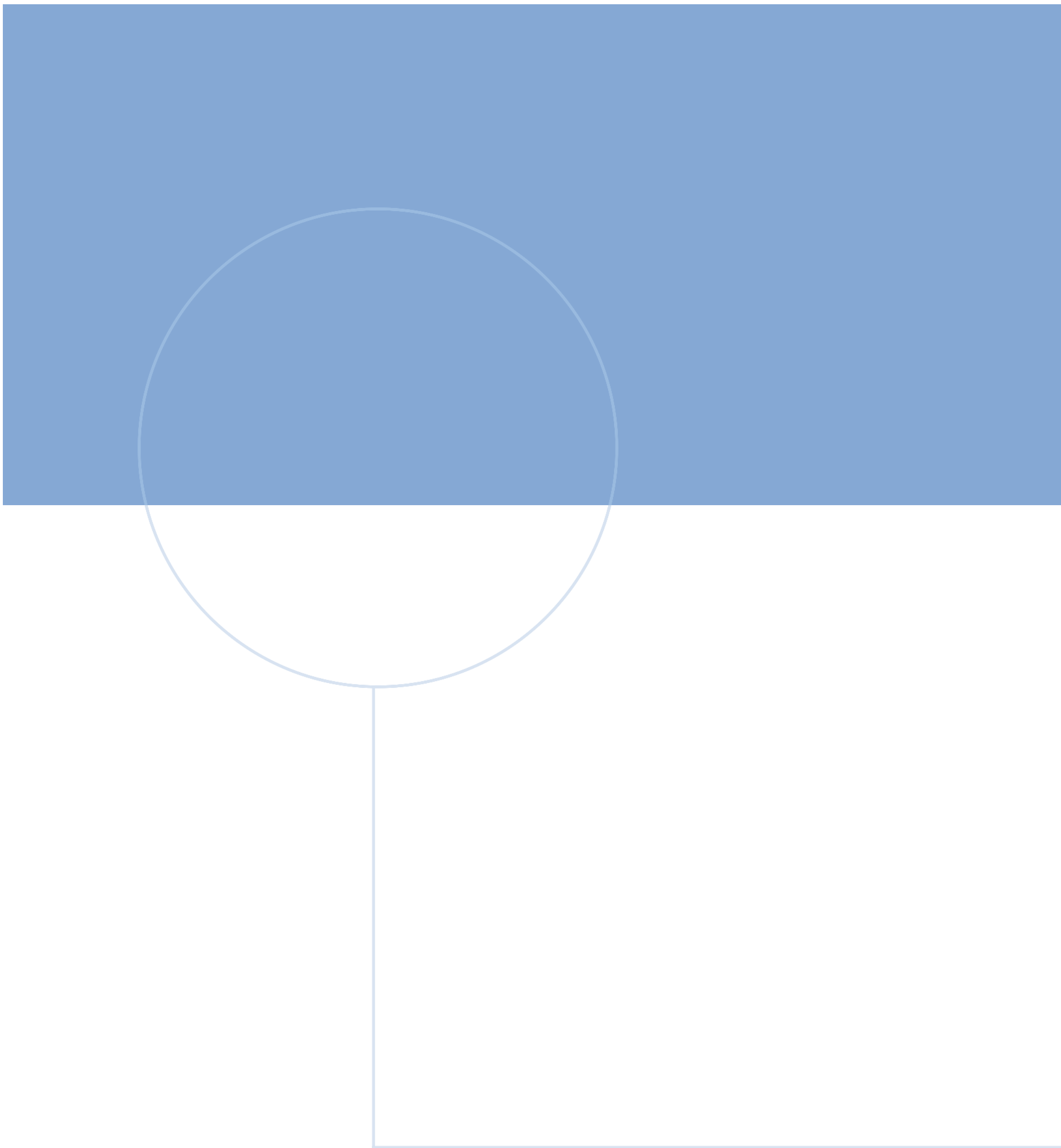

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