TØI report 1756/2020

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From Market Penetration to Vehicle Scrappage

The Movement of Li-Ion Batteries through the Norwegian Transport Sector

TØI-rapport
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Sammendrag:

Denne rapporten analyserer mulighetene for å nå kjøretøymålene i Nasjonal Transportplan om at det bare skal selges nullutslipps kjøretøy i personbil, lette varebiler og bybuss segmentene i 2025, og bare selges nullutslipps tunge varebiler og henholdvis 50% og 75% nullutslipps lastebiler og langdistansebusser i 2030. Kraftige virkemidler vil bli nødvendig. Personbilmålet er mest krevende pga. stor variasjon i brukerpreferanser. Varebil- og bussmålene for 2025 ser krevende ut, men kan være oppnåelige da kommende kjøretøymodeller i stor grad matcher behovene. Målet for tunge varebiler i 2030 vil trolig kunne oppnås da de ligger 5 år etter utviklingen til de lette. Målene for lastebiler og langdistansebusser er mer usikre da nullutslippsvarianter av slike kjøretøy ikke finnes i serieproduksjon enda. I disse segmentene kan hydrogen få en viktig rolle. Utviklingen i salget av elpersonbiler vil medføre ett estimert behov for å resirkulere 0.6 GWh Li-Ion batterier i 2025 og 2.2 GWh i 2030.

Summary:

This report analyses the potential for reaching the National Transport Plan targets of only selling zero-emission cars, small light commercial vehicles and city buses in 2025, and zero-emission large vans in 2030, along with 50% of trucks and 75% of long-distance buses. Strong measures will be required. The passenger car target is demanding due to the wide user preference variation. The city bus and small light commercial vehicle targets seem attainable, with technology developments so that more needs can be met. The 2030 heavy van target is within reach as they lag light van development by 5 years. The 2030 truck and bus targets are uncertain as no serial production is yet in place. Hydrogen may play a key role for long-distance heavy-duty applications. Sales of passenger battery electric cars will lead to a need to recycle 0.6 GWh Li-Ion batteries in 2025 and 2.2 GWh in 2030.

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Preface

The transport sector accounts for around 30 per cent of greenhouse gas emissions in Norway, around 21 per cent of EU greenhouse gas emissions and around 23 per cent of energy-related CO_2 emissions globally. At the same time, there is strong growth in the transport of people and goods in Norway and globally. It is therefore crucial to reduce global emissions from the transport sector to reach international climate target goals, and to utilize resources in an efficient manner.

Norway has ambitious targets for conversion to zero-emission vehicles. The Government has set the following objectives in National Transport Plan 2018-2029 (Report St. 33 2016-2017):

- By 2025, all new passenger cars, new light vans and new city buses will be zero-emission vehicles
- By 2030, all new heavier vans, 75 percent of new long-distance buses, and 50 percent of new trucks will be zero-emission.

Electrification of the vehicles (battery or hydrogen as well as plug in hybrids) is important to achieve the objectives. Norway is on its way, but there are many barriers to a full-scale conversion to zero emissions. The Norwegian materials industry organized in the EydeCluster wants to be at the forefront of recycling battery materials and needs to know how large volumes of batteries that will be available for recycling when these electrified vehicles have reached their end of life, and when these volumes starts to ramp up. They therefore wanted to study the market, technology and policy developments for battery electric passenger cars, light and heavy vans, city and long distance buses and trucks, and when large enough battery volumes to warrant investments in battery recycling will become available. The study is part of the BATMAN project funded by the Research Council of Norway and its partners (NFR: BATMAN – 299334). The report is also interlinked to a project for the Ministry of Climate and Environment where results were documented in TOI report 1744/2019 (in Norwegian). Large parts of that report have been translated to English and included in this report.

Chief Research Engineer, M.Sc. Erik Figenbaum has been TOI's project manager and has written the majority of chapters, many in collaboration with other researchers. Natural scientist Rebecca J. Thorne is co-author of chapters 5, 6 and 9, and environmental economist Daniel R. Pinchasik is co-author of chapter 9. The exceptions are chapters 7 and 13, which the geographer Astrid H. Amundsen has written and chapter 12 that Rebecca J. Thorne has written (which includes data on the scrappage of vehicles extracted from the BIG model by Lasse Fridstrøm). All employees have commented on parts of the report along the way.

We express our gratitude to all of these, as well as to BATMAN's project leader Stephen Sayfritz at Eyde-cluster and Fernando Aguilar Lopez at NTNU who provided constructive feedback on the work.

Oslo, May 2020
Institute of Transport Economics

Gunnar Lindberg — *Jardar Andersen*
Managing Director — *Research Director*

Content

Vehicle types – Definitions and acronyms

BEV	Battery Electric Vehicle	Passenger car with battery electric propulsion
PHEV	Plug in Hybrid Electric Vehicle	Passenger car that uses electricity stored in the vehicles batteries in an electric motor as well as an ICE for propulsion (or to produce electricity in a generator)
FCEV	Fuel Cell Electric Vehicle	A passenger car using electricity produced on-board from hydrogen in a fuel cell for propulsion.
FC-PHEV	Fuel Cell PHEV	Functions as a PHEV where the fuel cell replaces the ICE for production of electricity from hydrogen while driving
ICE	Internal Combustion Engine	Common name for diesel, gasoline and gas engines
ICEV	Internal Combustion Engine Vehicle	Vehicle where the ICE is the only power source used for propulsion
LCV	Light Commercial Vehicle	Small and large panel vans used by Craftsmen etc.
BE-LCV	Battery Electric LCV	LCV with battery electric propulsion
PH-LCV	Plug in Hybrid LCV	LCV that uses electricity stored in the vehicles batteries in an electric motor as well as an ICE for propulsion (or to produce electricity in a generator)
FCE-LCV	Fuel Cell Electric LCV	LCV using electricity produced on-board from hydrogen in a fuel cell for propulsion.
BE-Bus	Battery Electric Bus	Bus with battery electric propulsion
FCE-Bus	Fuel Cell Elecric Bus	Bus using electricity produced on-board from hydrogen in a fuel cell for propulsion.
BE-Truck	Battery Electrick Truck	Heavy Duty Truck with battery electric propulsion
FCE-Truck	Fuel Cell Electric Truck	Heavy Duty Truck using electricity produced on-board from hydrogen in a fuel cell for propulsion.
HEV	Hybrid Electric Vehicle	A small battery and electric motor is used to partially run the vehicle (using electricity which has been produced from re-generative braking).
Hybrid Bus	See HEV	See HEV
Hybrid Truck	See HEV	See HEV
BRT	Bus Rapid Transit	Articulated bus in the styling of a Tram
WLTP	Worldwide Harmonized Light Vehicles Test Procedure.	Test procedure for light vehicles (Passenger cars and LCVs) CO_2-emission and other exhaust emissions. Mandatory since 2019, designed to better reflect real-world driving than the NEDC.
NEDC	New European Driving Cycle.	Old test method used prior to the WLTP becoming mandatory
SUV	Sports Utility Vehicle	
CUV	Crossover Utility Vehicle	
MPV	Multi Purpose Vehicle	

Summary

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Authors: Erik Figenbaum, Rebecca J. Thorne, Astrid H. Amundsen, Daniel R. Pinchasik, and Lasse Fridstrøm
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This report analyses the potential and the prerequisites for reaching the Norwegian National Transport Plan targets of only selling zero-emission vehicles. In addition, the report presents analysis of the resulting volumes of vehicles and batteries that will pass through the (passenger) transportation sector towards scrappage and recycling by 2030, so that enterprises involved in battery recycling can plan for recycling capacity. The concrete targets are that passenger cars, small light commercial vehicles (LCVs) and city buses sold in 2025 and onwards shall be zero-emission, and the same goes for large LCVs, 50% of new trucks and 75% of new long distance buses from 2030. The passenger car target for 2025 is demanding due to the wide variation in user needs and preferences. Strong measures will be required to meet the goal. The goals for city buses and small light commercial vehicles can potentially be attainable with the right policy instruments. The technological developments seem to converge with user needs over the coming years. The 2030 target for the largest Light Commercial Vehicles also seems within reach as this segment lags behind the small light commercial vehicle development by about 5 years. However, the 2030 truck and bus targets are much more uncertain as no commercial offerings are yet in place for these demanding sectors. Hydrogen may play a key role for long distance heavy duty applications. The calculation of the flow of batteries through the passenger vehicle segment shows that by 2025 0.6 GWh of Li-Ion batteries will need to be recycled and 2.2 GWh by 2030. Very few battery electric trucks, buses and LCVs will need to be scrapped before 2030 so analysis is not performed here for these segments.

Introduction

Battery electric technology is currently the most mature zero emission technology in use, relying primarily on lithium-ion batteries (Li-Ion). Many battery electric vehicles have been introduced into the electric vehicle fleet already, and further transitioning to electro-mobility will lead to a continued rapid growth.

This report, which is a deliverable of the BATMAN project financed by the Research Council of Norway and BATMANs industrial partners, analyses how far the introduction of battery electric vehicles in different road transportation segments can reach by 2025 and 2030, and the factors that influence this. This was carried out by studying and analyzing the individual elements that need to be in place for the goals to be achieved, as presented in Figure S1. As illustrated by the figure, these elements include technological and cost development, supply and demand for zero-emission vehicles, driving forces and instruments. Based on this analysis, a forecast of potential battery volumes available for recycling from the scrappage of passenger vehicles was made for the period 2020-2030 for Norway, and for the EU as a whole.

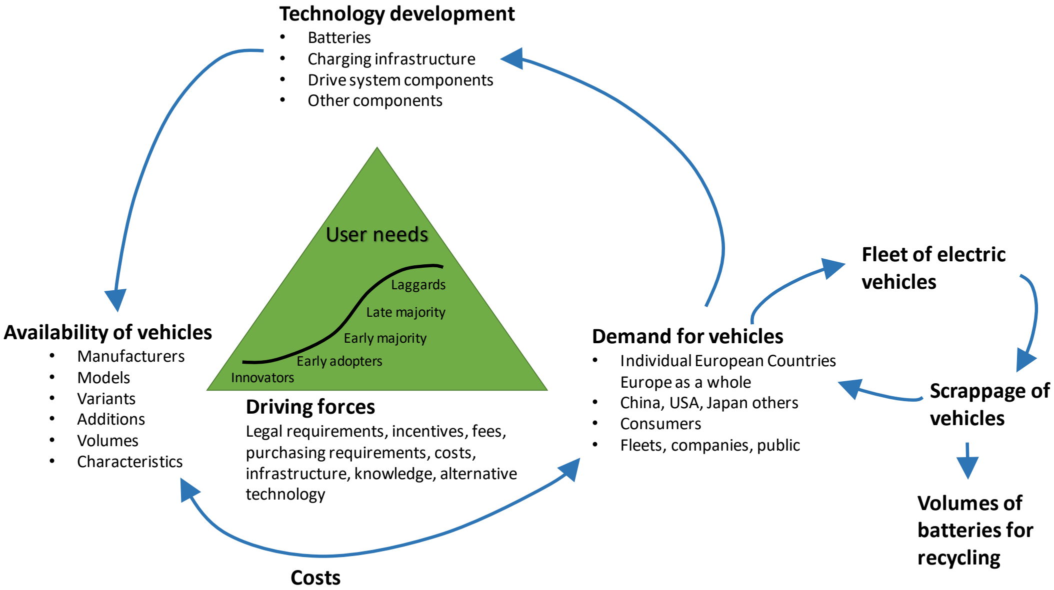


Figure S1: Elements that affect the ability to reach the zero emission vehicle targets in the Norwegian National Transport Plan (NTP).

Background

Norway is a leading nation in the drive towards electromobility with ambitious zero-emission vehicle targets set in the Norwegian National Transport Plan (NTP) (Norwegian Department for Transport 2017); by 2025, all new passenger cars, light LCVs and city buses are planned to be zero emission vehicles. Additionally, by 2030 all new heavier LCVs, 75 % of long-distance buses and 50 % of new trucks are planned to be zero-emission vehicles.

Battery electric vehicles have thrived in the Norwegian market. The share of new battery electric passenger vehicle sales passed 40 % in 2019, with another 13 % comprised of plug-in hybrids, meaning a total of 55 % of passenger vehicles have the opportunity to be powered by grid electricity.

Sales in the LCV segment are not as high, with the market share for electric LCVs at approximately 6 % in 2019. The year 2019 also marks a breakthrough year for battery electric buses, with over 420 planned for Norwegian cities in 2020 and 199 on the road at the end of 2019. Cities elsewhere in Europe are also increasingly introducing battery electric buses into their bus fleet. The first demonstration projects with BE-Trucks have also started. Going forward from 2020-2025, and until 2030, it is expected that there will be further large-scale upheaval in the vehicle market.

But it is in the passenger car market that the major changes have taken place; in the year 2009 fewer than 200 new BEVs were registered, but ten years later in 2019 more than 60000 new BEVs were registered. This is largely due to incentive use (which is more powerful than in the LCV market), with exemptions from value added tax (VAT), one-off sales tax and traffic insurance tax, reduced benefit taxation and some additional local benefits. In addition, usage characteristics have proven compatible with many user patterns, especially with a little support from fast chargers on longer trips. Electric passenger cars have become so favorable to buy and use that they have emerged despite the range and charging speed restrictions (which are particularly relevant in winter). The purchase price is lower or about the same as for petrol and diesel vehicles and the annual costs are significantly lower.

For LCVs, the policy scope has been a little too limited, the VAT exemption has no effect and the one-off tax exemption is a minor advantage because diesel LCVs have lower one-off taxes than passenger cars. Annual costs are on par or lower than for diesel vehicles, but the overall user experience and economics have not been favorable enough to date.

The bus market is driven by tenders, which means that development can proceed rapidly when the technology is mature enough for ordinary route usage in Norwegian cities, and economics are acceptable. For trucks, there are so few pilot projects that the cost side is still relatively unknown and more knowledge is needed on how to develop this market.

Whilst complementary to battery electric technology - hydrogen fuel cell vehicles are now considered less relevant within cities, although various test projects are underway. This technology is considered more relevant for long-range vehicles.

Methodology

A wide range of approaches, and different methods of analysis, were used here to assess i) key drivers for the market and ii) whether the NTP objectives are achievable, and iii) the resulting volumes of Li-Ion batteries that will become available for reuse or recycling as a result. Existing research and other knowledge was summarized through literature and document analysis. In addition, separate calculations were made with models that calculate disaggregated purchase prices and annual costs (TØI-TCO), a similar model for freight transport, and a model for bus costs. Previous use of a stocks-flow cohort model (BIG) was also summarized, in which various outcomes of policy changes were analyzed for the passenger car market. Furthermore, the effects of regulations and directives in the European Union (EU) were assessed together with other driving forces that may affect the vehicle market.

Results

Key drivers

Research shows that the main driver for electrification of the transport sector is the international climate and environmental focus, which in turn has made the EU adopt stringent requirements for new vehicle CO_2 emission limits (as shown in Figure S2). In addition, China and California have also adopted demands for the sale of increasing shares of electric vehicles in the future. New technology, primarily the development of Lithium battery technology, has made such demands possible.

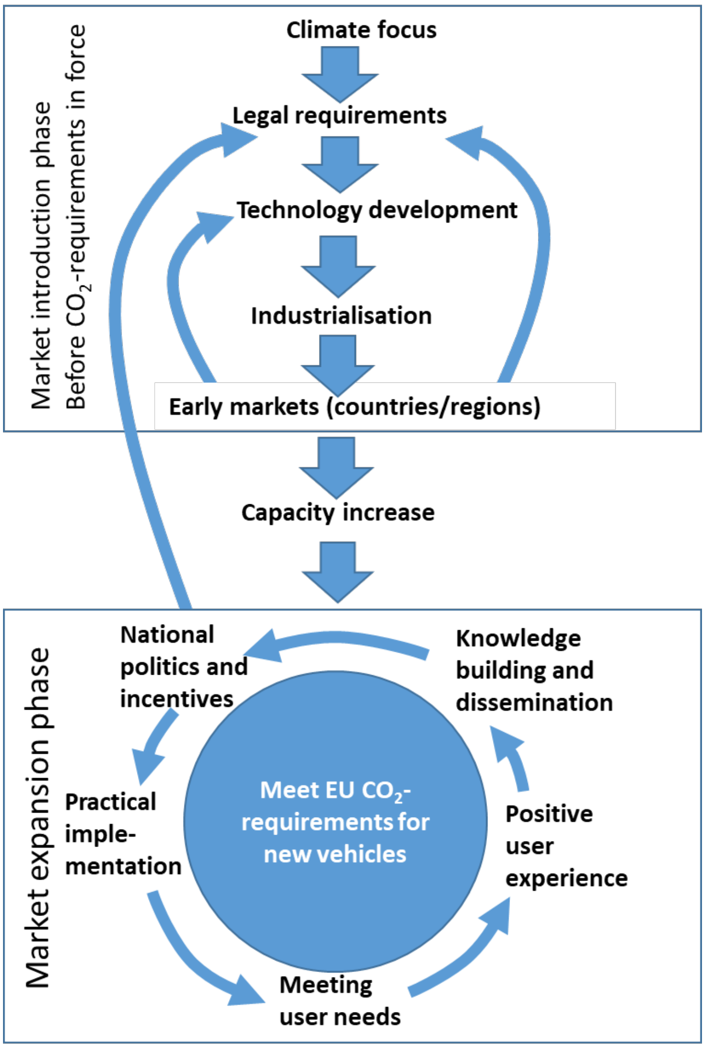


Figure S2: The dynamics that the EU requirements for new vehicle CO_2 emission limits create in the zero emission vehicles markets.

This has led to a rapid and comprehensive technological development, and the beginning of European electromobility industrialization. Electric vehicles have been sold and tested in early markets such as Norway where strong incentives have meant that the technology has become more competitive with conventional vehicles at an earlier date than in other countries. From 2020, EU CO_2-requirements for passenger vehicles, i.e. that new vehicles shall on average emit less than 95 g/km in 2020, 80 g/km in 2025 and 60 g/km in 2030, will have full effect with heavy fines if the target is not met. Thus, the market is in an expansion phase where electric vehicles are becoming standard products for most vehicle manufacturers. Where the vehicles end up, and how many will be sold beyond the EU minimum requirements, depends on how well these vehicles work for different types of users, how effective countries are in ensuring positive user experiences, and how this knowledge is disseminated. Norway is included in the EU CO_2-requirements.

In Europe, the EU is thus the major electromobility driver with its requirement to reduce the average CO_2 emissions not only from new passenger vehicles, but also from LCVs and trucks. Requirements by 2025 and 2030 are so stringent that electrification of the model range is inevitable. If manufacturers do not meet the requirements, then fines are so large that completing the requirement is a better option. China has adopted similarly stringent requirements for quota shares with zero emissions vehicles. The EU requirements trigger the development of electric vehicles to a large extent.

It is estimated that globally vehicle manufacturers will invest € 300 billion in electrification over the coming years, of which approx. 45 % will be invested in China. This means that there is also a corresponding industrialization and development of battery technology. Thus, investment decisions are made and development costs are to be regarded as sunk costs to fulfill the EU requirements when the production starts. In a situation where one has to produce in order to meet legal requirements, this cost may not entirely be passed on to the purchasers.

The regulatory requirements in the EU will mean that (in the passenger car market) approximately 1.9 million BEVs and 0.9 million PHEVs must be sold in Europe in 2025, and 4.3 million and 2.2 million respectively in 2030, in order for the CO_2 requirement to be met. The actual number may be higher, depending on the extent to which emissions from ICEVs are reduced. In the light commercial vehicle market, 0.26 and 0.64 million electric LCVs will probably need to be sold in Europe in 2025 and 2030, respectively. Trucks are sold in smaller volumes, which means that the CO_2 requirement could lead to sales of 16000-28000 zero-emission trucks in Europe in 2025 and 32000-60000 in 2030. For city buses there are as of yet no corresponding CO_2 requirements, but the EU requirements for public procurement of buses will provide a solid boost for battery electric city buses, and should ensure minimum sales of 20-40 % of the city buses sold. Hydrogen is particularly interesting for truck operation over longer distances. Hydrogen has low priority among passenger car and light commercial vehicles manufacturers (with a couple exceptions). It therefore seems unlikely that hydrogen vehicles will have a major role in meeting CO_2 requirements in these light vehicle segments. The same goes for city buses which are suitable for using batteries with locally adapted charging solutions.

The development is also expected to be driven in the future by (partially) new stakeholders, including manufacturers such as Tesla, Nikola and various Chinese manufacturers who seek new opportunities in Europe. Additionally, charging infrastructure is being developed and partly operated by new stakeholders, and increasingly also by gas station companies. National policy controls not only the volume of sales in a country, but also which countries are prioritized by vehicle manufacturers when new models are launched, and sales volumes are allocated.

Barriers to the technology, as shown in Figure S3, include technology limitations such as range and charge time, lack of knowledge, lack of consensus on charging solutions, existing transport habits, and infrastructure that is not yet fully integrated with the rapid development of the fleet, and which is not capable of handling large variations in transport volume throughout the year. This competes against a system that has been optimized for over 100 years powered by ICEs. Barriers are reduced over time with better technology, increasing knowledge through use, and with increasing number of demanding customers.

Other trends such as population growth and the growing number of elderly people in Norway, and elsewhere in Europe, will probably not reduce the demand for transport by vehicles until 2030. Automation of vehicles is likely to take a long time to establish (in a sound manner) for Norwegian winter traffic conditions, and is not expected to limit the demand for vehicles up to 2030. In fact, the effect may even be the opposite, i.e. that during the drive towards automation the vehicles are made safer and more comfortable to drive, but still require a driver, which will contribute to increased sales of BEVs and vehicles in general, and thus increased traffic. It is also considered unlikely that trends such as micro-mobility or vehicle sharing in the foreseeable future will reduce vehicle purchases significantly over the next 10 years. These deliberations seem valid also for EU countries.

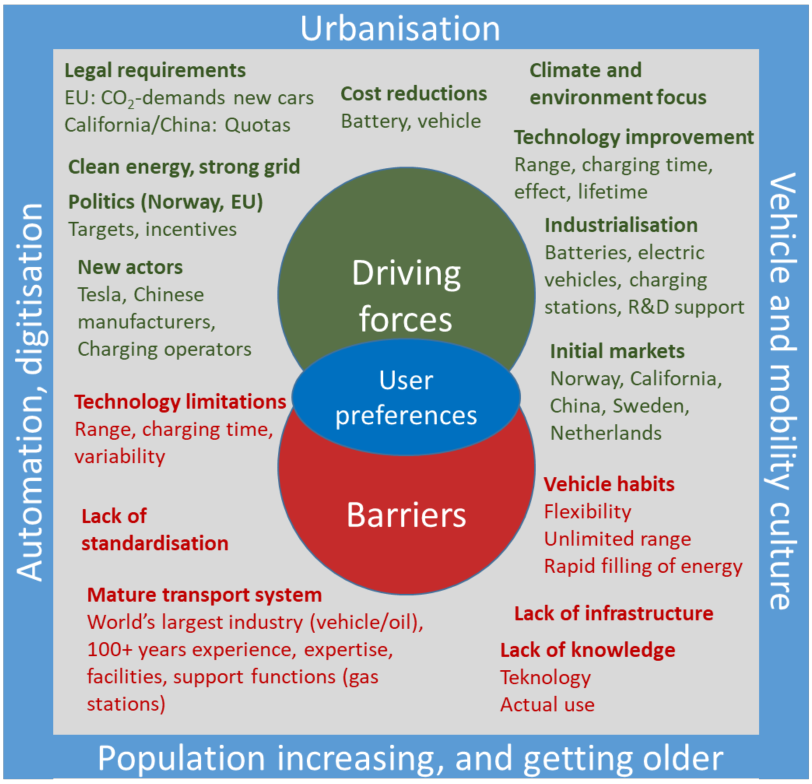


Figure S3: Drivers and barriers to a market dominated by zero emission vehicles.

Passenger car segment

The passenger car market is facing a major upheaval. A large number of electric vehicles and plug-in hybrid models will be launched in the period 2019-2022, and existing models will be renewed and develop longer ranges. This upheaval will make it easier for the automotive industry to meet the requirements for average CO_2 emission targets of new vehicles in the EU, which are strengthened towards 2025 and 2030, and to meet quota requirements for the sale of electric vehicles in China. The investment in electric vehicles is greater than the investment in plug-in hybrid vehicles. Within the passenger vehicle market, a continuous price and model range will be developed from the smallest and cheapest electric vehicles to the largest and most expensive luxury vehicles. More users will thus be able to find vehicles with a suitable range to meet their transport needs at a cost they can afford, but there may be some flexibility limitations. Vehicles to be launched over the coming years will also be able to recharge faster.

The purchase price of compact size electric vehicles has in Norway, thanks to the tax exemptions, matched petrol and diesel vehicles since approx. 2015 with small batteries, and from 2019 with large batteries. Annual costs became compatible as early as 2012, which has resulted in the rapid market expansion from that year. From 2023 to 2025, electric vehicles are expected to become a socio-economically profitable climate measure in Norway. In the rest of Europe, BEVs are more expensive to buy than ICEVs due to the fact that they are more expensive to produce than ICEVs, and fewer and weaker incentives are available. The total cost of ownership calculations shows that without incentives the cost can be comparable with that of diesel vehicles from around 2022-2023, assuming the same residual value in percentage of the new car cost. Some markets offer BEV buyers up to 6000 Euro purchase bonuses for BEV buyers leading to a lower total cost of ownership than for ICEVs.

LCV segment

In the LCV segment, the market for electric variants has been slow. It is expected to improve in 2020, but it will not be until 2021 that a major upheaval is expected. The majority of small LCV models are then expected to have a battery-electric variant that can meet the needs of most LCV users. Electric LCVs have not yet achieved cost parity upon purchase price, as mentioned, since there are fewer incentives available than for passenger cars. Purchase price parity is expected to be achieved in 2022-2023, but in terms of annual costs, electric LCVs have been comparable for the last 2-3 years. By 2021, producer costs are expected to have fallen so much that electric LCVs can become socio-economically viable.

Bus segment

Most bus manufacturers already have (or are about to launch) battery-electric powered city buses of all sizes. These buses are tailored to local operating conditions in terms of battery size, range, heating and cooling, and charging solutions, and route patterns are adapted to enable full route usage. As a result, there are no longer any major technical or accessibility barriers to the increased use of battery electric city buses. The annual costs (as of 2019) are higher than for corresponding ICE vehicles, but are expected to fall rapidly towards 2025 where electric buses can become cost competitive. This is given that the battery lasts the life of the tender the bus is used in, or that a battery warranty can be provided within a cost corresponding to the savings in annual maintenance compared to diesel operation. Battery life uncertainty can be eliminated through such maintenance agreements with bus suppliers. Until these buses are in normal operation under Norwegian conditions, it is not possible to know more about battery lifetime.

The city bus segment is controlled through tenders where the requirements for buses can be specified so that battery electric buses become the preferred option.

Long-haul buses are more uncertain and the assessments are the same as for long-haul trucks.

Truck segment

Trucks are at the very beginning of a market introduction and will gradually come into series production from 2020-2022. It is an open question whether hydrogen or battery-electric solutions are the optimal alternatives for long-distance driving, while for urban logistics and other applications in the city, battery-electric solutions are expected to be the major player due to the low cost of electricity, and because many of these vehicles return to the depot every day where they can be recharged.

As yet, there is very little experience in practical operation, meaning that there is great uncertainty over the cost of batteries and the complete BE-Truck, as well as the lifetime of the batteries. There is also great uncertainty over the cost of hydrogen solutions and its operation. It is therefore not possible to conclude whether or not the 2030 target can be met.

Some targets are potentially achievable, others are more challenging

The NTP goals for the introduction of zero-emission vehicles are five and ten years ahead, respectively. Therefore, some vehicle models for sale in 2019 will still be for sale in 2025. Most of the models launched in 2020-2021 will still be on sale in 2025, possibly with a minor mid-life update. This means that much is already known about vehicle models that will be on sale in 2025, and it is easier to assess resulting progress towards 2025 targets than for those in 2030. In 2025, according to NTP targets, only zero-emission passenger vehicles, LCVs and city buses will be sold. By 2030, all major LCVs will also have to be zero emissions, along with 50 % of trucks and 75 % of long-haul buses. The analysis of whether the objectives can be achieved is summarized in Table S.1. To summarise - some

NTP goals are achievable whilst others are more challenging. The targets of EU will likely be met due to the heavy fines for non-compliance.

The flow of batteries from market introduction to scrappage

It is primarily BEVs that will contribute to significant volumes of Li-Ion batteries that are available for reuse or recycling by 2025 and through to 2030. The calculation of the number of batteries entering and leaving the fleet is therefore limited to BEVs in this report. This means that the volume of batteries is somewhat underestimated as volumes of batteries from PHEVs and BE-LCVs is not taken into account. These are estimated to be relatively small volumes compared to BEVs since the volume of BE-LCVs entering the fleet has been small with only approx. 7,300 in the fleet at the start of 2020, against 260,600 BEVs. Li-Ion batteries from heavy duty trucks and buses are unlikely to be available for reuse or recycling in significant number until after 2030, as very few entered the fleet before 2020.

Vehicles entering the fleet was fed into a stocks and flows cohort model, and combined with estimates of the types and sizes of batteries used in electric passenger vehicles in Norway 2011-2030, to produce a flow of batteries that will become available for recycling each year. Battery types and sizes for 2019 were assumed the same as 2018, whilst battery sizes for production years 2020-2030 were estimated by assessing battery sizes of known BEV models arriving on the market from 2020. All these were assigned as unknown Li-ion type, as the battery type of future models is unknown.

The estimate for the total battery capacity installed in new BEVs in Norway across Li-Ion battery types was estimated to be 2.4 GWh for 2018, rising to ~8.5 GWh in the year 2030. The net battery stock change in Norway from all contributions (i.e. assumed end of life battery quantity from BEVs older than 1 year) is estimated to be around -0.6 GWh in 2025, and - 2.2 GWh in 2030. These batteries could potentially be used to feed ~70,000 and ~271,000 8 kWh home/cabin battery energy systems in 2025 and 2030, respectively, but it might be more economical to recycle them. No net battery stock change of Li-ion batteries is estimated prior to 2011 since these vehicles were assumed to either be registered as non-passenger car type (4 wheel motorcycles) or to contain other batteries than Li-ion. Due to the very small numbers of vehicles involved, this added uncertainty to the analysis is small.

The volumes of installed batteries and batteries that will be available for reuse or recycling in the EU and EFTA countries outside Norway could, in total, amount to about 2 times the Norwegian volumes in 2025, and 4 times the Norwegian volumes in 2030. Then the volumes will grow a lot faster in other countries than in Norway, because the EU's CO_2 requirements for cars will hit the EU car market from 2020 onwards. By 2025, if the goal of selling only zero-emission passenger cars is reached, Norway could account for about 8% of total European electric car sales volumes, and the proportion will fall to less than 4% in 2030. Thus, during the period 2035-2040, 10 times higher recycling / recycling volumes could be available in the EU than in Norway, and 20 times higher volumes about 5 years later.

Table S1: Summary of the possibilities for achieving the zero emission targets for vehicles in the Norwegian National Transport Plan (NTP) and for the EU to reach the targets of the CO_2-legislation for new vehicles.

Targets	Ability to reach target	Effort needs in Norway
NTP: Only sell zero emission passenger cars from 2025 EU: New cars, 15% reduced CO_2-emission in 2025 compared to 2020, 37% reduced in 2030.	Some areas of the passenger vehicle market are challenging, making full voluntary compliance of the NTP target costly. Nonetheless, production costs are reducing and much innovation is happening from vehicle manufacturers. There will be a large number of new models on the market from 2020-2022, but some buyer groups have extra demanding vehicle use, others have little to gain from buying an electric vehicle and some have other major barriers. In particularly cold areas and large range reduction will suppress the market even though the vehicles have greater range than before. The target will be easier to achieve if long-range plug-in hybrid vehicles have a place in the strategy, e.g. that for instance 20% of the target can be such vehicles. The EU target will be met due to the fines for lack of compliance.	Strong incentives are still needed, along with better charging infrastructure, to achieve this goal. Charging infrastructure in particular needs to be improved in cities where people do not have their own parking, and there must be better solutions for financing fast chargers that enable long journeys. A major challenge will be vacation periods when roads are overcrowded
NTP: Only sell small zero-emission vans from 2025 EU: New Vans, 15% reduced CO_2-emission in 2025 compared to 2020, 31% reduced in 2030.	The NTP goal may be possible with the costs and characteristics of the battery electric LCVs that are coming on the market now. The supply of electric LCVs is increasing significantly, making the range more compatible with required applications. There may be challenges in areas where less information is available about the use, and in particularly cold areas due to range reduction. The segment is cost-sensitive and needs reliable, flexible transport. The EU target will be met due to the fines for lack of compliance.	This NTP goal will require more powerful measures than currently implemented to be achievable. The most important electric vehicle incentive, VAT exemption, has no effect in this segment. Enova support from 2019 is positive. Dissemination of knowledge in the sector will be essential.
NTP: Only sell large zero-emission LCVs from 2030 EU: New Vans, 15% reduced CO_2-emission in 2025 compared to 2020, 31% reduced in 2030.	The technology may be good enough for the NTP goal to be achieved, but in 2019-2020 large LCVs that will allow target attainment are not available on the market (too short range). However, since the goal is 10 years ahead and large LCVs are lagging approximately five years behind small LCVs in terms of market development, the goal can possibly be reached if the manufacturers develop large LCVs with long range in good time. The EU target will be met due to the fines for lack of compliance.	This NTP goal will require more powerful measures than currently implemented to be achievable. The most important electric vehicle incentive, VAT exemption, has no effect in this segment. Enova support from 2019 is positive. Knowledge dissemination between companies will be essential.
NTP: Only sell large zero-emission city buses from 2025 EU: Requirements for public procurement will lead to 20-40% battery electric share.	The goal may be achievable. There is good availability of battery electric buses on the market and they are tailored to local conditions according to battery size and charging capacity. 2019 costs are higher than for diesel bus operations, and there are some significant infrastructure investments, but by 2025 costs may have fallen to a level compatible with diesel buses. 5-10% more buses may be needed on busy routes due to charging needs, which can lead to increased costs compared to diesel operation. This segment may potentially be the first to be fully electrified in Norway. The EU requirement will likely be met.	Requires active use of environmental requirements in public tenders. This is decentralized to Norwegian counties. National guideline to be considered. All buses can be replaced within approx. 10 years by tenders. Knowledge dissemination on practical operations between counties / operators is essential, e.g. in user forums.
NTP: Sell 75% zero-emission long-distance buses from 2030	The long-distance buses can theoretically be electrified, requiring large batteries and fast charging, or use of hydrogen. There is only one electric bus available on the market (short range) and none with hydrogen. For buses in fixed routes, charging or hydrogen infrastructure can be established to varying degrees of complexity. Coaches are the most challenging. They can run anywhere and must have a basic infrastructure for filling hydrogen / recharging the batteries that covers much of Norway.	In this area, technology and product development are primarily needed. There are no suitable products on the market, and thus no basis for national planning of policies, incentives or infrastructure.
NTP: Sell 50% zero-emission trucks from 2030 EU: New trucks, 15% reduced CO_2-emission in 2025 compared to 2020, 30% reduced in 2030.	Theoretically, trucks can be electrified for many applications, or use hydrogen as an alternative. The market is in an initial phase with little information available on how this will in practice work in Norwegian conditions. There were no electric or hydrogen trucks in regular sales in 2019, only some rebuilds from diesel operation. By 2020-2022, large truck manufacturers and new companies such as Tesla and Nikola will offer series-produced BE-Trucks (and a hydrogen truck from Nikola and one from Hyundai). Market price and technical characteristics are unknown. In cities and other places where trucks are used locally, battery-powered solutions can work. This is a very limited part of the truck market. Much technology and product development will take place from 2020 to 2030, and the EU's requirements for average CO_2 emissions from new trucks will lead to the industrialization of electric and hydrogen trucks, and will be met due to the fines for lack of compliance. It is too early to say whether this, together with an effective policy with good incentives, can achieve the NTP goal	Systematic collection and dissemination of knowledge about how this works in practice for Norwegian companies, and the economy of using BE-Trucks, will be essential to increase the likelihood of the goal being achieved. A rights-based system to support purchasing is likely to be needed to achieve a wider and faster rollout. More research is needed on how a nationwide heavy-duty vehicle charging and hydrogen infrastructure should look, how it can be established, and how transboundary transport could take place.

Sammendrag

Fra markedsopptak til vraking. Li-Ion batteriers vei gjennom vegtransportsektoren

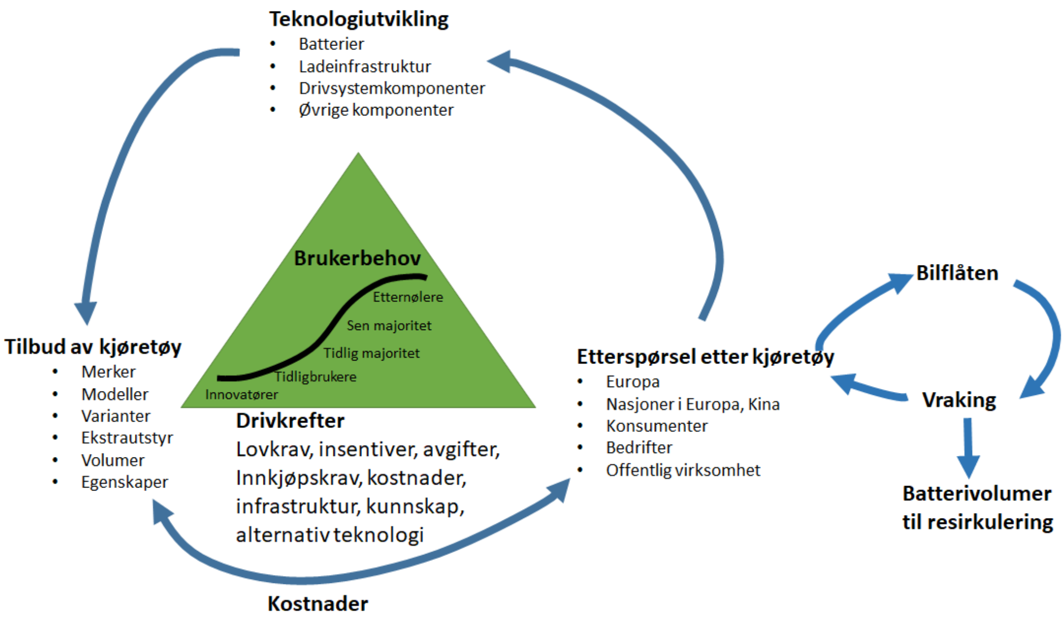
TØI rapport 1756/2020
Forfattere: Erik Figenbaum, Rebecca J. Thorne, Astrid H. Amundsen, Daniel R. Pinchasik og Lasse Fridstrøm
Oslo 2020 178 sider Engelsk språk

Denne rapporten vurderer potentsialet for og forutsetningene for å nå målene i NTP om at det bare skal selges nulllutslipps personbiler, små varebiler og bybusser fra 2025, og fra 2030 store varebiler. Fra 2030 skal og henholdsvis 50% av lastebiler og 75% av langdistansebusser som selges være nullutstlipp. Videre beregnes hvilke volumer av Li-Ion batterier som går inn i bilparken og som kan komme til gjenbruk eller resirkulering som følge av denne elektrifiseringen fram til 2030. Fokus er på batterielektriske personbiler da det er fra dette transportsegmentet de store volumene blir tilgjengelig i løpet av den tidshorisonten. Rapporten ser også på hvor store volumer av elkjøretøyer som vil kunne selges totalt i Europa som følge av EUs krav til at det gjennomsnittlige CO_2-utslippet fra nye kjøretøyer i Europa skal reduseres med 15% innen 2025 (fra 2020-nivået) og 30-37,5% innen 2030 avhengig av kjøretøykategori. Den tekniske utviklingen av kjøretøyene konvergerer i retning av brukeres behov slik at målene lettere kan nås. Resultatene viser at 0,6 GWh batterier vil bli tilgjengelige for gjenbruk eller resirkulering i Norge i 2025 og 2,2 GWh i 2030. Volumene i EU+ andre EFTA-land kan totalt ligge på ca. 2 ganger de norske volumene i 2025 og ca. 4 ganger i 2030. EUs CO_2-krav vil ikke medføre at det kommer store volumer av batterier til gjenbruk eller resirkulering før etter 2030.

Introduksjon og forskningsspørsmål

Denne rapporten, som er utført som del av BATMAN-prosjektet og finansiert av Norges Forskningsråd, belyser fra ulike vinklinger hvor langt introduksjonen av batterielektriske kjøretøy kan komme i 2025 og 2030 i ulike kjøretøykategorier, hva som påvirker dette, og hvor store volumer av Li-Ion batterier som vil bli tilgjengelig for gjenbruk eller resirkulering mellom 2020 og 2030, i Norge og i EU.

De enkelte elementene som må på plass for at kjøretøyflåtene skal kunne elektrifiseres er presentert i Figur S1. De omfatter brukerbehov, teknologiutvikling, tilbud av kjøretøyer, kostnader, etterspørsel etter kjøretøyer, og drivkrefter som påvirker utviklingen av tilbud og etterspørsel.



Figur S.1: Elementer som påvirker mulighetene til å nå nullutslipps-kjøretøymålene i NTP og volumene av batterier som kommer til resirkulering.

Bakgrunn

Elbiler har slått gjennom for fullt i Norge med en markedsandel i nybilsalget som passerte 40 prosent i 2019. Ytterligere 13 prosent var ladbare hybrider slik at totalt 55 prosent av bilene som ble nyregistrert i 2019 har mulighet til å bruke strøm fra nettet. For EU som helhet var andelene bare 2,0% og 1,2%, men med stor variasjon mellom landene.

I varebilsegmentet har ikke salget gått like bra - markedsandelen for elvarebiler var på ca. 6 prosent i Norge i 2019. 2019 markerer også elbussenes store gjennombrudd og i løpet av 2020 vil det gå over 420 elbusser i norske byer. De første demonstrasjonsprosjektene med elektriske lastebiler kom også i gang. I andre EU-land er elbusser på vei inn i mange byer, mens markedet for el- og hydrogenlastebiler ikke har komme i gang enda.

Men det er i personbilmarkedet at de store endringene har skjedd fra det ble registrert under 200 nye elbiler i Norge i 2009 til at det i løpet 2019 ble registrert mer enn 60 000 nye elbiler, bare 10 år senere. I personbilmarkedet er insentivbruken mye kraftigere enn i varebilmarkedet, det er fritak for merverdiavgift (MVA) og engangsavgift, redusert fordelsbeskatning for firmabileer, ingen trafikkforsikringsavgift, enkelte lokale fordeler, og lavere energkostnader. Bruksegenskapene har vist seg kompatible med manges bruksmønster, spesielt med litt støtte fra hurtiglading underveis på lengre turer. Elbilene har rett og slett blitt så gunstige å kjøpe og anvende at de har vunnet fram på tross av rekkevidde- og ladehastighetsbegrensninger (spesielt om vinteren). Disse ulempene har blitt betydelig redusert med den seneste generasjonen elbiler. Kjøpsprisen er lavere eller omtrent lik som for bensin- og dieselbiler, og de årlige kostnadene er betydelig lavere.

For varebilene har rekkevidden vært litt for begrensende. MVA-fritaket har ingen effekt og engangsavgiftsfritaket er en mindre fordel fordi dieselvarebiler har lavere engangsavgift enn personbilene. De årlige kostnadene er likevel litt lavere enn for dieselvare-biler, men den totale kombinasjonen av bruksegenskaper og kostnader har ikke vært god nok fram til 2019.

Bussmarkedet styres av anbud, noe som gjør at utviklingen kan gå fort dersom teknologien blir god nok til at bussene kan brukes til å levere ordinær ruteproduksjon i norske byer til akseptable kostnader. Hydrogen anses nå som mindre aktuelt i bybusser selv om det foregår ulike testprosjekter. El- og hydrogenløsninger for lastebiler har kommet så kort at kostnadssiden er lite kjent og det er behov for mer kunnskap om hvordan dette markedet kan utvikles, og om hvilken teknologi som vil bli foretrukket til ulike bruksområder.

Metode

Fremover fra 2020-2025 og videre til 2030 vil det bli en stor omveltning i kjøretøy-markedene. Den mulige fremtidige utviklingen har vært vurdert ut fra et bredt spekter av innfallsvinkler, og med ulike analysemetoder. Videre er det vurdert om målene i NTP er oppnåelige, og hva som kan bli effekten av EUs CO_2-krav til kjøretøy.

Eksisterende forskning og annen kunnskap er oppsummert gjennom litteratur- og dokumentanalyser, og delvis er det gjort egne beregninger med modeller som beregner disaggregerte kjøpspriser og årlig kostnader (TØI-TCO), en tilsvarende beregningsmodell for godstransport, og en modell for busskostnader. Det er også oppsummert tidligere kjøringer med en bilvalgsmodell (BIG), der ulike utfall av politikkendringer er analysert for personbilmarkedet. Effekten av EUs forordninger og direktiver er vurdert sammen med andre drivkrefter som kan påvirke kjøretøymarkedet. Videre er det gjort en beregning av framtidige volumer av Li-Ion batterier som kan bli tilgjengelige for gjenbruk eller resirkulering fram til 2030.

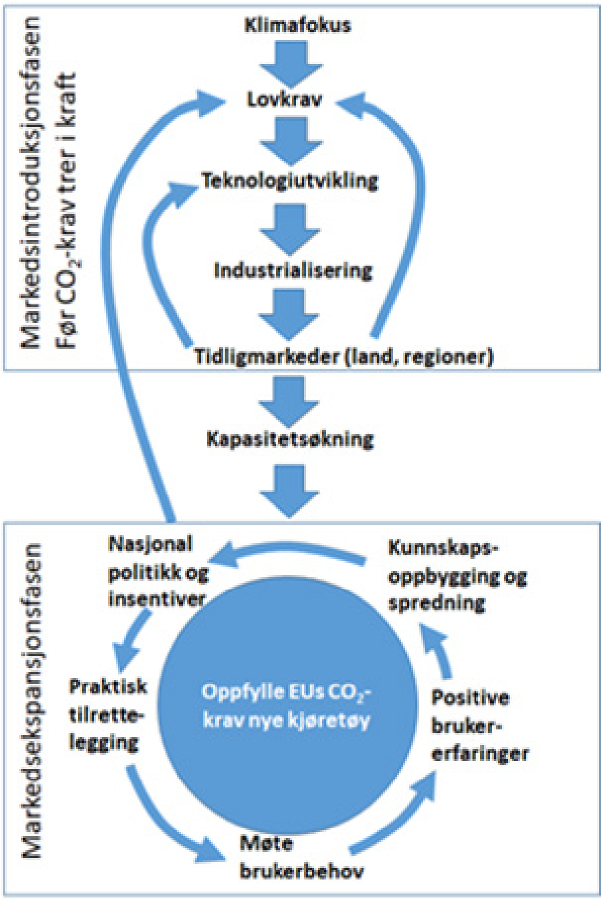
Resultater

Drivkrefter

I Norge vil nullutslippsmålene for kjøretøy i Nasjonal Transportplan (NTP) ha stor betydning for markedsintroduksjonstakten fordi de brukes som styringsmål for avgiftspolitikken og insentivbruk overfor elkjøretøy. Målene innebærer at:

- I 2025 skal alle nye personbiler være nullutslippskjøretøy
- I 2025 skal alle nye lette varebiler være nullutslippskjøretøy
- I 2025 skal alle nye bybusser være nullutslippskjøretøy, eller bruke biogass
- I 2030 skal alle nye tyngre varebiler være nullutslippskjøretøy
- I 2030 skal 75 prosent av nye langdistansebusser være nullutslippskjøretøy
- I 2030 skal halvparten av nye lastebiler være nullutslippskjøretøy

De største drivkreftene for elektrifisering av transportsektoren er det internasjonale klima- og miljøfokuset, som igjen har gjort at EU har vedtatt strenge krav til nye bilers gjennom-snittlige CO_2-utslipp, som vist i Figur S2, og at Kina og California har vedtatt krav om salg av økende andeler elbiler i fremtiden. Ny teknologi, først og fremst utviklingen av Li-Ion batteriet med stadig høyere energitetthet og lavere kostnader, har muliggjort slike krav.



Figur S.2: Dynamikken EUs krav til nye biler CO_2-utslipp skaper i markedene for nullutslippskjøretøy.

Dette har medført en rask og omfattende teknologiutvikling og begynnende industrialisering av elbiler i Europa. Disse har blitt solgt og testet ut i tidlig-markeder som Norge der kraftige insentiver har gjort at elbilene har blitt konkurransedyktige tidligere enn i andre land. Fra 2020 får EU-kravene til personbiler full effekt med kraftige bøter hvis målene om at gjennomsnittsutslippet fra nye biler skal reduseres til 95 g/km i 2020, 80 g/km i 2025 og 60 g/km i 2030, ikke nås. Dermed er markedet over i en ekspansjonsfase der elbiler blir standardprodukter hos de fleste bil-merkene. Hvor bilene ender opp og hvor mange som vil bli solgt utover EUs minimumskrav avhenger av hvor godt bilen møter brukernes behov og hvor effektivt landene får tilrettelagt for brukerne slik at de får positive erfaringer og kunnskapen om at elbiler dekker brukerbehovene kan spres i samfunnet.

I Europa er EU dermed den store drivkraften med kravene til at det gjennomsnittlige CO_2-utslippet fra nye personbiler, varebiler og lastebiler skal reduseres, og det så mye fram mot 2025 og 2030 at elektrifisering av hele eller deler av modellutvalget er uunngåelig. Lovkravene i EU gjelder også for Norge. Dersom bilprodusentene ikke klarer kravene vanker det så store bøter at å klare kravet er en bedre opsjon. Kina har tilsvarende strenge krav til kvoteandeler med nullutslippsbiler. EUs krav utløser industrialisering av elbiler i stort omfang.

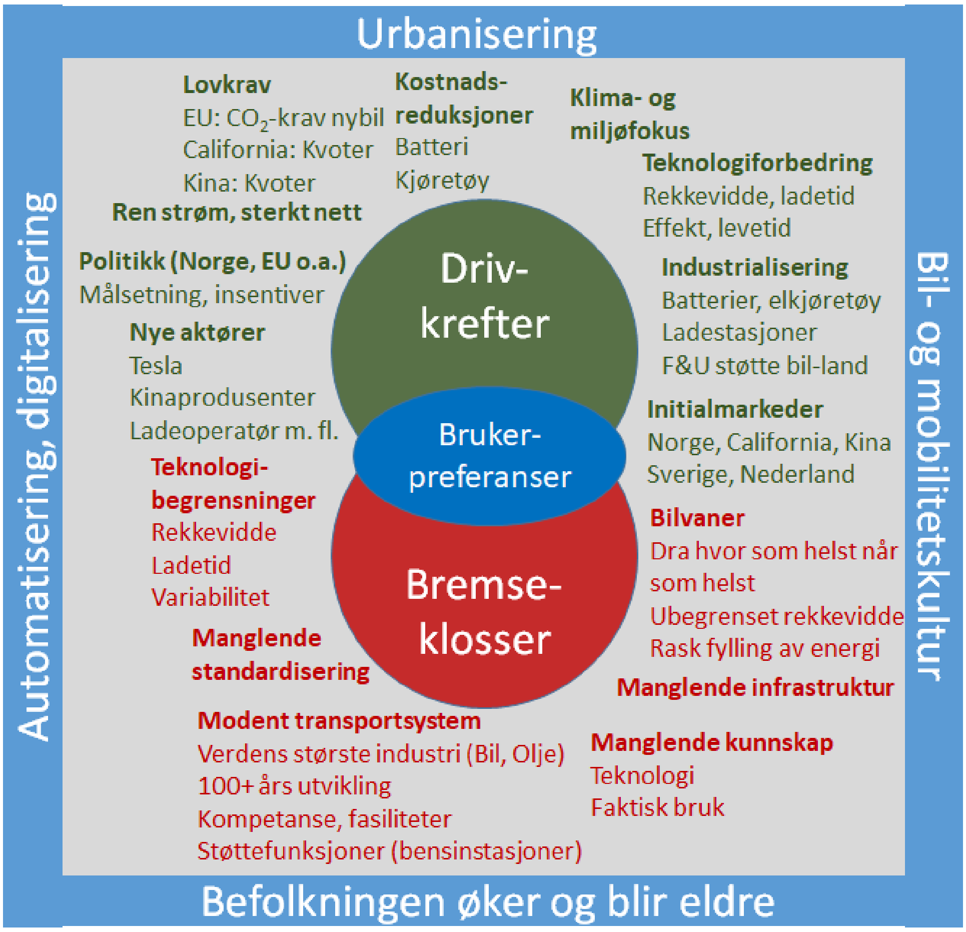
Det anslås at kjøretøyprodusentene investerer 300 milliarder Euro i elektrifisering de kommende årene, hvorav ca. 45 prosent for Kina. Dette innebærer at det også skjer en tilsvarende industrialisering av batterier. Dermed er investeringsbeslutningene tatt og utviklingskostnadene er å betrakte som avskrevne kostnader når produksjonen starter. I en situasjon der man må produsere for å klare lovkrav er det ikke gitt at denne kostnaden veltes fullt ut over på kjøperne.

EU kravene vil innebære at det i personbilmarkedet i Europa minimum må selges omlag 1,9 millioner elbiler og 0,9 millioner ladbare hybridbiler i 2025 og henholdsvis 4,3 millioner og 2,2 millioner i 2030. I varebilmarkedet vil det trolig bli solgt henholdsvis ca. 260000 og 640000 elvarebiler i Europa i 2025 og 2030. Lastebiler selges i mindre volumer og CO_2-kravet vil kunne innebære at det selges anslagsvis 16000-28000 el-lastebiler i Europa i 2025, og 32000-60000 i 2030. For bybusser er det ikke tilsvarende CO_2 krav, men EU-krav til offentlige innkjøp av busser vil gi et solid oppsving for elbusser, og sikre et minimumssalg på 20-40 prosent av bybussene som selges. Den nasjonale politikken i hvert enkelt land vil være styrende for hvor store volumer som selges i landet, men også for hvilke land som prioriteres av bilprodusentene når produksjonsvolumer tildeles.

Utviklingen drives også fremover av til dels nye aktører, herunder kjøretøymerker som Tesla, Nikola og ulike kinesiske merker som nå ser på forretningsmuligheter i Europa. Ladeinfrastrukturen bygges ut og driftes delvis av nye aktører og i økende grad også av bensinstasjonene.

Barrierer og bremseklosser utgjøres som vist i figur S.3 av teknologibegrensninger knyttet til begrenset rekkevidde som varierer betydelig mellom sommer og vinter, og at det tar betydelig lenger å lade en elbil enn å fylle diesel på en dieselbil. Andre barrierer er knyttet til kunnskapsmangel, manglende konsensus om ladeløsninger, eksisterende transportvaner, og infrastruktur som ikke helt henger med i den raske utviklingen i bilparken, og som ikke kan bygges ut fullt ut til å håndtere store variasjoner i etterspørsel gjennom året. Dette konkurrerer mot et system som har vært optimalisert gjennom over 100 år med forbrenningsmotorbiler, der energien er raskt tilgjengelig fra et stort antall fyllestasjoner. Disse barrierene og bremseklossene blir redusert over tid med bedre teknologi, utbygging av infrastruktur, og gjennom kunnskap opparbeidet i møtet med krevende kunders bruk.

Andre trender som befolkningsøkning og at det blir flere eldre i Norge vil trolig ikke redusere etterspørselen etter transport eller kjøretøyer fram mot 2030. Automatisering av kjøretøyer vil ta lang tid å etablere på et forsvarlig vis for norske vintertrafikkforhold og vil trolig ikke i seg selv begrense ønsket om å eie egen bil fram til 2030. Effekten kan også bli motsatt. Det vil si at på veien mot selvkjøring så gjøres kjøretøyene sikrere og mer bekvemme å kjøre, men krever fortsatt sjåfør, hvilket vil bidra i retning økt salg av kjøretøy og økt trafikkmengde. Det vurderes heller ikke som sannsynlig at trender som mikromobilitet eller bildeling i overskuelig framtid reduserer bilkjøp i Norge. Disse vurderingene vil langt på vei også være gyldige for andre europeiske land fram mot 2030.



Figur S.3: Drivkrefter og bremseklosser på veien mot et marked dominert av nullutslippskjøretøy.

Personbilsegmentet

Personbilmarkedet står foran en stor omveltning. Et stort antall elbiler og ladbare hybrid-modeller lanseres i perioden 2019-2022, og eksisterende modeller fornyes og får lenger rekkevidde. Denne omveltningen vil gjøre det enklere for bilindustrien å nå kravene til nye bilers gjennomsnittlige CO_2-utslipp i EU, og for å oppfylle kvotekrav om salg av elbiler i Kina. Satsingen på elbiler er betydelig større enn satsingen på ladbare hybridbiler. Innenfor personbilmarkedet vil det fra 2020 gå fra å være et marked med relativt få modeller, utvikles et marked med et kontinuerlig pris- og modellspekter, fra de minste og billigste elbilene til de største luksuselbilene. Ladbare hybridbiler vil være i kompaktsegmentet og oppover i størrelse. Langt flere enn i dag vil finne en bil med god rekkevidde som møter deres transportbehov, men det kan være noen begrensninger i forhold til transport-fleksibilitet. Bilene vil også kunne lades raskere med større batterier.

Kjøpsprisen på kompaktstørrelse elbiler med små batterier har takket være avgiftsfritakene matchet bensin- og dieselbilene på kjøpspris siden ca. 2015 og fra 2019, også de med store batterier. Årlige kostnader ble kompatible i Norge allerede fra 2012, noe som har resultert i en rask markedsekspansjon. Fra perioden 2023 til 2025 blir elbiler et samfunnsøkonomisk lønnsomt klimatiltak i Norge. Elbilene vil kunne få økt konkurranse fra den nye generasjonen ladbare hybridbiler med realistisk sommerrekkevidde på 50-100 km. Også disse vil få en attraktiv pris i Norge slik avgiftssystemet er utformet, men vil ikke være konkurransedyktig på pris med elbilene. I resten av Europa er elbiler dyrere enn bensin- og dieselbiler fordi de er dyrere å produsere og det er færre og dårligere insentiver tilgjengelig.

I noen av markedene med bonuser på opptil 6000 Euro for kjøp av elbiler kan de totale kostnadene per år konkurrere med bensin- og dieselbilene.

Varebilsegmentet

I varebilsegmentet har markedet for elvarianter i Norge og andre land vært tregt fram til 2019. Det vil bli litt bedre i 2020, mens det først vil være fra 2021 at den store omveltningen starter. Et flertall av de små varebilmodellene får da en batterielektrisk variant som kan dekke de fleste varebilbrukeres behov med en rekkevidde på 200-300 km avhengig av årstid og land. Elvarebilene har ennå ikke oppnådd kostnadsparitet ved kjøp fordi det som nevnt er færre insentiver tilgjengelig enn for personbilene. Kostnadsparitet i Norge forventes nådd i 2022-2023, men varebilene har vært kompatible på årlige kostnader de siste 2-3 årene. I 2021 forventes produsentkostnadene å ha falt så mye at elvarebiler kan bli samfunnsøkonomisk lønnsomme.

Bussegmentet

De fleste bussprodusentene har allerede lansert batterielektriske busser for bybruk i ulike størrelsesvarianter. Disse skreddersys for lokale driftsforhold i fht. batteristørrelse, rekkevidde, varme og kjøling, og ladeløsninger, slik at full ruteproduksjon blir mulig (rutetider og antall passasjerer). Dermed er det ikke lenger tekniske eller tilgjengelighets-barrierer mot økt bruk av elbybusser. De årlige kostnadene er i 2019 høyere enn for dieselbusser, men forventes å falle raskt mot 2025 da elbusser kan bli konkurransedyktige på totale kostnader, gitt at batteriet varer anbudets levetid, eller at en batterigaranti kan gis innenfor en kostnad som svarer til innsparingen i årlig vedlikehold sammenlignet med dieseldrift. Sistnenvte vil eliminere operatørens risiko i fht. batterilevetiden. Batterilevetiden vil en ikke kunne vite sikkert hvordan det går med før busser er i ordinær drift i Norge. Langdistansebusser er mer usikkert og vurderingene blir som for langtransportlastebiler.

Lastebilsegmentet

Lastebiler er helt i oppstarten av en markedsintroduksjon og serieproduksjon starter fra 2020-2022. Det er åpent om det blir hydrogen eller batterielektriske løsninger som slår gjennom for langdistansekjøring, mens for bylogistikk og andre lokale bruksområder vil batterielektriske løsninger stille sterkest, pga. den lave kostnaden for el og fordi mange av disse kjøretøyene vender tilbake til depot hver dag og kan lades der. Også for lastebiler er det veldig lite erfaring fra praktisk drift og derfor stor usikkerhet rundt kostnader, og levetiden på batteriene. Det gjelder også for hydrogenløsninger og -drift.

Noen mål er oppnåelige, andre er utfordrende

Målene i NTP om introduksjon av nullutslippskjøretøyer ligger henholdsvis 5 og 10 år frem i tid. Noen kjøretøymodeller som er til salgs i 2019 vil fortsatt være til salgs i 2025. De fleste av modellene som lanseres i 2020-2021 vil være i salg i 2025, eventuelt med en mindre midtlivsoppdatering. Det betyr at en allerede vet mye om kjøretøymodeller som vil være i salg i 2025, og det er enklere å vurdere hvordan dette vil slå ut enn for mål som gjelder for 2030. Målene for personbiler, varebiler og bybusser kan være oppnåelige. De andre målene er mer usikre som oppsummeringen i tabell S.1 viser. EUs mål vil trolig nås pga. de høye bøtene for manglende måloppnåelse.

Tabell S.1: Oppsummering av mulighetene for å nå nullutslippsmålene til kjøretøy i Nasjonal Transportplan og for å nå EUs CO_2-krav til nye kjøretøy.

Mål	Mulighet for å nå mål	Innsatsbehov i Norge
NTP: Kun selge nullutslippsperson-biler fra 2025 EU: Nye biler 15% lavere CO_2-utslipp i 2025 i fht. 2020, 37% lavere i 2030.	Personbilmarkedet er spesielt utfordrende, og NTP-målet vil bli veldig krevende og kostbart å nå 100% med frivillighet. EU-målet vil trolig nås pga. store bøter. Produksjons-kostnadene går nedover og mye innovasjon skjer hos bilprodusentene. Det kommer et stort antall nye modeller på markedet fra 2020-2022. Noen kjøpergrupper har ekstra krevende bilbruk, andre har lite å tjene på å kjøpe elbil, og noen har andre store barrierer. I spesielt kalde områder vil stor rekkeviddereduksjon holde markedet nede, selv om bilene får økt rekkevidde. Målet vil bli enklere å nå hvis man gir ladbare hybridbiler med lang rekkevidde en plass i strategien, f.eks. at 20% av kravet kan være slike biler.	Fortsatt gode insentiver og bedre ladeinfrastruktur er nøkkelfaktorene for å nå dette målet. Ladeinfrastrukturen må særlig bedres i byene der folk ikke har egen parkering, og det må finnes bedre løsninger for finansiering av hurtigladere som muliggjør lange reiser.
NTP: Kun selge små nullutslipps-varebiler fra 2025 EU: Nye varebiler 15% lavere CO_2-utslipp i 2025 i fht. 2020, 31% lavere i 2030.	NTP-målet kan være mulig å nå ut fra kostnader og egenskaper ved elvarebilene som kommer på markedet. EU-målet vil trolig nås pga. store bøter. Tilbudet av elvarebiler øker betydelig, og rekkevidden blir kompatibel med bruksområdet. Det kan være utfordringer i spredtbygde strøk der det er mindre informasjon tilgjengelig om bruken, og i spesielt kalde strøk pga. rekkeviddereduksjon. Segmentet er kostnadssensitivt og avhengig av pålitelig, fleksibel transport.	Dette målet krever kraftigere virkemiddelbruk for å nås. Det viktigste elbilinsentivet, MVA fritak har ingen effekt i dette segmentet. Enova-støtten fra 2019 er bra. Kunnskapsspredning mellom bedrifter blir essensielt.
NTP: Kun selge store nullutslipps-varebiler fra 2030 EU: Nye varebiler 15% lavere CO_2-utslipp i 2025 i fht. 2020, 31% lavere i 2030.	Teknologien vil kunne bli god nok til at NTP-målet kan nås, men i 2019-2020 er det ikke store varebiler tilgjengelig i markedet som muliggjør måloppnåelse. Til det er rekkevidden for kort. Målet ligger 10 år frem i tid og store varebiler ligger ca. 5 år etter de små i markedsutviklingen, så målet kan nås dersom produsentene utvikler store varebiler med lang rekkevidde. EU-målet vil trolig nås pga. store bøter.	Dette målet krever kraftigere virkemiddelbruk for å nås. Det viktigste elbilinsentivet, MVA fritak har ingen effekt i dette segmentet. Enova-støtten fra 2019 er bra. Kunnskapsspredning mellom bedrifter blir essensielt.
NTP: Kun selge nullutslippsbybusser fra 2025 EU: Krav til offentlige innkjøp vil bety 20-40% el-andel	NTP-målet kan være mulig å nå. EUs krav vil trolig nås pga. at det er et krav. Det blir god tilgjengelighet av batterielektriske busser i markedet og de skreddersys til lokale forhold ifht. batteristørrelse og ladekapasitet. 2019-kostnadene er høyere enn for dieselbussdrift, og det er til dels betydelige infrastrukturinvesteringer, men i 2025 kan kostnadene ha falt til et nivå som er kompatibelt med dieselbusser. Det kan bli behov for 5-10% flere busser på travle ruter pga. ladebehov, noe som gir økte kostnader i forhold til dieseldrift. Dette segmentet kan bli det som først helelektrifiseres i Norge, og i resten av Europa.	Krever aktiv bruk av miljøkrav i offentlige anbud. Dette er desentralisert til norske fylker. Nasjonale føringer bør vurderes. Alle busser kan være byttet ut i løpet av ca. 10 år ved anbudskrav. Kunnskapsspredning om praktisk drift mellom fylker/operatører er essensielt, f.eks. i brukerfora.
NTP: Selge 75% nullutslipps - langdistanse-busser fra 2030 EU: Ingen spesifikke	Langdistansebussene kan teoretisk elektrifiseres, det krever store batterier og rask lading, eller bruk av hydrogen. Det er bare én elbuss tilgjengelig i markedet (med kort rekkevidde) og ingen med hydrogen. For busser i faste ruter kan det i varierende grad av kompleksitet etableres lade- eller hydrogeninfrastruktur. Turbusser er mest utfordrende. De kan kjøre overalt og må ha en basis-infrastruktur for fylling av hydrogen/lading av batteriene som dekker mye av Norge. Det er uklart om NTP målet kan nås.	På dette området er det først og fremst behov for teknologi og produktutvikling. Det finnes ikke egnede produkter på markedet, og dermed ikke noe grunnlag for nasjonal planlegging av politikk, insentiver eller infrastruktur.
NTP: Selge 50% nullutslipps-lastebiler fra 2030 EU: Nye lastebiler 15% lavere CO_2-utslipp i 2025 i fht. 2020, 30% lavere i 2030.	Teoretisk kan lastebiler elektrifiseres for mange bruksområder, eller benytte hydrogen. Markedet er i en initial fase med lite informasjon tilgjengelig om hvordan dette i praksis vil fungere under norske forhold. Det var ingen el- eller hydrogenlastebiler i ordinært salg i 2019, bare enkelte ombygninger fra dieseldrift. 2020-2022 vil store lastebilprodusenter og nye selskaper som Tesla og Nikola tilby serieproduserte batterielektriske lastebiler (Nikola også hydrogen). Markedspris og tekniske egenskaper er ikke kjent. I byer og andre steder der lastebiler brukes lokalt kan batterielektriske løsninger fungere. Dette er en svært begrenset del av lastebilmarkedet. Mye teknologi- og produktutvikling vil skje fra 2020 til 2030, og EUs krav til gjennomsnittlig CO_2-utslipp fra nye kjøretøy vil medføre en industrialisering av el- og hydrogenlastebiler. Det er for tidlig å si om dette sammen med en effektiv politikk med gode insentiver kan gjøre at NTP-målet kan nås. EUs mål vil nås pga. de høye bøtene for manglende oppnåelse.	Systematisk innsamling og spredning av kunnskap om hvordan dette fungerer i praksis for norske bedrifter, og økonomien i bruk av el-lastebiler, vil være essensielt for å øke sannsynligheten for at målet kan nås. Et rettighetsbasert system for å støtte innkjøp vil trolig bli nødvendig for å få til en bredere og raskere utrulling. Det trengs mer forskning rundt hvordan en landsdekkende lade- og hydrogen-infrastruktur for tunge biler skal se ut, hvordan den kan etableres, og hvordan transport på tvers av grenser vil kunne foregå.

Volumer av batterier til resirkulering

Det er først og fremst elbiler (personbiler) som vil bidra til betydelige volumer for resirkulering av Li-Ion-batterier innen 2025 og frem til 2030 i Norge og i resten av Europa. Beregningen av antall batterier som kommer inn i bilflåten og vrakes etter bruk er derfor begrenset til batteri elektriske personbiler i denne rapporten. Dette betyr at volumet av batterier er noe undervurdert da volumet av batterier fra ladbare hybridbiler og el-varebiler ikke tas med i beregningen. Disse anslås å utgjøre relativt små volumer sammenlignet med elbiler siden bare ca. 7300 el-varebiler var i bilparken i starten av 2020 mot 260600 elbiler, og fordi ladbare hybridbiler selges i mindre volumer enn elbiler, har mye mindre batterier og trolig kan ha noe lenger levetid fordi de gjennomgående er større enn elbilene. I tillegg kom de på markedet i større volumer først fra 2016 og få vil være gamle nok i 2030 til å bli skrapet. Li-Ion-batterier fra tunge lastebiler og busser er det usannsynlig at blir tilgjengelig for gjenvinning i betydelig antall før etter 2030.

Kjøretøyer som kommer inn i den norske bilparken ble lagt inn i en modell (BIG-Bil Generasjon) over bilparkens utvikling over tid. Modellen genererer antall biler som vil bli tilgjenglig for skraping per år. Ved å kombinere dette tallet med estimater av typer og størrelser på batterier som har blitt brukt, brukes og estimater for fremtidig utvikling av batteristørrelsen, for perioden 2011 til 2030, kan det beregnes et estimat for mengden batterier som vil bli tilgjengelige for gjenbruk eller gjenvinning hvert år fremover i tid. 2018 var det siste året med tilgang på historiske salgstall. Batterityper og -størrelser for 2019 ble antatt å være lik som i 2018. Batteristørrelser for produksjonsårene 2020-2030 ble estimert ved å ta hensyn til batteristørrelser på kjente elbilmodeller som kom på markedet fra 2020. Alle elbiler solgt etter 2019 ble tilordnet som ukjent Li-ion batteritype, ettersom batteritypen for fremtidige modeller og i salgsmiksen i 2020 er ukjent. Anslaget for den totale batterikapasiteten installert i nye elbiler i Norge på tvers av Li-Ion-batterityper ble estimert til å være 2,4 GWh for 2018, økende til ~ 8,5 GWh i år 2030. Netto mengde batterier som blir tilgjenglig for gjenbruk eller resirkulering per år ble for Norge beregnet til å være ca. 0,6 GWh i 2025, og ca. 2,2 GWh i 2030. Disse batteriene kan potensielt gjenbrukes til ulike bruksområder, f.eks. hyttestrøm, men det kan være mer økonomisk å resirkulere dem. Det ble ikke estimert mengde Li-ion-batterier som stammer fra årsklasser før 2011 siden disse kjøretøyene var få og flertallet ikke hadde Li-Ion-batterier.

Volumene av installerte batterier og batterier som blir tilgjengelig for gjenbruk eller resirkulering i EU og EFTA-land utenom Norge, vil samlet sett kunne utgjøre om lag 2 ganger de norske volumene i 2025, og 4 ganger de norske volumene i 2030. Deretter vil volumene vokse mye raskere i andre land enn i Norge, fordi EUs CO_2-krav til biler slår inn for fullt i bilmarkedet fra 2020 av. I 2025 vil Norge, om målet om bare å selge nullutslippspersonbiler nås, kunne stå for om lag 8% av de totale Europeiske elbilsalgsvolumene, og andelen synker til under 4% i 2030. Dermed vil det i løpet av perioden 2035-2040 kunne bli omlag 10 ganger høyere gjenbruks/resirkuleringsvolumer tilgjengelig i EU enn i Norge, og 20 ganger så høye volumer om lag 5 år senere.

1 Introduction

The transport sector accounts for around 30% of greenhouse gas emissions in Norway (Norwegian Environment Agency, 2019), and around 23% of energy-related CO_2 emissions globally. At the same time there is strong growth in global transportation demand. Therefore, it is crucial to reduce global emissions from the transport sector to reach international climate targets (Sims R. et al., 2014). An important way of reducing such emissions is to electrify the various vehicles in all the market segments of the transport sector. The electrification process has just started on a global and European scale but has reached quite far in the Norwegian passenger vehicle segment. The European Union targets for average CO_2-emission of new vehicles will push the market towards introduction of large volumes of Zero- and low-emission vehicles containing batteries over the coming decade. Similarly, quotas for zero-emissions vehicles in China and California will give a similar effect in those markets.

The government in Norway has set targets for zero emission vehicles in the National Transportation Plan 2018-2029 (Meld. St. 33 2016-2017) which should be reached by 2025 and 2030.

These goals are:

- By 2025 all new passenger cars will be zero-emission vehicles
- By 2025, all new light LCVs will be zero-emission vehicles
- By 2025, all new city buses will be zero-emission vehicles, or use biogas
- By 2030, all new heavier LCVs will be zero-emission vehicles
- By 2030, 75% of new long-distance buses will be zero-emission vehicles
- By 2030, half of new trucks will be zero-emission vehicles.

The term zero emission vehicle in these national goals encompasses both battery electric vehicles (BEVs) and fuel cell hydrogen electric vehicles (FCEVs). This report focuses on BEVs as the means to achieve these goals. In order to achieve these goals, zero-emission vehicles must be economically competitive to buy and own as compared to petrol and diesel vehicles. They must also be widely available and meet many different user needs. There is also a category of low emission vehicles that have batteries installed, such as Hybrid vehicles (HEVs) and Plug-in Hybrid vehicles (PHEVs). The former uses a small battery and an electric motor, in tandem with the ICEV to reduce the vehicles fuel consumption. The latter can in addition be powered solely by electricity charged from the grid and stored in the vehicles battery. In the passenger vehicle segment, a BEV may have batteries ranging in size from 16-100 kWh, a PHEV 8-24 kWh and a HEV would have a battery of less than 1 kWh capacity.

Vehicle manufacturers' efforts in relation to zero-emission vehicles are therefore, to date, strongly dependent on different countries' national incentives to bring these on to the market. Market developments depend, inter alia, on *technological developments and the development of the total costs for consumers*, i.e. how profitable zero-emission vehicles are in purchasing, operating and reselling, as compared to their alternatives. The technological developments are also influenced by other factors, such as *EU regulations, national regulations and local regulations*. For the car market, for example, the EU's CO_2 regulation is expected to have a decisive effect on the number of BEVs on the market.

At the same time, there are more factors than cost trends that are important for the distribution of various zero-emission vehicles. For example, if the charging infrastructure is insufficient, different buyer groups will not be as interested because it becomes too cumbersome to use these electric vehicles. Other barriers include, for example, skepticism towards new technology. In recent years there has been a roll-out of charging infrastructure for BEVs and small electric LCVs on a large scale in Europe and along transport corridors. The same cannot be said for BE-Trucks or long-distance bus routes.

Another factor is that there must be sufficient volume in the production of such vehicles, as otherwise many will not be able to acquire such vehicles even though they may want them. BEVs and FCEVs are also currently more expensive to produce and develop than gasoline and diesel vehicles due to the added cost of the battery for the BEV and the fuel cell and hydrogen system for the FCEV. The low production volumes prior to production are scaled up significantly, causes additional cost disadvantages because there are fewer cars to allocate development-, production-, tooling and equipment-costs to. Vehicle production is thus very volume sensitive in terms of cost. In addition, low sales volumes lead to additional cost in the service and sales networks, as the cost of educating service and sales personnel is split between fewer vehicles.

This report deals with two main questions. The first question is how rapidly the sales volumes of battery electric vehicles will increase in the different segments of the vehicles market at the Norwegian and European scale. A second question is how large volumes of batteries will eventually become available for recycling in Norway, when these vehicles have been scrapped. This calculation will be limited to battery electric passenger vehicles and will not include PHEVs or HEVs. Later work in the BATMAN project will look into the volumes of batteries also for these vehicle types and for the other vehicle segments.

An overview of the chapters of the report is found in Figure 1.1. Chapter 2 provides a brief background to the mission and the status of zero-emission vehicles and incentives in Norway. Chapter 3 provides an overview of the research questions, while Chapter 4 describes the methods and sources of data used in the analysis. The main part of the report is structured so that the chapters build on one another and, thus, they are given in a specific order. Chapter 5 describes the technological developments that have enabled the large market introduction of electric vehicles in all the vehicle categories, which are given an overview of in Chapter 6. Infrastructure development is a necessary prerequisite for introducing electric vehicles, and the developments in this area are presented in Chapter 7 for Norway and other selected countries. Countries have different prerequisites for electrification, and Chapter 8 presents data that can affect the phasing-in of zero-emission vehicles in different countries in Europe. Chapter 9 presents calculations of future purchase prices and annual costs for various car types and energy carriers for Norway and for selected EU countries. The cost picture presented in Chapter 9 is an important factor in understanding the user experience and experiences with electric vehicles presented in Chapter 10. Chapter 11 presents, evaluates and ranks the overall driving forces for the phasing in of electric vehicles, and the effects of transnational and national incentives and policies. Chapter 12 presents a scenario which shows the quantity of Li-Ion batteries that will flow through the Norwegian transport sector from when the vehicles are first used until they are scrapped. Chapter 13 provides an overview of possible scenarios for the future development of the global and regional BEV market, based on major works done by IEA, BloombergNEF, DNV GL and others. Chapter 14 contains a summary and conclusion.

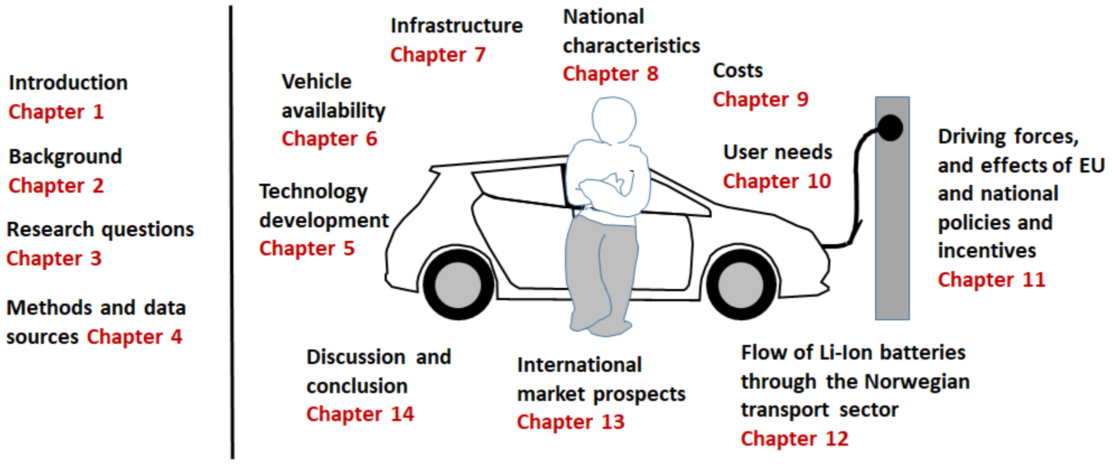


Figure 1.1: Overview of the structure of the body of the report.

As can be seen from the overview above, this material is complex and there are several links between the various influencing factors that are dealt with in this report. This means, among other things, that some of the key facts will be repeated throughout the report. This has been done deliberately to provide the best possible basis for a comprehensive understanding of the material.

2 Background

Norway is at the forefront of the world in the introduction of electric means of transport. This applies, *inter alia*, to the introduction of BEVs and PHEVs in the passenger vehicle segment, and battery electric ferries. Due to strong incentives (Table 2.1) in combination with the international development of batteries which allow for BEVs with increased range, a generally high standard of the new generation of BEVs, and the fact that political actors have used the windows of opportunity available to them, Norway currently has the largest BEVs share of the vehicle fleet in the world (Figenbaum et al., 2019).

Table 2.1: Overview of Norwegian national and local incentives for electric vehicles in Norway as of November 2019. Source: Updates from Figenbaum and Kolbenstvedt (2016).

Incentive	Year	Comment
National economic incentives		
One-off tax exemption	1990/1996	Introduced de facto from 1990, formally from 1996.
Exemption from VAT	2001	Introduced from July 2001.
Exemption from traffic insurance fee	1996/2018	Previously called annual fee with full exemption until 2003, then partial exemption for 2018. From 2018 full exemption from traffic insurance fee.
Reduced benefit tax on the disposal of a company car	2000	Introduced around the year 2000 (half rate of gasoline and diesel cars) when BEVs had limited reach and the private benefit was considered small. The current rate means that the value of the BEV is assumed to be 60% of the purchase price when calculating the benefit.
Exemption from registration fee	2018	The exemption means that it is free to re-register an BEV.
Local incentives		
Reduced rate or exemption from tolls	1997	From 1997-2017 it was statutory that BEVs were exempt from tolls. From 2018 up to half the rate of petrol / diesel rates can be introduced. In most toll systems, there is still a full exemption, but in 2019 low rates were introduced for BEVs in certain places.
Reduced ferry fare	2009	This incentive was introduced on the national highway ferries in 2009 and did not apply to county ferries which could, as a result, charge full rates. Since 2018, there has been a maximum half rate of the rate for petrol and diesel cars on both national- and county-road ferries.
Reduced rate or exemption from parking fees	1999	There has been free parking for BEVs at all public car parks until 2017. From 2018 tariffs can be introduced that reach up to 50% of tariffs for gasoline and diesel cars
Free charging	1999	Free charging has often come with free parking.
Access to bus lane	2003/2005	BEVs had full access to bus lanes, first as an experimental scheme in Oslo and Akershus from 2003, and then in the whole country from 2005. From 2015, restrictions have gradually been introduced. In some places around Oslo, there must be more than one person in the car during rush hour.
Support for infrastructure		
Normal chargers in public areas	Current	There are various support programs for the establishment of normal chargers in public areas. Some municipalities are expanding themselves.
Normal chargers in housing cooperatives	Current	There are various support programs available in municipalities and counties.
Fast chargers along main roads and in municipalities without fast chargers	Current	Enova (Transnova before merging with Enova) has supported the development of fast chargers since 2011, partly through support schemes and partly through tenders. specifying a certain number of fast chargers per 50 km stretch along main roads.

For passenger cars, the BEV share of the vehicle fleet reached 9,4% in 2019 based on the latest figures from the Norwegian Public Roads Administration. Figure 2.1 provides an overview of the market shares by month for BEVs since 2011. The overall market shares in 2019 were: BEVs 42%.

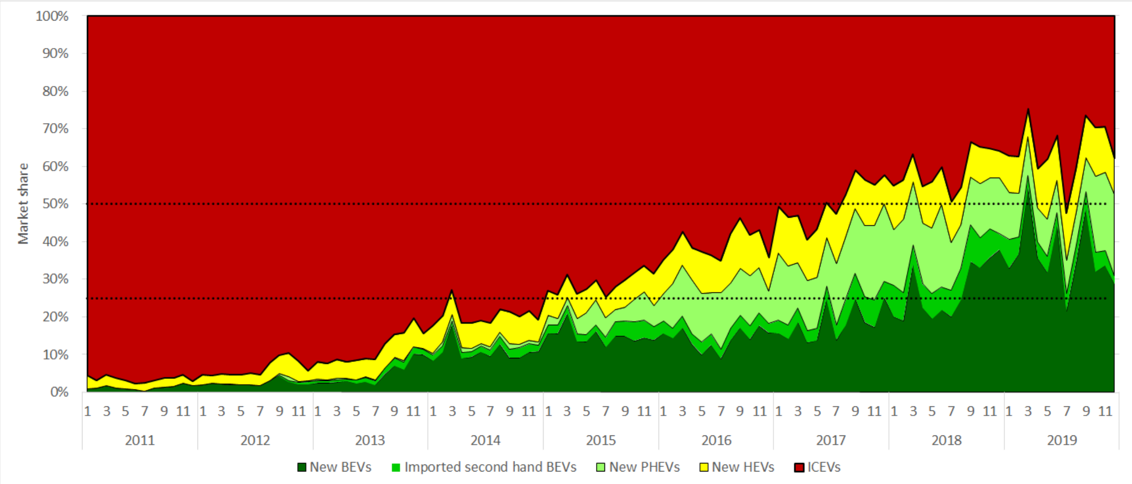


Figure 2.1: Market share passenger cars, percentage of new registrations by month for BEVs, PHEVs, HEVs, ICEVs. Source: OFVAS (2020).

Sales of Light commercial battery electric vehicles (BE-LCVs) remained limited until 2018, but have since 2019 increased rapidly with the introduction of models with 50% increased range. In addition, the economic incentives have been somewhat improved with the introduction of a new Enova support program for these vehicle types. The BE-LCV market share in 2019 was 5.7% and their share of the fleet reached 1.6%.

However, the sale and distribution of other types of electric vehicles, such as large electric LCVs and BE-Trucks, is very limited in Norway, much like in the rest of the world at present, mainly because there haven't been any such vehicles available on the market. An exception is battery electric city buses that have almost taken over the market in major cities in China (BloombergNEF, 2018) and are quickly moving into many European countries (Sustainable Bus, 2019a,b), and are the vehicle segment that is expected to be electrified the fastest (BloombergNEF, 2019a). Electric buses have also seen a strong upswing in Norway as more and more public companies are investing in electric buses. During 2020, the number of eletric buses in Norway will exceed 400 (Hovi et al., 2019a, 2019b).

Globally, BEVs and PHEVs sales are growing rapidly in different countries, especially in China and in some EU/EFTA countries. There are now more than 5 million BEVs and PHEVs in the world (IEA, 2019a) and over 2 million were sold in 2018 (BloombergNEF, 2019a) and approximately 2.26 million (EV-volumes 2020) in 2019. The development of a market for BEVs in Norway has most likely been important for creating a market for BEVs internationally. For example, Norway has a double digit-share of the worldwide sales volume of the Nissan Leaf, VW E-Golf and Tesla Model S and X.

At the turn of the decade (2019/2020) there were approximately 260,000 BEVs in Norway, as shown in Table 2.2 (Norwegian Public Roads Administration, 2020) and approximately 116,000 PHEVs along with 7300 BE-LCVs. In other vehicle segments, the introduction has been slower. The table gives an overview of the Norwegian vehicle fleet as of 31.12.2019, and sales of vehicles in Norway in 2019, by BEV, HEV, PHEV and FCEV, as well as total vehicle fleet and total vehicles sold.

Table 2.2: Vehicle fleet as of 31.12.2019. Sale of different types of vehicles in 2019, and percentage of overall sales (Passenger cars). Source Norwegian Public Roads Administration (2020).

	Total vehicle fleet as of December 31, 2019				
Car Type	**Battery electric**	**Hybrid**	**Plug-in Hybrid**	**Fuel Cell Hydrogen**	**Total vehicle fleet**
Passenger cars	260581	110665	116029	149	2770550
LCVs	7331	78	39	1	485742
Buses	199	154	54	5	15850
Trucks	19	18	2	1	71496
	Total vehicle sales in 2019 (excluding used imports[1])				
Car Type	**Battery electric**	**Hybrid**	**Plug-in Hybrid**	**Fuel Cell Hydrogen**	**Total sales**
Passenger cars	60246 (41%)	19241 (13%)	18864 (13%)	28	145985
LCVs	2011	23	5	0	35628
Buses	158	6	63	0	2314
Trucks	1	1	0	1	5956

Sales of BEVs and PHEVs have also increased in the EU countries as shown in Figure 2.2. Sweden had the second highest market share in 2019 with 11.3%, behind the Netherlands with 15%. Then follows Finland at 6.9%, Portugal and Switzerland with 5.6-5.7%, and a number of countries with 3.0-4.2% market shares, including the large UK and German markets at 3.2% and 3.0% respectively, followed by France at 2.8%. Eastern European countries have the lowest share of BEVs and PHEVs in new vehicle sales; all are below 1.0% with the exception of Hungary. In the large Italian market, the share is below 1.0%. On average, EU countries had a BEV share of new vehicle sales in 2019 of 2.0%, wheras 1.2% were PHEVs. The mix of sales between BEVs and PHEVs varies substantially between the countries due to differences in how incentives and policies are formulated.

Over the next few years, access to battery-electric vehicles in different vehicle groups and segments according to different scenarios and investigations will increase rapidly (BloombergNEF, 2019a; T&E, 2019a; DNV GL, 2019; IEA, 2019a; IEA, 2019b). The introduction of regulations for new vehicles' CO_2 emissions will accelerate the sale of zero emission vehicles in Europe, while quotas and regulations for sales in China and California will contribute to increased sales there. A number of countries have introduced various types of incentives to support the market introduction of zero-emission vehicles, thus helping to establish global demand for this types of vehicles. The industrialization of BEVs, electric LCVs and electric buses is therefore now accelerating, and a real market introduction of BE-Trucks will start from 2020.

[1] 15462 passenger vehicles were imported second hand and registered first time in Norway in 2019, of which 6802 where BEVs. 102 BE-LCVs were also imported second hand.

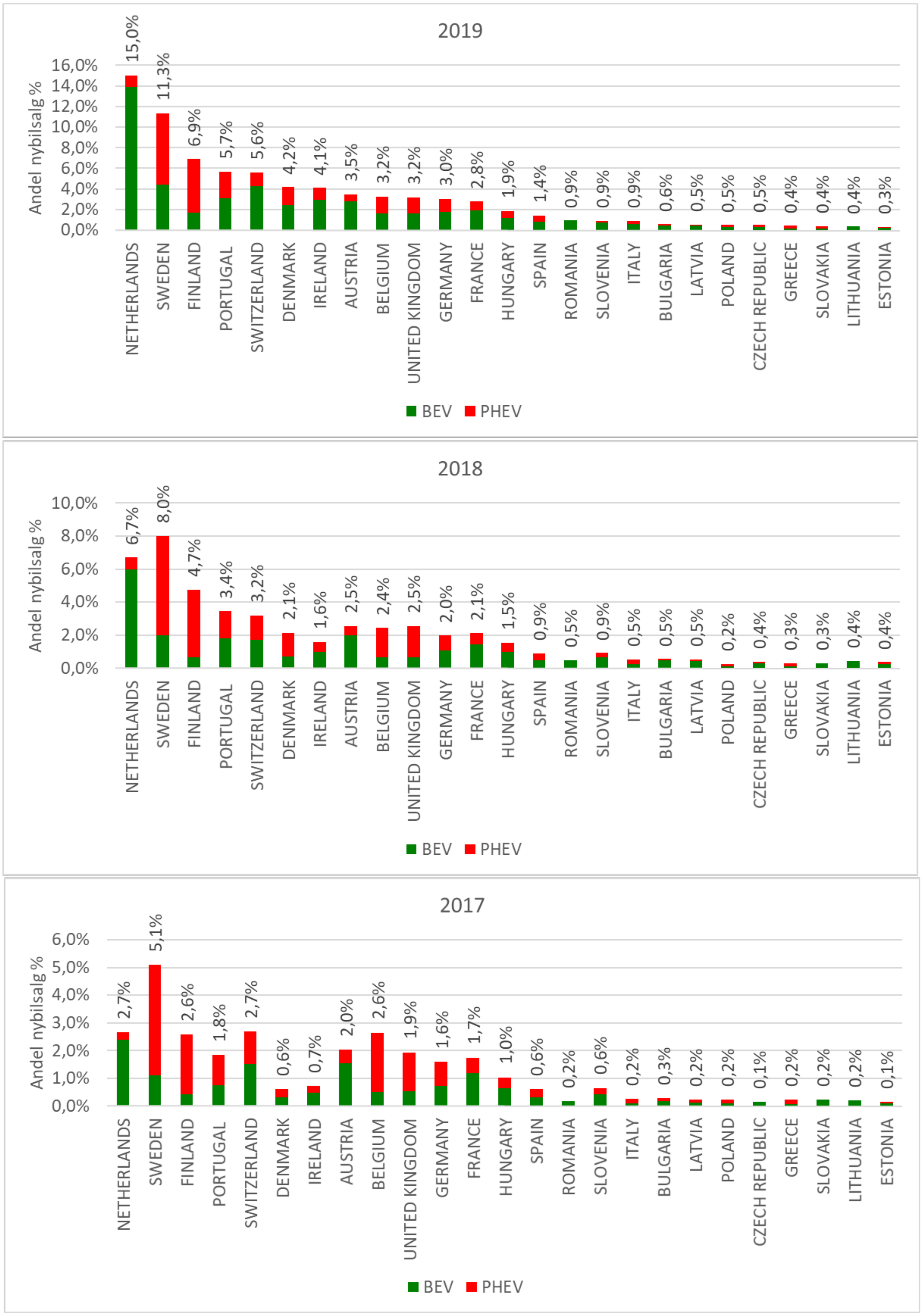


Figure 2.2: Market shares for electric vehicles and rechargeable hybrid vehicles in EU countries in 2017,2018 and 2019. Sources: ACEA (2020, 2019b)

3 Research Questions

This report is part of the Research Council of Norway funded research project BATMAN, "Lithium ion BATeries-Norwegian opportunities within sustainable end-of-life MANagement, reuse and new material streams" (NFR project number 299334), conducted in co-operation between the Southern Norway based energy and materials industry, as well as other research partners. In BATMAN the overall target is to understand when the flow of Li-Ion batteries, which enter the automotive markets in new vehicles, will become available for re-use and end-of-life recycling on Norwegian, European and global scales.

It is important to understand the key factors that drive the uptake of battery electric solutions in the fleet, and understand the volumes that will be sold (and where they will be sold) in Europe. Once these vehicles are in the fleet, they are used over a number of years by different users until they are scrapped. Finally, the batteries are taken out and sent for re-use and/or recycling.

The key research question of BATMAN is:

When will large enough volumes of Li-Ion batteries be available for re-use/recycling to justify investments in the re-use market and increased recycling capacity?

This report contributes to the understanding of this question by:

- Analysing the future markets for Zero-emission vehicles in Europe and Norway, and the availability of zero emission vehicles for sale in different segments in coming years.
- Analysing the effects of the Norwegian governments targets for sales of zero-emission vehicles in different transportation segments and the prospects of Li-Ion battery powered vehicles.
- Analysing the effects on sales of zero- and low emission vehicles in Norway and in Europe of EU requirements for a reduction of new vehicles CO_2-emission up to 2030.
- Calculating the flow of Li-Ion batteries into and through the Norwegian passenger vehicle fleet, and the volumes of batteries that will become available for recycling by 2025 and 2030.

4 Methods and Data Sources

4.1 TØI-TCO model – Passenger cars and LCVs

A new Total Cost of Ownership model (TØI-TCO) was developed and used for the cost calculations. In the model, TCO is calculated as an annual average cost for different vehicle segments. The model includes many different parameters for the different types of vehicles using different energy carriers (electricity, hydrogen, gasoline, diesel). The cost elements are broken down into units that enable sufficient detail, and which are relevant for an extended analysis of correlations and sensitivity to variation/uncertainty in costs. Figure 4.1 shows a flow chart for the model, which calculates cars' future purchase prices, total annual costs and socio-economic costs. The model is implemented in Excel.

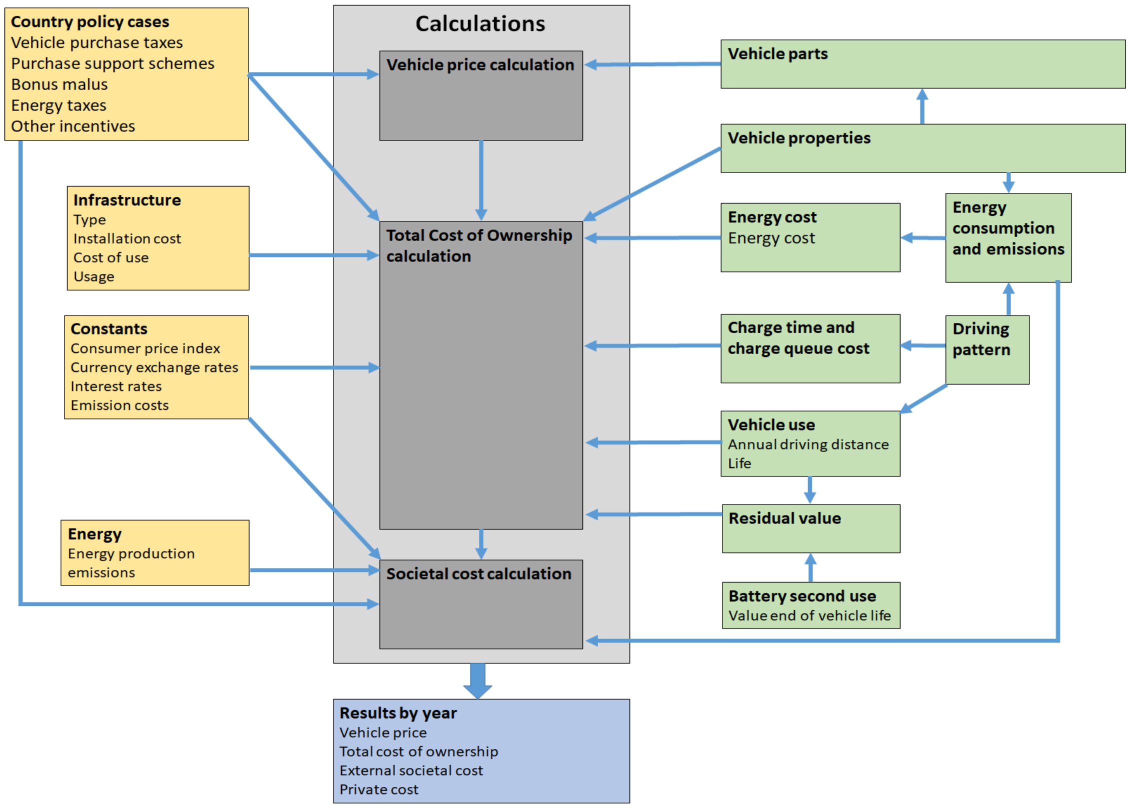


Figure 4.1: Overview of TØI-TCO model for total annual car ownership and utility costs. The model includes all relevant costs such as depreciation, capital cost, energy, maintenance, insurance, etc.

The consumer and business economy part of the model calculates cost losses over a given number of years, capital costs for tied-up capital, energy and maintenance costs and other variable costs, insurance, fast-charge costs based on an average driving pattern, depreciation on home/depot chargers, effects on annual costs of various purchase and user incentives, taxes and fees.

Disadvantage costs related to long distance driving such as long charging time and limited range have been accommodated by calculating queue and charge time costs. The

Norwegian Environment Agency calculated the disadvantage cost as the difference in annual cost between a BEV and a diesel car in a report from 2018 (Norwegian Environment Agency 2018), and use it to explain why not everyone chooses an BEV. This is methodically problematic because there have been (and are) long queues to buy the models that customers prefer, i.e. models with a long range. There has also not been full access on the market as there are many brands that cannot supply BEVs.

In this report, the disadvantage cost is considered to be related to the time cost of charging on longer distance trips. It consists of one element consisting of the cost of the actual time used for the charging process (with the exception that some of the time would be a normal break on a long distance trip), and one element covering the variable queue time cost for fast charging. In addition, the cost of using the charger itself is also taken into account.

The data included in the model is described further in Annex 2 of TOI report 1744/2019 (Figenbaum et al., 2019).

4.2 TØI – BIG model

The BIG model is described in Fridstrøm & Østli (2018), and the description below is taken from that report.

BIG is a stock-flow vehicle generation model that follows cohorts of passenger cars, buses, vans and trucks through their life cycle. For the passenger car market, Østli et al. (2017) developed and estimated a discrete choice model that predicted the market shares of the various car model variants. The first version of this car choice model, which is thus included in the BIG model for projecting the vehicle fleet (Fridstrøm & Østli 2016, Fridstrøm 2017), built on complete assignments of all first-registered new passenger cars in Norway over 16 years (1996-2011). The car selection model is a disaggregated, hierarchical logit model ('nested logit', see Ben-Akiva & Lerman 1985). The hierarchy has two levels. On the top level, sales are distributed among the various car brands and on the level below sales are distributed between the different model variants within each car brand (Figure 4.2).

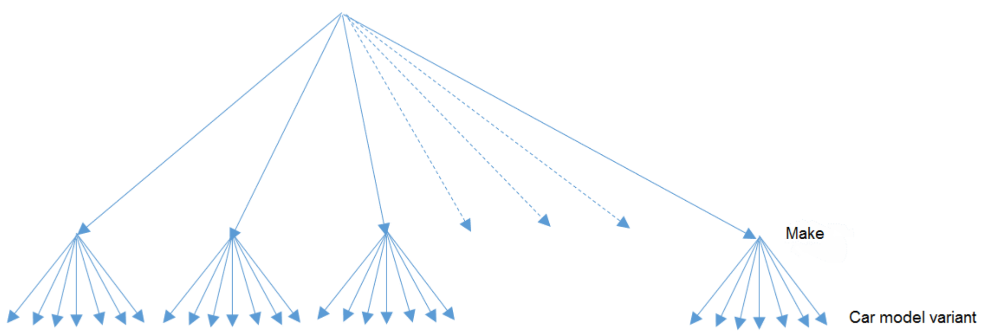


Figure 4.2: The hierarchical structure of the car purchase model. Source: Østli et al. (2017).

Nevertheless, the choices at both levels are determined simultaneously. The availability of cars at the lower level, and their characteristics and prices, help to determine the attractiveness of the individual car brands, and thus also their market shares, through so-called logsums which summarize how favorable each alternative is overall within each nest.

Using the maximum likelihood method and the Biogeme Python software, the car purchase model in 2017-2018 has been re-estimated on data material for the period January 2002 - October 2016.

The data material contains information about the characteristics and qualities of the various car models, as shown in the Motor Vehicle Register.

The list prices of the individual car models, stated by Opplysningsrådet for Veitrafikken (OFV), has been coded for the material.

After removing all passenger cars without price information and all cars with more than 7 seats, approximately 99.1 percent of all first-time new passenger cars registered remain.

The fuel cost in the model is represented by the calculated present value of the car's energy cost during its lifetime. In accordance with Fridstrøm et al. (2016), one assumes an annual mileage of 13,000 km, 17-year life expectancy and a 4 percent discount rate. For petrol, diesel and hybrid vehicles, type-approved fuel consumption is assumed to be multiplied by the current real price of fuel at the time of purchase. For battery electric vehicles (BEVs), we have assumed the current consumer price of electricity multiplied by 0.2 kWh/km, and for plug-in hybrids a power consumption of 0.1 kWh/km is assumed.

The model contains 81 parameters, of which 19 are logsum coefficients – one for each nest. The model is fully generic, meaning that no coefficients are associated with specific vehicle models. In this version of the BIG model, the market shares of the various model variants are determined by the list prices, which include the one-off registration tax and VAT, as well as a number of characteristics of the cars, such as car make, energy technology, fuel cost, driving range, size, number of seats, rear-wheel, front-wheel or four-wheel drive, gearbox and body type.

At the lower level, the model is very detailed. For the year 2015 alone, there are 2356 different model variants in the database. Many variants differ little from each other. Therefore, at the level of individual model variants, the model cannot provide particularly reliable predictions. Experience has, however, shown that if one aggregates to certain main groups of vehicles, the model provides fairly good explanatory power (Østli et al., 2017).

The car model selection module differs from virtually all other such models in the literature in that BIG contains no data on car buyers. In general, car purchases, in line with other consumer behavior, are modeled using sample data on a number of households, individuals or companies[2]. Letting go of all data about car buyers involves a radical simplification. It is this simplification that makes it possible to look at all the details of the cars themselves and estimate the model directly on a rich, disaggregated and almost complete data set consisting of around 1.8 million single transactions.

The simplification has its price, of course. It is not possible to predict how vehicle demand would change as a result of changes in household income or in other socio-demographic or micro- or macroeconomic conditions. When the utility functions for each option do not contain information about the buyers, but only about the cars, it essentially means that all buyers are considered equal. For example, the model does not take into account that some potential car buyers do not have a charging option at home or at work.

According to the national travel behaviour survey 2013-2014 (Hjorthol et al., 2014), 75 per cent of the population has parking facilities on their own land. The remaining 25 percent have a relatively low probability of obtaining a rechargeable car. This means that the model

[2] See for example. Lave & Train 1979, Manski & Sherman 1980, Berkovec 1985, Berkovec & Rust 1985, Brownstone et al. 2000, Kitamura et al. 2000, Choo & Mokhtarian 2004, Train & Winston 2007.

is unlikely to give reliable predictions when the proportion of rechargeable cars exceeds 70-75 per cent. However, considering the effects of marginal changes in prices and taxes based on the current situation, the absence of data on car buyers is likely to have little significance. The advantage, of course, is that one can predict changes in the passenger car market without having to make specific assumptions about car buyers or other social conditions.

The model also has another important limitation for our purposes: since the car purchase model is a market share model, it does not capture the effect on overall car demand if the prices of cars or fuel change. If some cars become cheaper, without others becoming more expensive, one must expect that the total car demand will go up. This rebound effect does not appear in the BIG calculations. The effect probably means that the direct price elasticities will be somewhat under-rated (in numerical terms).

The model can be used to show how changes in key characteristics of the cars are reflected in the market shares and thus also in energy consumption, CO_2 emissions and tax revenue. By simulating a, e.g., 10 per cent change in list price or energy cost and aggregating over the relevant category of cars, one can calculate direct and cross price elasticities, etc. for petrol cars, diesel cars, ordinary (non-rechargeable) HEVs, PHEVs, and BEVs, respectively.

4.3 Cost calculation for trucks and buses

The cost of electricity and hydrogen solutions for trucks and buses is taken from Hovi et al. (2019a), and is based on interviews with users, studies of literature and existing freight transport models. More information on this work can be found in Hovi et al. (2019a) and is not repeated here.

4.4 Literature analysis and knowledge summaries

In connection with the preparation of most of the chapters, analysis of research literature, reviews of TØI's own research and various other documents have been carried out, and data and information have been obtained from the websites of vehicle suppliers, public agencies, news media, organizations and a number of other actors.

Substantial parts of the report have been based on results documented in TOI report 1744/2019 (in Norwegian language).

4.5 Calculating the flow of Li-Ion batteries through the sector

The quantities of batteries entering and leaving the Norwegian passenger vehicle fleet annually are estimated by combining results from a stock-flow cohort model with statistical data.

4.5.1 Application of the stocks and flows cohort model

Stocks and flows of electric passenger vehicles were estimated between 2011 and 2030 using the stock-flow cohort model BIG developed by Fridstrøm et al. (2016), presented in section 4.3. The model estimates annual new vehicle sales and net change of vehicle numbers in the fleet, for BEVs given by production year and classified into nine weight categories until 2030. To estimate the change in stocks per year, the model assigns characteristics to each vehicle category (see Figure 4.2) including mean annual distance driven, annual rate of scrapping, annual rate of second hand import, and a non-differentiated residual annual outflow of vehicles (second hand export or deregistration).

Since there is limited data available on the lifetime of battery electric vehicles, survival rates for these vehicles have been set similar to those of mid-size petrol driven vehicles, or somewhat lower. Knowing the survival rate of each vehicle segment to the next year, and accounting for secondhand sales, allows annual fleet changes to be calculated for all vehicles older than one year (i.e. not including new vehicle sales). In this way, estimates are made of the change in the number of vehicles from different production years and for different weight segments, where a negative value means a decrease in numbers. Summing these gives total fleet change for all vehicles older than one year.

To estimate annual new vehicle sales, the model accounts for a conservative implementation of electric vehicles according to the scenario of sales in "Perspektivmeldingen" (Norwegian Government, 2019). This is an account of likely future societal and economic developments in Norway developed every fourth year by the Ministry of Finance. The model was also built around historical sales data.

Weight segments used in the model are <999 kg, 1000-1199 kg, 1200-1299 kg, 1300-1399 kg, 1400-1499 kg, 1500-1599 kg, 1600-1799 kg, 1800-1999 kg and >2000 kg. Note that in the model, 'age' is defined as the number of years completed by Dec. 31, rounded upwards to the nearest integer. For example, vehicles aged '3 years' in 2021 are those first registered in 2019. The model includes electric vehicles produced between the years 1981 (when the first registered electric vehicle sales in Norway occurred) and 2029).

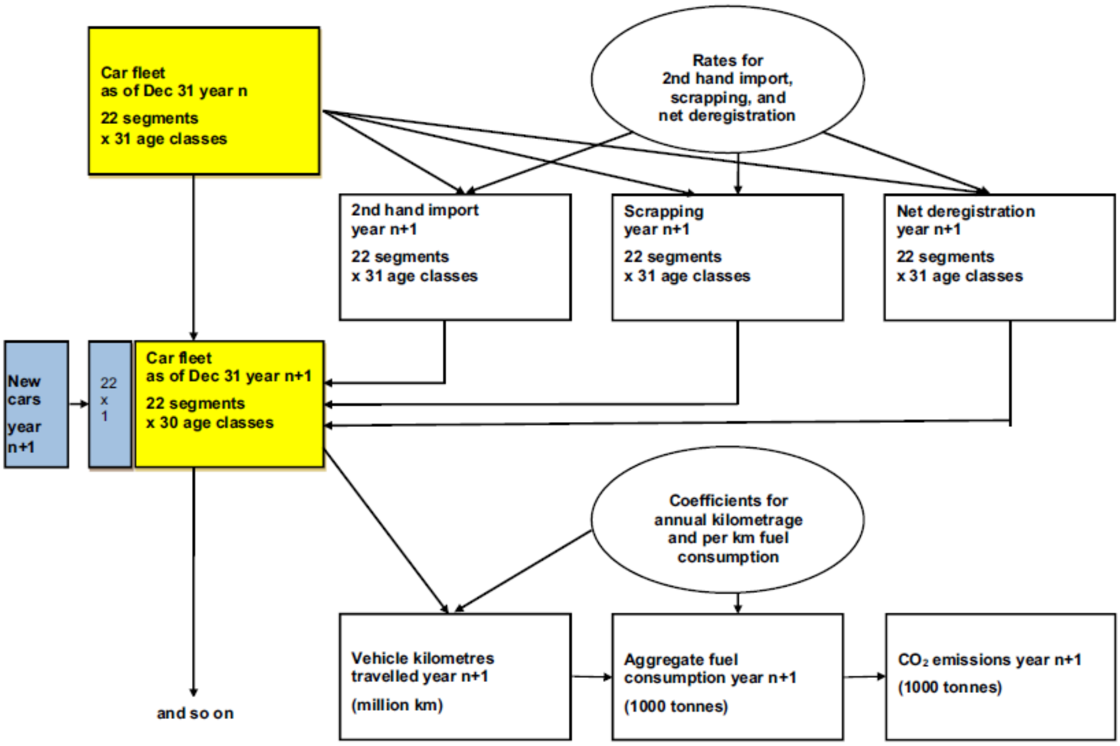


Figure 4.3: Overview of stocks and flows cohort model. Source: Fridstrøm et al. (2016).

4.5.2 Assessment of electric vehicle battery characteristics

Historical sales data of electric passenger vehicles between the years 2011 to 2018 was obtained from Opplysningsrådet for Veitrafikken AS (OFV 2019b). Vehicles sold within the <1000 kg vehicle segment were excluded since it was assumed these were not within the passenger vehicle segment under analysis (i.e. 4-wheel MCs). It was also assumed that electric vehicles sold prior to 2011 (the year the modern BEV was launched) were either not of LI-ION type, or were registered as 4-wheel MCs, and were also excluded from the battery calculations.

Data on all electric vehicle make/model characteristics available on the market (including nominal battery capacity, kWh) was obtained from the Electric Vehicle Database (EV Database 2019). This was supplemented with information about the type of each battery for each make/model (where available), sourced from Kelleher Environmental (2019) and Wagner et al. (2019). Battery types in use in the electric passenger vehicles included lithium manganese oxide (LMO), lithium nickel manganese cobalt oxide (NMC), lithium nickel cobalt aluminum oxide (NCA), lithium iron phosphate (LFP) and combinations thereof. In this analysis only overarching battery material types are applied, and not a subcategory breakdown (such as categorizing NMC according to NMC111, NMC622 or NMC811), due to a lack of data.

Using the associated vehicle weights in the OFV (2019b) dataset, types of passenger vehicles (and their associated battery characteristics) were grouped into the same weight categories as for the cohort model. Combining both sales and background battery data together in this way allowed the estimation of the (sales weighted) average battery size and type for Norwegian electric passenger vehicles purchased in each weight category and for each vehicle sale year (2011-2018). Where several battery types were used for vehicles sold within one weight category (and for one vehicle sale year), a weighting factor was calculated to enable the later distribution of vehicles between battery types. Any gaps in weight categories/years were filled with data from an adjoining weight category.

Types and characteristics of batteries in use were next estimated to 2030, by using the known vehicles available from 2020 as a basis (shown in Table 4.1). Due to a lack of data, the same battery characteristics were implemented between 2020-2030, and all battery types were set to unknown Li-ion type. To account for uncertainty, a high scenario (+15 % battery size for each weight segment) and a low scenario (-15 % battery size for each weight segment) were also utilized.

Table 4.1: Known BEV models available from the year 2020, and which were used for an assessment of model battery characteristics for the years 2020-2030. Vehicles in red are available in 2020 but will be phased out.

Weight (kg)	Models available from 2020				
	Mini	**Small**	**Compact**	**Medium**	**Large/luxury**
1000-1199	Mitsubishi i-Miev (1110 kg): 16 kWh, Peugeot ION and Citroen C-zero, Smart EQ forfour (1125 kg): 17.6 kWh, Smart EQ fortwo (1110 kg): 17.6 kWh, VW E-up (1160 kg): 36.8 kWh, Seat Mii (1160 kg): 36.8 kWh				
1200-1299	Skoda Citigo (1235 kg): 36.8 kWh		BMW i3 (1270 kg): 42.2 kWh		
1300-1399	VW E-up	Mini-E (1365 kg): 32.6 kWh			
1400-1499		Peugeot E-208: 50 kWh	Hyundai Ioniq (1420 kg): 38.2 kWh, MG ZS EV (1491 kg): 44.5 kWh		
1500-1599	Renault Zoe (1502 kg): 52 kWh	Kia Soul (1593 kg): 39.2 kWh, Opel E-Corsa (1530 kg): 50 kWh, Honda-E, (1525 kg): 35.5 kWh	Nissan Leaf (1580 kg): 40 kWh DS 3 E-tense (1530 kg): 50 kWh, VW E-Golf (1540 kg): 36 kWh		
1600-1799		Kia Soul (1682 kg): 64 kWh	Mazda MX30 (1645 kg): 35.5 kWh, VW ID3 1st (1719 kg): 55 kWh, Nissan Leaf (1756 kg): 62 kWh, Hyundai Kona (1685 kg): 64 kWh, Kia E-Niro (1737 kg): 64 kWh, Opel Ampera (1616 kg): 60 kWh		
1800-1999				Tesla Mod 3 SR (1847 kg): 75 kWh, Tesla Mod 3 SR (1801 kg): 47.5 kWh, Tesla Model Y (1950 kg): 75 kWh, Jaguar I-Pace (2133 kg): 90 kWh, Lexus UX 300E (1850 kg): 54 kWh	
2000+				Polestar 2 (2198 kg): 78 kWh, Volvo XC40 (2150 kg): 78 kWh	Audi E-Tron 50 (2379 kg): 71 kWh, Audi E-Tron 55 (2565 kg): 95 kWh, Tesla Model S (2290 kg): 100 kWh, Tesla Model X (2533 kg): 100 kWh, Ford Mustang Mach E: 75.7-98.8 kWh, Mercedes EQC (2420 kg): 85 kWh

4.5.3 Estimation of new batteries and net change annually until 2030

The amounts of batteries of different types entering the electric passenger vehicle fleet, as well as the net change of batteries in use of different types, were calculated by multiplying results from the stock-flow cohort model with the assumptions of battery type and size for each vehicle production year and weight category until 2030.

5 Battery technology

5.1 Batteries

The battery is the main component of BEVs and one of the main components of PHEVs. Inventors of the Li-Ion battery received the Nobel Prize in chemistry in 2019. This type of battery has become completely dominant for BEVs and PHEVs and is available in various sub-variants, the most important being NCA, NCM, LTO and LFP. The chemical variants have advantages and disadvantages for use in different vehicle segments (see table 5.1). Car manufacturers can optimize and choose the chemical variant based on what is most important in each segment; cost, lifetime or other characteristics.

Table 5.1: Comparison of different types of lithium-ion-battery variants (Andwari et al., 2017).

Technology	Advantages	Disadvantages
Lithium Cobalt Oxide ($LiCoO_2$)	Power and energy density	Safety, cost
Nickel Cobalt and Aluminium (NCA)	Power and energy density, calendar and cycle life	Safety
Nickel Manganese Cobalt (NMC)	Power and energy density, Cycle and calendar life	Safety
Lithium Polymer ($LiMnO_4$)	Power density	Calendar life
Lithium ion phosphate ($LiFePO_4$)	Safety	Energy density, calendar life

The lifetime of the batteries depends on how they are used and how the car is designed. There are two main aging mechanisms. The first is due to the use of the battery. That is, how often the battery is discharged and recharged and in which environment it occurs. Battery cooling and heating will extend the life of the battery by keeping the battery temperature more optimal. Battery life is most reduced by recharging at high temperatures but charging at very low winter temperatures can also reduce battery life and capacity. Large batteries (in terms of kWh energy content) need recharging less often than small batteries if the car they are sitting in is used equally, and if users actually charge them less frequently. Even if charged equally often, the large batteries should have a longer life than small batteries, as partial discharges cycles sum up to fewer full discharge cycles the larger the battery is. PHEV batteries have robuster batteries that can allow for more frequent charging and discharging, at the cost of a lower energy content per kg battery and a higher cost. The second aging mechanism is due to the fact that the materials in the battery are affected over time regardless of use, "a calendar effect".

Under Norwegian climate conditions, the batteries in the electric cars have remained in good shape over time (Figenbaum, 2018a). There have been no complaints of systematic poor battery life on any electric car model in the market. Therefore, there are no indications that the battery life will be shorter than the life of the car, but the capacity may gradually decrease towards 80% of original capacity. How much they degrade is vehicle and battery specific. However, it is still uncertain whether "calendar effects" will lead to higher degeneration rates on older cars, as no electric cars with Li-Ion batteries are yet old enough. This report assumes that the original batteries remain in the cars until the cars are scrapped.

Li-Ion batteries have passed a critical level of development. With Li-Ion batteries, electric cars of all sizes can reach driving ranges of 300-500 km (more is also possible) with full space available in the car for passengers and luggage. Fast charging is also becoming more powerful and varies between 50-150 kW, and for some models coming on the market up to 350 kW charging will be possible[3].

Li-Ion batteries have also proven to be sufficiently good for city buses. The buses can be equipped with different variants and sizes of Li-Ion batteries depending on the specific route layout and where and when charging is to take place. The most important parameters to choose for an E-bus are the size and capacity of the battery, since they affect the range between charges, charging time, and thus charging power, and the ability to carry passengers (Jordbakke et al., 2018). According to Gohlich et al. (2018) LFP, LTO and NMC are the most common batteries currently in use in electric buses. Different manufacturers favor different types of batteries; for example, BYD favors LFP in its buses (BYD, 2019), while Solaris has preferred LTO (Sierszynski et al., 2016).

Urban logistics battery electric trucks (BE-Trucks) have the same type of technology, weight and engine requirements as city buses, and Li-Ion batteries may be sufficiently good for this segment as well, although the payload can be reduced (a new EU directive allows up to 2 tonnes extra total weight for electric trucks so this will not mean much, see chapter 6). For long-haul trucks, it is technically possible to carry up to 1 MWh of batteries to provide for a range of 800 km between recharges, but the cargo weight capacity can be reduced as the vehicles have a maximum permissible weight.

According to Talebian et al. (2018), current electric trucks using lithium-ion batteries have a range of 150-400 km, depending on battery size. A relationship between typical battery capacity and available payload (and maximum range) is shown in Figure 5.1 (Mareev et al., 2018). BE-Trucks is the land transport application that will require the largest batteries, and where there is the greatest need for high energy density, fast recharging and long service life, as measured by the number of recharges (the calendar effect is less important as trucks have shorter lifetimes than passenger cars).

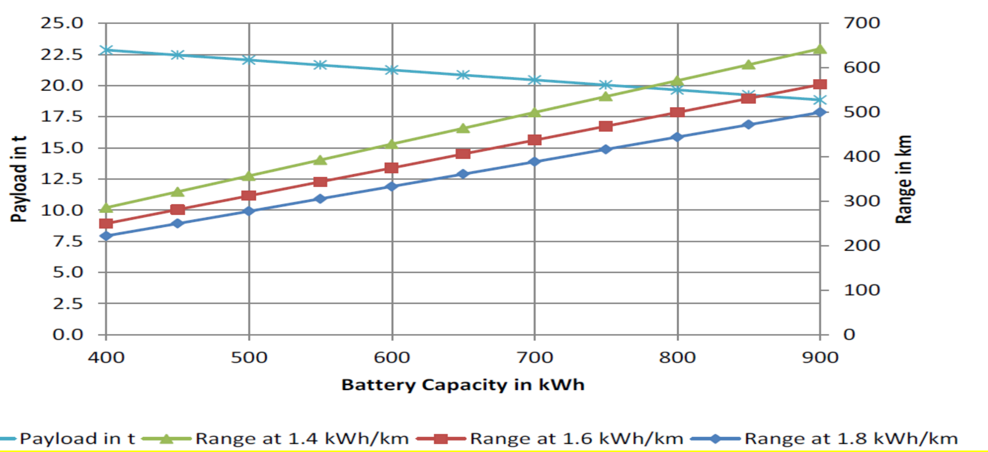


Figure 5.1: Payload and driving range for BE-Trucks dependent of average energy consumptions (Mareev, Becker, & Sauer, 2018).

[3] Porsche models with large battery packs. Peak power can be up to 350 kW, average substantially lower.

The cost of electric vehicle batteries is rapidly falling, even though the biggest cost cuts are over. Going forward, there will be more marginal, yet significant, cost reductions as shown in the BloombergNEF estimates in Figure 5.2. Bloomberg's historical figures are based on information from battery and car manufacturers about the actual price weighted for sales volume for the models. The projections are based on 18% future learning effects on the price as the accumulated sales volumes increase. GM in a recent event for investors claimed to have achieved a battery cell cost below 100 US$/kWh for their new Ultima battery cell developed together with LG Chem (GM 2020). They also stated that the cost has nowhere near bottomed out, so even lower costs will be possible during the 2020s.

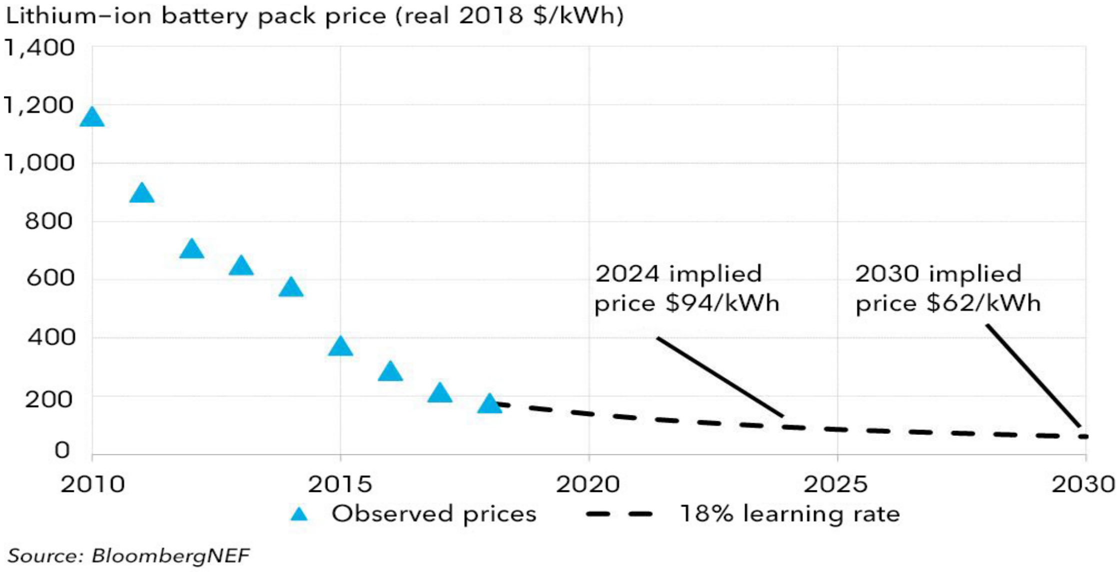


Figure 5.2: Estimate of future battery pack prices (battery electric passenger cars). USD/kWh. Kilde: BlombergNEF (Bloomberg NEF 2019b).

These estimates apply to passenger cars. Continued cost reductions form the basis for calculations of future prices for electric cars in this report (see Chapter 9), and in various organizations' projections and scenarios for the future (see Chapter 13). Future cost reductions are a prerequisite for electric cars to be competitive in the market without incentives.

The assessment of the future cost of battery packs for passenger cars and vans is based on BloombergNEF's estimates as the main scenario in this report, with a 5% surcharge for warranty for the battery cells. For heavy vehicles, the methodology of Hovi et al. (2019a and 2019c) was followed, and the results for costs for electric trucks and electric buses are taken from there.

When stretching learning curves as far ahead of time as BloombergNEF does, you run the risk of approaching the cost of the materials the battery is composed of (MIT Energy Initiative 2019). Bloomberg's estimate for a battery pack in 2025 is US $ 87 / kWh, and US $ 66 / kWh in 2030. The latest figure is close to the raw material cost for NMC batteries, which is approx. 50 US $ / kWh according to the estimates shown in Figure 5.3.

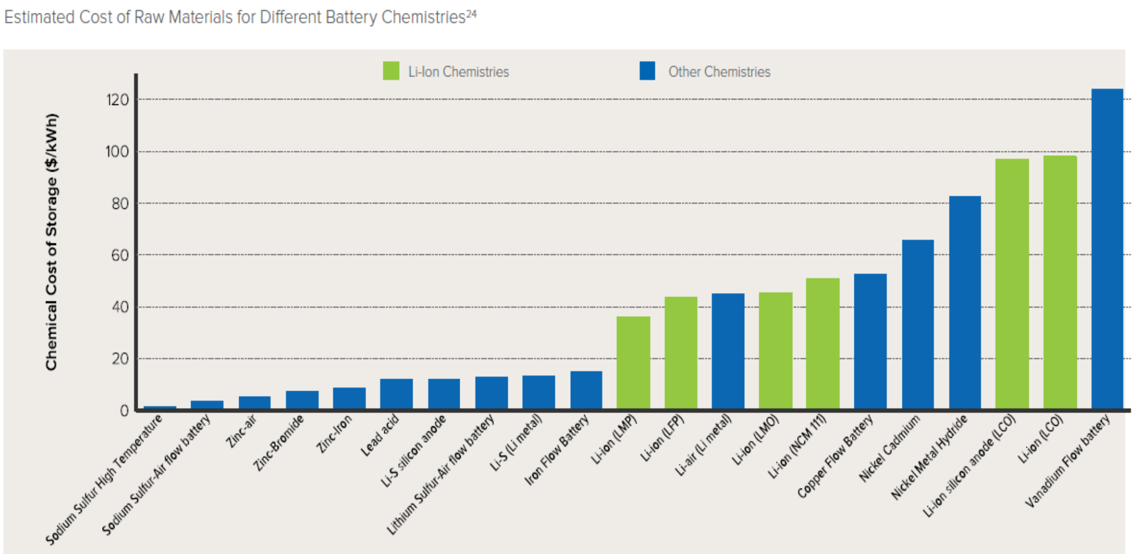


Figure 5.3: Costs of raw materials in different batteries. Source: RMI (2019).

With the huge volumes now to be produced and delivered to all the electric cars on the market (see Chapter 6), production volume effects will apply as battery manufacturers can supply the same battery cells to many car manufacturers. On the other hand, the huge increase in demand can make the materials (of which the batteries are composed) more expensive, at least periodically until supply and demand are balanced. Therefore, in addition to calculations with Bloomberg's cost path, an alternative cost path with higher price has been made, based on the assessment in the MIT Energy iniative (2019) report. Both cost paths are shown in Figure 5.4.

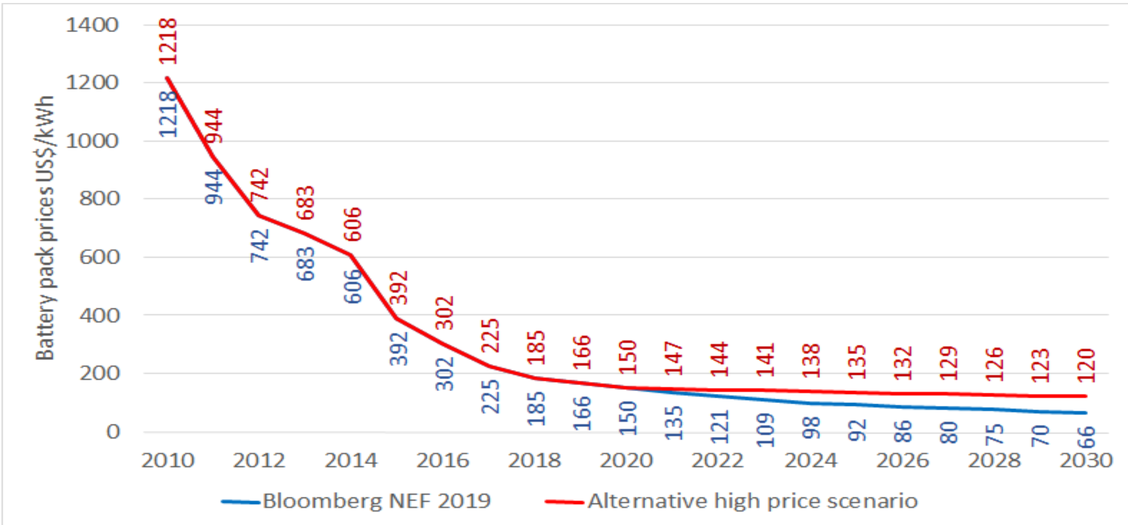


Figure 5.4: Battery prices used in this report. Bloomberg NEF 2019 is the main alternative, Alternative price is used to evaluate the price sensitivity. Source: Bloomberg NEF (2019a, 2019b) and own assumptions.

New battery generations have higher energy density, lower cost, can often deliver more power, have improved temperature properties and longer life, while reducing the use of expensive materials as far as possible. The Li-Ion battery can still be developed, but new types of batteries are being researched, including solid state (solid) and Li-S, which may have a larger energy density than Li-Ion batteries, but are not yet ready for mass production. Therefore, this report only considers Li-Ion batteries.

6 Vehicles on offer

6.1 Process for the development and production of cars

6.1.1 Interaction between producer and subcontractors

Car production and construction is a complex process. Typical development time for new models is 3-4 years when the platform on which the car is built is available. In addition, if a new platform is being developed for several cars or perhaps across the manufacturer's car brands it may take even longer. The car manufacturer purchases parts from a large number of subcontractors, as shown in Figure 6.1

Figure 6.1: Overview of a selection of the suppliers of the BEV Opel Ampera-e. Source: Autonews (2017).

The large number of subcontractors means that car production is a complex logistical operation, where the car manufacturer's factory gets parts delivered from a number of sub-factories where the parts are produced. The subcontractors often have to make production tools for the parts they are going to produce, and they have to set up production lines. This can be financed in one of two ways, either in the parts price paid by the car manufacturer or by the car manufacturer covering the investment cost of the subcontractor. In order to set a price for the part, subcontractors need to know the planned production volume. The car manufacturer must commit to a minimum volume per year which can be increased under the terms in the agreement between the parts supplier and the car manufacturer. This is especially important for products that are new and where the sales volume is uncertain. For large model series such as the VW Golf this is probably not a problem as the suppliers know that large volumes will be produced.

The volume that the car manufacturer actually produces does not have to correspond to the volume that the car manufacturer says in press releases that there is production capacity for. For example, the car factory may be prepared for increased volumes, and it may be possible to introduce one additional shift if demand is high. However, if demand is greater than expected, the car part suppliers must also increase production capacity. This is not done overnight and can result in anything from adding one additional production shift to additional investments in production tools and production lines, and can take from 6 months to over a year to become operational. In the worst case, subcontractors of, for example, materials for the car parts supplier further down the value chain also have to increase their investments. This may be the case for batteries.

If, on the other hand, the car manufacturer promises the suppliers volumes that are too high, they risk claims of compensation if those volumes are not realized. The scheduled volumes can also have a bearing on whether car part production methods that can be easily scaled up are chosen. These issues are one of the major challenges that faces car manufacturers in the current phase of the global BEV market. It is difficult for each manufacturer to estimate the real demand for their cars. Thus, the challenges that Hyundai-Kia have faced in delivering sufficient numbers of the BEVs Kia E-Niro, Hyundai Ioniq and Hyundai Kona can arise and persist for a long time. Therefore, there is reason to be skeptical of car manufacturers' announced production volumes, which can take a long time to reach from the level they have actually committed to with their subcontractors.

6.1.2 Price and capacity challenges

Another dilemma for car manufacturers and car importers is to set the right selling price. If it is set too high at the outset, so that it has to be lowered after a short time, the first buyers of the model will be dissatisfied because they will suffer a great extra loss of value. If it is set too low, demand can exceed the planned production capacity with long waiting times as a result. In a market where technology is changing rapidly, e.g. battery prices are reducing significantly year by year, potential buyers may be put off since this could mean that a competitor could launch a new model at any time for which the cost base is lower and which can, thus, be sold at a lower price. Proper pricing is therefore a major challenge.

Several manufacturers have had challenges with production capacity and have not been able to deliver the number of cars the market has demanded, such as Opel, Kia and Hyundai. Other manufacturers have invested in a large production capacity and have always been able to deliver, such as Nissan.

These types of challenges are likely to resolve as car manufacturers gain better control of the value chains and sales volumes become more predictable and based on real market experience. It is therefore assumed, even though these challenges may still emerge occasionally, that they will not create obstacles to achieving the Norwegian 2025 goal of only selling zero-emission passenger vehicles and small LCVs. There will be a much higher number of BEV models available on the market from 2020-2025; challenges surrounding the delivery of a single model will therefore in any case be less significant for the market as a whole. If the overall global demand for BEVs is increasing faster than the car manufacturers expect, imbalances in the production of parts and raw materials, such as batteries, can occur. This means that the escalation of production volumes may take longer. It can also affect access to cars at a national level.

6.2 Passenger cars

6.2.1 Models on the market before 2019, in 2019 and until 2025

A survey of the plans of passenger car manufacturers, described in detail in Table V.1.1 in Figenbaum et al. (2019), shows that they plan to launch approx. 185 BEV models, 110 PHEV models, and 3-10 hydrogen car models until 2025. The BEV share is approx. 60%, PHEV share approx. 37% and the hydrogen car share approx. 3%. These percentages are about the same as the announced and known specific models per 2019-2022. Renewal of existing models may be included in the estimated number of new models, since in the 5-year term, such a comprehensive renewal of existing models is undertaken that they often can be regarded as new models in practice. It is thus uncertain to what extent existing models are included in this number. As of 2019, some manufacturers have launched specific BEV models (Tesla, Nissan, Mitsubishi, BMW, Renault), a few have made fully flexible models that can have any drive system (Hyundai), while others have made BEV versions of regular cars (VW, Ford, Mercedes, Smart and others). The large SUVs that have been launched in the last two years are in many cases BEV specific. Table 6.1 provides an overview of models on sale by year from 2011 (the year the modern BEV was launched) to 2019. Prior to 2011, a small number of mini electric cars (registered as 4-wheel MCs) were sold by a number of different small brands. None of these are on the market anymore.

Looking towards 2022, several manufacturers are launching their own BEV platforms[4] and some are launching fully-flex platforms that make BEV, PHEV, HEV and petrol / diesel engine versions of the same model. In a specific BEV platform, advantages can be more easily realized, such as a less complex chassis structure and a longer wheelbase, which provides more flexible space in the interior. In principle, variants of existing models can be produced relatively easily and flexibly on the same line as the petrol and diesel versions, with modification of the production line. In reality, there are often quite large and relatively expensive modifications that have to be made to both the car model and the production line, i.e. the total production costs per vehicle may increase. On the other hand, many parts of the car will be produced in large volumes, reducing costs again and the production will be more flexible and it will be easier to adapt production to a variable demand.

Fully flexible platforms provide low risk and great market flexibility but all the cars will be a little more expensive due to the flexibility that needs to be built into the platform, and that it will be more difficult to optimize for the various system concepts. The largest car manufacturers are migrating from modifying existing models to making either their own BEV platforms, or fully-flexible platforms. Smaller manufacturers face challenges in creating such platforms and appear to be aiming to modify existing models, and/or to partner with larger manufacturers to develop common platforms across brands.

A survey of BEV and PHEV models that are on the market and that are coming to the market is shown in detail in Appendix 1, Table V.1.1 of Figenbaum et al. (2019), and summarized in Figure 6.2. It clearly shows that of the electric vehicle types, BEVs dominate the smallest car sizes and PHEVs the largest car sizes in 2019, but that it will be leveled out by 2022. Mini and small car segments are heading towards becoming fully BEV segments, as several car manufacturers are phasing out diesel variants of mini and small cars due to high exhaust gas cleaning costs. Car manufacturers are also to some extent phasing out gasoline engines in these segments due to the CO_2 fleet requirement in the EU.

[4] platform is a main model base from which which vehicle variants sharing many components are derived, such as hatchbacks, estates, SUVs, CUVs, Cabriolets etc. An example: VW Golf which comes in many shapes

In this segment, there are small profit margins and a low willingness to pay for advanced ICE concepts. Therefore, there are no PHEVs or FCEVs planned for these segments.

Table 6.1: BEV models for sale in Norway 2011-2019, and the number of main models (MM) sold in total in Norway in 2019. Source: Own analysis.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	Quantity Main Models 2019
Nissan	C	C	C	C C	C C	C C	C C	C C	C C	7
VW			S	S C	S C	S C	S C	S C	S C	12*
Mitsubishi	S	S	S	S	S	S	S	S	S	3
Peugeot	S	S	S	S	S	S	S	S C	S C	12
Citroën	S	S	S	S	S	S	S	S C	S C	9
Renault		C	C	S C	S C	S C	S C	S C	S C	9
Tesla			L	L	L	L L	L L	L L	M L L	3
Jaguar								L	L	7
Audi									L	14
Ford			C	C	C	C	C	C		14
Mercedes					C	C	C	C	L	25
BMW			S	S	S	S	S	S	S	19
Hyundai						C	C	C C	C C	11
Kia				S	S	S	S	S C	S C	11
Opel							C	C	C	9
Porsche									L	11
Smart							S S	S S	S S	2
Subaru										4
Toyota										15
Suzuki										4
DS										2
Volvo										7
Mazda										7
Seat										7
Mini										4
Landrover										4
Skoda										7
Honda										5
Fiat										4
Sum	Total 4 3S 1C	Total 4 3S 1C	Total 9 5S 3C 1L	Total 13 7S 5C 1L	Total 14 7S 6C 1L	Total 16 7S 7C 2L	Total 19 9S 8C 2L	Total 24 9S 12C 3L	Total 26 9 Small 10 Compact 1 Medium 6 Large	248 in total 178 among those who sell BEVs

S=Small, C=Compact, M=Medium, L=Large.

*for example for VW: Up, Polo, Golf, T-Cross, T-Roc, Tiguan, Passat, Touran, Touareg, Caddy, Caravelle, Multivan

In 2019, 61% of the electrified car models available in Europe were BEVs and 39% were PHEVs. 31% of BEV models for sale in 2019 were mini or small cars, 43% were compact cars, 5% were medium sized and 21% were large BEVs. By 2020, the share of mini and small BEV models has been reduced to 24%, while the share of compact BEV models has been reduced to 37%. Medium-sized BEV models have increased to 11%, while large BEV models have increased to 27% of the models available For 2021-22, the proportion of large BEVs will increase to 30% and medium to 15%, while the other segments have slightly smaller shares. For BEVs, there will thus be a good availability in all size classes by 2021-2022.

The compact segment makes up 25% of the available PHEV models, the medium-sized 42% and the large 33% in 2019. There were no small/mini car models available. In 2020, the compact car segments' share of PHEV models will increase to 35%, while the large car share will increase to 37% and the proportion of midsize models will decrease to 28%. In 2021-22, the figures are, respectively, 35% (compact), 29% (medium-sized) and 35% (large). For PHEVs, model availability is thus smoothed out between compact, medium and large vehicles. This is probably due to the fact that several large vehicles manufacturers make PHEV variants of their entire product line-up except the smallest models.

Figure 6.2 shows how available models in Europe change over time, and how the models are distributed among BEVs, PHEVs and segments within each year.

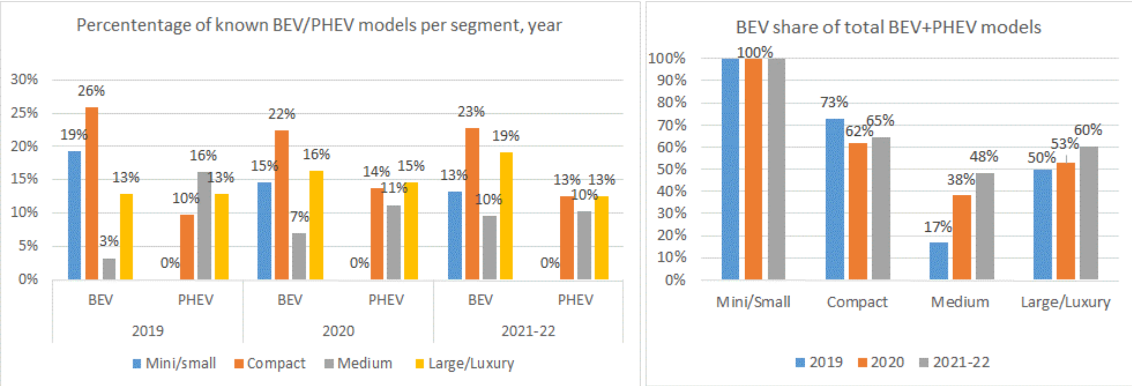


Figure 6.2: Left: Percentage of BEV and PHEV models relevant for Europe by segment 2019-2022. 100% is the sum of BEV models and PHEV models available within one year. Right: Percentage of BEV models per segment and year. Source: Own analysis and Table V1.1 in Appendix 1 of Figenbaum et al. (2019).

Figure 6.3 shows the distribution of car sales by sub-segments in 2018 and 2017, respectively. Compact cars (including SUV, MPV, Sports variants) were the largest segment (about 43%) in 2018, followed by the medium sized segment (about 27%, including SUV, MPV Sports variants). Small and mini cars and variants of these account for approx. 12%. The rest belong to the category of large cars (about 18%) which also includes luxury cars and SUVs. This figure gives an indication of which car types will be most in demand in the future towards 2025. Medium size cars are a large part of the market.

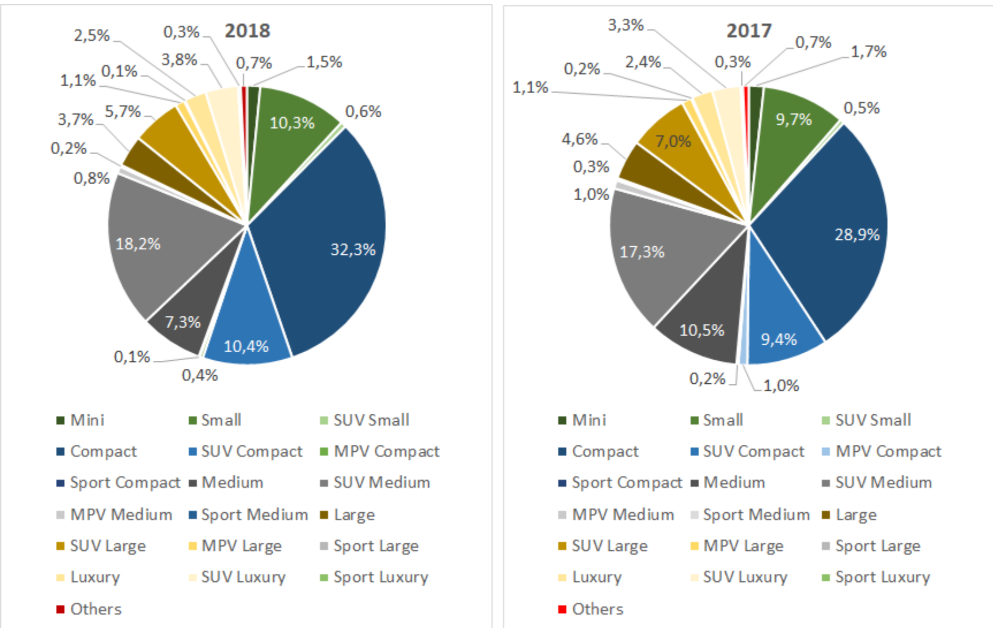


Figure 6.3: Market shares for segments in Norway 2018 and 2017. Green colors: Small and mini cars. Blue colors: Compact. Gray: Medium. Brownish-Yellow: Large. Source: Figenbaum & Nordbakke (2019), OFVAS (2020).

The biggest uncertainty for the Norwegian new car market's ability to be 100% electrified from 2025 will be the availability of medium-sized cars, such as the VW Passat and other station wagons, and medium-sized SUVs and Crossovers. There are relatively few BEVs advertised in this size class over the next two years, and there is little information about what sort of technical features they will get. In this segment there are relatively many PHEVs available. In the big car and the luxury segments, there is also a large proportion of PHEV models.

In the period 2020-2025, the first Chinese car brands will enter the Norwegian automarket. These brands will probably only sell BEVs. If they launch medium sized cars, this could make a positive contribution towards meeting the 2025 goal. In other segments, there is probably no "need" for more brands and models to be able to reach the target, but the Chinese cars can push prices down. As so little investment and effort is put into the development and industrialization of FCEVs, this technology is unlikely to make a significant contribution towards the target for 2025.

McKinsey (2019a) has done a similar analysis globally, as shown in Figure 6.4. However, it includes a number of models not sold in Europe and also does not differentiate between BEVs and PHEVs. A large proportion of these models are probably only intended for the Chinese market and to some extent India, Japan, USA and Korea. Some are probably renewals of existing models. The distribution of the sizes of the cars is roughly the same as the mapping above. Both surveys show that most of the focus is directed towards the compact models due to this segment's share of the total vehicle markets, and the least attention is given to the smallest cars where the market opportunities are limited and the willingness to pay for new technology is low.

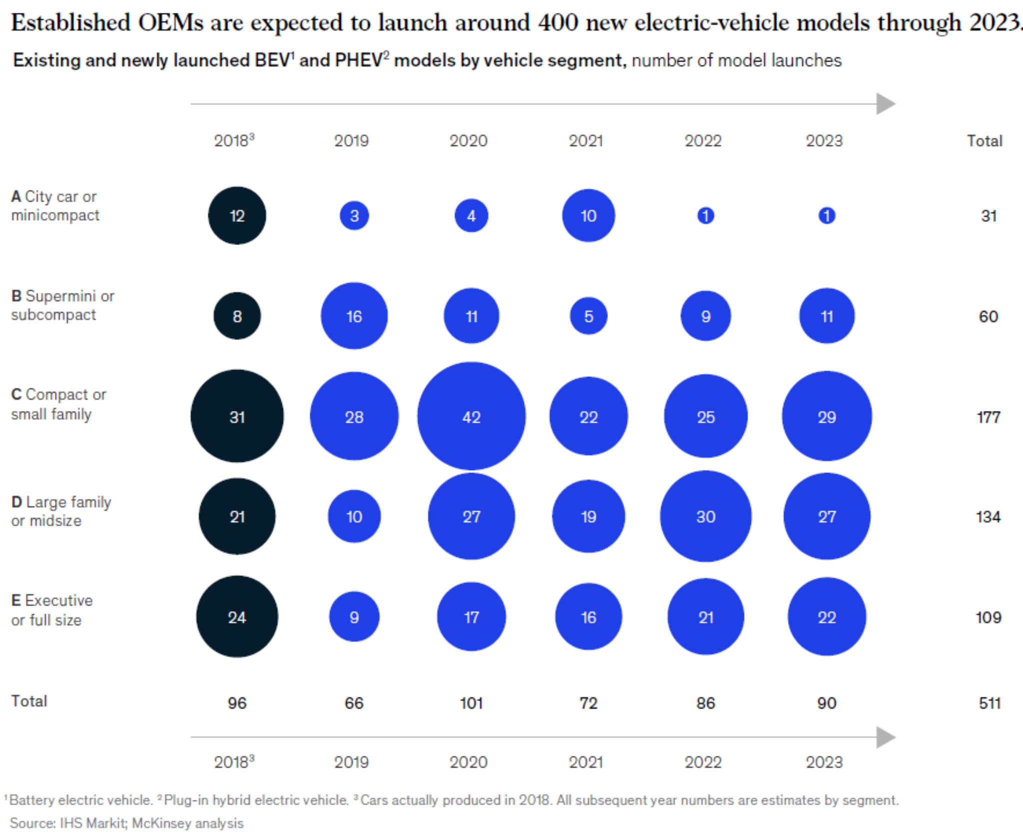


Figure 6.4: McKinsey charting of upcoming BEV and PHEV models in different segments globally. Source: McKinsey (2019a).

Transport & Environment (T&E 2019) has also made predictions of the number of BEVs, PHEVs and FCEVs coming on the market by 2025 in Europe as shown in Figures 6.5 and 6.6, with similar results as the analysis in this report. For hydrogen, they found that there was little interest among car manufacturers and only 5-15 models were planned until 2025, which is in sharp contrast to their estimate that about 170 BEV models will be on the market by 2025. The Volkswagen Group (VW, Audi, Skoda, Seat) and BMW lead the way in terms of the number of models coming.

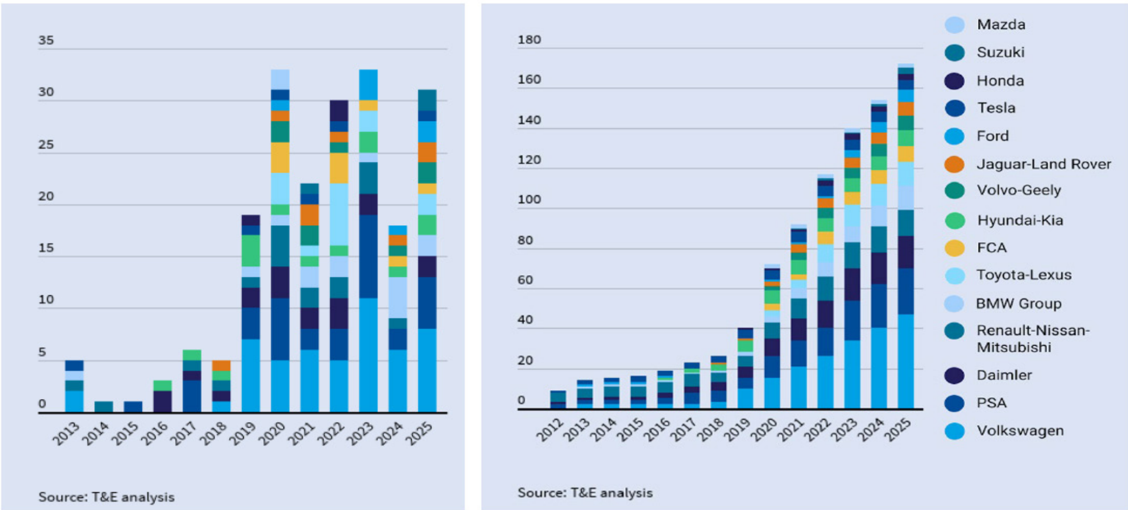


Figure 6.5: Number of new BEV models on the market 2012-2018 and upcoming models 2019-2025 (left), and the total number of available models for the same period (right). Source: T&E (2019).

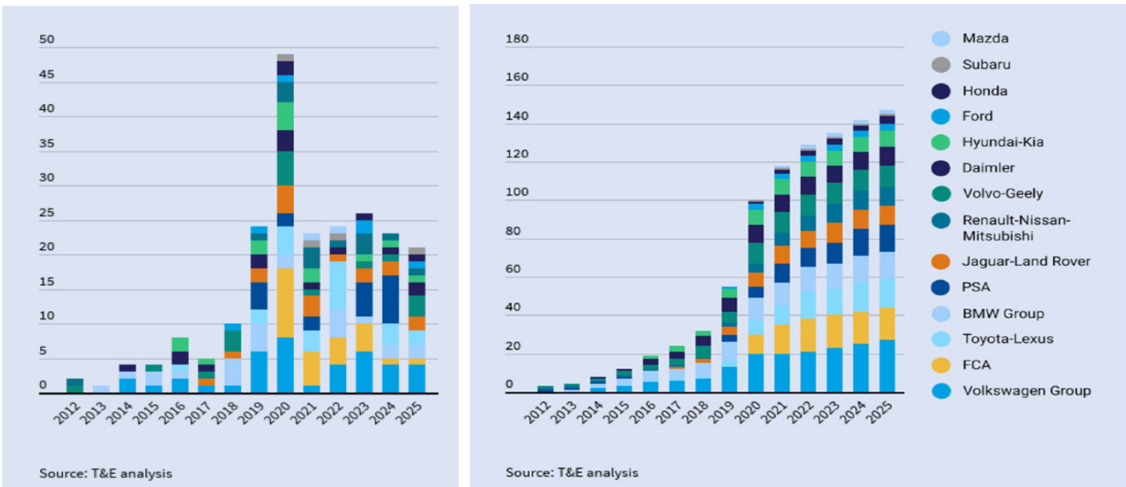


Figure 6.6: Number of new PHEV models on the market 2012-2018 and upcoming models 2019-2025 (left), and the total number of available models for the same period (right). Source: T&E 2019a.

6.2.2 Development – Technical and usage characteristics

Well functioning and attractive BEVs are important to achieve the 2025 target. Among the most important technical features of BEVs are battery size, range, energy consumption and charging rate, as discussed in Table 6.2. Practical properties of significance, such as load capacity and winter characteristics, are discussed in Table 6.3.

Table 6.4 gives an overview of the technical characteristics of available BEVs and Table 6.5 divides the BEVs in the Norwegian car fleet into BEV generations and typical properties.

Table 6.2: Overview of main technical characteristics of BEVs and PHEVs. Own analysis.

Property	Elaboration	BEV	PHEV
Battery size	Battery size indicates how much electrical energy can be charged from the grid and stored in the car. Battery size also affects how fast the car can be recharged.	The first-generation compact cars that came on the market in 2011-2014 typically had a 24-28 kWh battery that weighed about 250-300 kg. These cars were upgraded after 2-3 years with 30-40 kWh batteries. Now come second generation electric vehicles with batteries of typically 45-75 kWh. Large and luxury cars have batteries from 75-100 kWh, which can increase up to 120 kWh for luxury cars in coming years.	1st generation compact cars had 8-10 kWh batteries. From 2019 this increases to 10-15 kWh, while in larger cars there are batteries up to 20 kWh.
Range and energy consumption	For a given battery size and the car's physical design, which give a specific energy consumption per km, that varies with climate and driving conditions, the given range varies (in electric mode for PHEVs).	The range increases in the generation of BEVs that will be sold in the period 2020-2025 to a minimum of 250 km according to the WLTP test for small cars, 300 km for compact cars, 400 km for the larger cars, and up to 500-600 km for luxury cars. Range reduction in the winter will be less in the future, as all BEVs will have heat pumps and more advanced heating/cooling systems for the batteries. In 2020, a range loss of 20-30% compared to the WLTP range seems to be a normal value.	The all electric range is a measure of the proportion of transport that can be electrified. In the first generation cars, the electric range was 30-50 km, while second generation cars have a range of 50-100 km. The cars get full functionality in pure electric mode as well, while this varied from model to model earlier. The average annual proportion of driving done in BEV mode will increase from an average of about 50% up to 2019, to 60-75% with the generation of cars that were launched in late 2019 and onwards.
Charger	The charger in the car must increase in size if the car is to be charged from 0-100% during the night, when the battery size increases.	First generation cars had chargers in the car that allowed 3.6 kW of charging power. This has increased gradually over time for existing models and typical onboard chargers as of 2019 allow 7-11 kW charge power.	Usually they are fitted with 7 kW chargers
Fast charge speed	Affected by battery size and battery cooling / heating system and charging strategy from manufacturer	Larger batteries can potentially be fast charged with a higher power, but there must be faster chargers available for use, otherwise the charging time will increase significantly. The market will go from fairly homogeneous fast charging (50 kW chargers) to heterogeneous fast charging (50-350 kW) solutions, as the batteries grow larger. The first generation cars could typically achieve charging powers from 25-45 kW on average. From 2020, BEVs will be able to handle 70-150 kW of fast charge, but compact cars will hardly handle more than 100 kW of power. Large luxury vehicles will be capable of using chargers that can provide up to 350 kW charge power.	Some vehicles will get a fast charge option when the batteries get larger, but the charging speed and the ability to fast charge is not critical for PHEV owners who can take longer trips using their vehicles' gasoline or diesel engines.

Table 6.3: Practical usage characteristics for BEVs and PHEVs. Source: Own analysis.

Property	Elaboration	BEV	PHEV
Cargo capacity	Luggage compartment volume	BEVs have been relatively small, with little luggage space, but several large BEVs have come onto the market. BEVs that are variants of a petrol/diesel car have somewhat reduced space. There are no station wagon BEVs on the market. It is a trend to develop dedicated BEV platforms, and it seems that station wagon versions with more space are not yet intended apart from one VW model under development.	The majority have a reduced luggage compartment volume to accommodate power systems and batteries in addition to the internal combustion engine, tank and exhaust system.
	Roof rack	Several BEV manufacturers make solutions that do not allow for a roof rack, cf. Tesla Model X and VW ID3. This is not favorable in Norway where there is a need to transport skis on the roof. ID3 does have a ski hatch in the luggage compartment but the consequence is that a lot of luggage space and a seat space is lost, and the vehicle becomes a 4-seater with little luggage space.	This is not a challenge for PHEVs. They are usually a variant of a regular car that can accommodate a roof rack.
	Tow hook	Available, but only to a small extent, on mini / small or compact cars. Some have a solution that can carry bicycles and skis but with a very limited weight.	Most PHEVs can tow trailers, even heavier trailers.
Winter-properties	Reliability	More reliable start in very cold conditions, but the range is considerably shorter.	Reliable start in cold conditions either on the electric system or the internal combustion engine.
	Accessibility (4-wheel drive)	Few BEVs with 4-wheel drive, but more coming in 2020-2022.	More and more models with 4-wheel drive available as PHEVs.

Table 6.4: Technical characteristics of BEVs for sale in Norway 2019, and upcoming models.

Model and variant	Battery			Charging				Energy Consumption (kWh/100 km)		Range (km)		
	Nominal size (kWh)	Usable size (kWh)	Type	On-board charger (kW)	Fast Charging (max) (kW)	Fast Charging Speed Summer/Winter* (km/min charging)		Sum-mer (real)	Win-ter*	WLTP	Real Summer	Real Winter
Audi e-tron 55 Quattro	95.0	83.6		11.0	155	9	6	23.2	30.2	417	360	252
Audi e-tron 50	71.0									> 300		
Audi e-tron 55 Sportback (2020)	95.0									477		
Audi e-tron 50 Sportback (2020)	71.0									372		
BMW i3 120 Ah	42.2	37.9		11.0	49	4	3	16.1	20.9	310	235	165
BMW iX3 (fra 2020)	75.0	75.0	C/NMC-LMO	11.0	150	8	6	21.4	27.8	400	350	245
Chevrolet Bolt	Sold as Opel AmperaE		C/NCM									
Citroen Berlingo Multispace	22.5	20.5		3.7	40	7	5	18.6	24.2		110	77
Citroen C-Zero	16.0	14.5	LMO/ NCM	3.7	40	5	3	16.1	20.9		90	63
DS 3 Crossback E-Tense (fra 2020)	50.0	47.5		7.4	100	8	5	17.0	22.1	320	280	196
Ford Mustang Mach-E (fra 2020) 75 kWh	75.0			Ukjent	115					420		
Ford Mustang Mach-E (fra 2020) 99 kWh	99.0			Ukjent	150					600		
Honda E Advance (fra 2020)	35.5	32.0		6.6	60	6	4	16.0	20.8	220	200	140
Hyundai Ioniq	28.0		C/NMC									
Hyundai IONIQ Electric	38.3	38.3	NCM	7.2	44	6	4	14.5	18.9	311	265	186
Hyundai Kona Electric 64 kWh	67.1	64.0		11.0	77	7	5	16.2	21.1	449	395	277
Jaguar I-PACE	90.0	84.7	NMC432	7.4	104	14	10	22.9	29.8	470	370	259
Kia e-Niro 64 kWh	67.1	64.0		7.2	77	10	7	17.1	22.2	455	375	263
Kia Soul EV (-2019)	33.0	30.0	C/NMC	6.6	100	5	4	17.1	22.2		175	123
Kia e-Soul 64 kWh (fra 2020)	67.1	64.0		7.2	80	11	7	17.3	22.5	452	370	259
Mercedes EQC 400 4MATIC	85.0	80.0		7.4	112	13	9	22.2	28.9	417	360	252
MG ZS EV	44.5	44.5		7.4	60	7	5	19.3	25.1	263	230	161
Mitsubishi I-MiEV	16.0	14.5	LMO/ NMC	3.7	40	5	3	16.1	20.9		90	63
Nissan e-NV200	40.0	38.0		6.6	46	7	5	20.0	26.0	200	190	133
Nissan Leaf	40.0	36.0	C/NMC	3.6	46	12	8	16.4	21.3	270	220	154
Nissan Leaf e+	62.0	56.0	NMC	6.6	100	10	7	17.0	22.1	385	330	231
Opel Ampera-e	60.0	58.0	C/NMC	7.4	46	9	7	16.8	21.8	380	345	242
Opel Corsa-e (fra 2020)	50.0	47.5		7.4	100	8	5	16.4	21.3	330	290	203
Peugeot iOn	16.0	14.5	LMO/ NCM	3.7	40	5	3	16.1	20.9		90	63

Model and variant	Battery			Charging				Energy Consumption (kWh/100 km)		Range (km)		
	Nominal size (kWh)	Usable size (kWh)	Type	On-board charger (kW)	Fast Charging (max) (kW)	Fast Charging Speed Summer/Winter* (km/min charging)		Sum-mer (real)	Win-ter*	WLTP	Real Summer	Real Winter
Peugeot e-208 (fra 2020)	50.0	47.5		7.4	100	8	5	16.1	20.9	340	295	207
Peugeot e-2008 (fra 2020)	50.0	47.5		7.4	100	8	6	17.3	22.5	310	275	193
Peugeot Partner Tepee Electric	22.5	20.5		3.7	40	7	5	18.6	24.2		110	77
Polestar 2 (fra 2020)	78.0	75.0		11.0	150	8	6	16.7	21.7	500	450	315
Porsche Taycan Turbo (fra 2020)	93.4	83.7		11.0	270	9	6	20.2	26.3	450	415	291
Renault Kangoo Maxi ZE 33	33.0	31.0		7.4		5	4	18.8	24.4		165	116
Renault Zoe ZE50 R110	55.0	52.0		22.0	45	3	2	16.3	21.2	390	320	224
Seat Mii	32.3				40					258		
Skoda Citigo	32.3				40					258		
Smart ForFour	17.6	16.7	C/NMC	4.6		5	3	18.6	24.2		90	63
Smart ForTwo	17.6	16.7	C/NMC	4.6		5	3	15.9	20.7		105	74
Tesla Model 3 Long range performance	75.0	74.0	NCA	11.0	250	8	6	16.4	21.3	530	450	315
Tesla Model S Long range	100.0	95.0	NCA	16.5	200	7	5	18.1	23.5	610	525	368
Tesla Model X Long range	100.0	95.0	NCA	16.5	200	7	5	20.7	26.9	505	460	322
Tesla Model Y Long range (fra 2021)	75.0	74.0	Probably NCA	11.0	145	8	6	16.8	21.8	540	440	308
VW E-Golf	35.8	32.0	C/NMC	7.2	40	5	4	16.8	21.8	230	190	133
VW E-up!	18.7	16.0	NMC	3.7	40	5	4	16.8	21.8	133	95	67
VW E-Up 2020	32.3				40					258		
Volkswagen ID.3 Long range (2020)	82.0	77.0	NMC	11.0	125	8	6	17.1	22.2	550	450	315
Volkswagen ID.4 (fra 2020)			NMC						0.0			0
Volvo XC40 P8 AWD Recharge (fra 2020)	78.0	75.0		11.0	150	8	6	20.0	26.0	425	375	263

*Winter values were estimated from basic information (summer conditions) under the assumptions that charging is 30% slower, energy consumption is 30% higher and range 30% lower.

https://www.greencarcongress.com/2019/07/20190709-adamas.html, https://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/li_ion_ev.html

https://edison.handelsblatt.com/erleben/vw-startet-countdown-zur-grossen-elektro-offensive/23093964.html
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https://electricrevs.com/2019/05/31/report-sk-innovation-to-begin-making-nmc-811-cells-in-q3-2019/,
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https://cleantechnica.com/2018/05/30/the-state-of-ev-batteries-lg-chem-sk-innovations-tesla-panasonic-improvements/
https://qz.com/1447251/jaguars-full-response-to-questions-about-the-i-pace-electric-cars-battery/

Table 6.5: BEV generations in Norway, adapted from Figenbaum (2018a).

	Year	Nominal range WLTP (estimated)	Typical range Winter-Summer	Battery size	Max fast charge power	Typical charging speed km/min Winter-Summer	Sizes and segments
		km	Km	kWh	kW	Km/min	
Pre Li-ion	- 2010	45-65	40-70	8-12	NA	NA	Mini
Gen 1	2010-18	110-170	70-140	16-24	50	3-6	Mini, Small, Compact
Gen 1 Tesla	2013-18	375-594	250-500	60-95	120	6-10	Large/Luxury
Gen 1+	2016-18	190-230	120-180	28-30	50	4-6	Mini, Small, Compact
Gen 2	2017-18	250-390	250-400	40-60	80	6-9	Mini, Small, Compact, Medium
Gen 3	2018-	250-450	300-450	40-100	150	10-18	Mini, Small, Compact, Medium, Large, Luxury, SUV, MPV, Crossover, Sport
Gen 4	2020-	400-520	400-520	>90	150-350	10-35	Large, Luxury, SUV, Sport

Figure 6.7 shows how prices for BEVs have developed from 2011 to 2019 (in 2019 NOK). There are several trends that affect price trends. Batteries have become cheaper and production volumes have increased, so the prices of BEVs have fallen. However, there has also been a general price increase for cars due to a weakened exchange rate. In addition, there has been an increase in the size of the batteries in the cars, as shown in Figure 6.8. Other vehicles than those in the figure have also increased battery size; for example, VW E-Golf increased its battery size in 2017 and Nissan E-NV200 increased its battery size in 2018. The net effect has been a fall in the price per kWh of battery (see Chapter 9). In other words, car manufacturers have used the price reduction in batteries and other components to, in large part, increase the battery size and thus the range.

In 2020-2022, it is especially the small cars and compact cars that will have increased range. Battery sizes for BEVs with less than 40 kWh batteries in 2019 will typically increase by 30-100% depending on the model, and the range will increase approximately accordingly. VW expects, for example, that for the ID.3 which is replacing the E-Golf, most people will choose the middle battery size of 58 kWh (Finansavisen, 2019). This vehicle has a corresponding range of 420 km, while the E-Golf in 2019 had a WLTP range of 230 km (with a battery of 36 kWh).

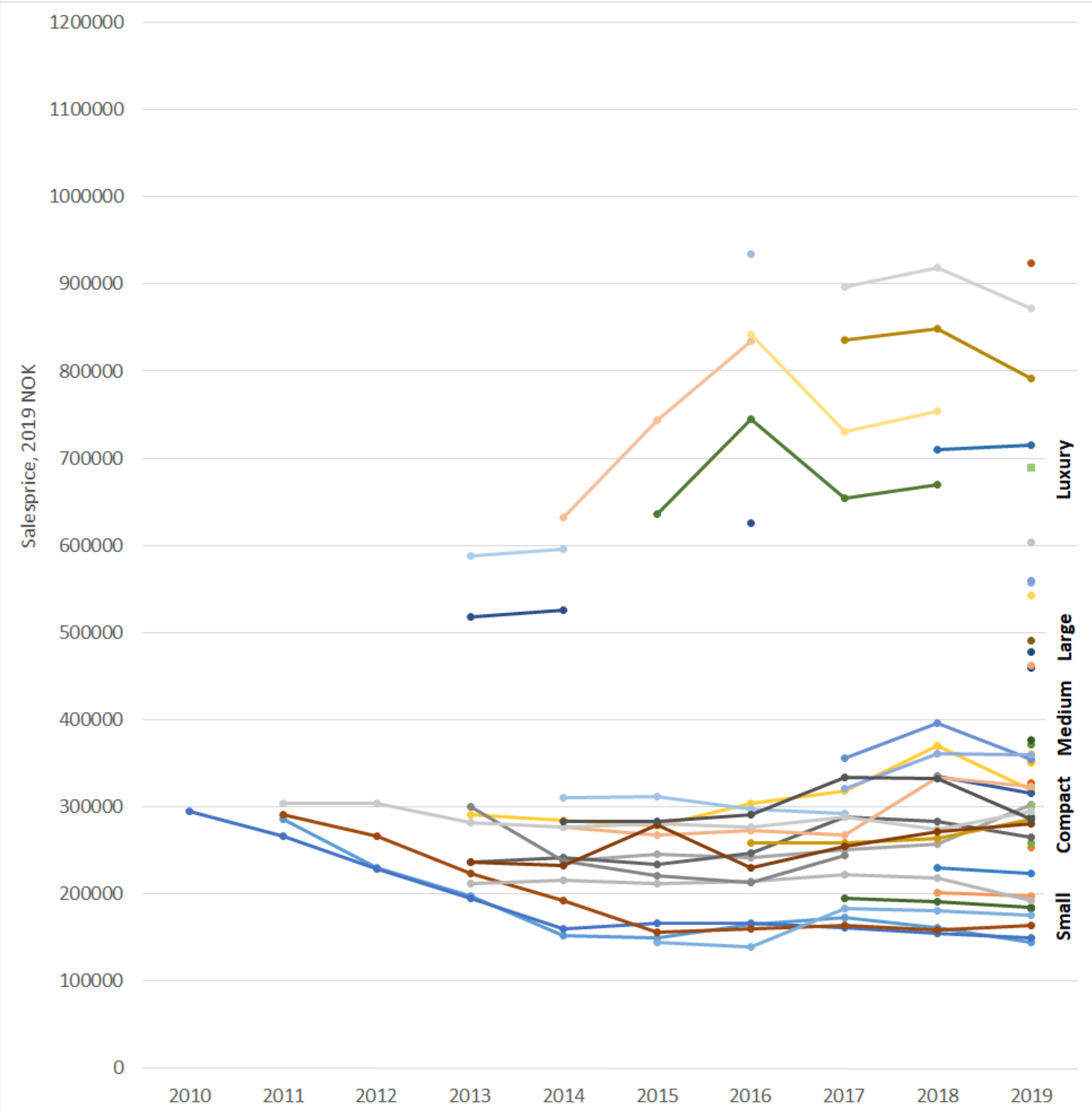

Figure 6.7: Developments in prices of BEVs, 2019 kr. Source: Own analysis.

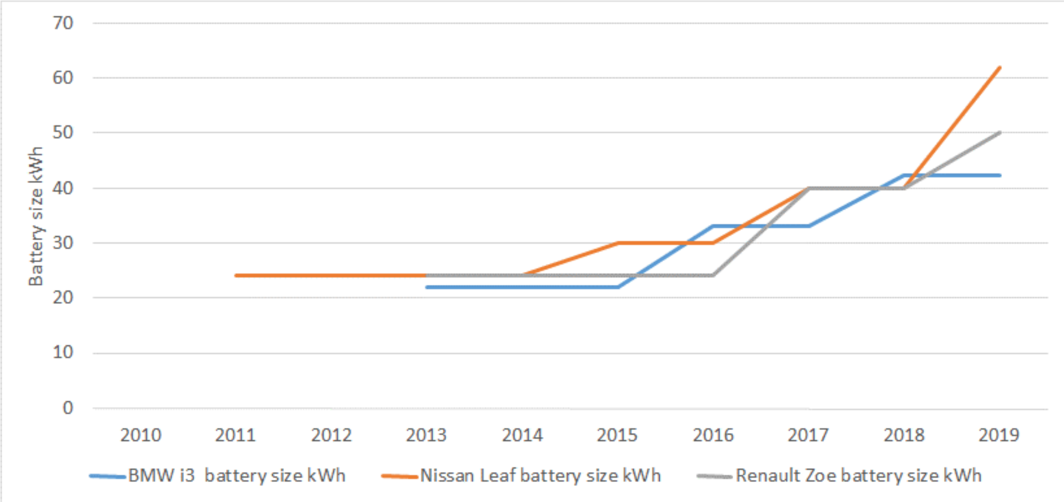

Figure 6.8: Battery size kWh for Nissan Leaf, BMW i3, Renault Zoe. Source: Data from car importers.

Of the properties described in Table 6.2 and Table 6.3, it is the electric vehicle range that will be of greatest importance in reaching the 2025 target. Nonetheless, the poorer load capacity and significantly reduced load flexibility of many electric vehicles threaten the achievement of the goal.

In a survey of BEV and ICEV owners, TØI investigated how important it was that one of the cars in the household had a roof rack and a tow hook (Figenbaum and Nordbakke 2019) as shown in Figure 6.9. The results confirm that these are sought after properties among many vehicle buyers. It is clear that the lack of tow hook on most BEVs is a major barrier to replacing the "main car" in the household. 55-67% say it is absolutely necessary and a further 19-27% that it is somewhat necessary that one of the household cars is equipped with this. Limited opportunities for 4-wheel drive is an issue for 32-64% of car owners, as seen in figure 6.9.

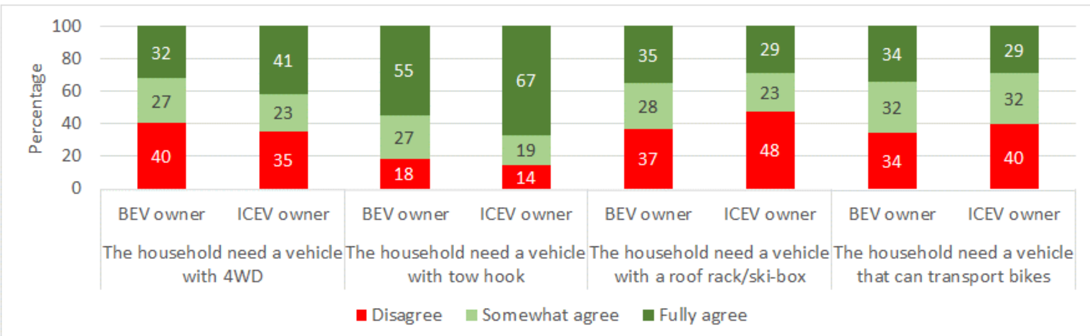

Figure 6.9: Household needs for 4-wheel drive, tow hook, roof rack/ski box and the possibility of bicycle transport. Source: Data from Figenbaum and Nordbakke (2019).

Some BEVs cannot however have a roof rack and most cannot have a tow hook. This is especially true of models developed specifically as BEVs, as shown in Table 6.6. This makes it difficult to expand the load capacity when it is needed on longer holiday trips. Car manufacturers that make electric versions of regular models (which are then also available as gasoline/diesel/hybrid cars) seem to pay more attention to such needs. Large and luxury BEVs and PHEVs usually have the option of both a roof rack (not Tesla Model X) and a tow hook. 4-wheel drive was previously only available on expensive BEVs, but the lower cost Tesla Model 3 came on the market in 2019. More models will come from 2020-2021.

Table 6.6: Operating characteristics of BEVs. 4-wheel drive, tow bar, roof rack. Source: Own analysis and sources listed below table.

Model	4 wheel drive	Luggage compartment (liter)	Roof load (kg)	Tow hook[4]	Permitted tow weight	
					Without brakes (kg)	With brakes (kg)
Audi e-tron 55 Quattro	Yes	600+60	75	Yes	750	1800
Audi e-tron Sportback 55 Quattro	Yes	565+60	Yes	Yes	750	1800
BMW i3 120 Ah	No	260	No[2]	No		
BMW iX3 (from 2020)	Yes		Unknown (probablyy)	Yes	Unknown	Unknown
Chevrolet US Bolt	No		50	No		
Citroen Berlingo Multispace	No	1350	100	No		
Citroen C-Zero	No	166	30-50	No		
Citroën Spacetourer (Jumpy)	No		Unknown	Yes	1000 for LCV, as passenger car?	
DS 3 Crossback E-Tense	No	350	Unknown	Ukjent		
Ford Focus (2013-2017)	No		75	No		
Ford Mustang Mach 1 (from 2020)	Yes	402+100	No	Yes	750	
Honda E Advance (from 2020)	No	171	Unknown	No		
Hyundai IONIQ Electric	No	357	No	No		
Hyundai Kona Electric 64 kWh	No	361	80	No		
Jaguar I-PACE	Yes	505	<75	Yes	750	
Kia e-Niro 64 kWh	No	451	100	No		
Kia Soul EV 64 kWh (- 2019)	No	281	80	No		
Kia e-Soul (from 2020)	No	315	100	No		
Mercedes EQC 400 4MATIC	Yes	500	75	Yes	Undisclosed	1800
MG ZS EV	No		75	No		
Mitsubishi I-MiEV	No	166	30-50	No		
Nissan e-NV200 (Evalia)	No	1190	75-100	Potentially	150 (5 seats)	
Nissan Leaf	No	435	35[1]	No		
Opel Ampera-e	No	381	50	No		
Opel Corsa-e (from 2020)	No	309	70	No		
Opel Vivaro Life	No		Unknown	Yes	1000 (LCV, tilgj. passenger car?)	
Peugeot iOn	No	166	30-50	No		
Peugeot e-208 (from 2020)	No	265	Unknown	No		
Peugeot e-2008 (from 2020)	No	405	Unknown	Unknown		
Peugeot Partner Teepee-Electric	No	544	100	No		
Peugeot Expert Traveller	No		Ukjent	Yes	1000 (LCV, tilgj. passenger car?)	
Polestar 2 (from 2020)	No	438	75	Yes	750	1500
Porsche Taycan Turbo (from 2020)	Yes	366	75	No		
Renault Kangoo Z.E. Maxi ZE 33	No	1300	100	No		
Renault Zoe ZE50 R110	No	338	No (1 aftersales)	No		
Skode Vision IV (from 2021)	Yes		Unknown, probably	Yes	Unknown	Unknown
Smart ForFour	No	185	No	No		
Smart ForTwo Coupe	No	260	No	No		
Tesla Model 3 Long Range Perform.	Yes	542	Estimated 68	Yes	500 or 910 depending on version	
Tesla Model S Long Range	Yes	894	Up to 100[3]	No		
Tesla Model X Long Range	Yes	1090	No because of doors	Yes	450	2250-2268
Tesla Model Y Long Range (f2021)	Yes		Yes (Unknown)	Yes	Unknown	
Toyota Proace city (from 2020)				Probably	Unknown, LCV versjon 1500 kg	
Volkswagen e-Golf	No	341	75	No		
Volkswagen e-up!	No	250	50	No		
Volkswagen ID.3 LongRange (2020)	No	385	No	No		
Volkswagen ID.4 (from 2021)	Yes	>550	Yes (Unknown)	Yes		1600
Volvo XC40 P8 AWD Rech. (2020)	Yes	413	75 (like Polestar 2)	Yes		1500
Total	~25% Yes		~ 83% Yes	~25% Yes		

Table explanation:

[1] The number given in type approval, but Nissan states that this is indicative - not a definitive number
[2] Permitted weight not stated in type approval. The car is not designed to have a roof rack.
[3] Tesla states that no exact figures have been provided. Max load for each roof rack is controlling. That means around 100 kg max.
[4] For several cars a separate device for bicycles and skis can be delivered which is mounted where the tow hook usually sits.

Sources: elbil.no (https://elbil.no/stor-oversikt-sa-mye-taklast-taler-din-elbil/), elbil24.no,ev-database.org, car importers, articles, own analysis, https://www.dinside.no/motor/dette-er-elbilene-med-storst-bagasjerom/70119812, https://www.elbil24.no/nyheter/vw-id4-er-elbilen-som-tilbyr-alt/71780679#_ga=2.65919917.2034223653.1569000485-1190795633.1535803371

6.2.3 Summary of car manufacturers' sales goals and expected development

In their electrification strategies, manufacturers state sales targets for 2025 (or for another year). The targets are most often stated at the producer group level and in relation to global sales volumes. This makes it difficult to assess the size of the sales volumes they envisage in Europe alone. Some of the models will for instance only be available on the Chinese market, which will account for a large part of the volume for the VW group, as shown in in Figure 6.10.

Table 6.7 summarizes the various car manufacturers' goals for 2025 in numbers or proportions of total sales, as well as an overview of the sales in Norway in 2018. Table V1.1 of TOI report 1744/2019 gives a more detailed presentation of the automakers' overall strategies for reaching different buyer groups, and the number of models they expect to produce in different segments from 2019 to 2022.

The most obvious challenge for meeting the Norwegian 2025 goal voluntarily is the Japanese car manufacturers' lack of historical will to develop and sell BEVs, as they have rather large overall market shares with diesel/petrol cars and HEVs in Norway. With recent strategy changes from these manufacturers, BEVs might also find a place in their selection of available models. Otherwise, the car brands that are important for the Norwegian market generally have an active strategy for developing and selling BEVs.

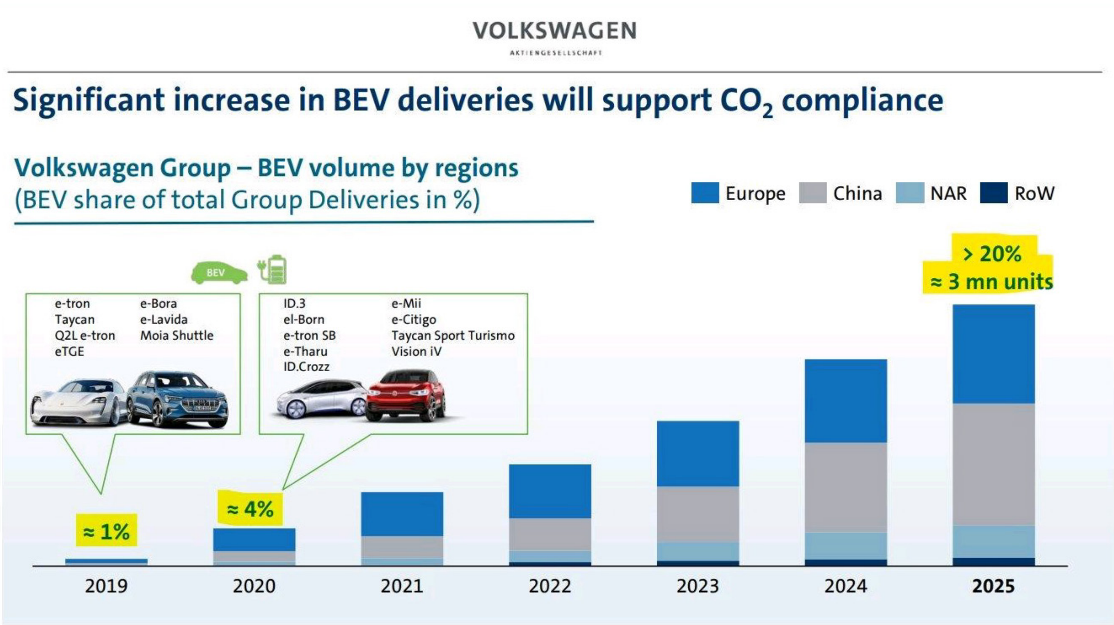

Figure 6.10: Volkswagen group. Sales volume estimates in different regions globally.

Table 6.7: Overview of various car manufacturers' strategies and goals for BEVs until 2025, the number of models under development, and market shares in Norway in 2018 of total cars and of BEVs. Source: Table V1.1 in Appendix 1 of Figenbaum et al. (2019). OFVAS (2020) and own analysis, and Figenbaum et al. (2019).

Producer	Brands	Strategy	Market share in Norway 2018	Number of vehicles sold in total in Norway 2018	Number of BEVs sold in Norway 2018	Percentage of BEVs sold in Norway 2018
VAG-group	VW	Become a global leading electric vehicle manufacturer, produce in electric vehicle specific factories and develop specific BEV platforms. By 2030, all 300 models in the group will have an BEV/PHEV variant. 75 BEVs and 30 PHEVs by 2025 (incl. LCVs, heavy cars etc.).	13.6%	20071	7864	17,1%
	Audi		3.3%	4813		
	Skoda		5.2%	7733		
	Seat		0.1%	151		
	Porsche		0.5%	749		
Ford	Ford	Electrification of all models (incl. Hybrid). Collaboration with VW on BEV(s) from 2023. 40 BEVs/PHEVs by 2022 (16 BEVs).	3.4%	5038	151	0,3%
PSA-group	Peugeot	Electrified version available of all new models in the group by 2019 (BEV, PHEV, hybrid). All models will have electrified alternatives by 2025. 50% by 2021. 7 BEVs in 2021. Flexible platforms, can make BEV/PHEV variants.	3.4%	5050	375	0,8%
	Citroën		1.2%	1704	249	0,5%
	Opel		2.2%	3196	920	2,0%
	DS		0.1%	76		
Daimler	Mercedes	Heavy investment with electrification of the entire product range, over 130 variants of Mild hybrid, BEV and PHEV within the passenger car group. Hydrogen car development has been pushed back in time and is more uncertain, although 1 hydrogen model is on the market. More than 10 BEVs marketed by 2025.	4.2%	6234	6	0%
	Smart		0.2%	242	242	0,5%
Volvo	Volvo	Active electrification strategy. PHEV variants of all models. BEV variant of the XC40. 50% of sales in 2025 will be BEVs, the remainder a high proportion of PHEVs. Polestar- to become a BEV specific brand.	7.7%	11368		0%
	Polestar		0%	0		0%
BMW	BMW	BEVs and PHEV version of all models in all segments from 2021-2030. Platforms and factories prepared for different drive systems. 15-25% of sales by 2025, 12-13 BEV models by 2023.	8.3%	12331	5687	12,3%
	Mini		0.6%	935		
Honda	Honda	Lagging behind but coming with 1-2 BEVs	0.6%	921		
JLR	Jaguar	Clear strategy. Battery factory for 150000/year. BEV/PHEV (including hybrid) variant of all Jaguar models and 2 Landrover models	0.9%	1360	1081	2,4%
	Landrover		0.2%	289		
R-N-M alliance	Renault	Pioneer in BEV in Renault/Nissan alliance from 2010. First modern BEVs Leaf and Zoe, tightly integrated in cross ownership. 12 new (expected BEVs and additionally renewal of existing models, including BE-LCVs, by 2022).	2.7%	4003	3140	6,8%
	Nissan		9.6%	14216	12644	27,5%
	Mitsubishi		3.4%	4996	205	0,4%
Hyundai group	Hyundai	Focuses on BEVs, somewhat less on hydrogen / PHEVs. Become the top 3 global manufacturer of BEVs. Active on hydrogen, planning serial production 44 electrified models in 2025 (some may be battery electric or hydrogen LCVs, busses, trucks)	3.3%	4931	3365	7,3%
	Kia		3.0%	4461	1503	3,3%
Fiat	Fiat	Lagging behind, but investing heavily now. 12 electric models from the group. At least 4 have been published to be pure BEVs. Joins the PSA group.	0.1%	131		
Toyota	Toyota	Lagging behind on BEV and PHEV which they need to meet the EU demands despite high proportion of HEV. Focuses heavily on hydrogen. 6 BEVs, 2 hydrogen before 2023-2025.	9.9%	14709		
	Lexus		0.6%	924		
Subaru	Subaru	Lagging behind. Collaboration with Toyota on BEV model	1.2%	1735		
Suzuki	Suzuki	Lagging behind. Collaboration with Toyota on BEV model	1.6%	2435		
Mazda	Mazda	Lagging behind. Collaboration with Toyota on BEV model. A self developed model will launch in 2020.	2.5%	3630		
Tesla	Tesla	BEV manufacturer, develop new models, enter new segments, 4-5 BEVs on the market in 2020-2021	5.8%	8614	8602	18,7%
Others			0.4%		35	0%
New producers		Several Chinese manufacturers will launch BEVs in Norway in 2020.				
Total	All		100%	147929	46069	100%

6.3 Light Commercial Vehicles

Light commercial Vehicles (LCVs, often called Vans) come in various sizes. The smallest LCVs are often equipped with similar engines and drive systems as compact passenger cars. In many cases, these LCVs are also offered in passenger car variants with the same drive system. The medium sized LCVs may still have drive systems derived from passenger cars whereas the largest LCVs tend to use drive systems taken from small lorries.

LCVs are used by large and small car fleets that more often take into account total ownership costs when buying a car than consumers do. Thus, they will more easily see the value of electrifying the fleet in the form of reduced annual costs, despite the higher initial purchase price. For these reasons, car manufacturers have been quick to introduce small Battery Electric-LCVs (BE-LCVs) on the market, but until 2019 sales volumes had been limited in both Norway and other countries. There are some large car fleets that have been responsible for larger purchases, such as the EDF Group in France and the Norwegian Postal service, while the market has been slow otherwise.

6.3.1 Producers, models on the market before 2019, in 2019 and until 2025

For LCVs, battery-electric variants have been the sole alternative to diesel propulsion until 2019 as shown in Table 6.8.

Ford will launch a Plug in Hybrid variant (PH-LCV) of its Transit LCV in 2020. No hydrogen fuel-cell LCVs (FCH-LCV) have been launched on the market before. However, a rebuilt Kangoo BE-LCV with a Symbio Fcell hydrogen "range extender" has been tested. This was a demonstration of a prototype solution.

The number of LCV models is a somewhat flexible value as each main model can be available in different lengths and with different cargo weight and volume limits. Some pick-ups fall into the category of LCVs, and some LCVs are delivered as chassis without truck bed or luggage compartment (the starting point for making different variants adapted to specific user needs), which is considered as a separate model in the overview in Table 6.7. Passenger cars that have been converted into LCVs are not included in the overview.

Table 6.8 also gives an overview of the strategies of all the LCV manufacturers. The PSA group is one of the major players in the market and consists of Peugeot, Citroën and Opel (and soon Fiat). In addition, they make the LCV Proace for Toyota (the same car as Peugeot Expert Traveler, Citroën Jumpy Spacetourer, Opel Vivaro Life). PSA's strategy is to offer electric versions of all the LCVs in its range, which they will achieve in 2020. In 2021 a new generation of small BE-LCVs with 300 km WLTP range will come on the market, as well as mid-sized BE-LCVs. The big BE-LCVs, Peugeot Boxer Electric and Citroën Jumper Electric are made by an external rebuilder, BD AUTO partner. Some of the large LCVs are not yet available with adaptations for cold weather, and will not be sold in Norway until these are in place.

Currently, Nissan only offers one electric LCV, the E-NV200, but they have a larger LCV, the NV-300, available on the market which currently only has a diesel version. It would have been a natural extension of Nissan's strategy to also electrify the NV300. The E-NV200 has the same battery and drive system as the Leaf, with 40 kWh battery capacity. Leaf is also now available with a 62 kWh battery, and since there is a passenger car variant of the E-NV200, it is not impossible that the E-NV200 will also get a version with a larger battery, especially when the competitors in 2020-2021 get a WLTP range of 300 km which is 50% more than what the E-NV200 has.

Renault electrified the small Kangoo at an early stage, and are also coming with a battery electric version of the Master. Master has the same drive system as Kangoo and is being rebuilt into an electric vehicle by a third party builder now owned by Renault. It will come with a cold weather package and can be sold in Norway from 2020. Renault also announced serial production versions of Kangoo and Master with a 10 kW fuel cell range extender[5] (5 kW or 5 kW heat) in October 2019 (based on the Symbio project), with delivery of the Kangoo by the end of 2019 and the Master, in mid-2020.

Volkswagen and MAN are part of the same group, and the eCrafter and eTGE LCVs are essentially the same model. Volkswagen additionally has smaller LCVs that will come as electric versions and is developing a brand new small model, the ID.BuzzCargo, which is the LCV variant of ID.Buzz in Volkswagen's range of ID BEV models that are under development.

Daimler makes commercial vehicles under the brand Mercedes. Two of the models will come as BE-LCVs in 2020 and the strategy is to launch battery-electric versions of all their LCV models.

Italian manufacturers Fiat and Iveco are also making battery electric version of some of their models.

There are also going to be Chinese models for sale, with the Maxus brand coming first. They currently offer a medium-sized LCV in Norway, but will present a new and smaller model in 2020. It is conceivable that more Chinese brands will follow suit. In Norway these brands will likely only offer BE-LCVs.

[5]The fuel cell produces electricity and heat while the car is running which is used by the drive system for propulsion and for heating the car (this extends the range).

Table 6.8: BE-LCV models for sale in Norway 2011-2019, and expected for 2020-2021, the manufacturers' strategies for zero-emission vehicles, and the number of main LCV models sold in Norway in 2019 regardless of the drive system. Status October 20, 2019. Source: Own analysis, Figenbaum et al. (2019).

	Available models					Availability in future		Strategy 2019 status	Total number of models 2019*
	2012-2013	2014-2016	2017	2018	2019	2020	2021		
Renault	Kangoo	Kangoo	Kangoo	Kangoo	Kangoo** KangooEl/H_2	Kangoo** KangooEl/H_2 Master Master El/H2	Kangoo** KangooEl/H_2 Master Master El/H2	Strategic focus on electrification	3
Nissan		E-NV200	E-NV200	ENV200	E-NV200	E-NV200	E-NV200	Strategic focus on electrification	4
VW					e-Crafter 35	e-Crafter 35 ABTe.	e-Crafter 35 ABTe IDBuzz Cargo	Part of the VW group's overall strategy, see section on passenger cars	5
MAN					eTGE	eTGE	eTGE	Part of the VW group's overall strategy, see section on passenger cars	2
Peugeot			Partner	Partner	Partner	Partner Expert	Partner (New) Expert	Battery electric version of all, Boxer not yet in Norway due to cold conditions problem.	3
Citroën			Berlingo	Berlingo	Berlingo	Berlingo Jumpy	Berlingo (New) Jumpy	Battery electric version of all, Jumper not yet in Norway due to cold conditions problem.	3
Opel						Vivaro	Combo Vivaro	Part of the Peugeot/Citroën (PSA) Group's overall strategy	4
Mercedes					eVito	eVito**** eSprinter	eVito**** eSprinter	The overall strategy is to make battery electric versions of all LCV models within a few years.	4
Maxus					EV80 EV80 Ch.	EV80 EV80 Ch. EV30	EV80 EV80 Plan EV30	Series of BE-LCVs of different sizes from Chinese SAIC. This will be a pure BE-LCV brand in Norway	1, but more available in the group
Ford						Transit PHEV	Transit PHEV Transit Elektr.	Electrification (from mild hybrid to battery electric) of all models	4
Mitsubishi								Unknown	1
Toyota						Proace City	Proace Proace City	Unknown beyond Proace	3
Hyundai								17 commercial vehicles by 2025. 7 electric and 10 hydrogen. Unknown number of LCVs.	1
Iveco					Daily El	Daily El	Daily El	Unknown beyond Daily El	2
Fiat						Ducato El	Ducato El Doblo El	Production capacity of 7000 Ducato Battery Electric per year	6
Sum	1 1 Small	2 2 Small	4 4 Small	4 4 Small	9 Total 5 Small 2 Medium 2 Large	20 Total 6 Small 9 Medium 5 Large	25 Total 6 Small 14 Medium 5 Large		46***

Ch. = Chassis version of the main model, allows for different customized configurations.

* Total number of main models, regardless of drive system. Each main model exists in different lengths, heights, weight classes. l.

** Renault Master is on sale in other countries but not in Norway because it is not adapted to cold climate use.
*** In addition, some are registered as work machine (not class N1), and some passenger cars are being converted into LCVs in Norway.
**** Version with a long range and fast charge is coming
Main source: overview of existing and upcoming BE-LCVs in Yrkesbil 04.10.2019. http://www.yrkesbil.no/artikkel.php?aid=52420+

VW. El: e-Crafter, ABT e-Transporter (2020). https://vwpress.co.uk/en-gb/releases/3482

MAN. El: e-TGE, https://www.nfz-messe.com/de/fachmagazin/fachartikel/mittlere-schwere-nutzfahrzeuge-nufam-elektromobilitaet-interview-mit-christoph-huber-man-truck-bus-deutschland-gmbh-2367.html

Mercedes. El: e-Vito, e-Vito Long-range/Fast charge capable version (2020), eSprinter (2020). https://media.daimler.com/marsMediaSite/en/instance/ko/eSprinter-Systematic-electrification-of-commercial-fleets-from-2019-the-eSprinter-will-add-to-the-drive-portfolio.xhtml?oid=39957895

Nissan. El: E-NV200
Peugeot. El: Partner Electric Mester, Expert (2020), ny Partner (2021)
Citroén. El: Berlingo Electric Proff, Jumpy (2020), ny Berlingo (2021)
Opel. El: Opel Vivaro (2020), Opel Combo (2021)
Renault. El: Kangoo Z.E. Master Z.E. cold weather versjon (2020)

Maxus. El: Maxus EV80, EV30 (2020). http://www.yrkesbil.no/artikkel.php?aid=51591

Iveco. El: Daily Electric. **Fiat**. El: Ducato Electric (2020), Doblo Electric (2021). *http://www.yrkesbil.no/artikkel.php?aid=51913*
Ford. El: Transit 2T (2021), Ladbar hybrid: Transit Custom Plug-in hybrid (2020).
https://media.ford.com/content/fordmedia/feu/en/news/2019/04/02/tailored-to-customer-need--ford-reveals-new-electrified-vehicle-.html

Toyota. El: Proace EV (2020/2021), Proace City EV (2020)

Hyundai: https://www.electrive.com/2019/08/31/hyundai-plans-for-17-electric-utility-vehicles-by-2025/

6.3.2 Development of technical and usage characteristics

Electric vehicle users demand longer-range LCVs, ideally with around 200 km year-round range, faster charging and trailer hooks. In addition, they ideally also need large LCVs (Figenbaum 2018b). An overview of the technical and practical characteristics of current and future models is shown in summary form in Table 6.9 and with more details and more properties in Table V.1.2 in Appendix 1 of Figenbaum et al. (2019).

Table 6.9: BE-LCV properties. Source: Own analysis, Figenbaum et al. (2019)

		Size	Price Cheapest version NOK	Battery capacity kWh	Range WLTP[2] km	Winter-range[3] km	Fast charging[4] kW	Payload		Trailer Yes/No
								Weight Kg	Volume m^3	
Renault	Kangoo Z.E. [1]	Small	260000	33	190	135	No	625	3-4	Yes
	Master Z.E.[1]	Large	Unknown	33	140	100	No	975-1128	8-13	No
Nissan	E-NV200	Small	289000	40	195	140	50	742	4.2	Yes
VW	e-Crafter 35	Large	651900	35.8	120	90	50	Ca. 975	10.7	No
	ABTe	Medium	Unknown	37.3	155	110	50	1000	6.7	Yes
	IDBuzz Cargo	Medium	Unknown	Unknown	Unknown		Unknown	Unknown	Unknown	Unknown
MAN	eTGE	Large	683000	35.8	114	90	50	Ca. 975	10.7	No
Peugeot	Partner	Small	230000	22.5	120	90	50	620	3.3-3.7	No
	Partner (New)	Small	Unknown	Unknown	Unknown		100	Unknown	Up to 4.4	Yes
	Expert	Medium	Unknown	50-75	200-300	140-210	100	1000?	5.1-6.6	Yes
	Boxer	Large	Unknown		160-200	110-140				
Citroën	Berlingo	Small	225000	22.5	120	90	50	620	3.3-3.7	No
	Berlingo (New)	Small	Unknown	Unknown	Unknown		100	Unknown	ca 4.4	Yes
	Jumpy	Medium	Unknown	50-75	200-300	140-210	100	1000?	5.1-6.6	Yes
	Relay (Jumper)	Large	Unknown		160-200	110-140				Yes
Opel	Vivaro	Medium	Unknown	50-75	200-300	140-210	100	1000 est.	5.1-6.6	Yes
	Combo	Small	Unknown	Unknown	Unknown		100	Unknown	Up to 4.4	Yes
Mercedes	eVito	Medium	476500	41.4	112-150	105	Nei	Ca. 1000	6-6.6	No
	eSprinter	Medium	Unknown	41-55	150	80-105	80	Ca. 1000	10.5	No
Maxus	EV80	Medium	530000	56	135	95	50	950	10.2	Yes
	EV80 Planbil	Medium	500000	56	135	95	50	980	11.5	Yes
	EV30	Small	Unknown	35-52.5	150-225	110-160	50	Ca. 1000	4.8-6	Yes
Ford	Transit PHEV[5]	Medium	Unknown	13.6	35 (electric)	25	No	1000	6	Unknown
	Transit Electric	Medium	Unknown	Unknown	Unknown		Unknown	Unknown	Unknown	Unknown
Toyota	Proace	Medium	Unknown	50-75	200-300	140-210	Unknown	1000 est.	4.6-6.1	Yes
	Proace City	Small	Unknown	Unknown	Unknown		Unknown	Unknown	Unknown	Yes
Iveco	Daily El	Large	838000	28-85	50-140	35-100	Unknown	600-1100	7.3-19.6	No
Fiat	Ducato El	Large	Unknown	47-79	155-250	110-180	Unknown	1100-1900	10-17	Unknown
	Doblo El	Small	Unknown	Unknown	Unknown		Unknown	Unknown	Unknown	Unknown

[2] If only NEDC is stated, WLTP is estimated to give 30% lower range and rounded off to the nearest 5 km.

6.3.3 Range

The BE-LCVs lag behind passenger cars in terms of technical development and it is thus unlikely that they will yet get the same range as the longest range BEVs. It is also not necessary based on how these cars are usually used. Today's small BE-LCVs manage approx. 200 km range according to the WLTP test with a 40 kWh battery. This provides a winter range of about 150 km. A 30% larger battery will be sufficient to increase the range to approx. 200 km year round. This is similar to the battery of the new Renault Zoe and is smaller than the long-range Nissan Leaf battery (62 kWh). 200 km year-round range can thus become possible in the next generation of small BE-LCVs as battery prices fall. This is a range that typical users (crafts and service companies in the Oslo area) say is sufficient to electrify their entire vehicle fleets provided it can be done economically (Figenbaum, 2018b).

Many of the small and medium sized LCVs also come in a passenger car variant with anywhere from 5 to 9 seats. Given that a long range is in demand in the passenger car segment, it is likely that the range for these models will increase for both the passenger car and the LCV variant. Range is thus likely to cease to be a significant market challenge for the electrification of small and medium-sized LCVs over the next few years.

However, the large LCVs are lagging behind technologically. The first large LCVs that have become available use, in part, the same drive system as the small LCVs or compact sized passenger cars. This results in a much shorter range and thus weight limitations in terms of use, due to its increased size and increased driving resistance of a large LCV compared to the much smaller vehicles the drive system was adopted from. These large LCVs are sold in smaller volumes than the small ones, and this may be why car manufacturers have so far opted for a «quick fix». Renault's large BE-LCV Master has the same drive system and battery as the much smaller Kangoo LCV, and the VW e-Crafter and the MAN eTGE has the same battery and drive system as the VW E-Golf. There are thus no large electric vehicles on sale with a long range. VW still only states the NEDC range for e-Crafter (173 km), which will probably decrease to 130 km if measured by the WLTP standard. These are similar to the range values that the small BE-LCVs had up to approx. 2017, and which proved to be too short for mass-adoption in the LCV segment. It is believed that the next iteration of large LCVs may allow for different battery sizes through modular solutions and perhaps they will share batteries and drive systems with small battery electric trucks that are expected to come on the market in the 2020-2022 timeframe.

6.3.4 Charging time

The available BE-LCVs can be recharged at variable power levels. It is assumed that fast charging will be available on all electric vehicles within a few years, so this will not be a limiting factor. On some models, there will also be higher fast charging capability, up from 50 kW power today to up to 100 kW on the next generation of BE-LCVs coming in 2021. Normal charging power will also increase to 11 kW for many models, which becomes necessary when they get larger batteries, to be able to fully charge them overnight.

6.3.5 Other operating characteristics

Many of the LCV models can be delivered in different lengths with different payloads (weight and volume). Some models can also be delivered as a chassis ready to be equipped with a flatbed or other user specific solutions. Of the LCVs in Table 6.8, 13 can tow trailers (nine in some cases can only tow light trailers, see Table V.1.2 in Appendix 1 of Figenbaum, et al. (2019), eight cannot, while it is unknown for six of the upcoming models whether or not they can tow trailers. For some BE-LCVs the full payload is maintained, while for others the payload measured in kg can be somewhat reduced depending on the battery size. The latter is mainly due to the use of standard suspension systems carried over from the diesel version, which has a maximum weight limit. For LCVs, a new rule allows for a total weight of 4250 kg for Battery electric versions (Anlegg og Transport 2020).

For the smallest LCVs, the battery electric drive technology has developed far enough to make a nearly 100% transition to BE-LCVs possible in the coming years. The generation of vehicles coming in 2020-2021 will have a year-round range of 200 km. This can, according to the analysis behind Figure 6.11, enable electrification of over 90% of the LCVs, even without charging during the day.

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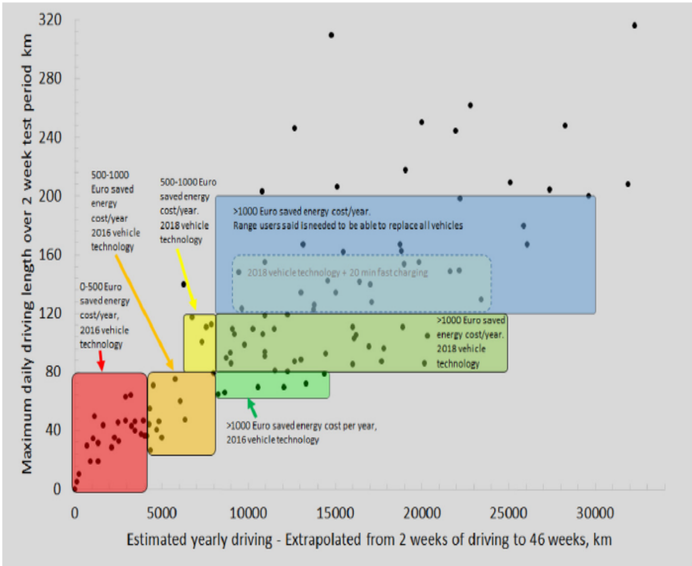

Fig. 13. Economics and practicality of BE-LCVs. Three vehicles had more than 320 km driving on max day (not shown).

Figure 6.11: Techno-economic potential for electrification of LCVs based on analysis of GPS data. Color codes: Red and orange = can be electrified but not economic for users, Light green = Economic for LCVs with 80 km all year range. Green = Economic with range possible from 2019. Yellow = Marginally economic with 2019 and newer year models. Blue = Economic with LCVs coming in 2020-2021. Source: Figenbaum (2018b).

6.4 Trucks

The truck market differs from LCVs and passenger cars in that the car manufacturers only supply complete vehicles to a limited extent. Some standard trucks are sold directly from the car manufacturer/importer to the customer, but they form a small part of the market. Usually, the manufacturers produce a chassis which is then sent to a body-builder who tailors the bodywork for the individual user. The bodywork often needs energy/power supply to various types of equipment, such as refrigerator units, loading cranes, hoisting buckets and compressors. This energy must be delivered from the chassis. In a Battery Electric-Truck (BE-Truck), this equipment must be powered by electricity. If BE-Trucks are to be sold on a large scale, this body-building industry must, to a great extent, also offer electrically powered solutions. Trucks are available in many different sizes and configurations to reflect different user needs. The high level of customization of trucks will mean that it will take longer to establish and expand the market for BE-Trucks or hydrogen Fuel cell trucks (FCH-Trucks) than for BE-LCVs which are more standardized.

Trucks lag other vehicle segments in terms of electrification and the use of hydrogen. However, there are segments where BE-Trucks can function acceptably with today's technology, and where series-produced products are coming. The EU CO_2 requirement for trucks appears to have caused vehicle manufacturers to develop battery-electric or hydrogen trucks for sale in Europe looking forward towards 2025 and 2030, as the overview of truck manufacturers' strategies in Table 6.10 shows (further details are found in Table V1.3 in Appendix 1 of Figenbaum et al.2019), and Daimler's assessment of the effects of the EU CO_2-requirement in Figure 6.12. None of the truck manufacturers have published a concrete launch plan for the next few years.

Table 6.10: Truck manufacturers' electrification and hydrogen strategies. Own analysis, Figenbaum et al. (2019)

Car manufacturer	Overall strategy
Volvo	BE-Trucks (FE and FL) of 16 and 27 tonnes will come onto the market first and will be on sale from the end of 2019. Production starts in March 2020. The range is adapted to the users and up to 300 km is possible. The trucks are designed for use in cities, for distribution, waste management etc.
Renault	Focusing on electrification with Truck Model D. Z.E up to 26 tonnes coming on the market in 2 versions with different battery sizes from 2020: 16 tonnes and 26 tonnes for distribution and renovation.
Volvo group	Modular strategy for 3 platforms based on weight classes. In 2019, the group entered into a strategic collaboration with Samsung SDI for the supply of batteries. Embarking on serial production for the US market in 2020 and Europe in late 2019.
Scania	Unclear strategy, no official information available on Scania's website. Part of the TRATON group. Participates in various test and development projects, including electric field testing of buses, hydrogen distribution trucks (Asko, Trondheim), hydrogen garbage truck being developed, participates in electric road test projects (dynamic charging), has short-range hybrid plug-in solutions, and has invested in the battery company Northvolt, which will establish Swedish battery production. In its annual report for 2018, it is stated that electrification has been highlighted in an internal study as important and profitable for the future, but the costs are currently too high. Products will be launched when it becomes sustainable for customers. Electric buses first released with new drive system in 2020.
MAN	MAN has developed a medium-sized e-truck that is in pilot testing and will, by 2020, produce electric city buses. They will have the capability to also produce serial e-trucks because of TRATON's modular e-flex system. They have presented the e-TGM truck for distribution of goods in cities. The e-TGE LCV is also part of the overall city logistics offering.
Volkswagen	Delivers large LCVs and pickup versions but not trucks in Europe. Part of the TRATON group. Volkswagen Caminhões e Ônibus (VWCO) delivers heavier vehicles in South America. It is not likely that there will be trucks in Norway with the VW name. In this case there will be a MAN or a Scania truck.
Mercedes	e-Actros is tested by selected customers. Series production for urban logistics from 2022. No other specific information available other than that presented to the Daimler group.
Fuso	e-Canter is tested in limited volume. Coming in a new version in 2022 and full industrialization hardly relevant before then. No other information available other than that presented to the Daimler Group.
Daimler-group	Consists of Mercedes trucks and buses, Fuso trucks, and the Freightliner and Thomas-built buses brands in the United States. The focus on electric buses and BE-Trucks in the group is gathered in the "E-Mobility group". An integrated solution is developed across brands and applications. The Group has launched a strategy to deliver only CO_2-neutral vehicles from 2039, starting the real market introduction of battery-electric vehicles from 2022, and hydrogen by 2030. The Group has halted the development of gas engines, which are considered an unattractive intermediate solution that produce too much CO_2. Believes that incentives need to be created to bring these types of technologies onto the market. Proposes, among other things, CO_2-based road tax to promote electricity and H_2 solutions, incentives for BE-Trucks, establishment of standardized charging and filling infrastructure.
Hyundai	Investment in hydrogen trucks, among other things, in collaboration with a Swiss consortium that will introduce 1600 H2 Xcient hydrogen trucks onto the Swiss truck market, 50 of which by 2020. The consortium also contains a supplier of hydrogen. It is conceivable that the model will be available in Norway in 2022.
E-Moss	E-Moss is a Dutch company that develops electric drive system solutions for trucks. The trucks are being rebuilt from a chassis with a diesel engine operation to a chassis with electric operation. They seem to have a flexible approach in which they develop models and solutions based on market demand. In total, the company has delivered hundreds of vehicles. They have 30 employees. There is a Norwegian representative/importer.
Tesla	Developing a semi-trailer with modular batteries and drive systems from the Tesla passenger cars. Two battery sizes stated giving approx. 500 and 800 km range. Starting a limited market introduction in 2020 in small volumes. It is therefore not certain that this will already be available in Norway by then.
IVECO	Currently, Iveco only has one BE-LCV in its range. In some versions, it leans over into the truck segment due to the higher total weight. Through the agreement with Nikola, electricity and hydrogen truck solutions will be developed that will be on the market towards the end of 2022.
Nikola (startup)	Electric and hydrogen truck manufacturer (start-up). Has entered into a partnership with Iveco's parent company and will have access to Iveco chassis, expertise, dealer, warranty arrangements and service network.
JV Iveco/Nikola	The parent company of Iveco CNH Industrial N.V. has entered the ownership side of Nikola and an agreement has been entered into which means that both companies will develop electric and hydrogen trucks together in a joint venture. The trucks will be in production by Q4 2022. Nikola's models will be out first. This means that Nikola Tre (the model designed for Europe) can enter the market in Europe before 2022, based on Iveco's S-Way truck.

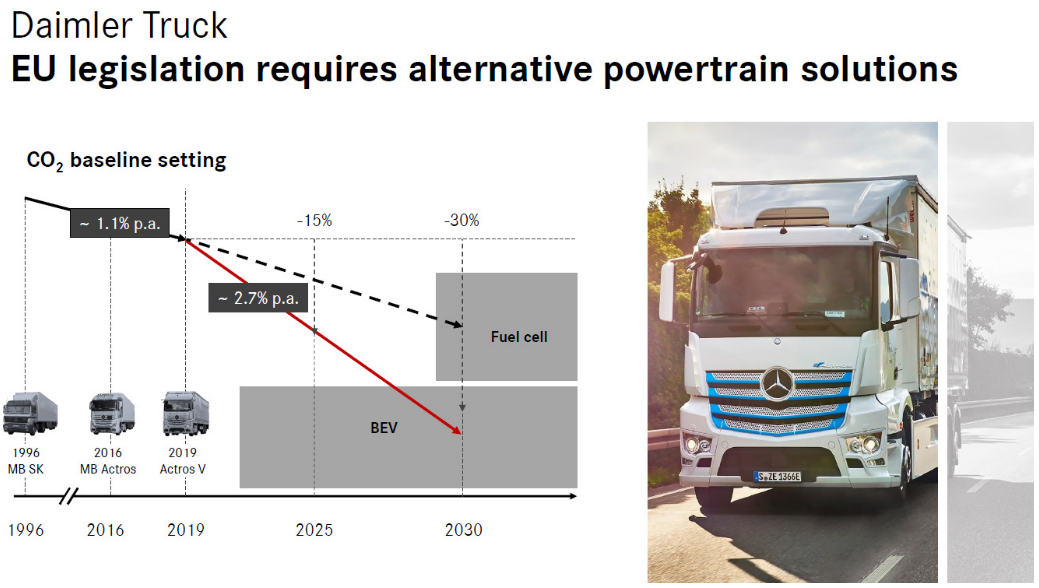

Figure 6.12: Need for hydrogen and battery electric solutions to meet EU CO_2 requirements for new trucks. Source: Daimler 2019.

The strategy overview shows that there is currently a great deal of uncertainty related to the electrification and use of hydrogen in trucks. As so many different variants of heavy duty vehicles are sold, the overall strategies say more about the direction the industry is going than the list of vehicles for sale in 2019 presented in the next section.

Chinese vehicle models are entering the passenger car market in Norway at full speed and are already present in the LCV and bus markets. Thus, it is likely that Chinese BE-Trucks can enter the Norwegian market by 2025 and 2030, thus improving the availability of such solutions on the market.

The first markets will be distribution trucks and waste management vehicles. These trucks run on fixed routes in cities where distances are limited and therefore do not need very large batteries. It is expected that more manufacturers will offer products for such use in the coming years.

Heavy trucks are also being developed for long haul transport, but the information about future models coming on the market is rather limited. More is known about what the startup companies are thinking, than what the traditionall manufacturers are planning for. Tesla is developing a battery-electric semi-trailer that they claim will have a range of 475-800 km (Tesla Norway 2019). Nikola is developing both hydrogen and battery-electric long-haul trucks and has partnered with heavy truck manufacturer IVECO (Iveco 2019). They also claim that they have developed a new battery with double the range (Autonews, 2019a). Whether Tesla and Nikola succeed is uncertain. However, it is likely that traditional manufacturers will also develop similar solutions and commercialize them to meet the 2025-2030 requirements of the EU Directive on CO_2 emissions from trucks.

Battery electric and fuel cell hydrogen solutions have been further developed for buses than for Trucks, and provide a glimpse of what will be possible. VanHool has for instance developed and put into operation a long-distance bus with a battery of 648 kWh and a range of over 300 km. A HD long distance BE-Truck would need a similar sized battery. This bus thus shows that there is a potential for developing BE-trucks for long distance use even with today's known technology. Several hydrogen buses have been developed and tested in different cities in Europe and several manufacturers can supply such buses on the market (see section 6.5), thus proving that such solutions work for heavy duty applications.

6.4.1 Availability of BE-Trucks and hydrogen trucks

Table 6.11 shows an overview of BE-Trucks that were on sale in 2019 and that are expected to go on sale in 2020-2021. There were no hydrogen trucks on sale.

Table 6.11: BE-Trucks that are on sale or coming on sale by 2021. Source: Hovi et al. (2019a).

Vehicle model	Battery kWh	Range, km	Cargo capacity, tonnes	Gross-weight, tonnes	Year on the market
FUSO Canter E-Cell		100	3		2014
Terberg YT202-EV					2015
Renault Truck D		120	6	16.0	2015
Renault Truck D		200-300	6	16.0	2018
Emoss converted truck(s)[18]		200	8	18.0	2016
BYD Auto	150	250		7.3	
BYD Auto	221	200		8.8	2018
BYD Auto	175	200		11.8	2018
BYD Auto		250		15.0	2018
BYD Auto T9	350	200		28.0	2018
Mitsubishi eCanter	82.8	120			
Freightliner eM2 106		370			
Renault Truck D.Z.E	300	300			
Volvo FL	100-300	250		16	2020
Volvo FE	100-300	200		27	2020
Mercedes-Benz urban E-truck	200-300	200		26	2021
Man E-truck TGM		200			2020
Man E-truck TGS		130		26	2020
Freightliner eCascadia	550	400			2021
Cummins		160	22	Class 7	2019
Tesla semi		800	40	Class 8	2020
Thor ET-one		480	36	Class 8	2019

6.4.2 Technological solutions

The EU has several legislative changes underway that will make it easier to build energy-efficient BE-Trucks. The CO_2 emission regulation allows the total weight to be increased by up to 2 tonnes (EU CO_2 Regulation heavy vehicles) to allow for the installation of batteries without losing payload. Furthermore, there is another directive that requires better visibility for the driver which will mean that the front of the trucks can be up to 90 cm longer in order to reduce the driver's field of blindness from the front to the side of the car (T&E, 2019b, Teslarati, 2019). This could at the same time also make trucks more aerodynamic.

Charging solutions for the trucks are not yet standardized. Normal charging will have to be at 43 kW AC (industrial contacts) or 50 kW DC for BE-Trucks with batteries of approx. 200-400 kWh. Battery sizes below 200 kWh can probably be charged with 22 kW AC wall boxes, similar to those used for passenger cars. Battery sizes above 400 kWh may require higher power chargers. For passenger cars, there is now a CCS charging standard that allows up to 350 kW of charge. It is believed that this can also be used to charge trucks. For filling hydrogen there are standard solutions developed.

The technology for BE-Trucks and FCH-Trucks is under development. Trucks are used more intensively than passenger cars and LCVs. They run longer and under heavier average load. The development of robust batteries and fuel cells is therefore essential for them to last the truck's technical life. It is therefore not given that one can take batteries or fuel cells developed for passenger cars that only need approx. 5000 hours of operating life and insert them into trucks that operate 10000-20000 hours throughout their lifespan.

It is therefore likely that batteries and fuel cells for trucks can be somewhat more expensive than for passenger cars, and that the development of the market will be slower.

6.5 Buses

Bus transport is mainly a closed transport system (with the exception of coaches). The buses run on fixed routes in urban areas, in regions or on national express bus routes. Charging of electric buses is adapted to the route arrangement, or the route arrangement is adjusted to suit the charging needs of the electric buses. The buses can be charged in depots overnight, in daytime depots between traffic peaks, at stops along the way (flash charging), or at end stops (fast charging). All of these solutions are available on the market and local conditions and the route will determine which solution is optimal in different areas (Hovi et al., 2019a).

6.5.1 Availability of buses with electric and hydrogen drive systems

In Norway there are three bus classes. Class I is to be considered a city bus and is thus exempted from the seat belt legislation. Class II is a suburban/long-haul bus where, according to the law, 40 percent of the bus's capacity can stand without a seat belt, while the rest who sit must use the seat belt for their own and others' safety. Class III buses are express/coach buses where there is only seating and here everyone must use a seat belt.

To be able to electrify the whole city bus fleet, there needs to be both Class 1 and Class 2 buses available on the market. Class 1 Battery Electric Buses (BE-Buses) have been available for 3-5 years for testing and are now industrialized on a large scale, as shown in the overview of the different manufacturers in Table 6.12. Table V1.4 in Appendix 1 of Figenbaum et al. (2019) gives a more detailed overview of the overall strategies and goals and the bus segments for which they offer electric and hydrogen solutions.

Class 2 BE-Buses became available in 2019 and resulted in Ruter cancelling an option on the use of hydrogen buses for the Bærum/Oslo west bus tenders, where the winner Unibuss could offer full electrification with BE-Buses by 2025 for all of Bærum (a municipality with 118,000 inhabitants). This does not mean that hydrogen will be irrelevant for bus operation. Some routes are so long that electric buses can become too expensive to buy, or they may require so much charging that more buses are needed in total, which can significantly increase the cost of bus operation. In such cases FCH-Buses may be an option.

The EU Clean Vehicles Directive will result in a comprehensive introduction of electric buses across Europe, which will probably mean that all bus manufacturers will offer a wide selection of BE-Buses suitable for public transportation in cities and regions to be able to win public tenders, as discussed in Chapter 11.

In 2019, there were also 2 Class III BE-Buses (Coaches) available on the market. One was developed by VanHool for the US market and has a battery capacity of 648 kWh and a range of over 300 km. The other is produced by BYD but has significantly less battery capacity and range and is probably intended for local operation.

Table 6.12: The bus manufacturers' strategies for electric and hydrogen solutions. Source: Own analysis and Figenbaum et al. (2019).

Manufacturer	Overall strategy	Models for sale 2022		
		City standard	City articulated	Regional Class 2
Volvo	Volvo offers both standard BE city buses and BE articulate buses (from October 2019) in a modular design, as well as a plug in hybrid bus. No information was found about Volvo developing Hydrogen buses on their websites or other sources.	El	El	
Volvo-group	Modular strategy for 3 platforms based on weight classes across trucks/buses. In 2019, the group entered into a strategic collaboration with Samsung SDI for battery deliveries.			
Scania	In October 2019 they launched Citywide electric bus for urban and sub-urban routes. The bus has a range of 80-150 km and has pantograph charging. With the smallest batteries, the weight and passenger capacity are unchanged from the diesel version. Scania has no public activity on hydrogen buses, but is working on hydrogen testing projects for trucks.	El		
TRATON-gruppen	The TRATON group, that is, Scania, MAN, Volkswagen Caminhões e Ônibus (VWCO) will invest 1 billion Euro towards electrification towards 2025. A modular electric heavy transport drive system (e-flex) ala VW MEB platform for passenger cars will be developed. This will be used across the brands in the group. First out are battery electric city buses. Every third bus model will have an electric alternative over the next 15 years, most of which will be battery-electric.			
VDL	VDL is building its own factory for efficient production of electric buses in Belgium, citing Elaad's research center that the proportion of electric buses in Dutch cities is expected to increase from 10% in 2019 to 75% in 2025. The factory will open in 2021 and can deliver buses from then on. As of October 2019, there were 500 VDL electric buses on the roads in European cities. Together with Siemens, various flexible charging solutions are tested at VDL's charging test center. Citea offers an electric city bus which can be supplied in different bus sizes (standard and Catenary) and battery sizes. Several charging solutions are offered. There were no hits for hydrogen on VDL's website.	El	El	
Solaris	Solaris offers both battery-electric buses (Urbino Electric in 8.9, 12 and 18 meter lengths) and a hydrogen bus model (Urbino 12 Hydrogen). The electric buses come with different charging solutions and battery sizes. Solaris has been the market leader in electric buses in Europe.	El, H_2	El	
Neoplan/MAN	Neoplan makes long-distance buses and has no battery or hydrogen buses. MAN has an electric city bus.	El		
IVECO/Heuliez	Supplies the electric minibus, Iveco Daily, while Heuliez supplies 18 meter electric articulated buses and 9.5, 10.7 and 12 meter electric buses which can be supplied with different battery and charging solutions.	El	El	
Van Hool	Can supply BRT battery electric and hydrogen buses (similar to trams) in 18 and 24 meter lengths and a 13-meter hydrogen bus. There is nothing on the website about standard electric buses. Offers in the United States a long-range electric electric bus with 648 kWh battery and over 300 km range.	H_2	El, H_2	
Mercedes	Citaro city bus with battery electric operation from 2018, new generation of batteries from 2021 and solid state (Lititum Polymer) from the second half of 2020, hydrogen based range extender from 2022. Articulated bus available from 2020.	El, H_2	El	
Daimler-group	Consists of Mercedes trucks and buses, Fuso trucks, and the Freightliner and Thomas-built buses brands in the United States. The focus on electric buses and BE-Trucks in the group is done in the "E-Mobility group". An integrated solution is developed across brands and applications. The Group has launched a strategy to deliver only CO_2 neutral vehicles from 2039, can already supply electric buses and work with hydrogen solutions for general launch before 2030. The Group has stopped the development of gas engines which is an unattractive intermediate solution with too low CO_2 gain.			
BYD	BYD is the world's leading electric bus manufacturer and has produced 50,000 electric buses to date. They are delivered to 300 cities worldwide. BYD can supply different types of electric buses from standard 8.7 and 12 meter buses to 18 meter articulated buses, and class 2 buses (with seat belts). They can also provide a coach (Coach).	El	El	El
IRIZAR	Offers an electric bus with up to 350 kWh battery in 10, 12, 15 and 18 meter lengths. Charge 50-600 kW (pantograph). Also has BRT electric bus (tram-like). Also makes a truck (bus front). Own factory for electric buses (capacity 1000 / year)	El	El	El

6.5.2 Technology development

The technology for BE-Buses is being developed to offer customer tailor-made solutions for different topographic, climatic and route-specific needs. This has resulted in BE-Buses having modular battery systems with the possibility of different battery sizes, and a number of different charging solutions, such as plug-based normal charging and fast charging in a depot, pantograph normal and fast charging in a depot, pantograph fast charging (typically 300 kW) at end stop, and flash charging (over 400 kW) at stops along the route. At present, the buses use different variants of Li batteries, but at least one supplier will offer solid state batteries (Li-Polymer) by 2021. The total bus and charging system is adapted to maximize battery life. Customers want a lifetime corresponding to the bus route tender's time period, which in Norway is 7-11 years.

There are no specific technological barriers related to the introduction of electric buses in Norwegian cities, beyond the local challenges of providing sufficient grid capacity and installing charging infrastructure in depots and/or at bus stops. However, there are few user experiences, as shown in Chapter 11, so unexpected problems may arise as the usage is ramped up.

6.6 Summary: Technological maturity and the offer of vehicles

Figure 6.13 gives an overview of the maturity and status of battery electric and hydrogen fuel cell propulsion solutions in different vehicle types, based on an assessment of the publicly available information presented in this chapter, and in more detail in Appendix 1 of Figenbaum et al. (2019).

The overall picture is that by 2025, battery-electric passenger cars, LCVs and city buses will be in full mass production, and many of the benefits associated with cost reductions will be realized. The other categories are somewhat lagging in terms of electrification, but some manufacturers will be in the process of serial production. Hydrogen passenger cars and long-haul trucks may be in series production with a few manufacturers, while other categories such as LCVs and city buses will hardly reach beyond small-scale production since battery electric solutions will be the optimal technology for these types of cars. Below is a thorough discussion and summary of the potential per vehicle type.

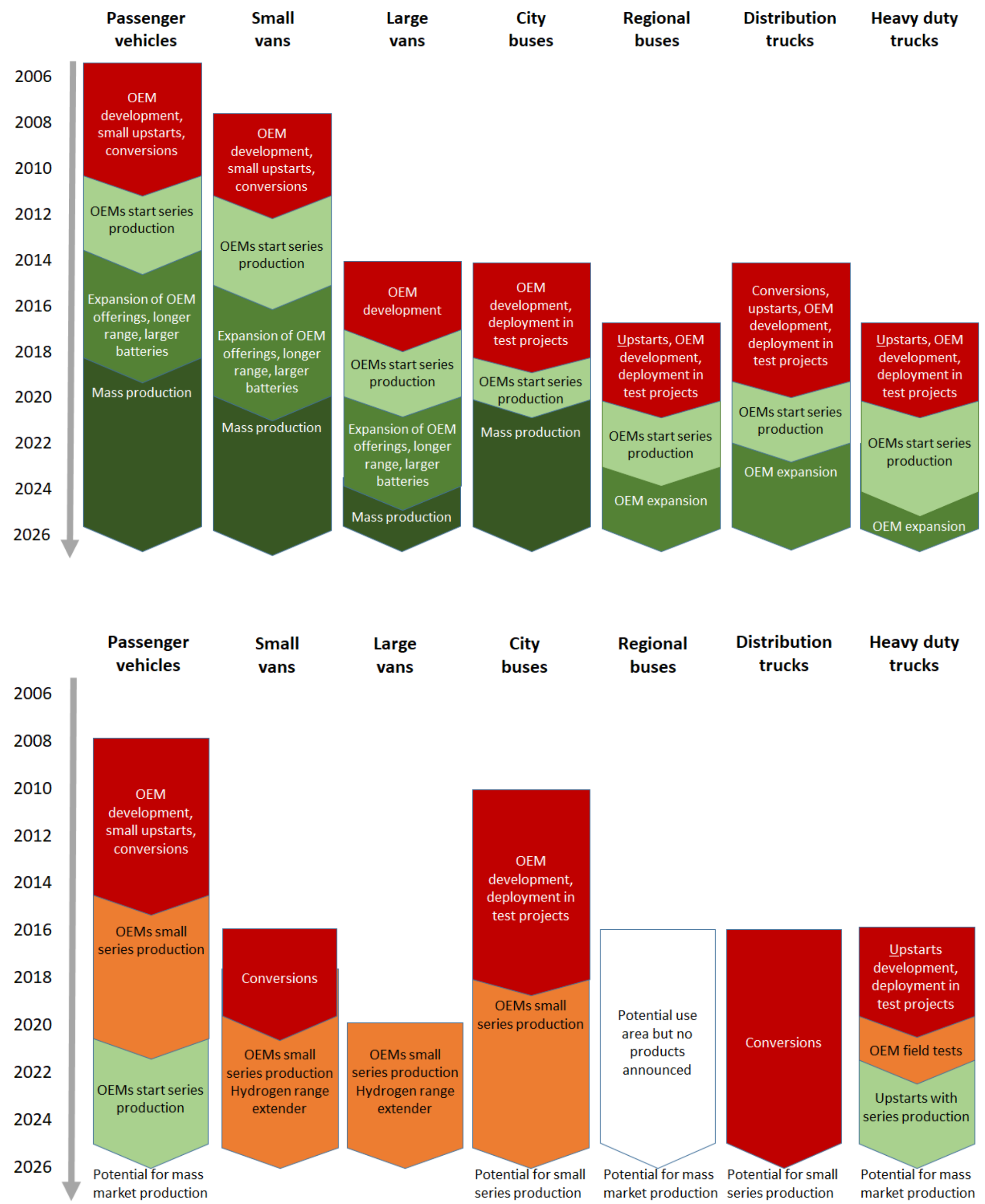

Figure 6.13: Technological maturity of battery-electric vehicless (top) and hydrogen vehicles (bottom). Source: Hovi et al.2019.

6.6.1 Passenger cars

BEV model availability will be significantly improved by 2022. In 2019, around 10% of the 250 main car models in Norway were BEVs or available as BEVs, yet BEV sales accounted for 41% of the total sales (see chapter 2). This could increase to 60% of models by 2025, with a large increase already from 2020-2021, assuming that all the BEV models that the car manufacturers have announced that they are developing come to Norway. This is however not realistic as some of the announced models will be specific to China, and in some cases to the United States. On the other hand, some Chinese manufacturers will start exporting their BEV models to Europe, thus increasing the total number of models sold. Some of the BEV models advertised by car manufacturers are BEV specific, which also increases the total number of models available. On the other hand, some existing car models may disappear because producing them is no longer profitable with the new CO_2-requirements. The best estimate (the authors' assessment) is that BEVs will partly be specific models and partly variants of standard models, and that model availability will increase to 30-60% of the total model range in Europe by 2025. This situation will make it much easier to reach the target of only selling zero-emission vehicles in the passenger car segment from 2025.

When the EU's CO_2 requirements are fully implemented and there are fines for non-fulfillment, there is a golden opportunity to start selling Chinese BEVs in Europe. In the beginning, these companies will probably focus mostly on the sale of BEVs. In Norway, they are likely to become pure BEV brands (the authors' assessment). The first 4-6 brands are already selling their vehicles and 3 of them have Norwegian importers. In some cases, they may fill gaps in the market. They are even more affordable than other BEVs produced in Europe, and they manufacture medium-sized BEV models that are in short supply on the European market.

From 2020-2021 there will be a number of large passenger car variants of small and medium-sized LCVs. These have large luggage compartments, most likely a tow hook capability (the LCV variants often have it), and some will have a range of up to 300 km. This significantly increases model availability in the medium-sized vehicle segment. However, these are cars where the focus is on transporting volume and less on comfort, so they are not an equivalent substitute for medium-sized passenger cars.

The driving range of upcoming BEV models increases to a minimum level of approx. 300 km (WLTP), with a few exceptions, and a normal level for compact and larger cars of approx. 400-500 km. The fast charge power they can utilize increases with increasing battery size, but some models launched in 2020-2021 will still only charge with 50 kW maximum power. However, there may be improvements within this, e.g. that the cars will be able to charge more consistently with the maximum power the 50 kW chargers provide over a greater temperature and battery charge range (InsideEVs 2019). The charger that sits in the car will in most cars be upgraded to charge at 7-11 kW power, and in some cases up to 22 kW.

A lack of practical features of BEVs such as smaller luggage compartments, few models with a tow hook and/or 4-wheel drive, will be barriers that can prevent the goal that 100% of car sales in Norway will be BEVs by 2025. Only approx. 25% of known models in 2019 can pull trailers, and of these again only 5-6 models can pull trailers over 1000 kg. 4-wheel drive is available on only about 25% of the known models. In 2018, 41% of Norwegian car buyers chose cars with 4-wheel drive. It may be that these types of features are better taken care of in new models that are launched closer to 2025. However, there is a trend that the BEVs that are launched often have less flexible usage characteristics than what gasoline and diesel cars have. For example, the VW ID.3 cannot have a roof rack and it cannot pull a trailer.

Most major car manufacturers now have a strategy of electrifying their entire range of car models, whether in the form of hybrid drive systems, PHEVs or BEVs. Up to 40% of car manufacturers' development and investments are aimed at developing PHEVs. A one-sided strategic focus on BEVs in the Norwegian vehicle policy will thus reduce the model supply, especially among medium and large cars that are medium expensive, a segment many choose to look to when buying the "main car" of the household.

Of hydrogen vehicles, only three identifiable models have been announced for the 2020-2025 market. Nonetheless, Transport & Environment (T&E 2019) believe that there can be up to 10-15 models. Except for the Hyundai Group and the Toyota Group, the hydrogen strategies of car manufacturers are less certain than the BEV strategies, and some manufacturers do not even consider FCEVs to be an interesting option. Within the BEV strategies, concrete investments in factories and new models are regularly announced, indicating that these are becoming realities. Hydrogen cars are likely to be available on the market but to a such small extent that they will likely only have a very marginal effect on whether the 2025 target of only selling zero-emission vehicles is met.

6.6.2 LCVs

BE-LCVs are the real alternative to diesel propulsion for the LCV sector. There is a large selection of BE-LCVs on the market, and most LCV models will eventually be found in a battery-electric variant. There is only one Plug-in hybrid LCV model, while there are two Renault BE-LCVs that will get an option with a hydrogen range extender. LCVs are one segment where users will be able to cope with shorter range than what passenger cars require, as they are most often operated in limited geographical zones. Thus, circumstances are well placed for increased sales of battery-electric variants. Other solutions are not expected to capture large market shares.

Several new BE-LCVs are coming onto the market in all size classes and there will be a renewal of existing models. Between 2019 and 2020, model availability will double and from 2021 more than half of the main models in the LCV market will have an electric version. The range will increase for several small/medium models to over 200 km in the winter. This is a level that users have said may be sufficient to electrify their entire LCV fleet (Figenbaum 2018b), at least in the larger city areas. The large models are currently lagging in range development and will only be able to cover parts of the market, but there are no technical limitations to increasing the range for these as well. Some small LCVs have 75 kWh batteries as an option; transferring this to a heavy LCV can allow for 150-200 km of winter range.

One can assume that all new models that are launched hereafter will get fast charging (except for the Renault Master). In some cases, the lack of cold climate adaptation will mean that some models are not sold in Norway, or that the start of sales will be postponed until cold climate modification can be delivered.

The LCVs get more flexible usage characteristics when more models are given the opportunity to tow trailers, and more models are available in different sizes, lengths and from more brands. BE-LCVs will thus be much more adapted to the users' needs by 2025.

All in all, the BE-LCVs that are on the market, or are coming to the market, will largely meet users' transport needs for the light and medium-duty LCV segments, while it is more uncertain for the large LCV segment. The most important providers in the LCV market have as a strategy to offer battery electric versions of all LCV models. This facilitates a much faster future development of the market for BE-LCVs, and the 2025 target for light LCVs may be within reach from a technology and market accessibility perspective.

6.6.3 Trucks

Trucks are lagging other vehicle segments when it comes to the introduction of battery electric and hydrogen propulsion systems. However, there are segments where BE-Trucks can function with today's technology and where series-produced products are coming. The EU CO_2 requirements for trucks appear to be leading car manufacturers to develop battery electric or hydrogen trucks for sale in Europe.

The first markets will be distribution trucks and waste management vehicles. These trucks run on fixed routes in cities where distances are limited and therefore do not need very large batteries. Several car manufacturers will offer products for such use in the coming years. Heavy trucks are also being developed for long haul transport, e.g. Tesla's battery-electric semi-trailer, which they claim has a range of 500-800 km. Nikola is developing both hydrogen and battery-electric long-haul trucks in collaboration with the heavy duty truck manufacturer IVECO. The other traditional manufacturers will develop similar solutions and commercialize these to meet the 2025-2030 requirements of the EU Directive on CO_2 emissions from trucks.

VanHool has developed and put into operation a long-distance bus with a battery of 648 kWh and a range of over 300 km, which will be on par with the battery size a long-haul truck will need and the range it must manage. Many hydrogen buses have been developed and tested in different cities in Europe. Thus, there are no technical barriers to making long-haul BE-Trucks or hydrogen powered trucks, although there can be challenges related to reduced cargo volume or weight with battery electric propulsion.

The truck market involves a high degree of tailoring. The truck manufacturers supply the chassis, which is then equipped with bodywork and often has to be supplied with power or energy from the chassis to operate mounted equipment. The bodywork must therefore also be electrified as part of a large-scale truck electrification.

6.6.4 Buses

The bus market has come much further than the truck market in terms of electrification. All leading suppliers offer battery-electric city buses of 12 meters in length. Most also offer battery electric articulated buses. At least one supplier can now offer Class 2 battery electric buses, and two suppliers offer battery electric coaches with a range of 200-300 km. One supplier supplies battery electric BRT (Bus Rapid Transit, ala tram) systems in 18 and 24 meter lengths. The buses are offered in different battery and charging configurations so that the buses can be adapted to local conditions in terms of range and time available for charging.

There are three suppliers of standard 12-meter hydrogen buses and one supplier of hydrogen articulated buses.

Given the strict requirements for the public procurement of buses in the EU (see Chapter 12), the trend will continue towards a complete supply of battery electric city buses of all sizes and configurations, and from all suppliers moving towards 2025. Battery electric buses will dominate for urban use while hydrogen can have opportunities in the long-distance segment.

The EU requirements for public procurement will probably be incorporated into the EEA agreement (which regulates trade between the EU and Norway) and will have an effect in Norway as well. Countries with similar climatic conditions as Norway, i.e. Sweden and Finland, will anyhow be subject to the EU requirements so buses that can withstand the Norwegian climate will be developed. Thus, there are no restrictions in relation to the availability of battery-electric bus models that can create problems for reaching the 2025 goal of selling only zero-emission city buses in Norway. It is however conceivable that the EU requirements for public procurement can create production capacity challenges so that there may be long delivery times in the latter part of the period to 2025.

7 Charging infrastructure

7.1 Charging infrastructure for passenger cars owned by consumers

Home charging

Home charging can take place via a regular outlet, which is not allowed as a permanent solution according to new regulations, or by mounting a wall mounted charging box (EVSE) that connects the vehicle to the building's electrical installation in a safe manner. Most Norwegian households have enough power to be able to install a charging box that allows 3.6 kW of charge, while most newer houses can handle 7-11 kW (Figenbaum 2018a).

When many chargers are to be installed in housing units for residential blocks, this may require upgrading of the electrical system in the block and possibly also the local power grid to cope with the extra load. This may result in high costs, but there are systems designed to control the power of each charger such that the available power of the building is distributed between the chargers that are in use at any point in time.

In Norway, the possibility of home charging is considered one of the greatest advantages of the BEV (Figenbaum and Kolbenstvedt 2016). Around 75 per cent of Norwegian households can establish an electric vehicle charger in their own garage/parking space, while a further 12-13 per cent have private parking within 100 meters of the home (Hjorthol et al., 2014), and will probably be able to establish a charging option. In other countries, where a small proportion of households have access to private parking on their own land, lack of public charging infrastructure will be a barrier to the purchase of BEVs.

Normal public charging

Until 2010, most publicly installed normal chargers were equipped with Schuko domestic type connectors (Figenbaum, 2018a). Today's normal charging points are now equipped with the more robust type 2 connectors, that also enable faster charging. The use of Schuko connectors is no longer legal in public charging stations due to the danger of overloading over time. All the BEVs from the best-known vehicle manufacturers sold after 2010 can use the type 2 charging standard for normal charging, and most are delivered with a cable that can be used to charge at these charging points.

Fast charging

The average BEV user in Norway uses fast chargers around 13-19 times during the year (Figenbaum and Kolbenstvedt, 2016; Figenbaum, 2019a, 2019b). Fast charging is an important safety net in everyday life. In fact, the most widely used fast chargers are in the cities (Figenbaum 2019b), which are now considered a commercial market. Further development in the cities is slowed by the lack of land to put the chargers on (Figenbaum, 2018a). The first gas stations have replaced fuel pumps with fast chargers (Elbil.no, 2019b). There are tendencies of charging queues (Figenbaum 2019b, Figenbaum and Nordbakke 2019) in several places in the country, both in daily traffic and on trips to other municipalities and on longer trips. Different vehicle models use different types of charging cables when charging. Therefore, most fast-charge stations have multi-standard/multiplug chargers that allow for the use of different types of cables. With support from ENOVA, a network of fast chargers has been put in place along the main roads in Norway (Figenbaum, 2018a). Some charging stations now offer ultra-fast charging with a power of 150 kW, and eventually 350 kW. Not all BEVs can take this high-power during charging, but several of the new cars on the market can do so (see Chapter 6).

Statistics on charging infrastructure in different countries

The European Alternative Fuels Observatory (EAFO) has statistics on infrastructure and vehicles powered by alternative fuels. EU and EFTA countries must submit statistics from their country annually. Table 7.1 provides an overview of some of the EAFO data. The data contains some uncertainty, especially regarding the number of charging points. Here, there have previously been double counts, which arose because a charging point could have two contacts (CHAdeMO and CCS). Given that only one of the contacts can be used at a time, this should be registered as one charging point, and not two. This error source should be corrected for fast chargers, but error counts may be left behind in the national statistics.

At the end of 2019, there were hundreds of thousands of publicly available charging points for BEVs around the world, see Table 7.1. In the EU, there were around 165,000 charging points, most of them in the Netherlands, Germany and France. In December 2019, Norway had 12,700 publicly available charging points. The score for fast chargers per 100 km motorway is not an accurate measurement of the availability of fast chargers along motorways, as it is merely the number of fast chargers in the country divided by the length of the motorway network, and as such a weak indicator. A better indicator would be vehicles per fast charger.

Table 7.1: Overview of publicly available charging points in different countries, Europe 31.12.2019 2019. Source: eafo.eu. (EAFO 2020)

	Number of charging points	Normal charging points	Fast[a] chargers	Vehicles[b] per charging point	Fast chargers per 100 km motorway
Norway	12,699	10,337	2,362[c]	30	452
Sweden	5,066	4,036	1030	23	48
Denmark	2,707	2,244	463	9	35
Finland	1,280	831	449	15	50
Netherlands	50,592	49,520	1072	4	35
Austria	4,336	3,742	594	9	34
Germany	40,272	34,203	6,069	7	47
France	29,701	27,661	2,040	8	18
EU	165,064	148,008	17,056	7	23
USA[d]	60,652				
China	466,101				
Japan[d]	27,000[e]	19,750	7,250		

[a] Fast charger, is defined as charger with> 22 kW charging power. [b] This includes both BEV and PHEV. [C] data from: Nobil 2020.

[d] Bloomberg 2019, October 2019 figures for China and June 15, 2019 for the United States. [e] InsideEVs 2018.

Tesla has developed its own network of superchargers, which are only available to Tesla owners. There were in January 2020 around 4,700 Tesla Supercharger charging points in 500 locations in Europe (Avondu 2020), of which 770 charging points (Nobil 2020) were located in Norway. They charge at a power of 120 kW, but the power is reduced to 60 kW if two cars are simultaneously charging from the same charger (Figenbaum, 2018a).

Access to public charging infrastructure in Norway

In Norway, data from Nobil (Nobil 2020) shows a slight deviation from the EAFO data. There are 18 BEVs per publicly available charging point (SSB, 2019b), or 25 cars per charging point if plug in hybrids are also included, see Table 7.2. There are major municipal differences in access to public charging, for example, Hamar and Sarpsborg have around 10 BEVs per charging point, while Sandnes has 68 BEVs per charging point (SSB, 2019b). In 149 Norwegian municipalities there is not a single fast charger (NRK, 2019).

At the end of December 2019, there were 13,734 publicly available charging points in Norway, see Table 7.2. Of this, around 1,600 were fast chargers, and 770 were Tesla superchargers.

Table 7.2: Overview of publicly available chargers in Norway. Overview as of November 2019. Source: NOBIL 2020.

	Quantity	Specification
Charging stations, total	2,651	Number of locations with chargers
Charging points, total	13,734	Publicly available, regardless of type (15,128 (incl. non public)
Normal charging up to 22 kW	4,431 6,940 1	Schuko AC type 2 CHAdeMO
Fast charging	1,487 1,592 51	CHAdeMO* Combo/CCS* AC type 2
Tesla superchargers	770	

* Most are dual standard CHAdeMO and CCS chargers, the number of physical chargers is demed approximately equal to the number of CHAdeMO chargers.

However, charging access is significantly better than these numbers indicate. More than 40 percent of BEV owners charge from a type 2 connector wallbox at home (Figenbaum and Nordbakke, 2019), which means that over 100,000 of these wall boxes have been installed in Norwegian households. All electric vehicles sold in Norway are still equipped with a Schukoplug charging cable. This charging cable allows charging when needed from electrical outlets mounted outdoors and in garages and parking facilities throughout Norway, but it is not meant for permanent use (as this is impermissible).

7.2 Charging of heavy vehicles

There are several different technological solutions for fast charging heavier vehicles, these can be:

- Conductive charging with plug
- Pantograph (movable arm that is lifted up to the charging rail or down to the bus)
- Induction (stationary and for moving vehicles)
- Electric road (either by overhanging cables or by installing a live rail in the roadway)
- Battery replacement

These solutions vary widely in cost and technological maturity. The major manufacturers of heavy vehicle charging infrastructure are: ABB, Siemens, Heliox, Proterra, Schunk and Bombardier

Electric buses are charged in several ways. Charging in the depot can be carried out when the buses are not in operation, with different charging effect. Depots with many buses are demanding for the local power grid, and reinforcement of the grid may be necessary. It is possible to install a system with smart charge management to reduce the load on the local power grid and reduce the power costs. The buses can also be recharged at the end stops, or at stops along the way when the route allows it with pantograph or inductive charging (under development). According to the International Energy Agency (IEA 2019a), there were around 157,000 fast chargers for electric buses in the world in 2018 (it is somewhat uncertain whether all of these have an output of 50 kW or higher).

7.3 National strategies - charging infrastructure deployment

The EU aims for European countries to implement a minimum of infrastructure enabling the use of vehicles with alternative fuels. In the case of electric vehicle infrastructure, a minimum of one charging point per 10 vehicles is recommended in 2020 (EC 2019). The European Commission also recommends that there be at least one fast charger per 60 kilometers of the TEN-T network by 2025 (Transport and Environment, 2018).

According to EU Directive (2014/94/EU) [6], all EU and EEA countries are required to develop national targets for how the infrastructure for alternative fuel vehicles will be expanded in the years leading up to 2020 and 2025. The infrastructure must also meet specific European requirements. The aim is to develop a minimum level of infrastructure in all EU countries, as well as to achieve a cross-border continuity of infrastructure. EU countries were supposed to report their targets and instruments by the end of 2016. The national strategy papers (National Policy Frameworks - NPFs) should have, amongst other things, included (EC, 2019):

- National targets for the number of publicly available charging points which are sufficient for electric vehicles to circulate in urban/metropolitan areas *by* December 2020.
- What measures were going to be used to achieve these targets.

Ideally, the targets should have been adjusted to at least one charging point per tenth BEV. Table 7.3 gives an overview of the number of chargers and the target for the number of vehicles in 2020.

Table 7.3: Reported national targets for development of charging infrastructure and filling stations based on the requirements of EU Directive 2014/94 EU, selected EU countries. Source: EC, 2019.

	Vehicle	Electric charging infrastructure		Achievement
	target 2020 (2017)	2017	2020	2017 vs 2020 (%)
Sweden	(34,633)	2,854		
Denmark	30,621 (10,228)	2,540	3,000	85
Finland	22,000 (3,436)	971	2,000	49
Netherlands	140,000 (115,502)	10,000-29,000[b]	17,844	58
Austria	64-175,000 (13,338)	2,486	3,500-4,700	53-71
Germany	1,000,000 (87,914)	18,078	43,000	42
France	960,000 (118,663)	16,081	35,000	46

[a] in 2030. [b]10 000 charging points reported in NPF, while 29,000 were reported to EAFO the same year. [c]Goal for 2020.

[6] Directive on the deployment of alternative fuels infrastructure

The European Commission has prepared an evaluation report (EC, 2019) based on the various countries' NPF reports. The national overviews below (except for Norway) are based on the text of this document.

Sweden

The Swedish plan is criticized for only describing some of the imposed requirements in accordance with Directive 2014/94/EU. Sweden had not stated future targets for the number of vehicles or infrastructure, which is contrary to the main purpose of the Directive.

The plan contains a relatively comprehensive overview of instruments and measures, which seem reasonable. However, it is difficult for the Commission to assess how appropriate these instruments will be when no targets are set for the future development of vehicles or infrastructure.

Denmark

The targets for the development of infrastructure in Denmark appear to consistent with the expected development in the number of electric vehicles. If the plans are followed, Denmark will have an infrastructure coverage of 10 vehicles per charging point in 2020, which is consistent with the EU's recommendations. Denmark estimates that the share of electric vehicles in the fleet will not exceed 1.0 per cent by 2020. The Danish Government is focusing on market-driven growth of infrastructure, and has limited financial support schemes.

The plan largely describes today's instruments and measures, and considers possible future instruments only to a small extent. The supporting measures mentioned in the plan are considered to have a limited effect on reducing market barriers. The plan does not contain information on cooperation with other countries.

Finland

The Finnish NPF meets the requirements imposed by Directive 2014/94/EU. In 2017, Finland had a high number of charging points relative to vehicles. The planned expansion of the infrastructure (11 vehicles per charging point in 2020) and its location seem satisfactory in relation to the expected growth in the number of electric vehicles. In 2017, there were 22 electric buses in Finland, which had been tested in four urban areas.

The Finnish plan contains a comprehensive overview of instruments, most of which were already in use. The instruments in the plan are considered to be of medium importance for the decisions of the market players. The plan also includes a number of measures aimed at bus infrastructure. Finland cooperates with other EU countries in certain areas of infrastructure planning.

Netherlands

The Dutch plan sets a target of a share of 1.5 per cent of BEVs in the fleet in 2020, which seems little ambitious compared to 2017 (in which there was a 1.0 per cent share of BEVs in the total fleet). In 2017, the Netherlands had a relatively well-developed network of charging infrastructure. The target figure for charging infrastructure in 2020 will correspond to 8 electric vehicles per charging point, which is considered well planned. The charging points in the Netherlands have a good national spread, and the focus on developing charging points for fast charging along the main transport corridors seems to satisfy future needs.

The Dutch plan contains a balanced overview of instruments and measures. The expected measures are believed to be effective in achieving the plan's goals. The Netherlands is actively collaborating with other EU countries in terms of infrastructure planning.

Austria

Austria's NPF reporting contained all the target figures they were obliged to provide. Austria has a target of achieving a fleet share of more than 1.3 per cent for electric vehicles in 2020, which is ambitious compared to a level of 0.3 per cent in 2017. In 2017, the country already had a relatively well-developed network of charging infrastructure. Austria already had several electric buses, which are partly charged via overhanging cables. The charging infrastructure network seems to meet the need in 2017, but if one reaches the target figures for the number of vehicles for 2020, the targets for infrastructure will correspond to 18-37 vehicles per charging point. Inadequate charging infrastructure can thus become a barrier to further sales of electric vehicles. It is important that the sales figures for electric vehicles are carefully monitored so that the charging infrastructure is better adapted to future needs.

The plan also contains a comprehensive list of instruments, most of which have already been implemented. Several of the instruments are considered to be of medium importance for the decisions of the market players. The plan also includes measures to promote the emergence of infrastructure for electric buses. Austria is actively working with other EU countries with regard to infrastructure planning.

Germany

Germany has an ambitious target of 1,000,000 electric vehicles by the end of 2020, equivalent to a fleet share of around 2 percent. Infrastructure coverage is sufficient to meet needs in 2017, but the target figures for 2020 will correspond to a coverage of 23 vehicles per charging point. This can be a barrier to further market development. The development of charging infrastructure should be monitored and better adapted to the development in the number of electric vehicles.

The German plan contains a comprehensive list of instruments. Most of them are considered to be of little or medium importance to market participants' decisions. Some of the instruments received a low score, as they were, in part, inadequately described or the investments allocated were not in proportion to the level of ambition. But the proposed measures seem sufficient to achieve the goals set out in the NPF. The plan also includes several supporting measures aimed at infrastructure for electric buses. Germany is actively cooperating with other EU countries in infrastructure planning.

France

The focus of the French plan is mainly on electric vehicles. France has a target of 960,000 electric vehicles by the end of 2020, which corresponds to a total vehicle fleet share of around 1.6 per cent for BEVs. Based on the targets for growth in the number of vehicles, the target for infrastructure in 2020 will not meet the need. Should the targets be met, this will mean that there are 27 charging points per electric vehicle, which is considered deficient in relation to the need. The requirement for at least one charging point per 60 kilometers of the TEN-T network seems to be covered.

The plan contains a number of instruments, most of which have already been implemented. France is praised for the description of the measures designed to promote electric vehicles and infrastructure. The country cooperates actively with other EU countries in facilitating the use of vehicles with alternative fuels across national borders.

Norway

At the end of 2019, there were around 260,000 electric vehicles in Norway, which accounted for around 9.3 per cent of the fleet (Figenbaum et al.2019). Norway has around 13,500 publicly available charging points. This corresponds to around 18 vehicles (BEV) per charging point. These are more vehicles per charging point than what the EU recommends, but on the other hand, unlike in many other countries, a high proportion of Norwegian households have access to home charging.

The ministries (Departementene 2019) have drawn up an action plan for infrastructure. It describes the current situation, as well as measures and methods that can promote the implementation of vehicles with alternative fuels. Norway is working, among other things, on implementing Directive 2014/94/EU's requirements for the technical standard of infrastructure into Norwegian law. Work is also underway to amend the law for apartments organized as co-ownerships («Eierseksjonsloven»), so that section owners may be allowed to establish their own charging points (Departementene, 2019). There has also been a proposal to set a ceiling for how high the additional costs of establishing charging points can be (1/2 G) before the board can say no to the section owners. The section owner shall pay for the installation of the charger itself.

In principle, the Government has a goal that the infrastructure development shall be market-driven and to the greatest extent possible without financial support (Departementene, 2019). Enova will be able to provide funding for various infrastructure projects, with particular focus on those projects that would not otherwise have been realized.

Today there are charging queues at several charging stations in Norway. Better user information on expected waiting times may reduce the problems somewhat (Departementene, 2019), but further development of the charging infrastructure in Norway is necessary.

The number of BE-LCVs is expected to increase, but it is assumed that they can utilize the existing network of public charging points (in addition to "home charging"). Norway already has a number of BE-buses, which use various technological solutions for charging. As the number of electric buses grows, it is important to establish national standards for charging solutions (Departementene, 2019). This is important in order to improve competition and interoperability (Departementene, 2019). The infrastructure can then be built and operated independently of the bus operator and can be used regardless of which bus operator wins the next tender round.

8 National characteristics

This chapter presents factors that can have an indirect impact on the proportion of electric vehicles that will be sold in a country.

8.1 Household economics

To compare the financial ability to buy a BEV across countries in Europe (which costs more than a regular car if there are no incentives available), the OECD's Monthly Comparative Price Levels statistics can be used. It shows that households in Switzerland, Norway and Iceland, and to some extent Denmark have higher purchasing power than households in other countries. Subsequently, a number of Western European countries follow, while countries in Eastern Europe have substantially lower purchasing power. Southern European countries lie between the Eastern and Western countries in purchasing power.

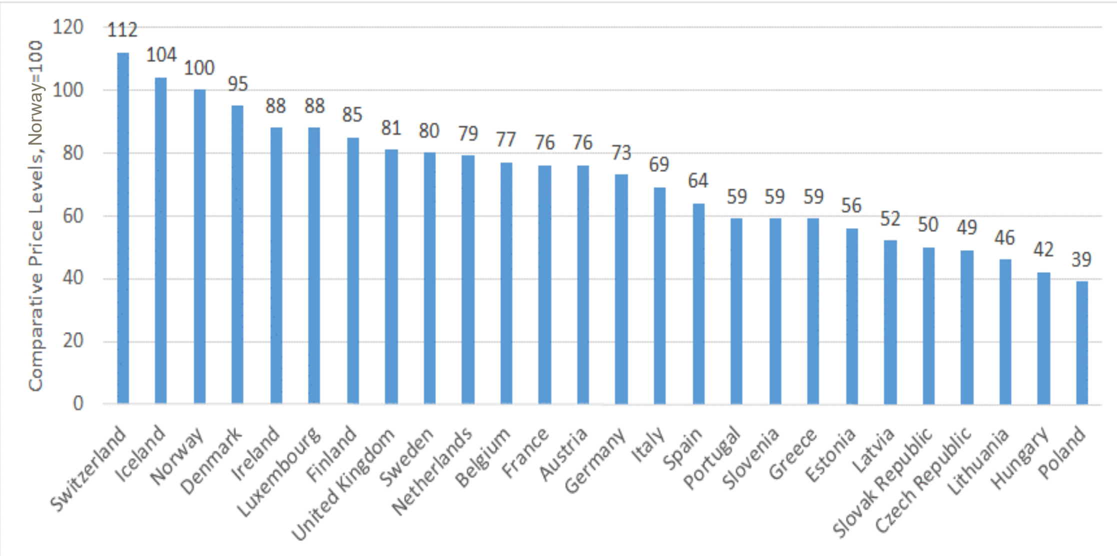

Figure 8.1: OECD Comparative Price Levels. Data for October 2019. Norway = 100. Source OECD (2019).

8.2 The fleet

In 2016, there were approx. 266 million passenger cars registered in Europe (EU28 + EFTA), as shown in Figure 8.2. The major car fleets in Europe are in Germany, Spain, France, Italy, Poland and the UK, but in the case of newer cars, Poland and Spain have smaller shares and the car-producing countries Germany, France and the UK have larger shares as shown in Figure 8.3.

With Brexit and right-hand drive cars, the UK is not the most relevant country for the BEV market in Europe. However, what happens in Germany, France, Italy and in part in

Spain will be essential, as these countries have over half of all cars in Europe, and over half of those that are 0-5 years old.

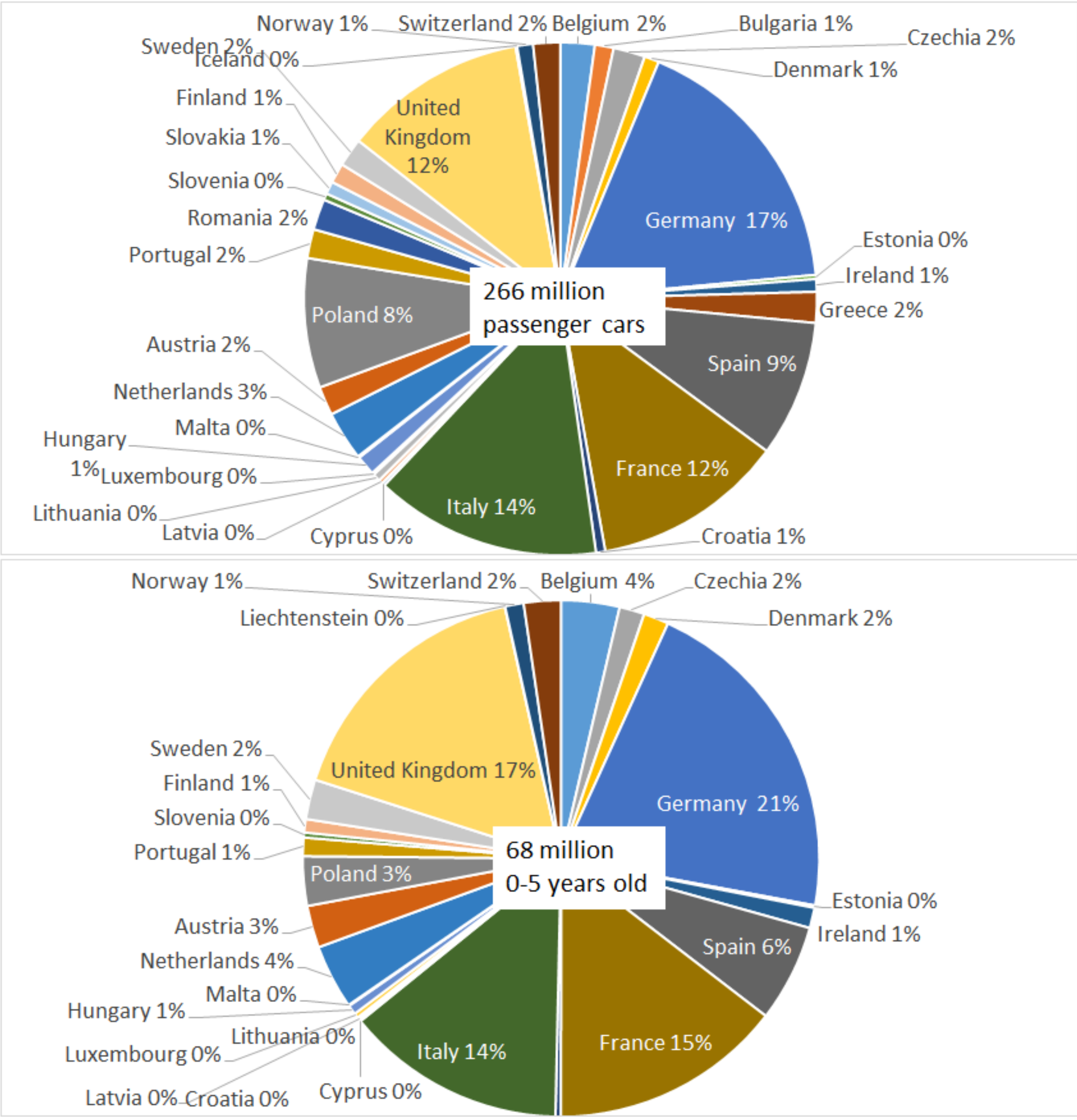

Figure 8.2: Passenger cars in Europe 2016, total distribution and cars that are 0-5 years old. Source: Eurostat (2019b) (excluding Iceland: Icelandmonitor).

The age of the car fleet in different countries is shown in Table 8.1. Here the Eastern and Southern European countries have the oldest cars in all vehicle categories.

Table 8.1: Average age of vehicles in different countries. Source: Acea (2019a).

	Passenger vehicles	Light commercial vehciles	Medium and Heavy trucks	Buses
Luxembourg	6.4	6.3	6.5	5.7
United Kingdom	8	7.8	7.4	9.8
Austria	8.2	6.5	4	5.4
Ireland	8.4	8.8	10.4	10.8
Switzerland	8.6	8	8.9	9.4
Denmark	8.8	8.4	10.3	10
Belgium	9	8.6	15.9	11.2
France	9	9.5	7.2	7.1
Germany	9.5	8	9.5	8.5
Sweden	9.9	8.6		6.7
Slovenia	10.1	9.1	8.9	8.3
Norway	10.5	9	12.2	9.6
Netherlands	10.6	9.5	9.1	9
Italy	11.3	12.4	14	12.5
Finland	12.1	12.7	13.8	11.6
Spain	12.4	12.8	14.4	10.8
Croatia	12.6	10.6	14.9	11.9
Portugal	12.9	14.3	13.8	14.3
Latvia	13.9	10.8	12.4	11.9
Poland	13.9	13.8	13.2	15.3
Slovakia	13.9	13.2	12.7	12.3
Hungary	14.2	12.6	12.6	13.3
Czech Republic	14.8	12.5	17	14.5
Greece	15.7	18.9	20.9	20
Romania	16.3	15.9	15.6	16.4
Estonia	16.7	15.5	18.2	13.9
Lithuania	16.9	11.9	11.6	
EU average	10.8	10.9	12.4	11.4

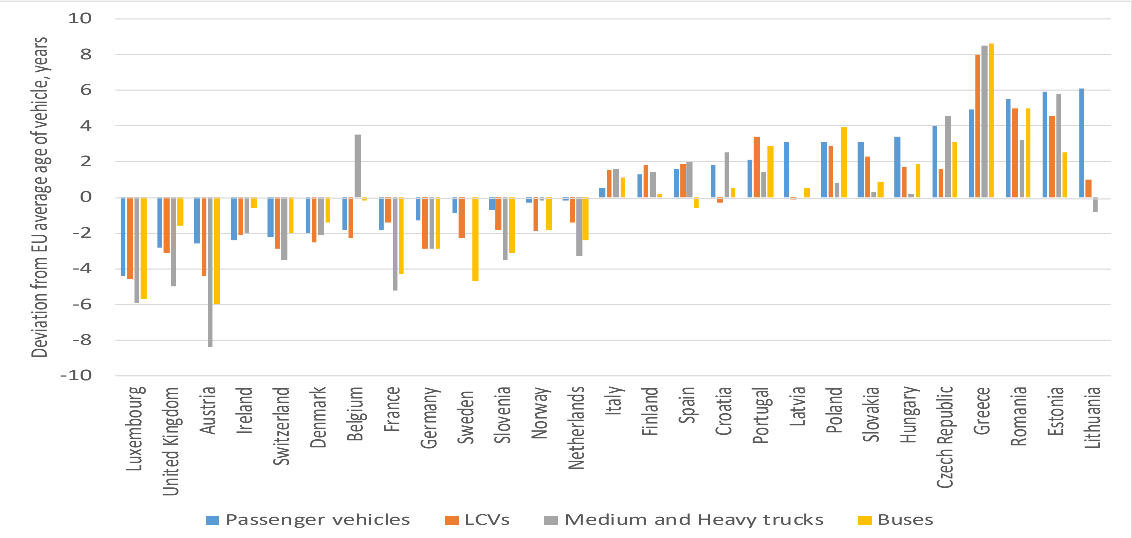

Figure 8.3: The number of years the average age of vehicles differs from the EU average age of vehicles. Source: ACEA (2019a) and own analysis.

8.3 Car parking and parking availability

In the COMPETT project, an overview was made of households' car ownership (zero cars, one car, several cars) and access to parking (Figenbaum and Kolbenstvedt, 2015). It is a few years old so the car ownership figures may have changed somewhat, but the trends will be the same as shown in Figure 8.4. The Eastern European countries have a relatively low proportion of multi-car households. There is also little information available about car owners' access to parking in those countries. At the other end of the scale, island nations (Iceland, Malta, Cyprus, Ireland) and Norway stand out as countries with a high proportion of multi-car households and a high proportion of households that own a car in general, and that have good parking access.

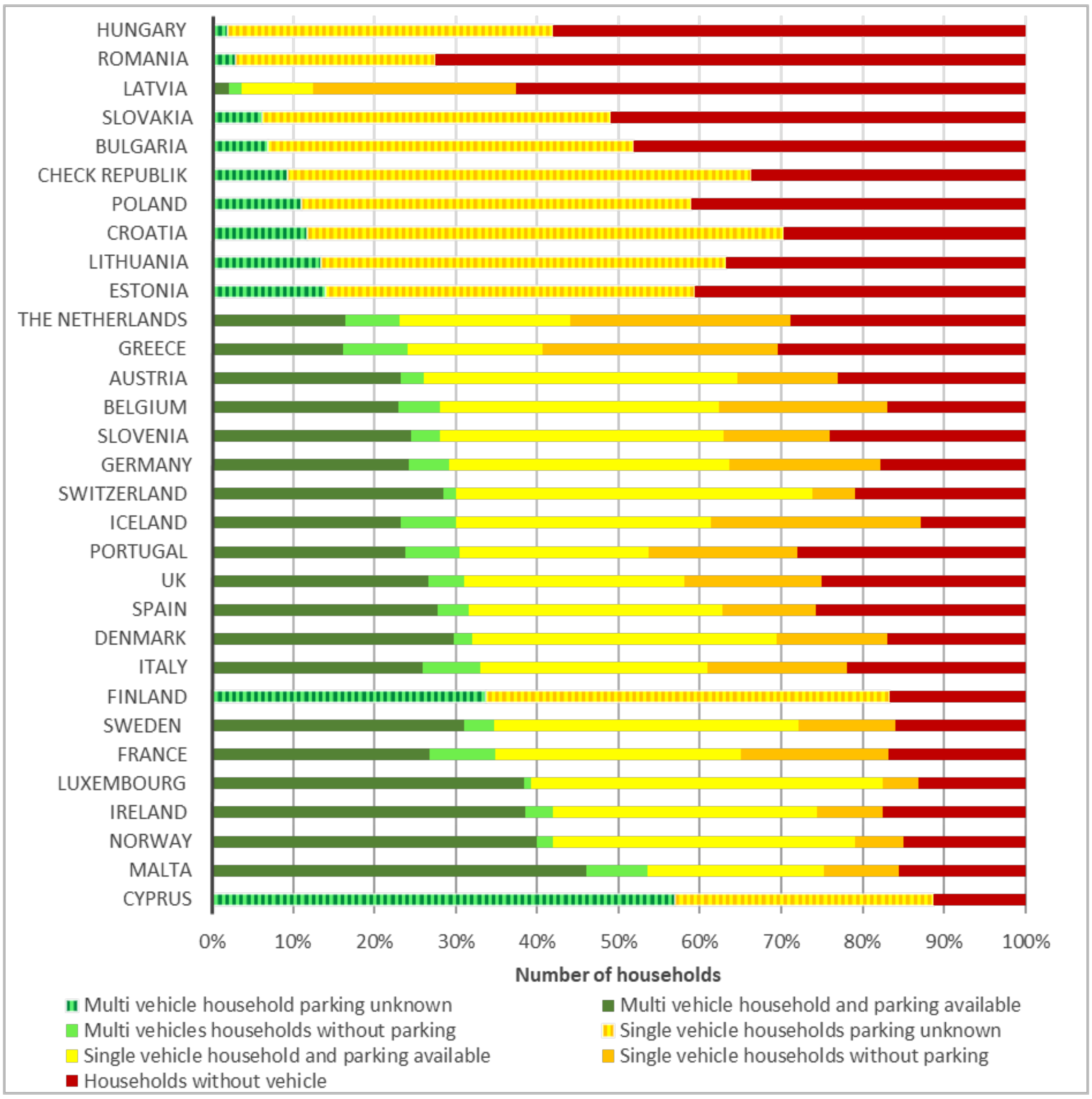

Figure 8.4: Car ownership and parking access in different countries. Source: Figenbaum and Kolbenstvedt (2015).

8.4 Carbon intensity in different countries' electricity production

Carbon intensity in electricity generation is lowest in Northern Europe and highest in some countries in Eastern and Southern Europe and some island states (Cyprus, Malta), otherwise the ranking is somewhat random, as shown in Figure 8.5.

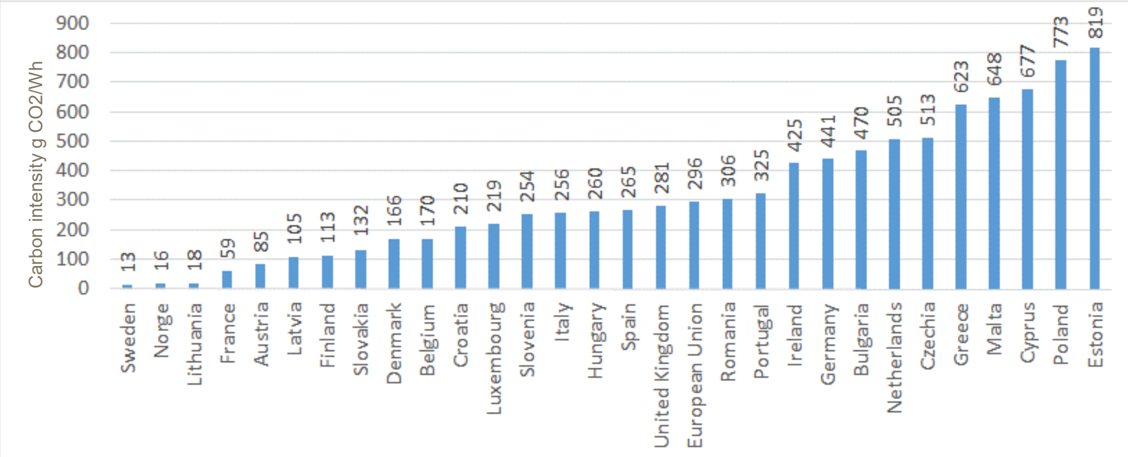

Figure 8.5: Carbon intensity in electricity generation in different countries, g CO_2/kWh. Source Eurostat (2019) and NVE (2019).

8.5 Energy prices

The energy prices are shown in Figure 8.6, together with a calculation of how much energy cost one can save by driving an BEV per year. Norway is the country in which you can save the most. In Germany, the savings are one third of that in Norway.

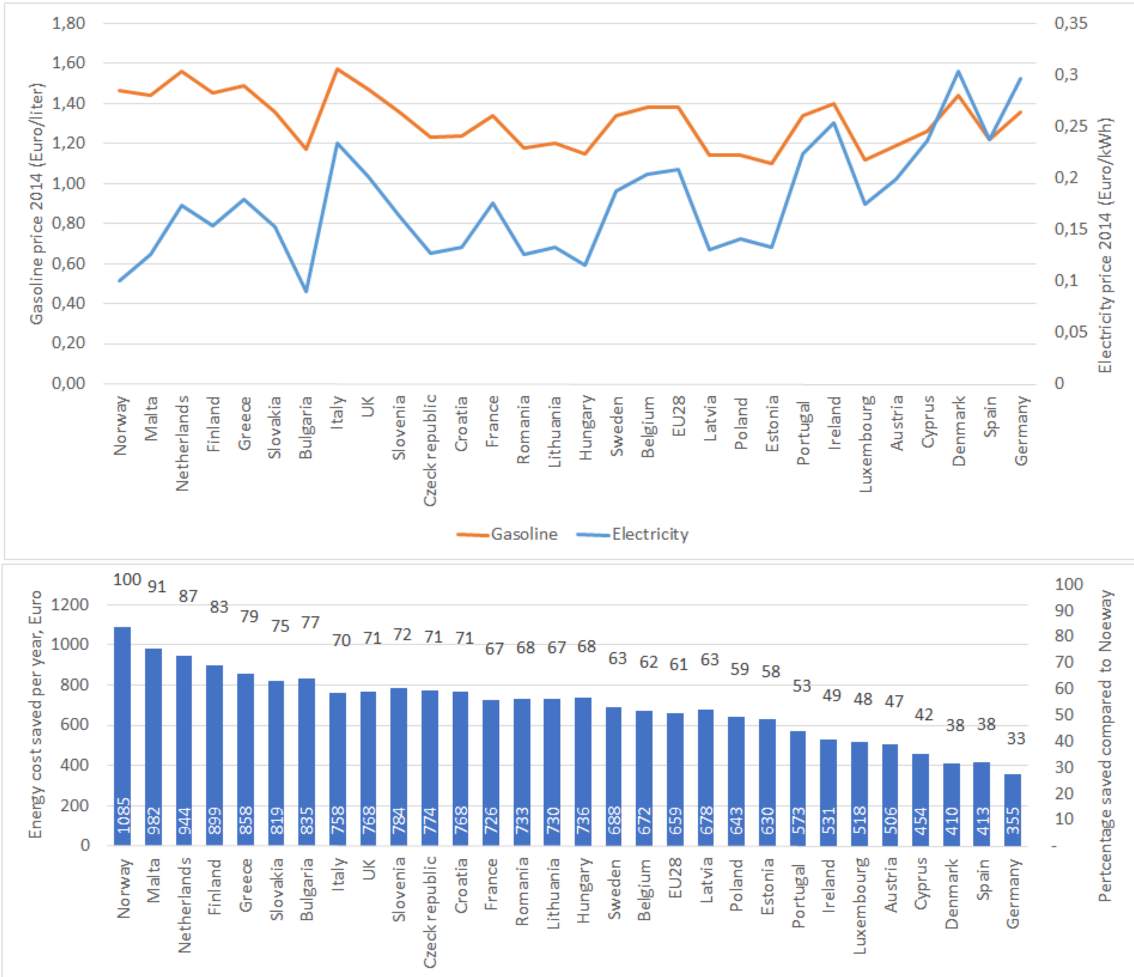

Figure 8.6: Energy prices (gasoline and electricity) in 2014 (top) and energy cost savings by driving an BEV compared to petrol car (bottom), assuming 16000 km/year 200 Wh/km and 0.06 liter/km. Source: Eurostat (2019c), Norwegian electricity price: Statistics Norway, own analysis.

8.6 Electricity consumption

There are no statistics on the power capacity of the grid connection of households in different countries, but the average annual electricity consumption in the household can be an indicator. A high annual electricity consumption would require a higher power grid connection than a low annual consumption would.

Household average electricity consumption is shown in Figure 8.7. Norway is not included in the figure, but with an average consumption of 16,000 kWh, it is far higher than all the other countries in Europe. In fact, Norway is one of the most electrified countries in the world. Sweden and Finland have a high average electricity consumption and Eastern and Southern European countries have a low consumption, while the rest are relatively low, as well.

It can be assumed that there might be particularly great challenges in establishing charging infrastructure in households in Southern and Eastern Europe, and that this is far more easily achieved in Norway, Sweden and Finland. There can be challenges in large parts of Europe where consumption is largely around 4,000 kWh/year.

The big difference here is that in Norway, Sweden and Finland, electricity is used for space heating and a strong connection to the power grid is therefore needed.

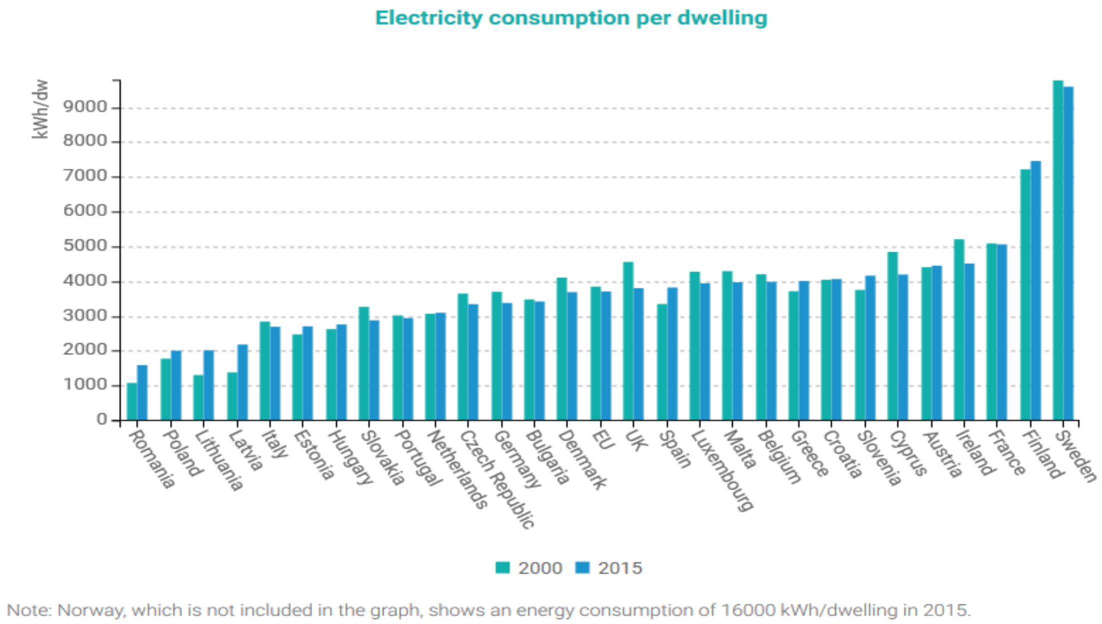

Figure 8.7: Average household electricity consumption kWh/year. Source: Odyssee-Mure (2019).

8.7 Climate

As shown in Figure 8.8, the climate is most stable in island states (Ireland, Iceland, UK), and in countries with a flat topography with a large coastline. The variation is greatest inland in Eastern Europe and in the Baltic, where they have cold winters and hot summers. For BEVs, mild winters and cool summers are the most optimal. Cold winters provide reduced range, while hot summers affect battery life negatively.

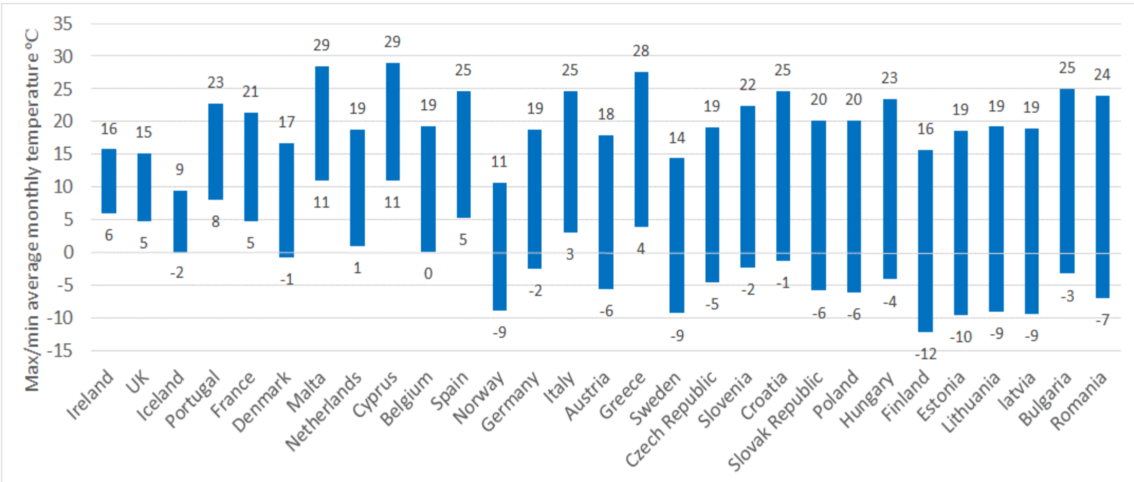

Figure 8.8: Climate variation. Variation between month with highest and lowest average temperature per country in 2012. Source: Statworld (2019), DMI (2019), and own analysis.

8.8 Motorway and highway speeds

Motorway and highway speeds are very important for the question of how far the BEVs can reach on one recharge on longer journeys. The variation between countries is limited but some countries have lower speed limits than others. Some Eastern and Southern European countries and Germany/France/Austria have higher motorway speed limits than most other countries have, as shown in Figure 8.9.

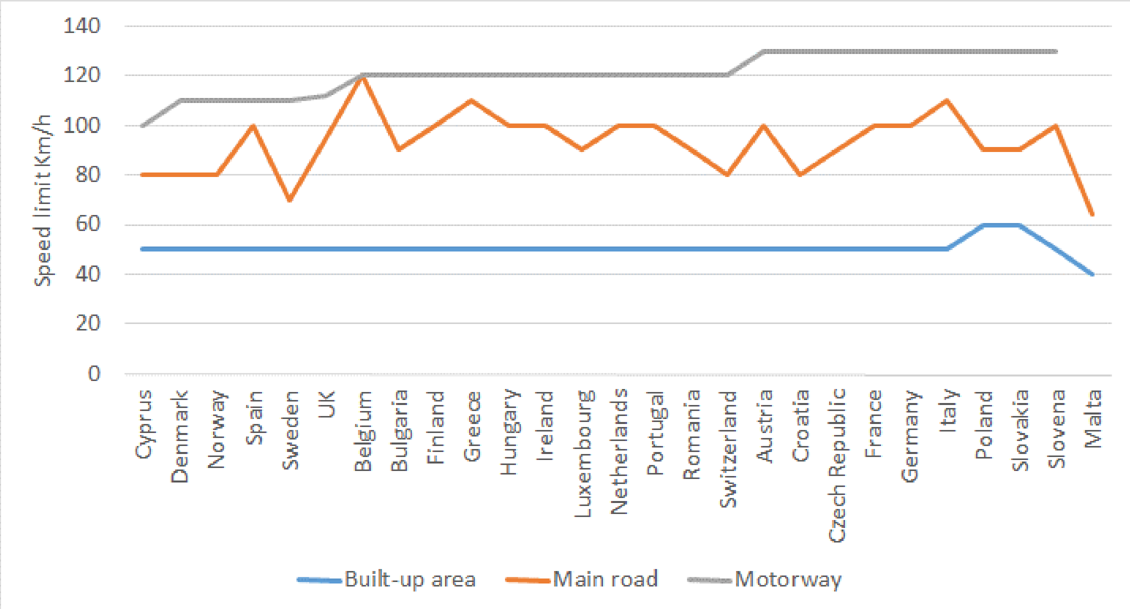

Figure 8.9: Speed limits by country.

8.9 Ranking of suitability for electrification

The data in this chapter indicates that the Nordic countries will be most suitable for market introduction of BEVs and will constitute the first wave in the market expansion of battery electric vehicles. Eastern European countries and the Baltic States are generally the least suitable for electrification and are likely to represent the latest wave in the market. Southern European countries will also lag somewhat behind Western European countries, which will constitute the second wave. The expected order in the market introduction will thus be the Nordic region, followed by Western Europe, Southern Europe and finally Eastern Europe and the Baltic region.

Nonetheless, some countries may have such a powerful policy that they can still establish the market earlier, despite being less suited to electrification in some areas than other countries.

9 Cost analysis

9.1 Cost calculations – Introduction and assumptions

9.1.1 Main calculation variations

In order to assess the competitiveness of zero-emission vehicles, it is necessary to calculate the annual total cost to the owner of owning and operating the vehicle ('total cost of ownership' or TCO), and compare it to the corresponding TCO of traditional gasoline and diesel cars. To carry out these calculations, the TØI-TCO model presented in Chapter 4 is used.

The model is used to perform the following five types of calculations for this report:

1. Breakdown of calculated purchase price with taxes in Norway for the period 2010-2030
2. Breakdown of calculated total annual cost of ownership with taxes in Norway for the period 2010-2030
3. Breakdown of annual socio-economic costs in Norway for the period 2010-2030
4. Cost-effectiveness of CO_2 emission reduction using a zero-emission vehicle
5. Calculated difference in total purchase price and total annual cost between electric vehicles and diesel vehicles for Norway and other countries.

The breakdown of costs and purchase prices are presented for the years 2019 and 2025, while the trend for the entire period 2010-2030 is shown for the total purchase price and the total annual cost of ownership (TCO). The calculation of the difference between the total purchase price and the total annual cost of ownership for BEVs, PHEV and FCEVs and a comparable diesel vehicle for Norway and other countries is presented for the period 2010-2030.

9.1.2 Vehicle types and characteristics

Calculations have been made for the following vehicle types and annual mileages (range is specified according to the WLTP test):

- Passenger cars:
  - Small (12000 km/y): El (250 km), gasoline, diesel
  - Compact (16000 km/y): BEV (150, 300, 400 km), gasoline, diesel, PHEV, FCEV
  - Medium (16000 km/y): BEV (400 km), gasoline, diesel, PHEV, FCEV
  - Large (18000 km/y): BEV (450 km), gasoline, diesel, PHEV, FCEV
  - Luxury (18000 km/y): BEV (500 km), gasoline, diesel, PHEV, FCEV
- LCVs:
  - Small (20000 km/y): Battery electric (200 km), diesel
  - Large (20000 km/y): Battery electric (200 km), diesel
- Trucks:
  - Tractor with trailer: Battery electric, hydrogen, diesel
  - Heavy distribution truck: Battery electric, hydrogen, diesel
  - Light distribution truck: Battery electric, hydrogen, diesel

- Buses:
    - City buses: Battery electric with different variants of depot charging, bus stop charging and solutions for heating, hydrogen, diesel
    - Regional buses and coaches: Not calculated, same technology as for trucks

There are vehicle models on the market with other ranges and characteristics, but the authors have selected these variants because they are considered typical for the segments.

In this chapter, all calculations are made with the assumption of a continuation of today's politics and incentives. That is, zero-emission vehicles are exempt from the one-off registration tax and VAT, while gasoline, diesel and PHEVs are subject to these taxes. The estimated average registration tax for the different car types and car sizes is shown in Table 9.1, based on the tax applied to typical 2019 models. It is assumed in the calculations that the taxes per car will be kept at this level in the future

Table 9.1: Estimated one-off tax based on typical 2019 models and 2019 percentage VAT. 2019 NOK, Percent. Source: Author's assessment based on the fee for typical models in each segment in 2019.

	Battery electric & Fuel cell hydrogen	Plug in hybrid	Gasoline	Diesel
VAT	0%	25%	25%	25%
Registration **tax cars**				
Small	0	Not calculated	50000	40000
Compact	0	0	70000	60000
Medium	0	0	100000	100000
Large	0	10000	150000	125000
Luxury	0	20000	250000	200000
Registration tax LCVs				
Small	0	Not calculated	Not calculated	25000
Large	0	Not calculated	Not calculated	100000
Average toll road fees for cars until 2019/from 2020	0/2600/year	5200/year	5200/year	5200/year

The cost of new technology is reduced as a result of increasing production volumes, innovation and competition in the market. The cost assumptions for batteries and hydrogen systems are based on the technology development presented in Chapter 5 (Figure 5.7 and Table 5.2, respectively), and the assumptions presented in Appendix 2 of Figenbaum et al. (2019).

The prices calculated are a typical price per size segment. Entrance models may seem to have a lower price, but with a few exttra features the real sales prices are higher. For passenger cars, it is assumed that BEVs are separate models, constructed from the beginning as BEVs. PHEVs are believed to be variants of gasoline car models. For LCVs, the BEVs are believed to be variants of the diesel versions.

The average CO_2 emissions of new gasoline and diesel cars are estimated to reduce to approx. 95 g/km in 2025 and remain constant until 2030, because it is assumed that after 2025 electrification will accelerate and become the preferred option for meeting the CO_2 requirements for new cars in the EU (see Chapter 11). This assumption does not influence the cost of BEVs, PHEVs or FCEVs, but it does influence the cost of ICEVs. The lower the CO_2-emission ICEVs achieve, the higher will their content of energy efficiency measures be, for instance will an increasing level of hybridization be required to reach lower CO_2-emissions.

9.2 Results – Passenger cars

9.2.1 Purchase price Norway

Figure 9.1 shows the estimated purchase price and taxes for small, compact, medium, large and luxury passenger cars with different drive systems. In 2019, small and compact BEVs cost roughly the same as gasoline and diesel cars, thanks to the fees imposed on the latter two types of vehicles. In the segments with larger cars, BEVs have a slightly lower price. Without fees, BEVs are a significantly more expensive alternative. The cost of hydrogen cars is far greater than all other car types (when taxes are not considered).

By 2025, BEVs will still be more expensive to produce (car prices without taxes), but will be the cheapest car in all the size segments when the taxes have been included in the price of the ICEV variants (including PHEVs). This is both because BEVs will become cheaper to produce and because gasoline and diesel cars will be more expensive to produce due to the technology needed to reduce CO_2 emissions. Hydrogen cars will have a more competitive purchase price, provided that the serial production that some suppliers have promised is realised and that they, like BEVs, remain exempt from the purchase taxes.

The purpose of the calculation is to compare the average purchase prices for the various technologies at a high level. Prices should therefore not be viewed as absolute differences, as they can vary considerably between cars of the same size, based on their car brand, what they have of comfort and safety equipment, and variations in engine and battery size.

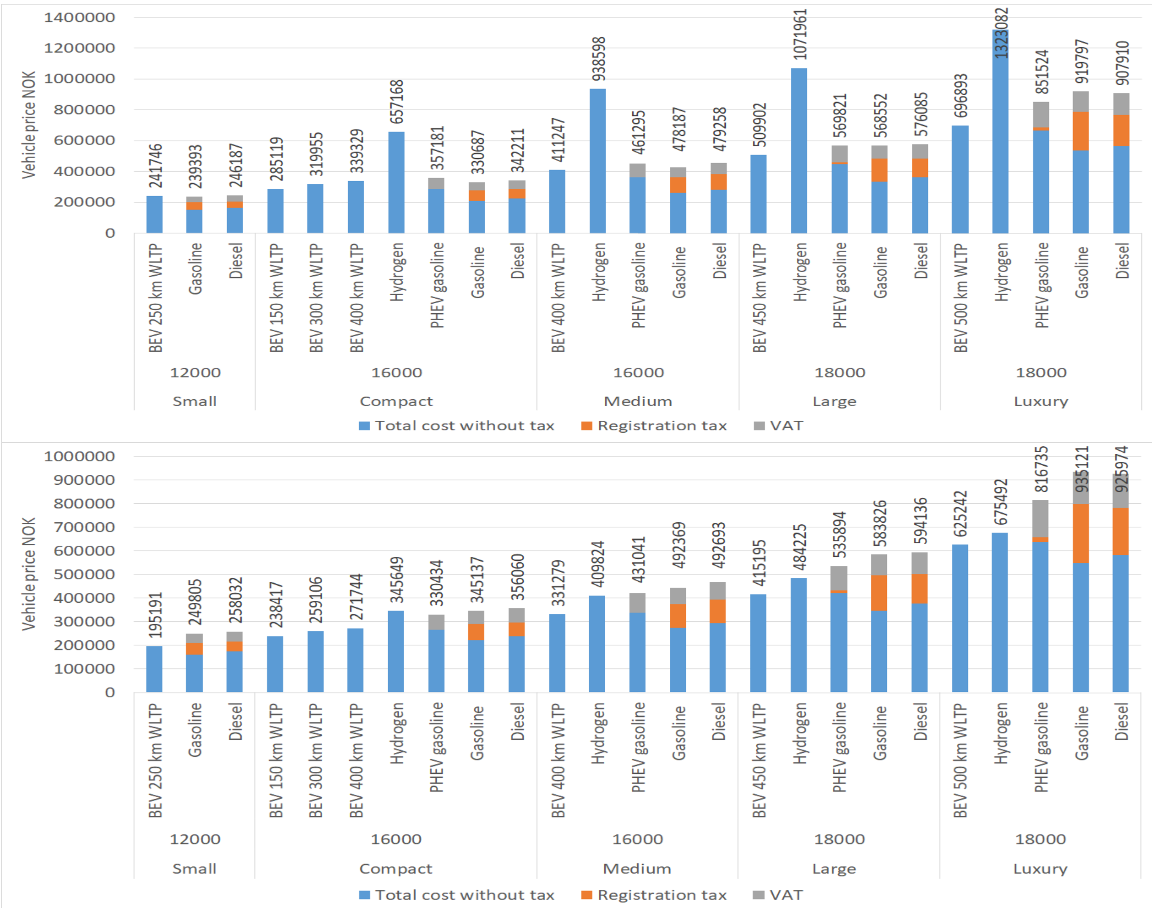

Figure 9.1: Estimated purchase prices and charges on cars in 2019 (top) and 2025 (bottom) for cars of different sizes and with different drive systems. BEV = Electric vehicle, PHEV = Plug in hybrid vehicle. NOK. Source: Own calculations with TØI-TCO.

Figure 9.2 shows how the purchase price (the price the consumer pays at the dealer) cost elements are distributed among different components and systems in a BEV in 2019 and a corresponding gasoline car and a BEV in 2025. The glider[7] is the biggest cost of all car types. After this, the taxes make up the largest part of the price of gasoline cars, while the battery makes up the largest part of the price for BEVs. By 2025, battery costs will have dropped significantly.

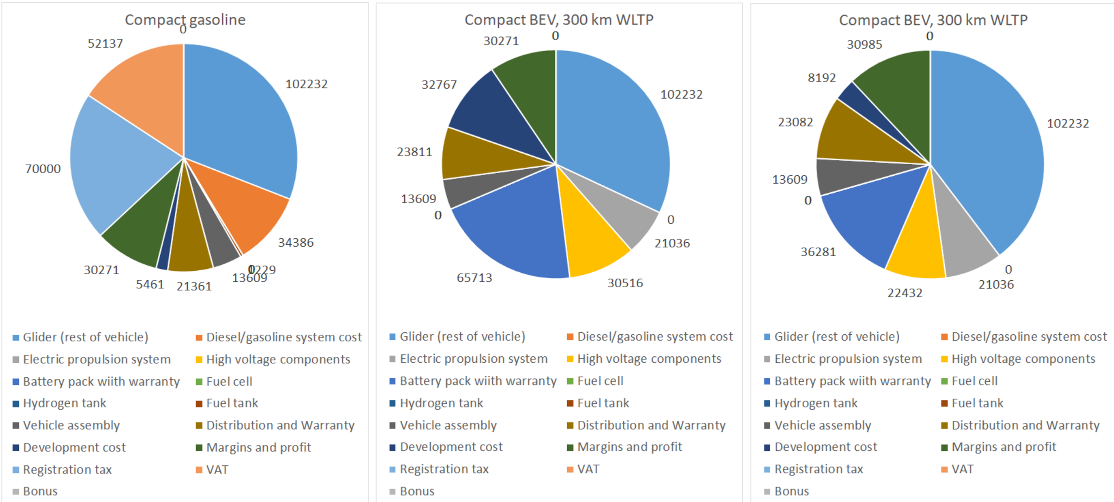

Figure 9.2: Decomposed purchase prices and charges for compact gasoline cars in 2019 (left), for compact BEVs with 300 km range in 2019 (middle) and in 2025 (right). BEV = Electric vehicle. NOK. Source: Own calculations with TØI-TCO.

Figure 9.3 shows the development in total purchase price with taxes between 2010 and 2030 for a compact car. Taxes are as described in Table 9.1. Comparing the purchase prices (shown in Figure 9.4 together with the model results), one can see that BEVs have not been particularly profitable to car manufacturers until approx. 2017-2019, if there have not been incentives available as the cost have been higher than for the diesel and gasoline versions. This is mainly due to the high battery costs from 2010 to approx. 2015 according to data from Bloomberg NEF (Chapter 5). The manufacturers that have produced BEVs in larger volumes, such as Tesla, have probably had lower than average battery prices. The massive cost decrease calculated for the hydrogen vehicle from 2021 is due to the anticipated start of real serial production in volumes of at least 30,000 vehicles per year. Up to 2021 hydrogen vehicles are made in small volumes (up to a few thousand per year) at high cost.

[7] Glider is the vehicle without the propulsion system components, i.e. body-in-white, lights, seats, wheels and tyres, windows, brakes etc.

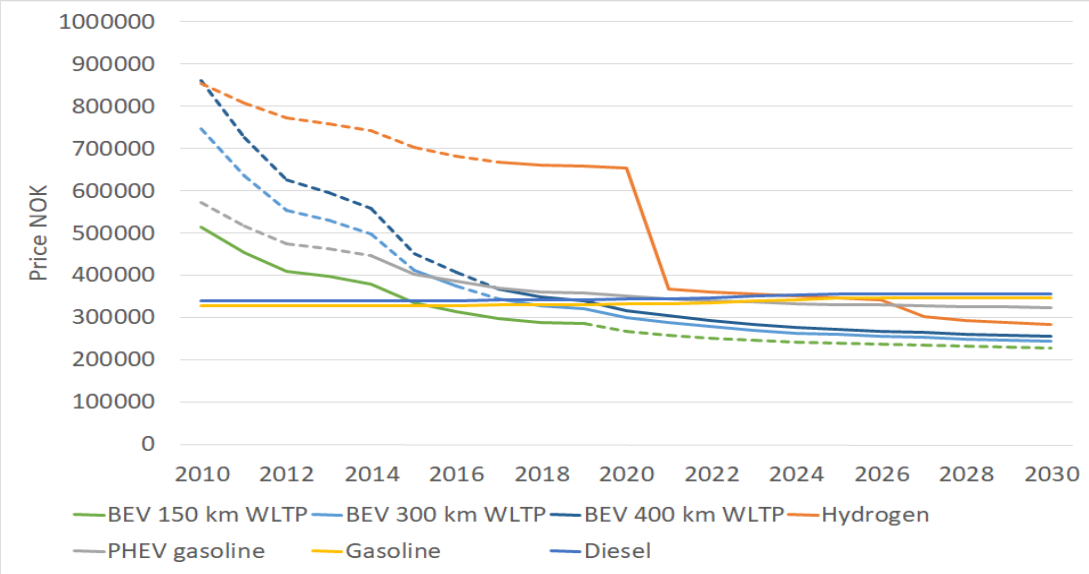

Figure 9.3: Developments in the calculated average purchase price for compact cars between 2010 and 2030. BEV = Electric vehicle, PHEV = Plug in hybrid vehicle, NOK. Source: Own calculations with TØI-TCO.

The model shows that the average compact car with a relatively small battery became cheaper than gasoline cars around 2015-2016, while the real prices on the market show that this already happened for some models from around 2013. This may be because these manufacturers had lower battery costs than average. The prices on the market might also be based on costs other than the production cost, for instance a desire to sell a specific number of vehicles. If the requirement is only that the car manufacturer's variable costs be covered (development costs and profit are then not included), the BEVs will be competitive in terms of price compared to taxed petrol and diesel cars about one year earlier on average than what is shown in Figure 10.3. The figure shows that the larger the battery, the longer it took before the BEVs became competitive in terms of price. In 2019, the BEVs with the largest batteries also became cheaper than diesel cars. For 2020, the model shows that giving an BEV with 400 km range 100 km extra range (about 15 kWh larger battery), only has a cost of about 1800-2250 US$. This means that the BEV with a 15 kWh larger battery will be cheaper than diesel cars about a year later.

FCEVs are produced at high costs in small series until 2021, after which a slightly larger production with up to 30000 cars/year starts at Toyota and Hyundai, which will lead to a significant drop in the expected sales price. If there is full-scale serial production in the next model edition of these vehicles, likely around 2027 (as included in the calculations, based on cost estimates from the US DOE), this type of car may also become cheaper than gasoline and diesel cars if current policies, taxes and incentives are continued.

It may seem that the TCO-model falls short in terms of describing the costs up to approx. 2015, but this is not necessarily the case. Most of the extra cost calculated is due to the fact that the average battery prices were very high, as shown in Chapter 5, and that the cars were produced in small volumes. Small volumes mean that development costs and modifications in factories and production lines are shared across relatively few cars. The period up to 2015 was also characterized by the fact that the availability of BEVs on the market was limited by the car manufacturers. One exception was Nissan. The factories where the Leaf is built were partly set up with loans and grants from the UK and US authorities, and the batteries were manufactured at a factory owned by Nissan (Figenbaum 2017). In Tesla's case, the use of standard batteries has probably led to far lower battery prices than average. Both of these manufacturers have thus been able to sell BEVs at lower costs than other manufacturers. By setting up a dedicated battery factory, Nissan first received significant public support, and secondly, they were able to choose how much of the battery development and production plant costs would be added to the sales price of the car. Nissan's own costs and investments will however not disappear. They simply become a loss provision in the accounts if the car sales price does not cover the entire cost.

The model presents the price developments as continuous. In fact, manufacturers will adjust prices in steps that can last for up to three years until an upgraded or a new model replaces the existing one. This is because car buyers will feel cheated if the prices for an identical model go down significantly within for instance a year after they bought their car. At the start of the 2011 market expansion, this was precisely the case with Mitsubishi I-Miev and the two Peugeot and Citroën twins (Figenbaum and Kolbenstvedt 2015), as shown in Figure 10.4. Some have solved this by running large discount campaigns to hide the downward price adjustments. Towards the end of a model's lifetime when a new model has been announced, it is common to lower prices on the outgoing model significantly and include more standard equipment in the price.

Finding the right price on the BEV market is thus a challenge for car manufacturers and importers when the developments happen so quickly, thus, it becomes difficult to estimate exactly which year one type of car will be cheaper than another on the market.

Figure 9.4 shows that there is about to be a continuous range of BEVs in all price categories and all segments from 2019. Several models were launched in 2019 and even more will come in 2020-2021, so even more gaps in the supply of BEVs will be filled.

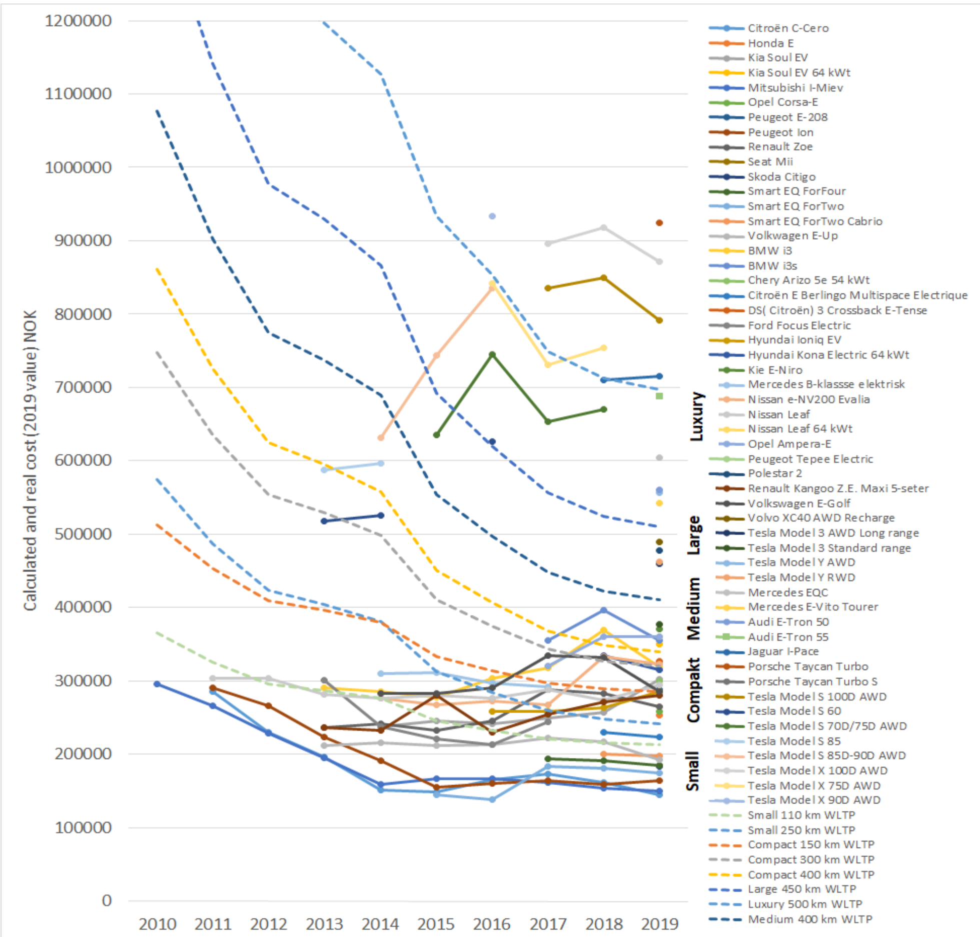

Figure 9.4: Calculated car prices against actual car prices. Dashed lines are the model's calculated cost. Whole lines are real market prices in 2019 (some of the 2019 models cannot be delivered until 2020). Source: Own calculations with TØI-TCO, and BEV prices from OFV (2019b).

Most BEVs that have been on the market for a long time, apart from the small ones, have been continuously upgraded. Cost reductions for batteries have mainly been used to increase the battery size and range, not to reduce the price, as shown in Figure 9.5.

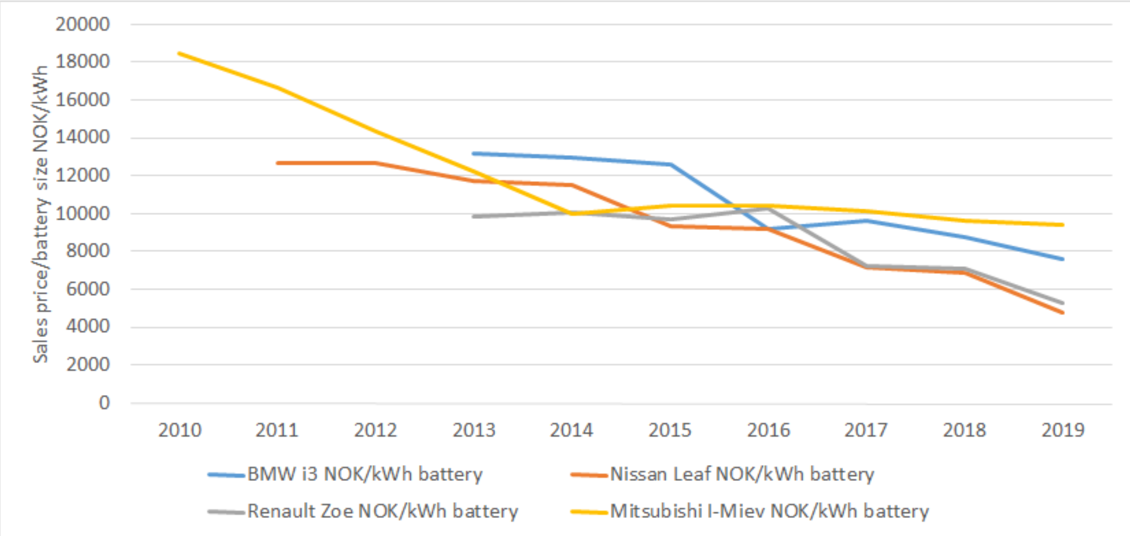

Figure 9.5: Trend in car price/kWh battery capacity for 4 BEVs. NOK/kWh. Source: Own calculations. Total annual costs of ownership Norway.

The total annual costs include depreciation of the car (including purchase fees) and all variable annual costs, including energy costs, energy taxes, VAT, insurance, tire wear, maintenance, fast charging costs (cost of use + cost of time), parking, toll fees, annual fees etc. It is assumed that the car is owned for 5 years and that the residual value is 47 percent of the new car price for all variants. The interest rate is set at 4 per cent. The results of the calculation are shown in Figure 9.6.

The calculations show that BEVs by far have the lowest annual cost in all size classes, and for all battery sizes in 2019. The cost advantage increases towards 2025. The larger the car, the greater the savings (in NOK) by choosing a BEV rather than a gasoline or diesel car. The savings increase between 2019 and 2025. There is so much to save on choosing a BEV that car buyers can choose to go up a size class and still get roughly the same annual cost as for gasoline or diesel cars.

The existing policy thus provides strong incentives to choose a BEV in 2019, and even more powerful ones in 2025. Hydrogen cars can also be competitive in comparison to gasoline and diesel cars in 2025, but nowhere near as favorable as the BEVs. This is mainly since electricity is an inexpensive energy carrier that is utilized very energy efficiently in a BEV, while hydrogen is assumed to be produced from electricity, which results in huge energy losses and added costs. The purchase price is low because the hydrogen cars are tax-free. PHEVs are expensive to produce compared to gasoline and diesel cars, but because they come out favorably from the one-off tax calculation, they end up having an annual cost roughly on a par with gasoline and diesel cars. Thus, they are not competitive with BEVs.

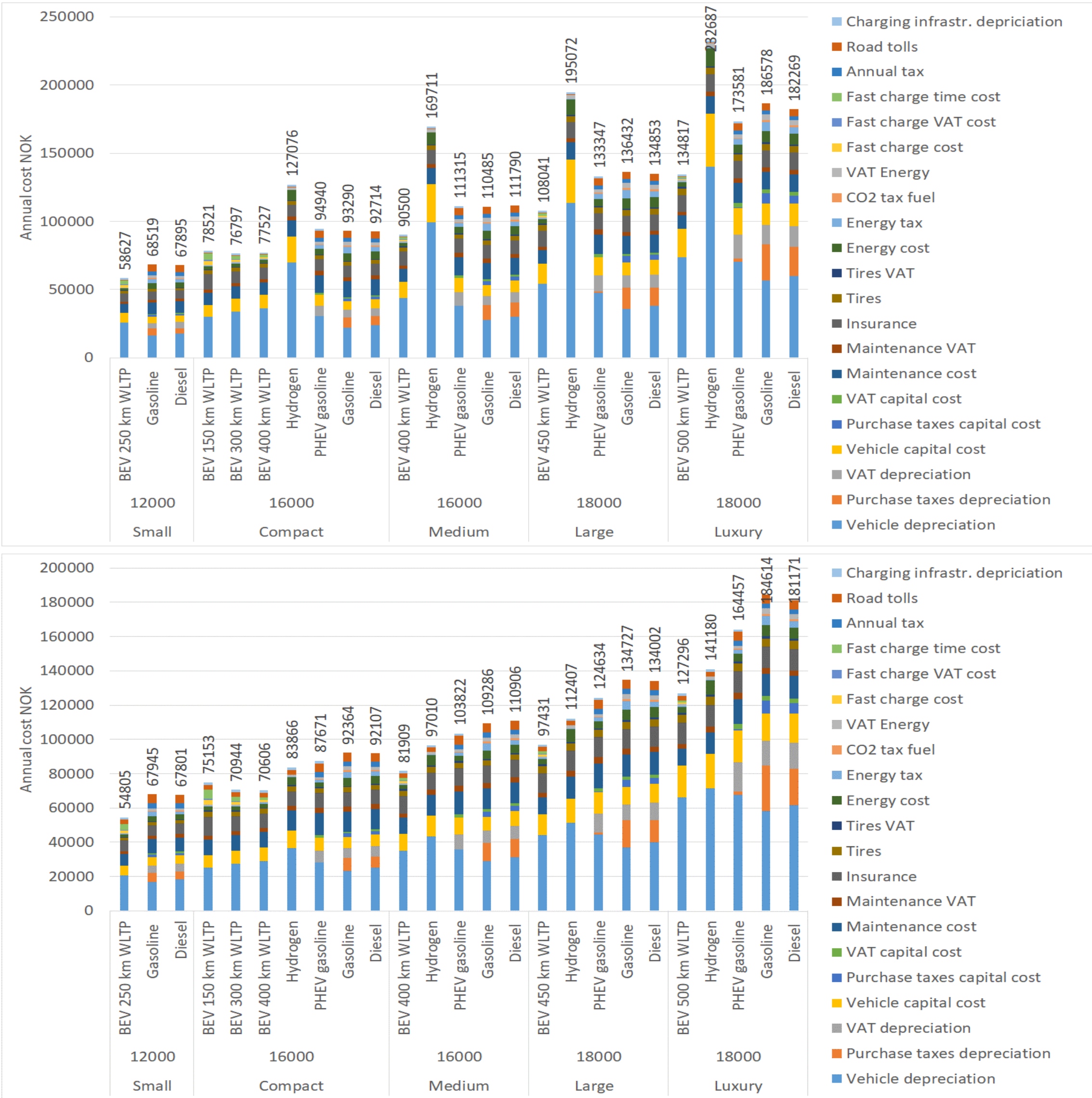

Figure 9.6: Broken down annual costs in Norway in 2019 (top) and 2025 (bottom). BEV = Electric vehicle, PHEV = Plug in hybrid vehicle. NOK per year. Source: Own calculations with TØI-TCO.

It became more profitable to choose a BEV with a moderate battery than a petrol or diesel car from 2012/2013, and a BEV with a large battery from 2015, as shown in Figure 9.7. Apparently, the lowest annual cost has been with a BEV with a small battery, given that the annual mileage is the same as for a BEV with a large battery. However, the two cars will have different uses. The car with the small battery will probably only be able to produce as many km per year as it is assumed in the calculation if it is used in a multi-car household where the car use is distributed so that the BEV is used as much as possible. BEVs with large batteries can work for single-car households as a general means of transport that can be used as much as a petrol or diesel car. The calculation also shows that BEVs with large batteries will have a lower cost than BEVs with small batteries from around 2019, because the need for and cost of fast charging (including the time cost and queue cost) is significantly lower for BEVs with large batteries compared to those with small batteries. This is also the reason why BEVs with small batteries are being phased out of the market from 2019. Battery prices have fallen so much that car buyers come out better overall with a larger battery in the car that reduces the need for fast recharging.

FCEVs will, due to their exemptions from purchase taxes, also be competitive in terms of total annual cost[8] compared to gasoline and diesel cars heading towards 2025, and even more so towards 2030, but BEVs will still have the lowest cost.

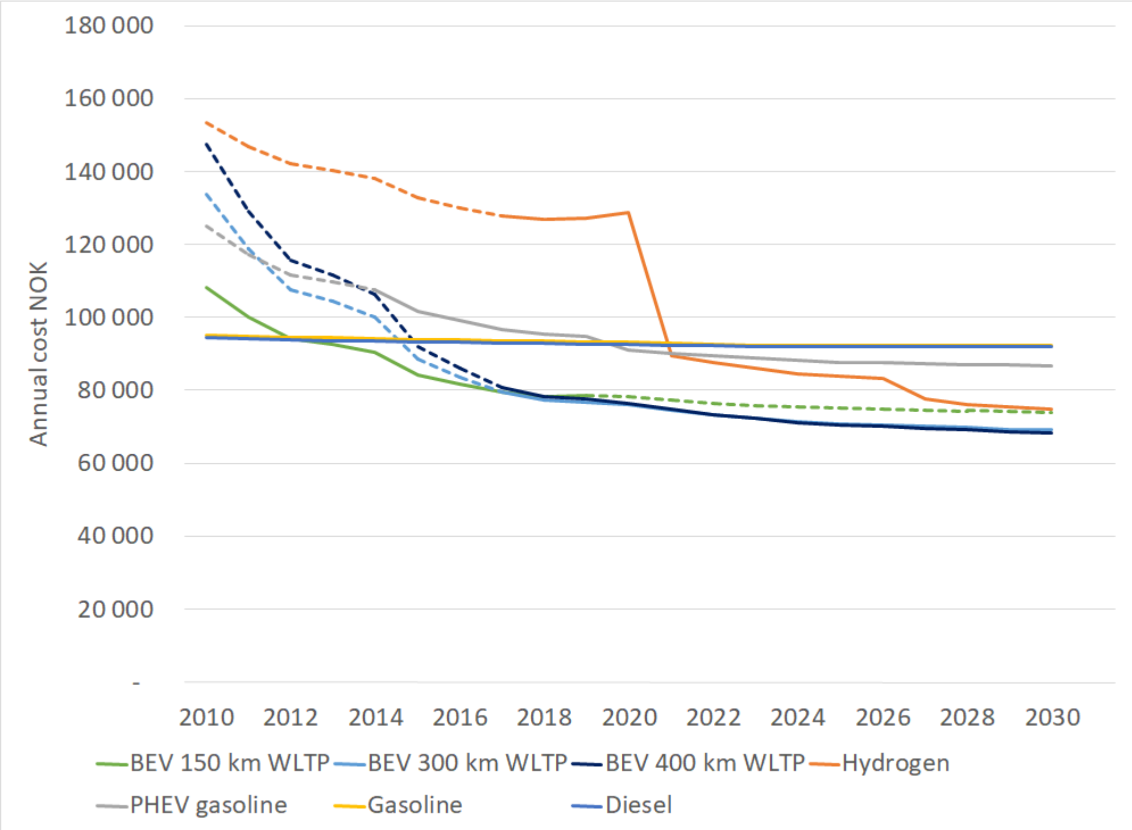

Figure 9.7: Estimated total annual cost of fees, compact cars. Dashed line indicates that models with these features were not on sale that year. BEV = Electric vehicle, PHEV = Plug in hybrid vehicle. Hydrogen=Fuel Cell Electric Vehicle. Kr/km. Source: Own calculations with TØI-TCO.

9.2.2 Purchase price and annual cost - European average - 20 percent VAT without registration tax/bonus/malus, average energy prices

In order to assess the overall competitiveness of the technologies, a generic calculation of costs for Europe, without registration fees, was carried out using 20 percent VAT, with average European energy prices, and other costs generally as in Norway. For the EU28 countries, average energy prices (2014) of approx. 2 NOK/kWh for electricity and approx. 1 NOK/liter less for petrol and diesel than in Norway, are used. Depreciation is higher than for Norway (40% residual value), see Appendix 2 of Figenbaum et al. (2019). The results are shown in Figure 9.8.

The purchase price for BEVs and hydrogen cars remains greater than for gasoline and diesel cars throughout the period until 2030. For the total annual costs, BEVs with the largest batteries will be cheaper than gasoline and diesel cars from approx. 2024, while hydrogen cars will remain more expensive throughout this period.

BEVs are thus marginally competitive in terms of annual costs in Europe in 2025, but quite a bit more expensive to buy. This is most likely not enough to kick-start sales as the BEVs still have disadvantages in terms of range, the time it takes to recharge the batteries, and the

[8]The cost is slightly up in 2020 due to the assumption of the introduction of half rate tolls.

costs and barriers to establishing charging infrastructure at home, at work and in public spaces.

BEVs must therefore be incentivized in order to be sold in sufficient volumes to enable car manufacturers to meet the EU requirements to reduce CO_2 emissions from new cars. This can be achieved by car manufacturers cross-subsidizing between their different car models and drive system variants, and/or as a result of the authorities in different countries offering incentives to those who buy BEVs. For car manufacturers, it will be cheaper to cross-subsidize BEVs from the sale of gasoline and diesel cars than it would be to pay the fines in the EU directive. This issue is discussed in Chapter 11.

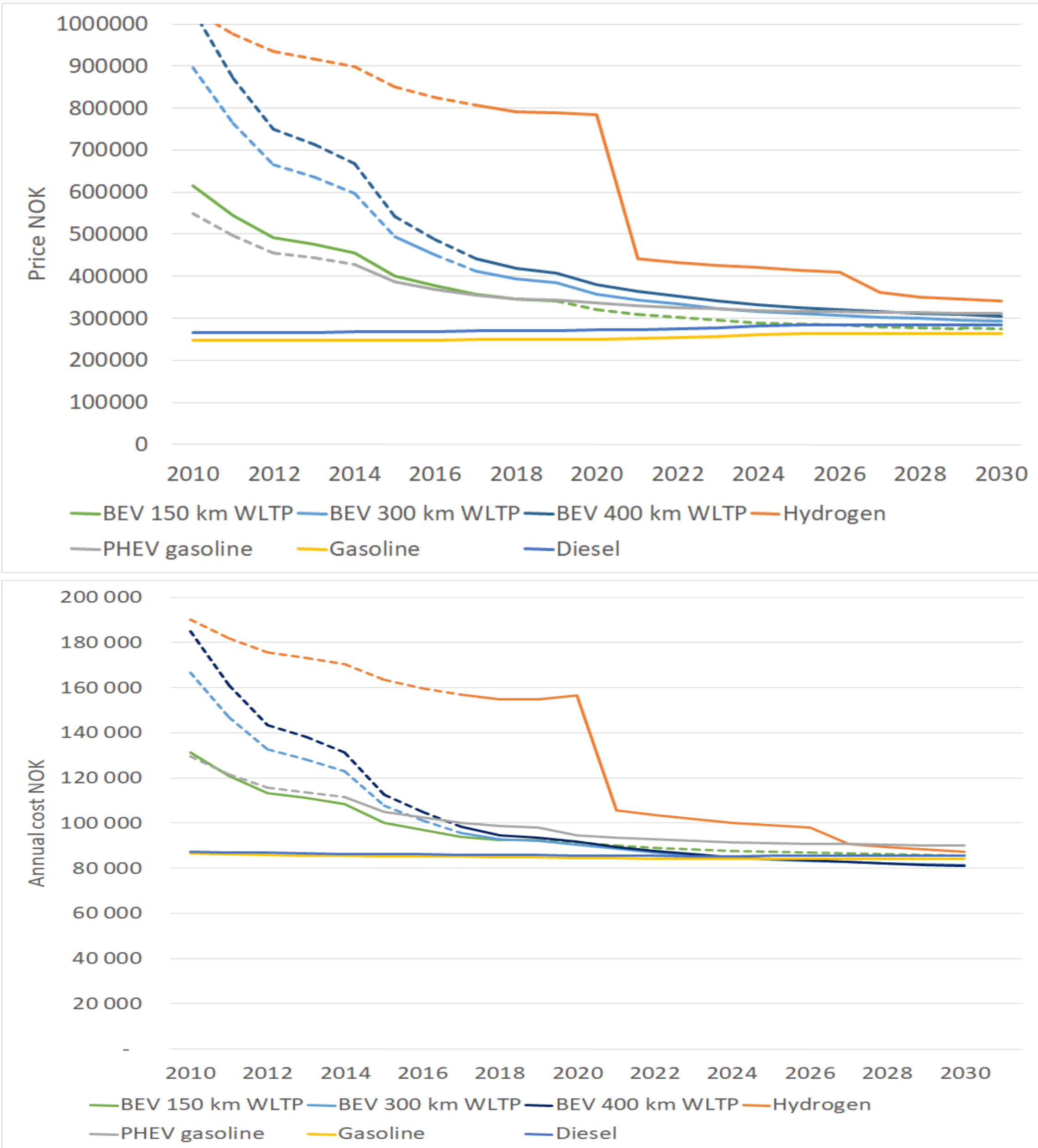

Figure 9.8: Generic sales price (top) and annual cost of compact cars (bottom) in Europe, without registration fees, with 20 percent VAT (about EU average), average energy costs (Eurostat 2014). Other costs as in Norway. BEV = Electric vehicle, PHEV = Plug in hybrid vehicle. Hydrogen=Fuel Cell Electric Vehicle. NOK. Source: Own calculations with TØI-TCO.

9.2.3 Socio-economic costs, cost-effectiveness CO_2 reduction

From a societal perspective, a transition to battery electric or hydrogen fuel cell propulsion for LCVs entails societal benefits that are not taken into account in a company's cost estimates, for instance lower external damage costs from local emissions than for diesel vehicles (NOx, PM from exhaust, sulfur[9]). Socio-economic costs include the use of societal resources (including time and use of environmental goods), whilst taxes and fees are not part of it. The toll road fee exemption and the exemption from road and CO_2 taxes result in a loss of revenue for the state (or the toll company) when diesel-powered LCVs are replaced with electric propulsion, and also result in a saving on the business side. The exemption itself does, therefore, not constitute a socio-economic cost, but can be regarded as a transfer between the state and companies. However, the loss of these revenues could result in a loss of efficiency, as the loss of income must be claimed elsewhere. The loss of efficiency is represented by a tax financing cost which, in accordance with the Ministry of Finance's circular (Finansdepartementet, 2014), is set at NOK 0.20 per NOK collected in tax.

The calculated socio-economic costs (without taxes and without VAT), for BEVs compared to gasoline and diesel cars, are shown in Figure 9.9. The socio-economic costs include CO_2 emissions based on the assumed future CO_2 costs that will be used by the transport agencies in future calculations for the transportation sector. According to this assumption, the cost per tonne of CO_2 is set at NOK 508 in 2019 and it will increase linearly to NOK 2159 in 2030 (Wangsness 2019). For the years 2010 to 2018, the 2019 value is used in the calculations. Before calculating the cost-effectiveness for reduced CO_2 emissions (NOK/ton reduced CO_2), this cost has been deducted. A tax loss cost of 20 per cent has also been included on the benefit of the VAT exemption but not for the one-time fee or toll. The registration tax rates can be adjusted to be government income neutral, but then taxes within the motorist group are transferred between vehicle buyers when the share of BEV buyers increase. Toll road fees are used to repay loans used to build the road or to support public transport (in cities), and are collected from road users paying a fee for passing. If some cars are exempt from road tolls, then others will have to pay more to pay down the loans or pay for the support to public transport.

The calculation shows a different picture than the calculation for the personal financial costs. Compact BEVs have greater socio-economic costs than gasoline and diesel cars in 2019, while hydrogen is considerably more expensive. BEVs and hydrogen cars still have greater socio-economic costs than gasoline and diesel cars in 2025, but the difference has decreased significantly. With an 18 kWh battery, small BEVs would be socio-economically viable (CO_2 abatement cost will be negative) from 2022. Some users may only need to charge their BEVs at home. For such users, the socio-economic costs will be marginally lower than for gasoline and diesel cars in 2025 for all car segments apart from small cars.

[9] Other external damage costs such as PM from tires, brakes, road dust, noise, queue, accident risk, etc. are assumed to be the same for all propulsion technologies.

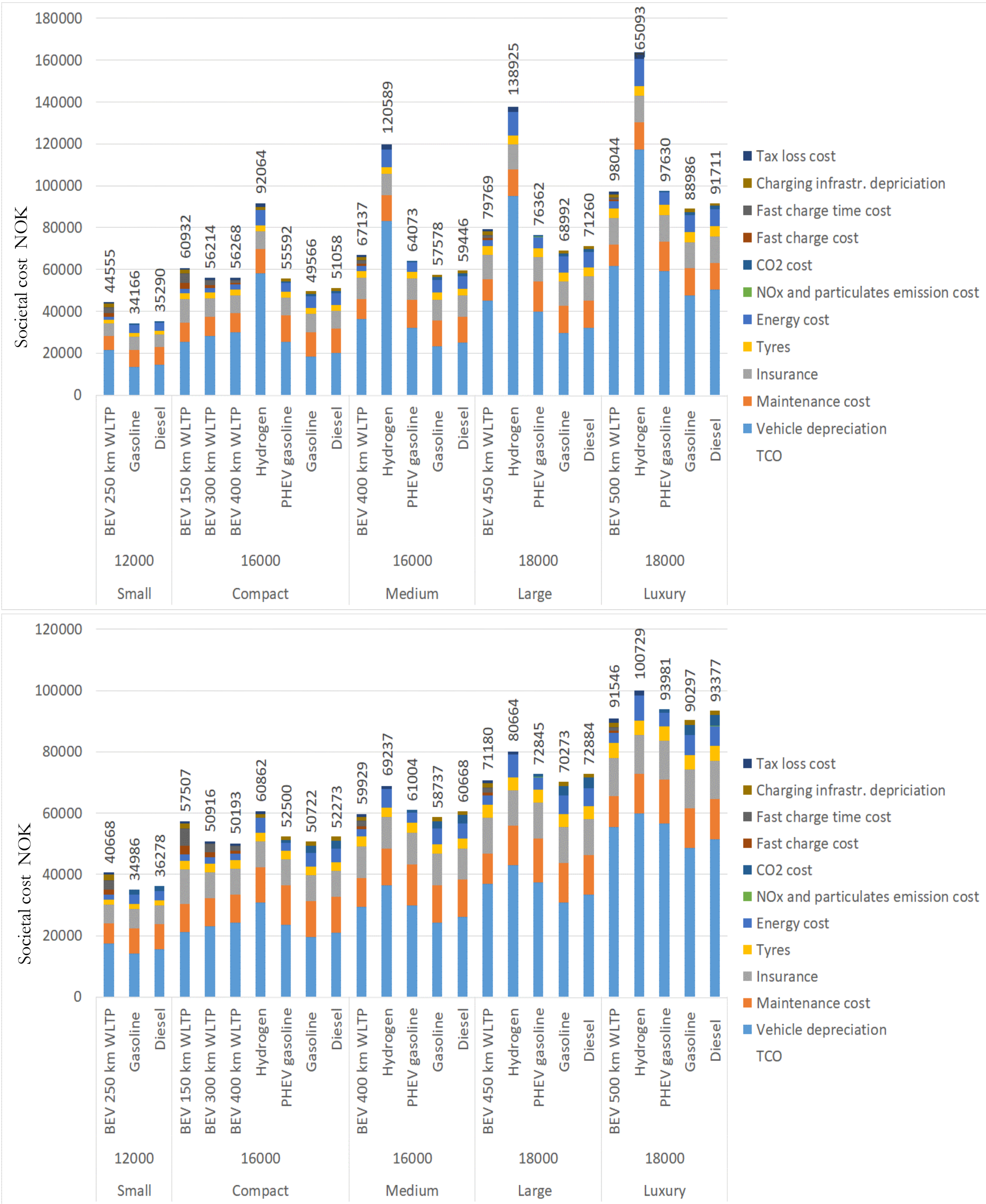

Figure 9.9: Societal cost 2019 (top), 2025 (bottom). BEV = Electric vehicle, PHEV = Plug-in hybrid vehicle. Hydrogen=Fuel Cell Electric Vehicle. NOK per year. Source: Own calculations with TØI-TCO.

The calculations presented in Figure 9.10 show that compact BEVs with medium-sized batteries will be socio-economically profitable from around 2023. PHEVs will be socio-economically profitable from approx. 2024 while BEVs with small batteries and hydrogen cars will not be profitable up to 2030. If you disregard the time and inconvenience costs calculated for fast charging according to the average long-haul travel pattern (see Appendix 2 of Figenbaum et al.2019), that is, the cars are only charged at home, BEVs will reach cost parity with gasoline and diesel cars between 2020 and 2021 (not shown in the figure). The calculations are based on average costs. This means that cars produced at a lower cost than average can reach cost savings earlier.

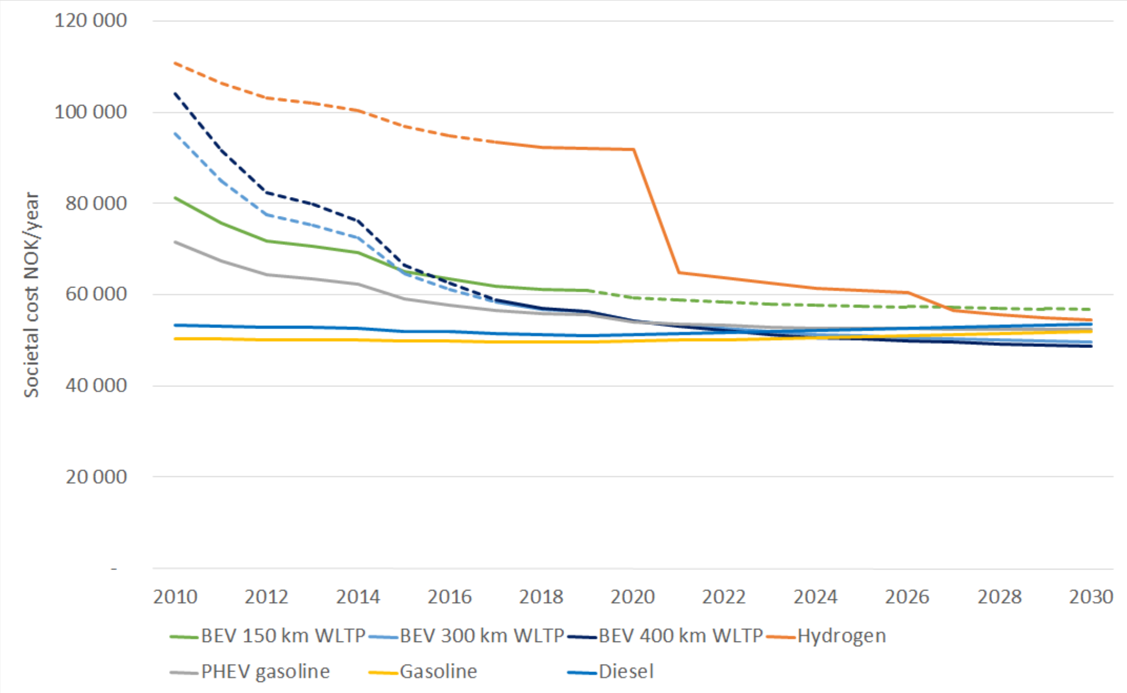

Figure 9.10: Societal cost per year, compact cars, 2010-2030. Dotted means that the car type was not available in the market. BEV = Electric vehicle, PHEV = Plug-in hybrid vehicle. Hydrogen=Fuel Cell Electric Vehicle. NOK/km. Source: Own calculations with TØI-TCO.

In Table 9.2, the cost-effectiveness of the CO_2 emission reduction in 2025 and 2030 is calculated, while Figure 9.11 shows how costs have changed and will change in the period 2010-2030. The small cars come out the worst because of relatively high calculated costs, fewer kilometers driven per year, low emissions from diesel and gasoline variants, and a greater need for fast-charging on long trips than is the case for BEVs with larger batteries. The BEV with the largest batteries comes out the best from this calculation due to reduced fast charging needs and high emissions from diesel cars in the segment.

Fast charging makes a big impact on the calculations due to the time costs associated with fast charging (time spent charging and in charge queues). Therefore, a calculation without fast charging has also been made in Table 9.2. The calculation shows that for users who do not need fast recharging, BEVs' CO_2 abatement cost is negative by 2025 already (except for the smallest BEVs).

Table 9.2: Socio-economic cost-effectiveness CO_2 emission reduction NOK/ton CO_2. Source: Own calculations with TØI-TCO.

	With fast charging		Without fast charging	
	Cost effectiveness 2025 NOK/Ton CO_2	Cost effectiveness 2030 NOK/Ton CO_2	Cost effectiveness 2025 NOK/Ton CO_2	Cost effectiveness 2030 NOK/Ton CO_2
Small BEV 250 km	5129	4299	1026	86
Compact BEV 300 km	703	-75	-2072	-2923
Compact BEV 400 km	243	-705	-1333	-2322
Medium BEV 400 km	1024	212	-399	-1248
Large BEV 450 km	772	-182	-451	-1437
Luxury electric car 500 km	692	-182	-90	-984

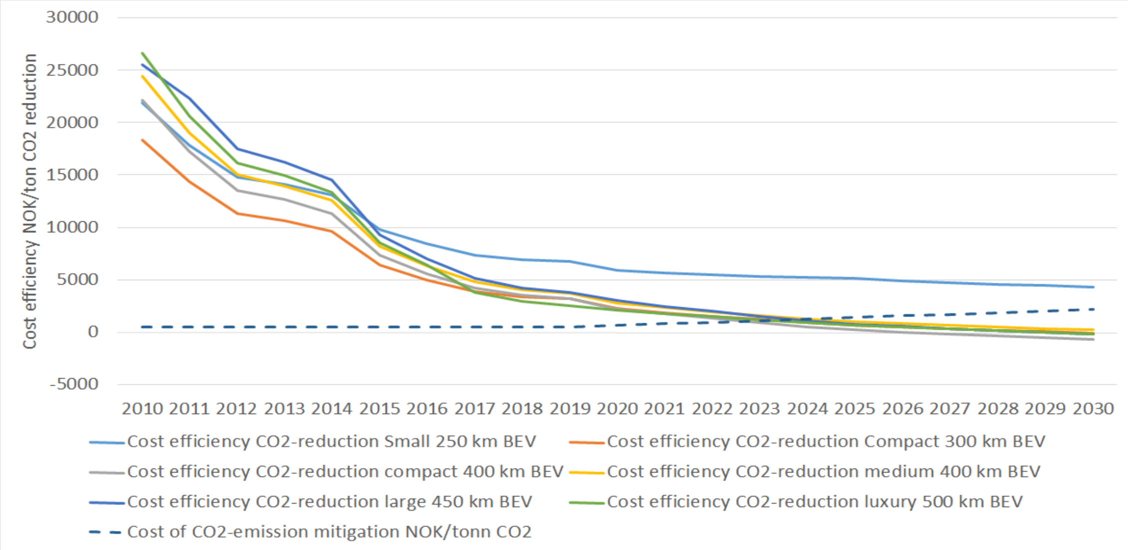

Figure 9.11: Cost-effectiveness CO_2 reduction when a BEV replaces a diesel car. NOK/Ton CO_2. Source: Own calculations with TØI-TCO.

9.2.4 Difference in purchase price/annual cost, electricity vs diesel in Norway and EU countries

The cost of buying and using a BEV in Norway and selected EU countries is compared by calculating the difference in the calculated sales price and km cost for BEVs and a diesel car for each country respectively. The result for the selling price is shown in Figure 9.12 and for the total annual cost in Figure 9.13. BEVs get a bonus of 6000 Euro in France and petrol and diesel cars pay a malus[10] that varies by emissions (see Chapter 10). A malus of 1000 Euro/car has been added to the calculation. French electricity is more expensive than Norwegian electricity. Overall, the smaller BEVs have a lower purchase price than petrol and diesel cars from approx. 2020-2022, and all BEV buyers in France receive a lower annual cost from approx. 2018-2019. For Germany, the results are similar; BEV buyers receive a bonus of 6000 Euro but there is no malus on petrol and diesel cars (see Chapter 10). Annual costs will be lower than with diesel cars from approx. 2023, which is later than France because Germany has more expensive electricity and higher VAT.

These results will also apply to varying degrees in other countries with bonus malus systems such as Sweden.

[10] The malus is a tax collected from ICEV buyers that is balance against bonuse payed to ICEV buyers. The system is self-financed, i.e. the bonuses are payed for entirely by the people who pays a malus for an ICEV

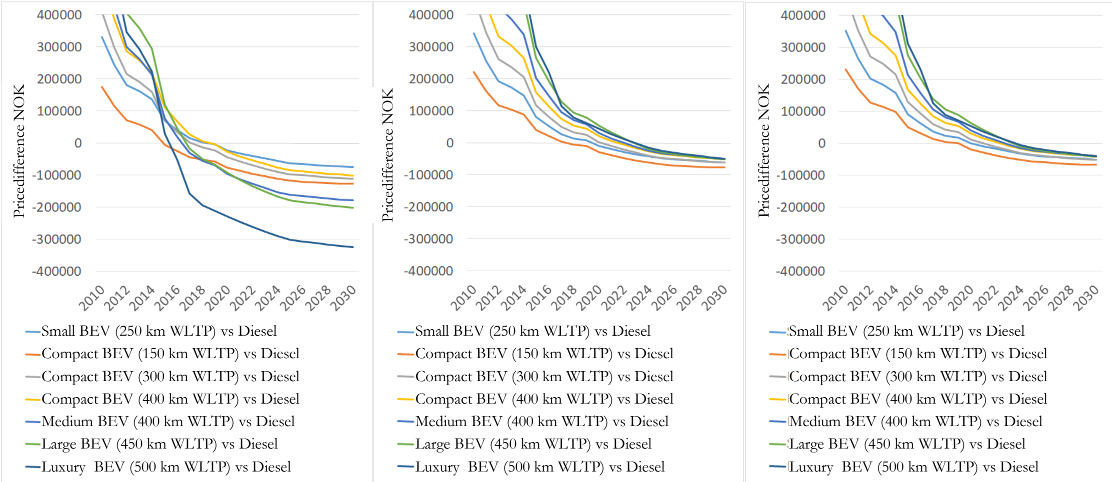

Figure 9.12: Difference between price of BEVs and diesel cars for Norway (left), France (middle) and Germany (right) 2010-2030. NOK/car. 2019 prices.

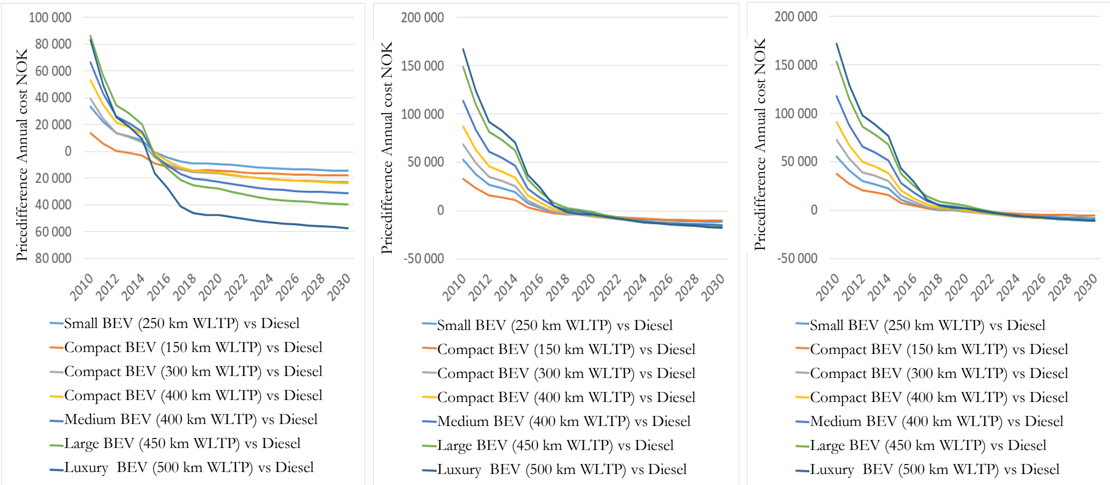

Figure 9.13: Difference annual cost BEVs and diesel car for Norway (left), France (middle) and Germany (right) 2010-2030. Electricity price France 1,75 NOK/kWh, Germany 3 NOK/kWh. Gasoline and diesel price 1 NOK less than in Norway. VAT France 19.6 percent, Germany 21 percent. Costs in NOK/km. Source: Own calculations with TØI-TCO.

9.2.5 Sensitivity in relation to estimated battery cost

Battery cost estimates are controversial and uncertain, as shown in Chapter 5. In the calculations in this report, BloombergNEF estimates have been used, as presented in Chapter 5. An alternative battery cost path (described in Chapter 5) was created to look at the sensitivity of this cost. The impact on annual cost with taxes will be relatively small, but the impact on society is greater. The CO_2 cost efficiency becomes considerably worse as shown in Figure 9.14, as compared to the result in Figure 9.11.

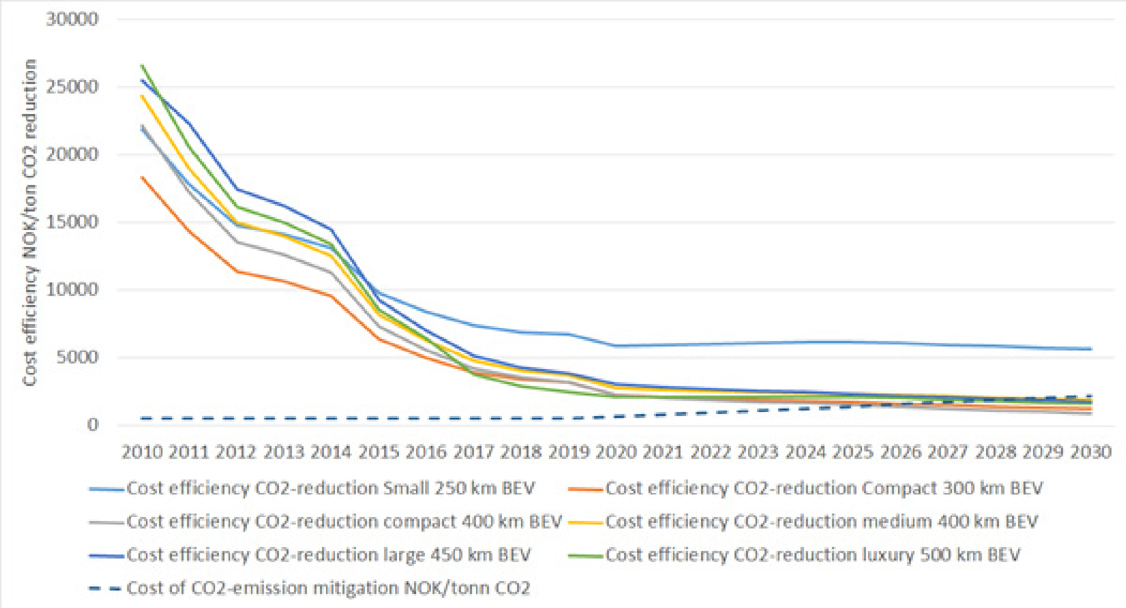

Figure 9.14: Cost-effectiveness in terms of reducing CO_2-emissions with BEVs. Alternative battery price, ref chapter 5. NOK/ton CO_2-reduction. Source: Own calculations with TØI-TCO.

9.3 Results – LCVs

LCV purchase costs and total cost of ownership are calculated for light and heavy diesel LCVs and BE-LCVs. BE-LCVs appear to have a driving range that is compatible with the needs of the segment according to the review in Chapter 6, and the overview of users needs in Chapter 10. Hydrogen is therefore not an option that will have any impact on the LCV segment within the time horizon until 2030. The only hydrogen solution found in this vehicle category are 2 variants of electric LCVs from Renault which are equipped with a small hydrogen range extender. The costs of these are very high.

9.3.1 Purchase price Norway

The BEVs were, as shown in Figure 9.15, more expensive than diesel LCVs in 2019, but competitive in price in 2025, as small BE-LCVs has become marginally cheaper than diesel LCVs and the large BE-LCVs are considerably cheaper than the diesel versions because the registration tax is significantly higher than for the small ones.

Prices will be lower from 2024 for the small BE-LCVs compared to diesel LCVs, and from 2022 for the large ones, as shown in Figure 9.16. The small LCVs will have by then utilized most of their cost reduction potential, while the larger LCVs will still become a little more affordable over time. But it is the higher registration tax that makes large BE-LCVs seem to be cheaper than the smaller ones in comparison to diesel.

VAT is not calculated for diesel LCVs as companies keep VAT accounts and can deduct this cost.

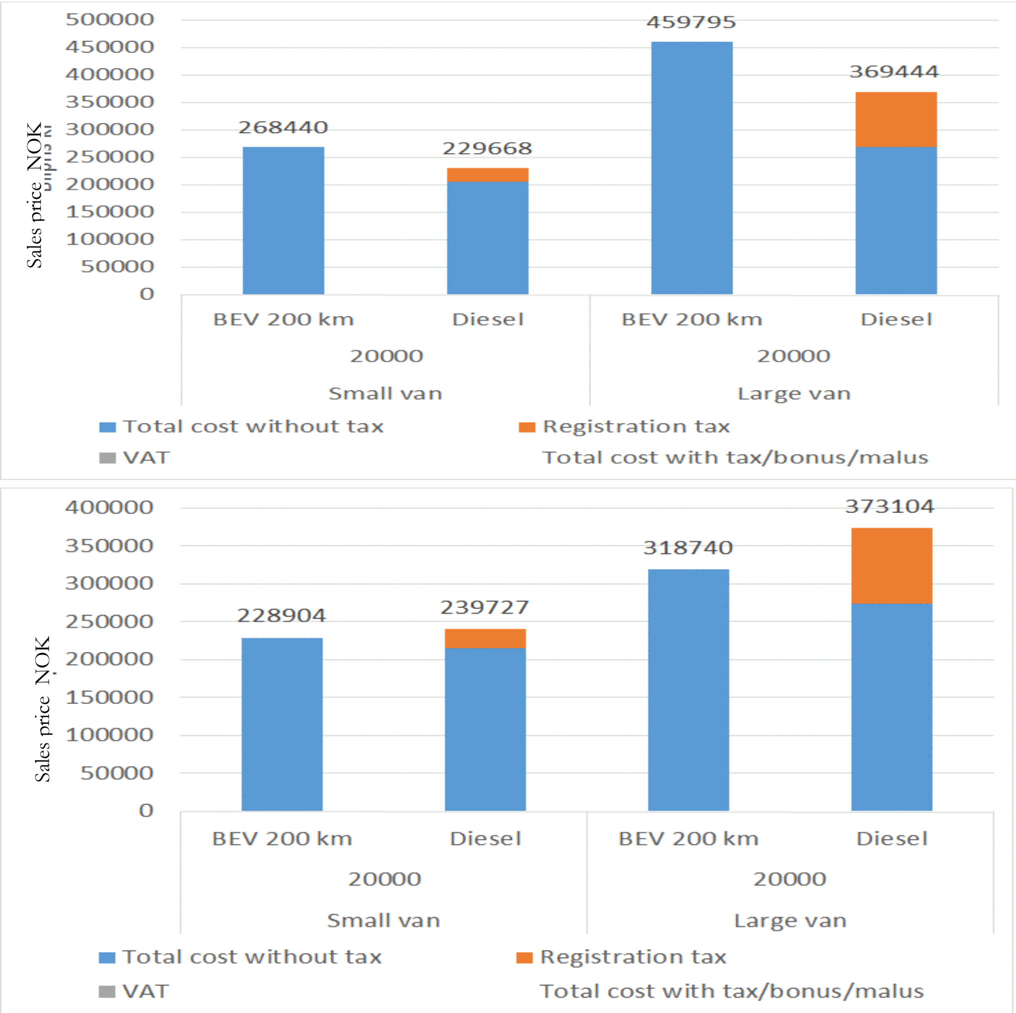

Figure 9.15: Sales price of small and large electric and diesel LCVs in 2019 and 2025. BEV = Electric vehicle. NOK. Source: Own calculations with TØI-TCO.

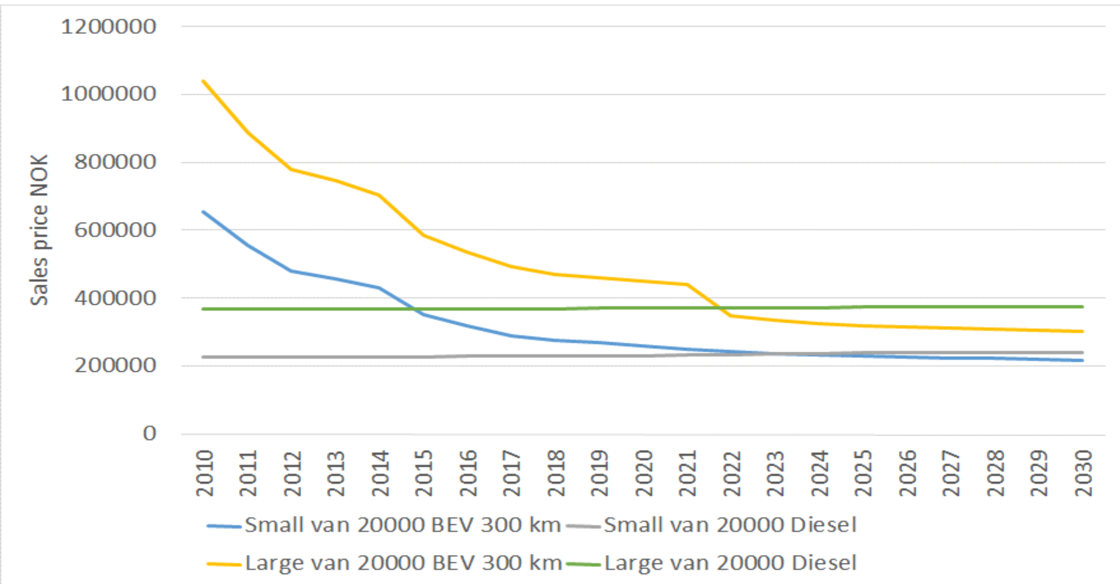

Figure 9.16: Development of sales price 2010-2030, small and large electric and diesel LCVs. BEV = Electric vehicle. NOK. Source: Own calculations with TØI-TCO.

The market is sensitive to costs. After Enova established a support program for BEVs, more than 2200 BEVs were sold in a short period of time (DN 2019). This support is not included in the calculations. For the smallest LCVs the purchase support is 15,000 NOK, for the largest it is 50,000 NOK. In addition, parts of the installation cost of chargers can be supported.

9.3.2 Total annual costs Norway

The total annual cost of ownership is calculated without VAT for the various cost elements, as shown in Figure 9.17. The calculations show that both the small and the large BE-LCVs have lower annual costs for the user than their diesel versions do. This happened in 2015 for the small and from 2017 for the big LCVs. Heading towards 2025 and beyond until 2030, the cost advantage increases somewhat as seen in Figure 9.18.

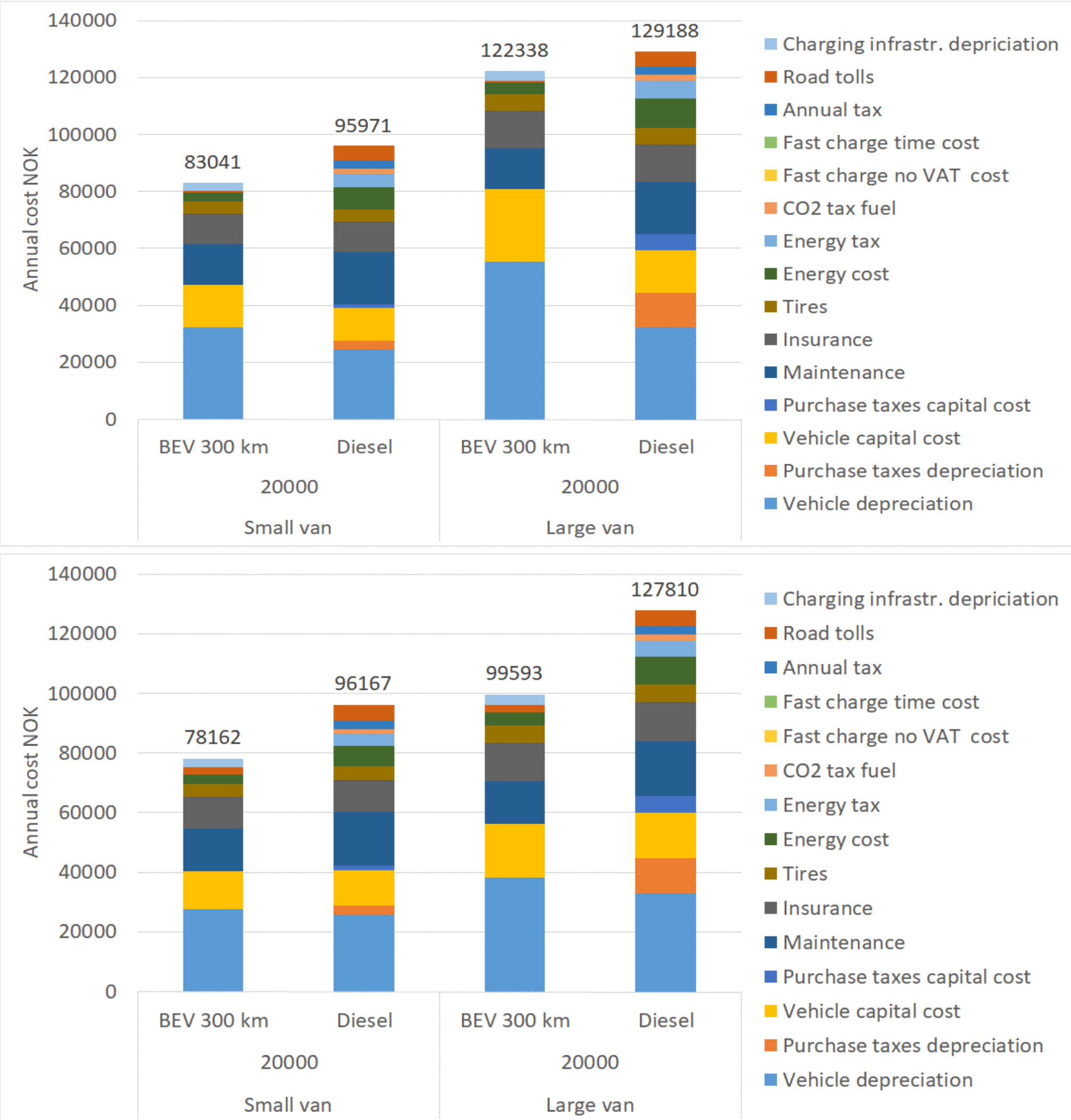

Figure 9.17: Annual costs for small and large electric and diesel LCVs in 2019 (top) and 2025 (bottom). 20,000 km/year. BEV = Electric vehicle. NOK. Source: Own calculations with TØI-TCO.

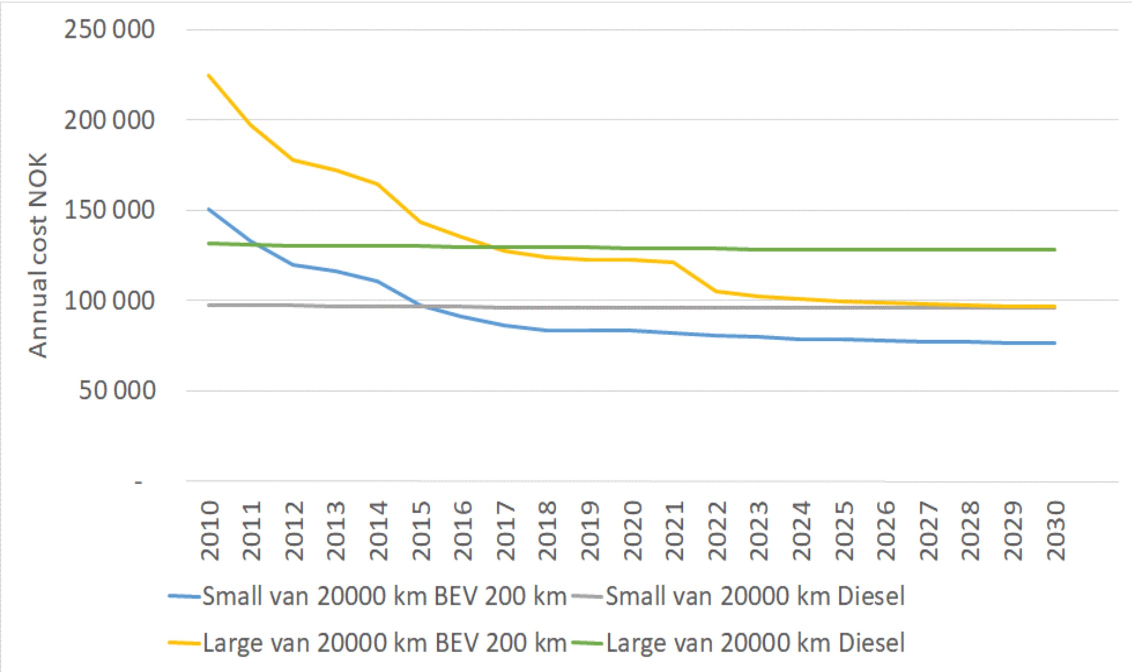

Figure 9.18: Development in annual costs for small and large BE-LCVs and diesel-LCVs 2010-2030. BEV = Electric vehicle. NOK. Source: Own calculations with TØI-TCO.

9.3.3 Socio-economic costs and cost-effectiveness CO_2 reduction

Small electric LCVs come out with a benefit to society (negative cost) from about 2019, and large LCVs from about 2022, and will be slightly more negative, that is, profitable until 2030, as shown in Figures 9.19 and 9.20. This is earlier than for cars, partly because it is assumed that they drive a little longer per year and that all charging of the batteries takes place where the car is parked at night at low cost.

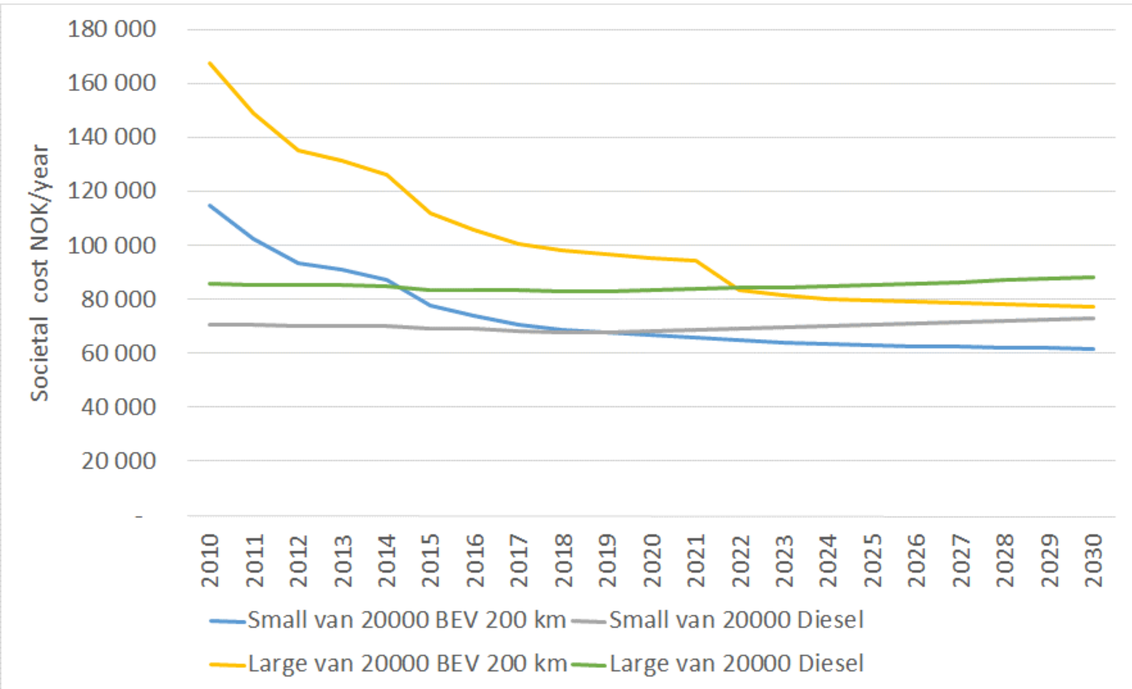

Figure 9.19: Development in socio-economic costs (without CO_2) for small and large BE-LCVs and diesel LCVs. NOK. Source: Own calculations with TØI-TCO.

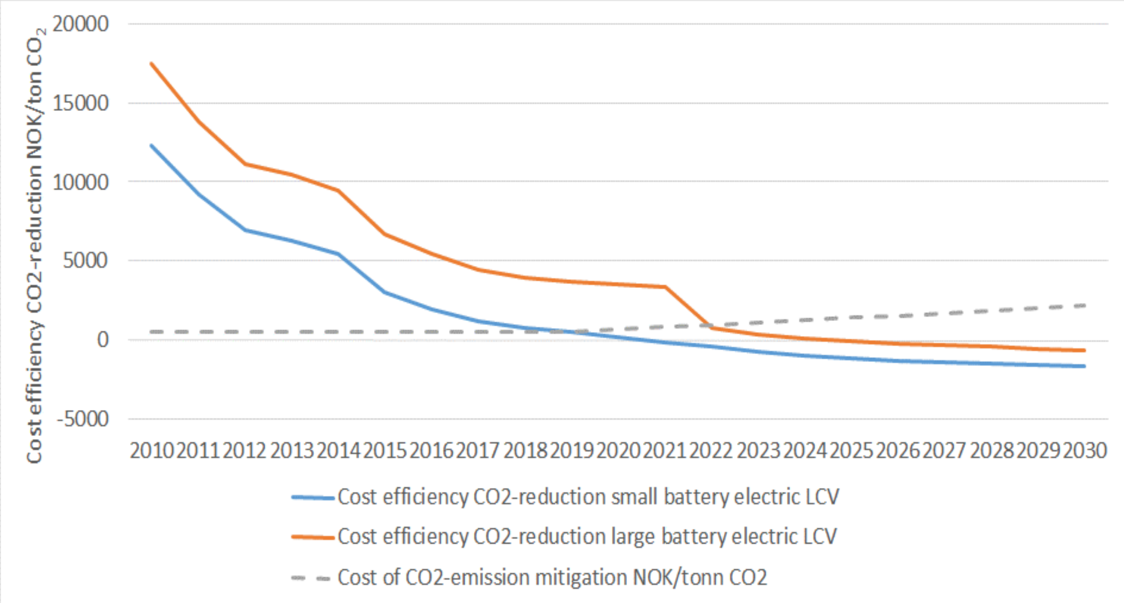

Figure 9.20: CO_2 cost-efficiency BE-LCVs as a replacement for diesel LCVs. NOK. Source: Own calculations with TØI-TCO.

9.4 Results – Trucks

For trucks, the main calculations are made for Norway, based on respectively light distribution trucks, heavy-duty distribution trucks, and semi-trailers. Neither Norway nor any other countries currently have specific fees for the purchase of zero-emission trucks, so cost differences between Norway and other countries will mainly be related to differences in energy/fuel-related costs and tolls. The calculations were made on the basis of data and calculations from Hovi et al. (2019a).

In Norway, through the ENOVA Zero Emission Fund, one can apply for support for zero- and low-emission trucks. 1 billion NOK has been allocated until the end of 2020, and this covers LCVs, trucks, construction equipment and sea transport (ENOVA, 2019).

9.4.1 Purchase price Norway

The phase-in of battery-electric and hydrogen-trucks is behind the phase-in for passenger cars, LCVs, and buses. Although several manufacturers have promised small series productions of BE-Trucks during 2019-2020, pilot projects have so far largely been based on vehicles that have been converted from internal combustion engines to electric propulsion.

This situation means that the purchase price of BE-Trucks in today's early production phase is significantly higher compared to similar diesel trucks (in addition to the fact that current-day battery-electric operation imposes some limitations related to, among other things, cargo capacity and range). Figure 9.21 illustrates today's average additional cost for battery-electric vehicles (and a hydrogen-truck) compared to corresponding vehicles with combustion engine vehicles.

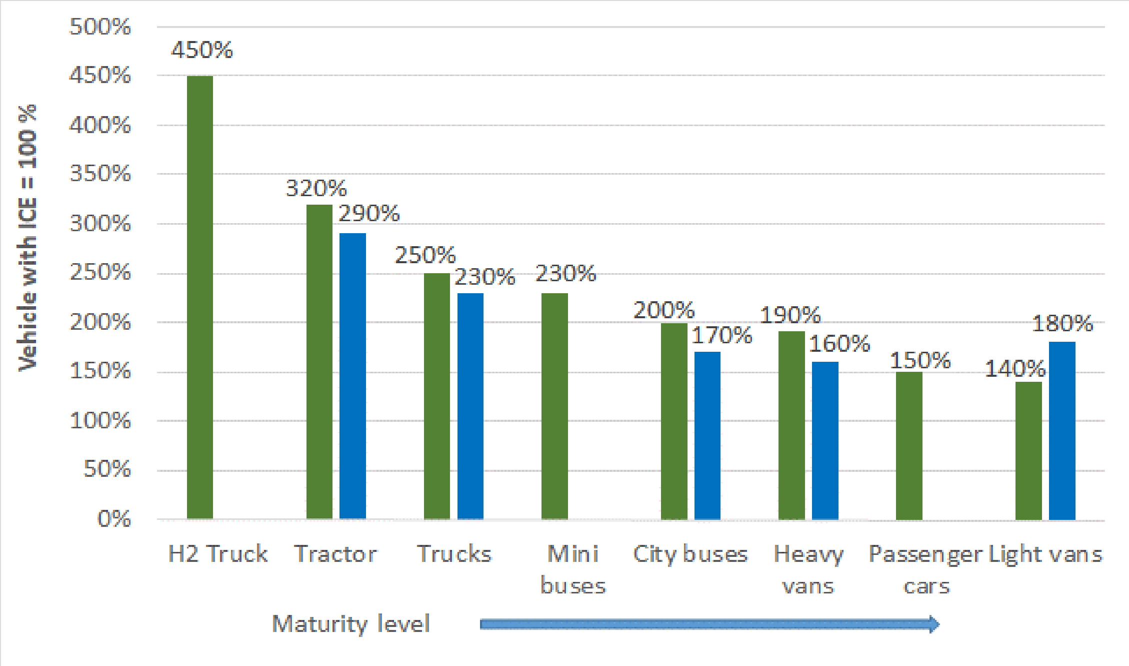

Figure 9.21: Average additional cost for battery-electric vehicles (and a hydrogen-truck (H_2)) compared to corresponding vehicles with internal combustion engine (without taxes). Based on a Norwegian sample where data is collected by the authors (green bars), as well as additional costs implied in a report by the Norwegian Environment Agency (2018) (blue bars).

From the figure, the battery-electric tractor is currently estimated to be between 1.9-2.2 times more expensive than the combustion engine tractor, while for trucks the additional cost of purchases is estimated to be between 1.3-1.5 times higher. The cost estimates in these figures do not include any subsidies for pilot projects.

When it comes to future purchase prices, towards 2025 and 2030, it is challenging to make projections, due to uncertainty around price developments for, among other things, batteries. Based on work done in the MoZEES project (see Hovi et al., 2019a), the following types of trucks were considered: light distribution trucks, heavy distribution trucks, and tractors for semi-trailers.

For BE-Trucks, it is assumed that small-scale serial production will be achieved by 2025 and that this will result in a reduction in the additional cost for BE-Trucks, so that by 2025 these will cost twice as much as corresponding diesel vehicles. It is further assumed that mass production will be achieved by 2030, and that in this phase BE-Trucks will be 1.5 times as expensive to buy as diesel vehicles. For hydrogen-trucks, it is assumed that small-scale series production can be in place by 2030, and that they at that point in time will cost three times as much as diesel vehicles. If larger volume production can be achieved, then the cost difference will be reduced.

The analysis is based on leasing periods of 5 years, as is common for Norwegian trucks. Residual values after this period are set conservatively (low) as compared to diesel vehicles, due to the uncertainty, lack of, or immaturity of a second hand market.

In the calculations, the cost of charging solutions is not included as it is assumed that the charging needs on the scale of use considered, can be met through connection to the mains via available 43 kW industrial contacts, using the charger located in the car.

9.4.2 Annual costs Norway

In terms of the TCO, the starting point is the cost per kilometer, at an annual mileage of 45,000 km and lease periods of 5 years. In addition to assuming reductions in purchase prices towards 2025 and 2030 (see Chapter 9.4.1), it is assumed that today's price of hydrogen (NOK 72/kg excl. VAT) could be halved in 2030, driven by greater demand and larger scale of production. Ownership costs for diesel trucks in 2025 and 2030 are expected to be at the same level as today. The assumptions are described in more detail in Hovi et al. (2019a).

Figure 9.22 shows, for the different vehicle types and technologies, a decomposition of ownership costs per km (for 2019, 2025 and 2030). Vehicle-related costs are grouped into the following components:

- Capital costs (taking into account differences in purchase price, residual value and the relatively marginal annual fee)
- Costs of administration, insurance, general maintenance (where battery and hydrogen BEVs are assumed to have lower costs), tires, washing, and supplies
- Energy: electricity/fuel (excluding taxes)
- Fuel taxes (i.e. road usage tax and CO_2 tax on diesel)
- A cost premium of 50 percent on electricity for fast charging which represents a higher cost of charging with a higher power output
- Road tolls.

As the focus is on vehicle-related costs, labor costs (which are approximately NOK 9.2/km) are not included in the figure.

The figure shows that in 2019, diesel-powered trucks have decidedly the lowest ownership costs. Savings that the other technologies have through lower fuel/energy costs (at today's hydrogen prices only BE-Trucks), lower maintenance costs, and toll exemptions are not sufficient to cover the higher capital costs. It can also be noted that these savings are greater per km for the larger vehicle categories, as these have a higher energy consumption per km.

By 2025, ownership costs for hydrogen-trucks are expected to remain much higher than for diesel-powered trucks. However, BE-Trucks are approaching competitiveness as compared to diesel operation. If technology permits, this will be especially true for intensive use, as each extra kilometer traveled saves money compared to diesel operation.

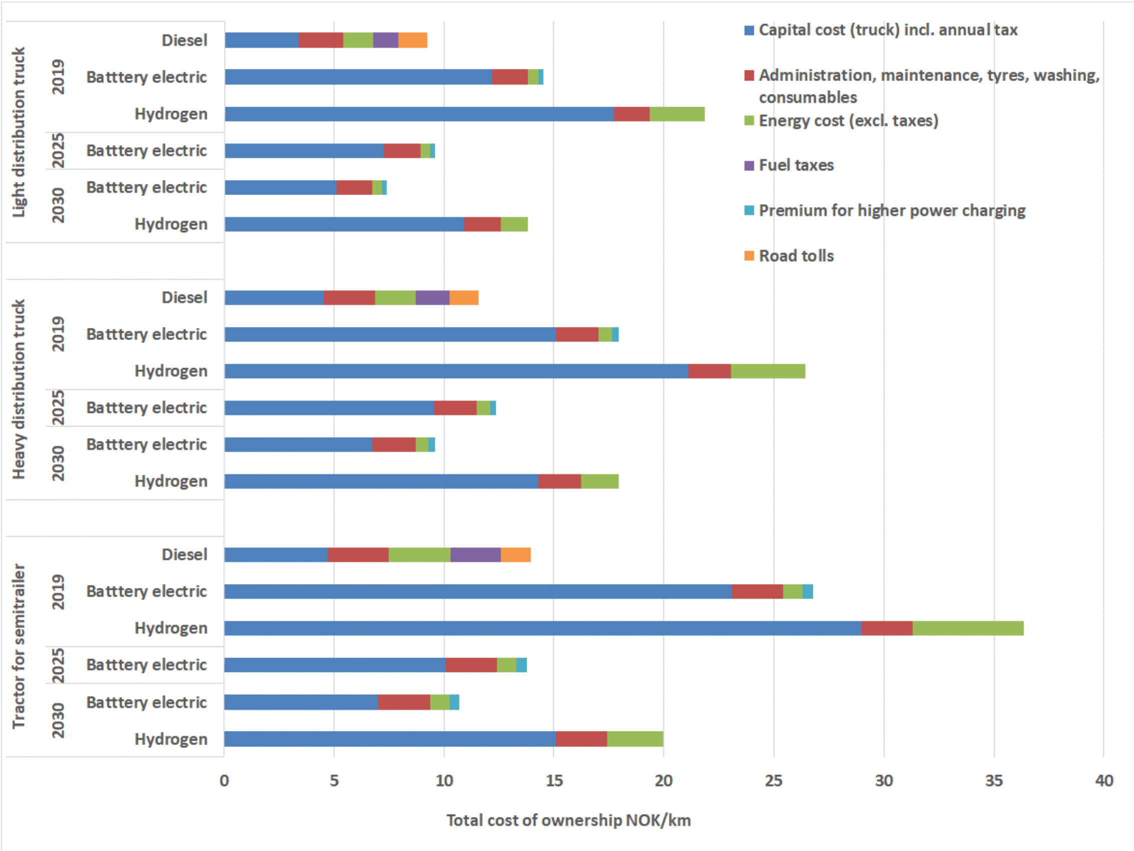

Figure 9.22: Decomposition of ownership costs for different vehicle categories with respectively diesel, battery-electric and hydrogen-operation, for 2019, 2025 and 2030. Figures in NOK/km.

By 2030, BE-Trucks are expected to have substantially lower ownership costs than diesel trucks, even if the toll exemption should be removed. Hydrogen-powered trucks, on the other hand, are still considerably more expensive, even though the price of hydrogen has been halved in the calculation. The energy costs of these hydrogen trucks are still expected to be higher than with battery-electric operation. In order to achieve cost-competitiveness, cheaper mass-produced hydrogen-trucks are likely to be needed. At the same time, it can be noted that hydrogen-powered trucks could still have a niche potential, for example in long-distance transport where BE-Trucks are less suitable due to range limitations, and the required charging time.

The intensity of use is an important factor for when technologies with higher capital costs, but lower distance-dependent costs, can be competitive. Table 9.3 shows the annual mileage required for ownership costs in electrical operation to be lower than for diesel.

Table 9.3: Annual mileage for battery hydrogen electric operation, which results in lower ownership costs per km than for diesel-powered trucks.

Year		Light distribution trucks	Heavy distribution trucks	Tractor
2019	Battery electric	Unrealistically high annual mileage (well over 150,000 km)		
	Hydrogen electric	Unrealistically high annual mileage (well over 150,000 km)		
2025	Battery electric	> 52 000 km	> 58 000 km	> 43 000 km
2030	Battery electric	> 21 000 km	> 23 000 km	> 19 000 km
	Hydrogen electric	Unrealistically high annual mileage (over 150,000 km)		> 134 000 km

The table illustrates that today, unrealistically high annual mileages are required for battery and hydrogen electric trucks to achieve lower ownership costs than diesel-powered trucks.

By 2025, however, BE-Trucks could be competitive compared to diesel engines provided annual driving exceeds 43,000 km (for tractors), 52,000 km (for light distribution trucks) and 58,000 km (for heavy distribution trucks). Vehicle usage data from Statistics Norway's truck survey and periodic technical inspection indicate that such lengths of travel are not uncommon for newer vehicles in these segments.

For 2030, the table shows that the cost of ownership for BE-Trucks will be lower than for diesel cars already from relatively low annual mileage. Before hydrogen-electric trucks become cheaper through mass production, the additional capital costs are unlikely to be recovered through reduced operating savings, unless the trucks are used very intensively and as a result will not be able to compete from a total cost of ownership perspective.

9.4.3 Socio-economic costs Norway

The socio-economic costs of replacing a diesel-powered truck with a similar truck with battery or hydrogen-electric operation, consist of any additional costs to the business, in addition to external costs/savings and tax financing costs incurred by society as a whole.

In order to calculate the socio-economic costs, underlying data from the ownership-cost analysis in the previous section were used, again looking at the years 2019, 2025 and 2030, for each of the three vehicle categories. Depending on the year considered, and the annual mileage that is assumed, a switch to electric propulsion entails a cost to the company, because there is a significant additional cost associated with the investment.

From a societal perspective, a transition to battery or hydrogen electric trucks results in changes that are not taken into account in the company's cost estimates as discussed in Chapter 9.3.3, including pollution costs. Taxes involve income transfers and are not a socio-economic expense in it self, but one assumes that there is a 20 per cent tax financing cost of collecting taxes. In addition, the socio-economic costs do not take into account the fact that companies that purchase a battery or hydrogen electric truck can in some cases receive a subsidy from ENOVA, covering up to 40-50 percent of the additional cost (compared to a conventional car). ENOVA subsidies are financed through an energy fund and, like the toll exemption and fuel tax exemption, should not be regarded as a cost to the state, but as a transfer. In light of the financing method for the energy fund, no tax financing costs have been calculated.

Figures 9.23, 9.24, 9.25 show, for all three vehicle categories and the years 2019, 2025 and 2030, the socio-economic costs per tonne of CO_2 reduced, compared to diesel-powered trucks. The figures also show a decomposition of socio-economic costs in the sum of commercial costs, external claims costs, and tax financing costs.

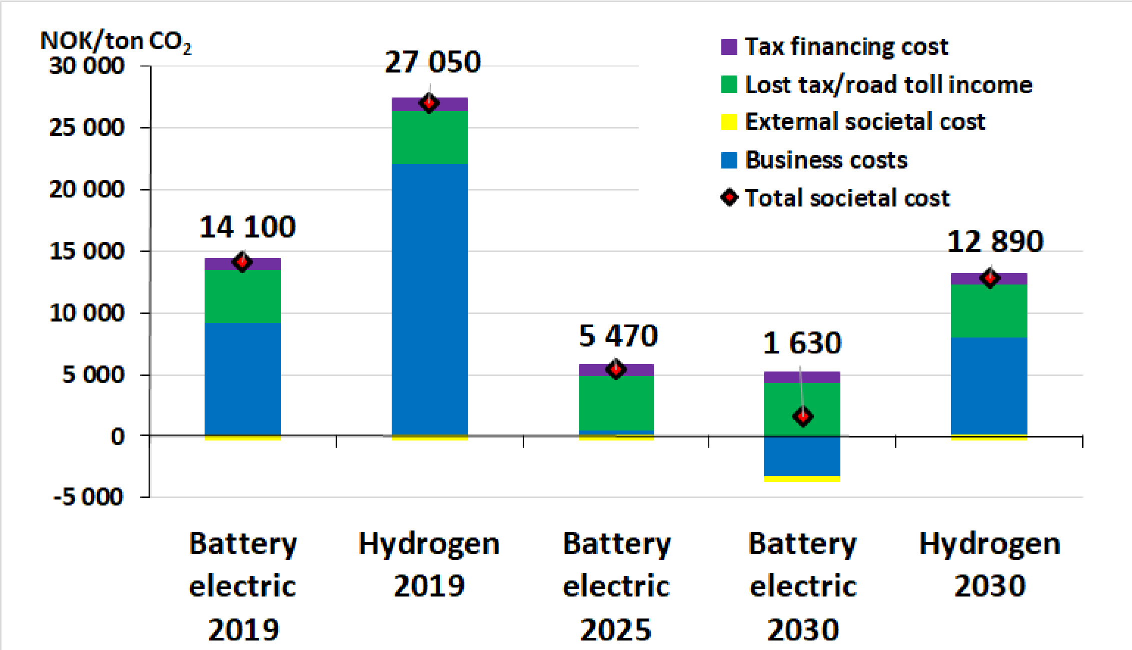

Figure 9.23: Socio-economic costs in NOK per tonne of CO_2 reduced compared to a corresponding diesel vehicle, and decomposition into business costs, external societal costs, and tax financing costs. For light distribution trucks in 2019, 2025 and 2030 and at an annual mileage of 45,000 km.

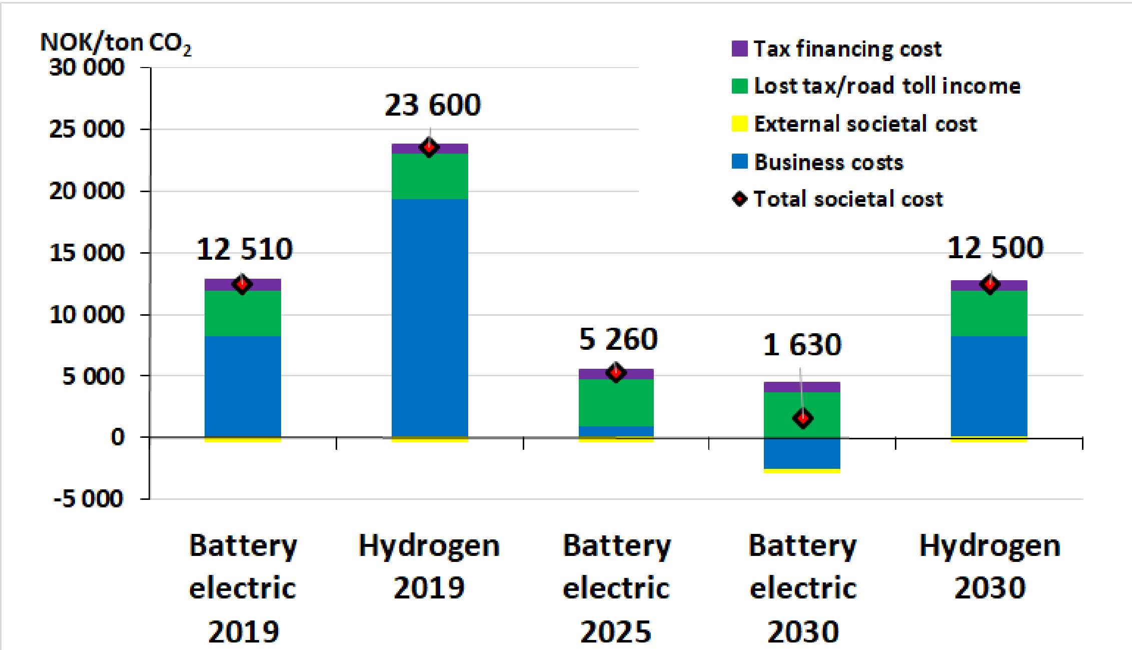

Figure 9.24: Socio-economic costs in NOK per tonne of CO_2 reduced compared to a corresponding diesel truck, and decomposition into business costs, external societal costs, and tax financing costs. For heavy distribution trucks in 2019, 2025 and 2030 and at an annual mileage of 45,000 km.

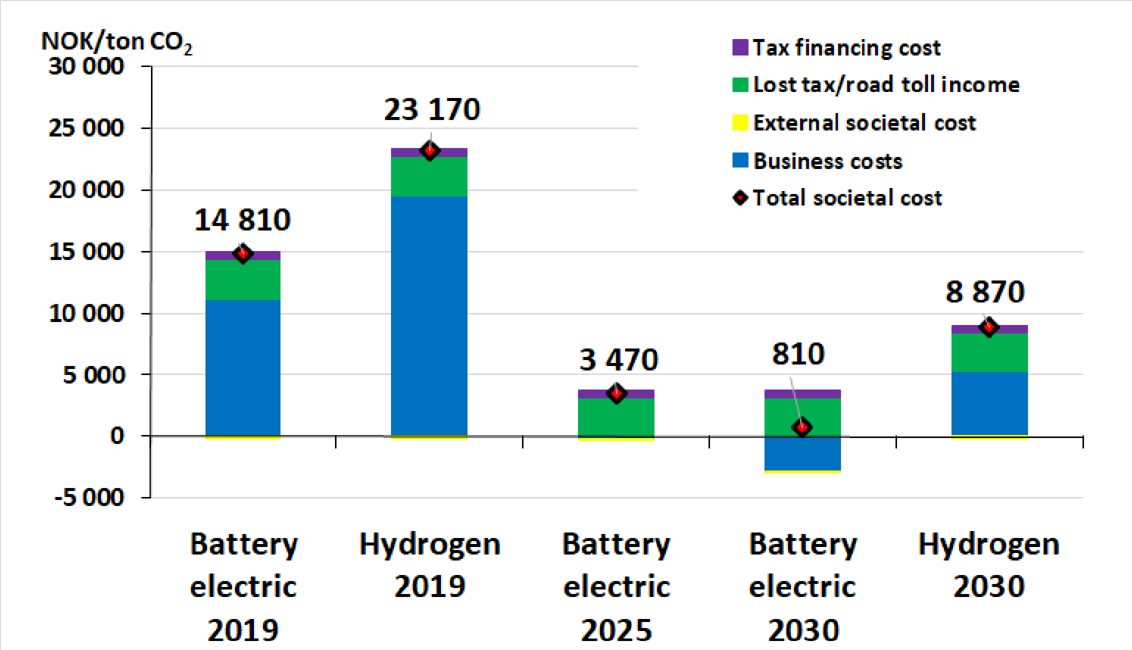

Figure 9.25: Socio-economic costs in NOK per tonne of CO_2 reduced compared to a corresponding diesel truck, and decomposition into business costs, external societal costs, and tax financing costs. For tractors for semi-trailers in 2019, 2025 and 2030 and at an annual mileage of 45,000 km.

The figures show that a transition to battery and hydrogen electric trucks provides savings to society through lower external damage costs. Today, however, the commercial costs of such a transition are so high that socio-economic costs in total are positive. The socio-economic costs per tonne of CO_2 reduced are between NOK 12,510 and 14,810 for BE-Trucks, and between NOK 23,170 and 27,050 for hydrogen-electric trucks.

By 2025, it is expected that at annual driving distances of 45,000 km, commercial costs will be low or negative compared to diesel-based operation. Combined with savings through lower external damage costs, this means that the socio-economic costs in 2025 are expected to be considerably lower than today, with between NOK 3,470 and 5,470 per tonne of CO_2 reduced by a switch to BE-Trucks.

In 2030, a transition to BE-Trucks will save money for companies, while socio-economic costs in total are expected to have dropped to between NOK 810 and NOK 1,630 per ton of CO_2 reduced. Hydrogen trucks are expected to retain a significant commercial cost by 2030, so that socio-economic costs in total are between approx. 8,870-12,890/tonne CO_2 reduced.

9.4.4 Comparison of annual costs in Norway and selected EU countries

As the cost of trucks in Norway is only to a very small extent affected by special taxes, differences between Norway and other countries will mainly be related to differences in costs for energy/fuel-related costs and tolls. The European diesel prices are quite similar to the Norwegian ones, but Norway has a lower electricity price than many other countries. Zero-emission trucks have free toll road passes in Norway for the time being, which can amount to up to NOK 60,000/year in reduced costs for zero-emission trucks.

9.5 Results - Buses

The cost analysis here for buses is limited to city buses in Norway. However, it is actually the national objectives and conditions in the tenders that control how many zero emission buses are used; since city and regional buses are purchased to fulfill county municipal tenders, the costs can thus be considered less important than competition between countries to gain access to zero emission buses.

Nevertheless, costs are relevant to the Norwegian counties themselves. By demanding zero emission solutions or weighting the environment so highly in the tenders that zero emission solutions become the only available alternative, if costs are too high they risk getting less transport capacity for the money used to support public transport.

In contrast, long-distance buses and coaches are purchased purely commercially as there are currently no specific fees or incentives for the purchase of zero-emission long-distance buses. The cost picture in relation to annual costs will be similar to that for large trucks in terms of energy savings and tolls.

9.5.1 Purchase price Norway

Interviews with operators of electric buses in Oslo (Hovi et al., 2019a) have shown that the purchase price for an electric bus in Norway is around twice that of a similar diesel bus, as was also revealed in previous studies (Hagman et al., 2017; Amundsen et al. al., 2018). The purchase price is around 1.5-4 MNOK per bus depending on the size (bus type), with about half of the costs deriving from the battery pack. The lifetime of the investment will be around 5-12 years (like a diesel bus), with some variation due to technology, lengths of contracts for bus operations and changes in operation.

The cost of infrastructure depends on the solution chosen. Depot charging can be optimal for trial operation, while fast charging can be more economical where a greater number of vehicles are used. Interviews with operators of electric buses in Oslo (Hovi et al., 2019a) showed that depot-mounted fast chargers cost around 0.41 MNOK pre-assembled, and if a pantograph is used, the cost increases by a further ~ 0.2 MNOK per vehicle.

9.5.2 Annual costs Norway

TCO results in this chapter presuppose an electric bus charging strategy based on depot charging, and that 10 percent extra buses are needed to run the routes due to charging time. It was assumed that only the number of vehicles changed and that the number of drivers did not increase. Charging costs when using a depot-based strategy were based on the assumption that a fleet of 30 electric city buses shares the use of 12 x 300 kW chargers and 18 x 50 kW chargers. These values are based on the current operations of an electric bus operator in Oslo. The costs were distributed over the life of the vehicle/infrastructure, which in the calculations was assumed to be a typical tender period. Charging costs are estimated to be reduced by 10 per cent by 2025, and by 2025 the technology is assumed to have matured so that the battery life is equal to the buses own life.

For the compared buses; The ICE (combustion engine) bus represents a Euro VI diesel (with a compulsory mix of biofuels), the H_2 bus has a commercial fuel cell, and the biodiesel bus represents a Euro VI diesel with 100 per cent advanced renewable biofuel. The assumptions for the ICE, H_2 and biodiesel buses are taken from Hagman et al. (2017) and Amundsen et al. (2018). Fuel prices are stated without VAT. Infrastructure for biodiesel and ICE buses is not included in the calculations (ie it was assumed that existing infrastructure could be used), while the infrastructure for H_2 buses was included as part of the fuel cost. A complete list of assumptions is given in Hovi et al. (2019a). The results are presented per km and assume an annual mileage per bus of 80,000 km per year.

Figure 9.26 shows the change in TCO per km driven from 2019 to 2025. For today's ICE buses, TCO was calculated here to be NOK 10.2/km. In other studies, the ICE buses had similar (but slightly lower) TCOs of USD 0.92/km (NOK 8.4 / km) with an annual mileage of 80,000 km (Bloomberg NEF, 2018) or USD 1.1/km (NOK 9.7/km) with an annual mileage of 90,000 km (Gohlich et al., 2018). The results indicate that although electric buses currently have a higher TCO than ICE buses using biodiesel and ordinary diesel (mainly due to the high capital costs for the vehicles), by 2025 electric bus TCOs can be comparable to ICE buses using diesel and biodiesel. This is true even when taking into account the additional 10 percent of electric buses needed to deliver the same transport capacity as an ICE bus fleet. Assuming that by 2025 the use of the electric bus fleet is optimized so that these extra buses are not required, the TCO for electric buses is only about 3 percent higher than for ICE buses (compared to ~ 8 percent higher with the extra vehicles included). The H_2-bus is also expected to be competitive by 2025.

Other studies find that TCOs for electric buses will be lower than for ICE buses by 2025 (Gohlich et al., 2018), or might even be lower already (Bloomberg NEF, 2018). Differences between the studies are due to variation in assumptions and great uncertainty. An example is lower investment costs combined with a long lifetime for the vehicle. According to calculations made by Ruter for bus operations in Oslo, the city's electric bus operation will be economically competitive with diesel bus operation by 2025 due to increased demand and greater production volumes of both batteries and vehicles (Ruter, 2018). For articulated buses, they believe that economic profitability will come somewhat later (~ 2028). Some operators also believe that ownership costs will soon be competitive with ICE buses, although others are concerned that increased demand may actually lead to a shortage of raw materials and an increase in costs.

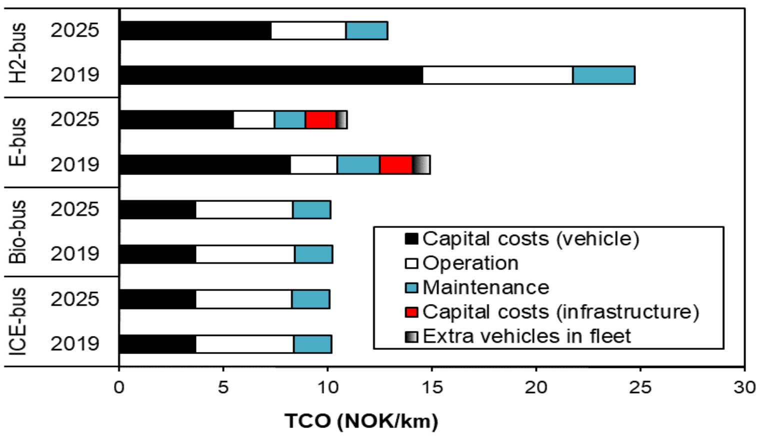

Figure 9.26: Total cost of ownership (NOK/km) for electric buses, H_2 buses, biodiesel buses and ICE buses in 2019 and 2025 (Hovi et al., 2019a, 2019b). The cost of extra vehicles in the fleet required for the electric buses is stated with graded fill, since there is great uncertainty here.

The uncertainties in this study are high. If one uses more optimistic values for the investment cost of the electric bus in 2025 (2.5 MNOK versus 3 MNOK), the TCO in 2025 is about the same as an ICE bus of around 10 NOK/km for both alternatives. Conversely, if one uses a more pessimistic investment cost for electric buses (3.5 MNOK against 3 MNOK), in 2025 the electric bus TCO is 19 per cent higher than for an ICE bus.

The analysis of electric buses shown in Figure 9.27 assumes that 30 depot chargers can be divided between 30 city buses, but this assumption may vary depending on the charging solution chosen by an operator. Optimization of the routes and use of electric buses will also be made, so that the relationship between bus and charger can be reduced. Therefore, further TCO analysis were performed to compare the TCO as a result of different charging solutions, both with and without route optimization. These analyses were based on the input of an electric bus operator in Oslo, and the charging solutions they use today. For more information on the calculation assumptions, see Hovi et al. (2019a).

Depot charging and bus stop charging are the charging solutions that give the lowest TCO values, with projected optimizations by the year 2025. Both solutions provide comparable TCOs to an ICE bus. Depot charging alone allows the use of chargers with relatively low costs, while the high cost of bus stop chargers or chargers at the end stops is offset by the high number of buses that can use them. Where a mixture of depot charging and bus stop charging is used, the high cost of charging points is not offset by a high number of buses. However, these solutions also have different practicalities. For example, if bus stop charging is chosen as the only solution, the buses may not be preheated before use. This will increase the need for heating the buses. This is not taken into account in the analysis.

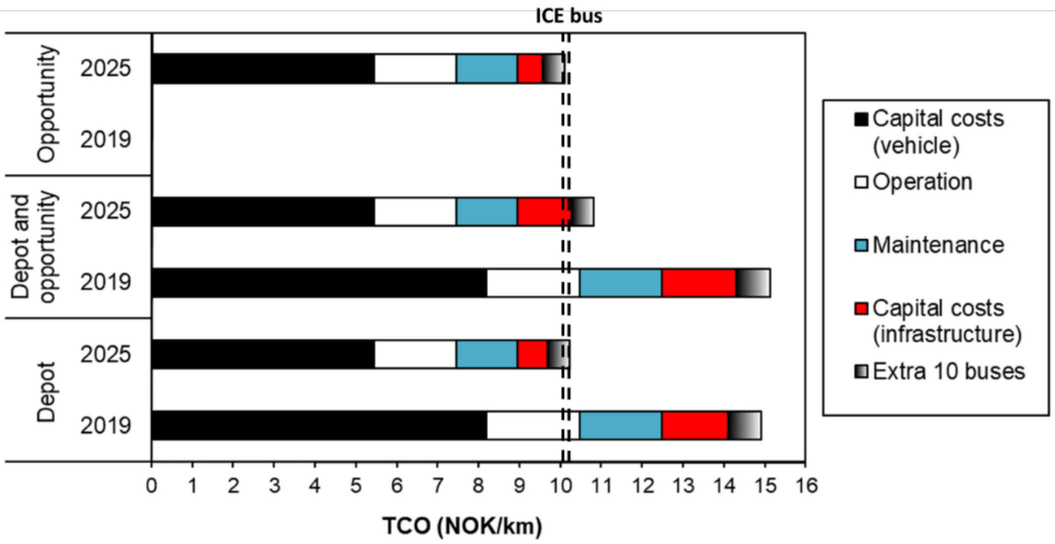

Figure 9.27: A summary of the total cost of ownership (NOK/km) for electric buses with depot-based, opportunity-based and a mixture of depot- and opportunity-based charging solutions in 2019 and 2025. The TCO for a corresponding ICE bus is shown with the dotted line. The cost of extra vehicles required for the electric buses is shown with graded fill due to great uncertainty. Source: Hovi et al. (2019a and 2019b).

Due to great uncertainty in the input parameters, the results presented here are merely indicative and have high uncertainty. Nevertheless, although a major challenge for electric buses at present is the high investment costs compared to diesel buses in mass vehicle production, it is clear the potential for competitive electric bus TCOs in the future is great, as compared to other technologies. When more electric buses come into mass production, it is assumed that prices will be reduced. The chosen charging solution must be carefully dimensioned and planned, and the best charging solution will be grid dependent.

9.6 Summary of calculation of prices and costs

The calculations for passenger cars show that the purchase price for compact BEVs became cheaper than for diesel cars for consumers from approx. 2015 depending on the battery size. The annual cost reached parity 3 years earlier, while the socio-economic cost will reach parity with diesel in 2023. Large passenger cars will reach cost parity approx. 2 years later in time. Electric LCVs have been relatively expensive to purchase compared to diesel variants because they have not benefited from the VAT exemption. Parity of purchase price will be reached in approx. 2022-2023 and annual costs was reached approx. 2016-2017. The socio-economic cost will be equal to diesel cars in 2021-2025 depending on the size of the LCV. The overall results for the different vehicle categories is shown in Table 9.4.

Table 9.4: Year when purchase price, annual cost and socio-economic cost will reach parity with diesel for battery electric vehicles. The interval is for vehicles with small-large battery. Source: Own analysis.

	Parity purchase price	Parity annual cost	Parity socio-economic cost
Passenger car compact	2015-2019	2012-2015	2023 (large battery)
Passenger car large	2017	2015	2025
LCV small	2023	2016	2021
LCV large	2022	2017	2025

The cost calculations are based on a large proportion of home charging. This underestimates the charging costs for those who cannot charge at home. If the charging cost is doubled, it costs approx. NOK 3000 extra per year for the owner of a passenger car. On the other hand, there will be users who just charge at home. For them, the BEVs will be even more profitable, and socio-economic costs will also be lower for these users. This means that for some users, profitability can be achieved earlier, and for others it is achieved later than calculated using the model.

The calculations for electric trucks show that ownership costs can be competitive in comparison to diesel trucks in 2025 in some size classes when the annual mileage is sufficiently long, but not unrealistically long for many applications. By 2030, electric trucks will be competitive even at relatively short annual mileage. Hydrogen is lagging behind the electric trucks in terms of maturity and therefore has higher costs and lower profitability, but can nevertheless become a real alternative for long-distance truck transport. The trucks will not be economically profitable until 2030 unless one assumes a long annual mileage. At a driving distance of 45000 km/year, the cost of reducing CO_2 emissions is approx. 3500-5500 NOK/ton in 2025 and about 800-1600 NOK/ton in 2030.

For city buses, the costs vary based on the assumptions that apply to charging solutions. It is assumed that the costs will be almost competitive per bus in 2025, but that there may be a need for 5-10 per cent more buses to achieve the same level of service in terms of bus kilometers driven (due to the time uses for charging during the day), which increases the costs compared to operation with diesel buses.

10 User experiences and needs

In analyses of fleet electrification potential, the user needs to be in focus. This chapter consequently describes the experiences users have had with electric passenger cars, LCVs, trucks and buses, as well as the assessments made by the (remaining) user groups that need to be motivated to purchase electric vehicles in the future.

10.1 Passenger car market

10.1.1 The Norwegian diffusion of BEVs accelerate, EU is far behind

Rogers' (1995) classic "Theory of diffusion of innovations" describes the adoption of new technology (a BEV) as a communication process involving the transfer of experience between different groups. An overview of the model is shown in Figure 10.1. The process starts with a potential user becoming aware of the innovation, being convinced and making a decision to use or reject the innovation. In the implementation phase the BEV is put into use. The confirmation phase is either that it was the right decision, leading to continued use, or that it was wrong and use ends.

The framework conditions, the characteristics of the person who make the purchase decision and the characteristics of the innovation, are important, but the relative advantage over an ICEV is the most important factor. BEVs have advantages, such as low energy consumption, zero exhaust emissions, low carbon footprint and less service needs, but also disadvantages such as long charging time, limited range and higher purchasing costs, than ICEVs. Some benefits are primarily achieved by the community, while the disadvantages are experienced by car owners. Consumers look at the total and then decides. Incentives can make adoption happen faster.

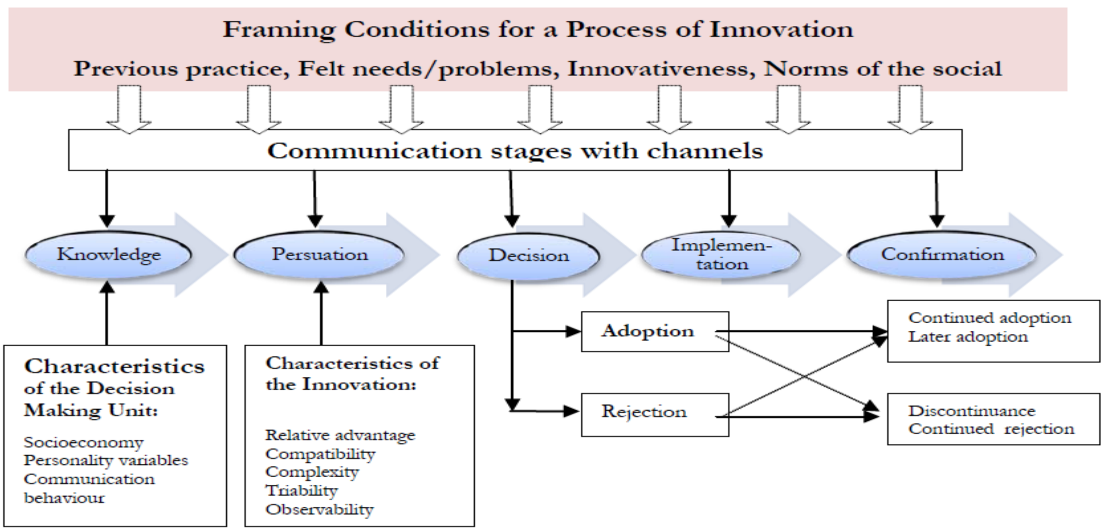

Figure 10.1: Factors that influences the diffusion of innovations in a population. Source: Figenbaum and Kolbenstvedt (2013) based on Rogers (1995).

Unfortunate early user experiences can result in the innovation being discarded and old practices resumed. Users can then convey bad experiences to potential users. If early user experiences are positive, they will influence others positively.

Knowledge of users' socio-demographics is important for developing strategies to reach new users. Rogers (1995) divides those who use innovation into: "innovators", "early users", "early majority", "late majority" and "posteriors", who successfully use innovation. Each group has some typical characteristics as seen in Figure 10.2.

Figenbaum and Nordbakke (2019) found that the BEV market in Norway now seems to have passed «early users» and is in the «early majority» group. The "late majority" group and the "posterity" group must however also become zero-emission vehicle owners to achieve the 2025 goal of only selling zero-emission cars.

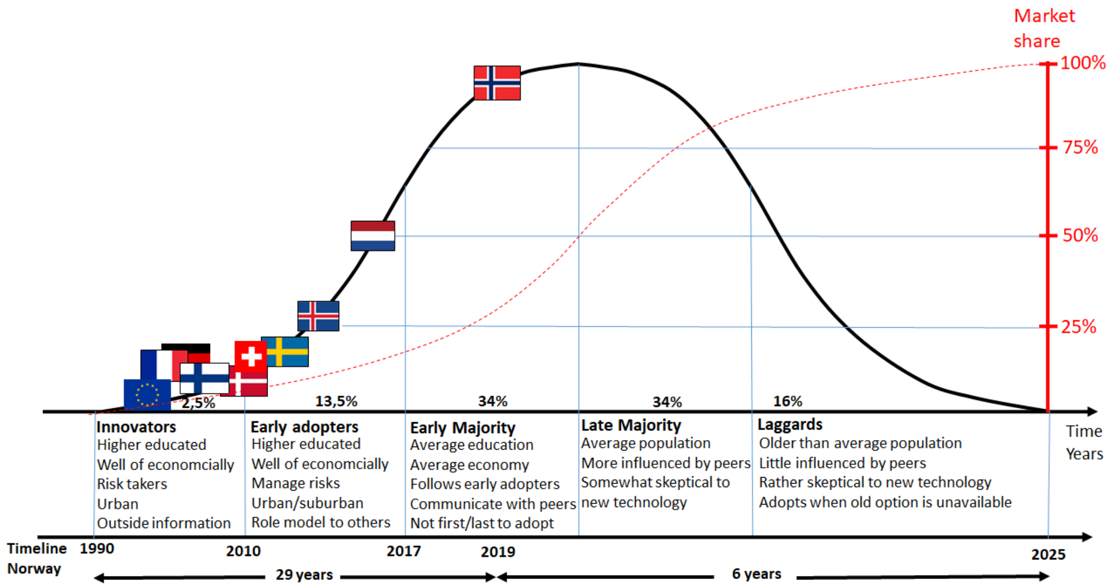

Figure 10.2: The adoption curve of consumers according to Rogers Theory of the diffusion of innovations (Rogers, 1995). Status for new BEV sales shares for different countries in Europe.

It can be assumed from the user experience that continued electric vehicle incentives and enhanced knowledge of needs are particularly important for reaching the following four specific user groups;

1. Laggards accounting for about 16 percent (according to Rogers theory) of the market. They are conservative, dislike changes and often have less resources than early users, and they prefer to continue using cars as they always have. Letting them drive PHEVs might be a wise strategy.
2. Infrequent users own a car but rarely use it. They have small incentives to choose an BEV, see few benefits, and can face challenges when they live in a dense city.
3. Extreme car users need to tow trailers or caravans, take longer car trips during extreme weather, or have large needs for luggage space. These are not the primary BEV buyers. Some BEVs can tow a caravan but it will be cumbersome (Figenbaum 2018a, Elbil.no 2019a) for the 5 per cent of Norwegian households that owns a caravan (SSB 2019a) or a the 1.1 million who own smaller trailers (SVV 2019, OFVAS 2012).
4. Households without parking and charging capability will find life with a BEV difficult, and the life of the battery life can be reduced when it is very cold or if it is left severely discharged. Access to home charging is therefore important.

An example illustrating these limitations is found in the work of Zarazua de Rubens (2019), who used a machine learning algorithm in a survey from 2016/17 among Scandinavian car owners to divide consumers into 6 segments:

1. Status seekers (20% of the market) are interested in BEVs, as a status product. They have a high willingness to pay and owns more cars than others. These would in Roger's theory be "innovators" and "early users".
2. Working moderates ("Blue collar moderates") and the Greens ("Greens") can be mobilized to buy BEVs when the price drops to the level they tend to spend on cars. In Roger's theory, they would be in the early (26%) and late majority (23%).
3. Skeptics (6%) and public mobiles (14%) are little interested in cars and no intention of buying a new car right away, and have low car ownership (48% and 39%). Those that have a car would in Roger's theory be "laggards" (8-9%).
4. Petrol heads ("petrol heads") make up 12 percent of users, have the second highest car team and are completely uninterested in BEVs and thus "laggards".

His analysis suggest that the Norwegian BEV policy may have mobilized the first two groups of buyers through incentives that have removed BEVs cost disadvantage.

BEVs are being further developed. Faster charging and increased range make them more like ICEVs. Nevertheless, much facilitation and infrastructure development will be required to continue the market expansion. Many Norwegian incentives existed already in the 1990s, yet it took 29 years before the BEV market in Norway went from "innovators and well into the "early majority" by 2019. The slow diffusion was due to a lack of access to BEVs, limited range, long charge times and high costs.

From 2019, were the market is close to entering the late majority, there is only 6 years left until 2025. By then, the late majority group, laggards and the four user types mentioned above must be motivated to buy BEVs. As the customer groups become more demanding, new strategies and continued incentives are required to reach the goal. BEVs must also increasingly be spread also to rural areas, see figure 10.3.

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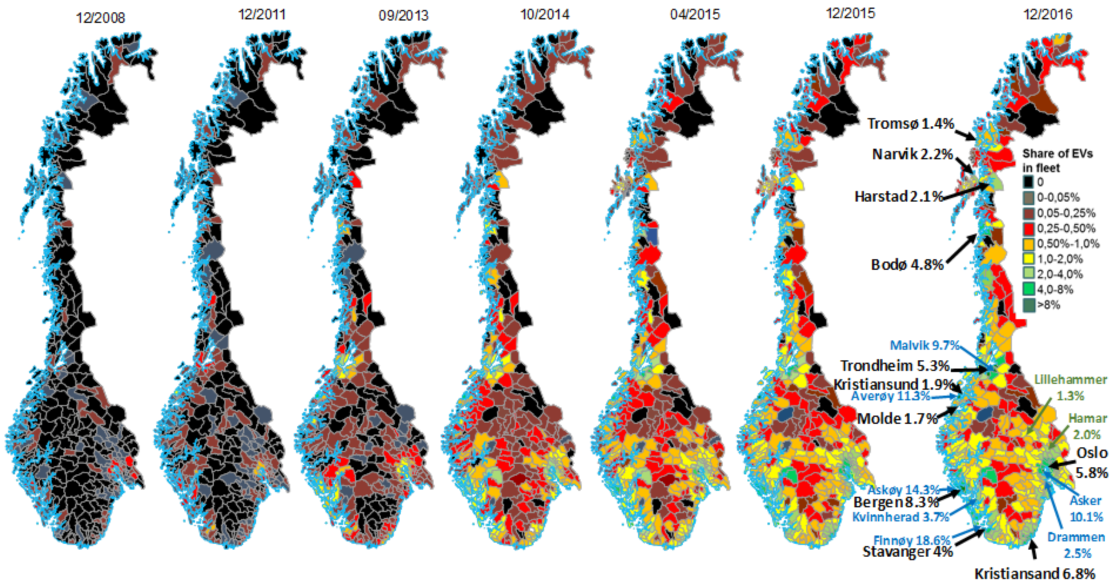


Figure 10.3: Diffusion of BEVs in Norway between 2008 and 2016. Based on Figenbaum and Kolbenstvedt (2015) and data from SSB.

The diffusion process is largely a communication process, in which knowledge transfer between peers, awareness and access to testing is essential. Because BEVs can cause a need to change car habits and transport behavior, reliable information from peers is especially important. Nine out of ten Norwegians know a BEV owner, and a third have tried one themselves. On average, 2016 BEV owners had inspired 2.5 people to buy a BEV (Figenbaum and Kolbenstvedt 2016, Kolbenstvedt and Assum, 2018). Different types of media have a huge impact on people's car purchases. 68 percent of BEV buyers compared with 21 percent of ICEV buyers felt that information from the media had a decisive impact on their choices. Most users had decided what kind of vehicle they wanted before going to a dealer, 78 percent of BEV owners and 69 percent of ICEV owners in 2016 (Figenbaum and Kolbenstvedt, 2016). ICEV buyers had primarily received information from dealers. Developing their expertise on new car types is therefore particularly important with regard to the new customer groups (Kolbenstvedt and Assum, 2018). Buyers of cars from Nissan (Kolbenstvedt and Assum, 2018) were very satisfied with the seller's knowledge and efforts.

10.1.2 The impact on the utility of vehicle usage

Characteristics of BEV owners versus ICEV owners

The background of the BEV owners is similar to the characteristics of the "early users" category and has over time moved in the direction of the characteristics of the "early majority" group. BEV owners are a little younger, have better finances, higher education, and more children than the average car owner (Figenbaum and Nordbakke 2019, Figenbaum and Kolbenstvedt 2016, Figenbaum et al.2014, and Olson 2018). They have become more like car owners in general from 2016 to 2018 (Figenbaum and Nordbakke 2019). This trend is expected to continue with more affordable models with good range entering the market (Figenbaum et al.2019).

Between 2016 and 2018 the share of BEVs owned by multi-car households dropped from 79 percent to 73 per cent (Figenbaum and Kolbenstvedt, 2016). Among car owners in the general population, 49 percent have 2+ cars (Hjorthol et al., 2014). This indicates that BEVs have given relative benefits to multi-car households. The proportion of single-car households is expected to increase as more BEVs in all size classes with longer range, and a lower price will become available.

Ryghaug and Toftaker (2016) interviewed 20 stakeholders on BEV development in Norway. They believed that the first users in Norway had been idealists, while in 2016 they were typical urban commuters with a usage pattern that suited the technological level of BEVs.

The family work horse

BEVs are in many ways the household workhorse, used extensively for daily local driving needs in multi-car households (Figenbaum and Nordbakke 2019). These households tend to be families with children with a greater local and care-related transport need. BEVs are for them economical to use, and they can escort their children in a BEV with a better conscience than in a car without emissions. BEV owners tend to have a longer journey to work than ICEV owners. The longer the commuter distance, the more it is to save on using an BEV, leading to the assumption that economy of use is important (Figenbaum and Nordbakke, 2019).

Life with the BEV is generally fine and slightly better in 2018 than in 2016 Figenbaum and Nordbakke, 2019). Few have had to cancel a trip (5-6 percent in both 2016 and 2018), and the proportion who had failed to complete a trip fell from 28 percent in 2016, to 21 percent in 2018. More BEV owners in 2018 than in 2016 say they use the BEV even if the range is too short. BEVs are used about as much per year (15000-16000 km) as ICEVs (Figenbaum and Kolbenstvedt, 2016).

Anfinsen et al. (2019) found that the BEV was domesticated through a learning process to handle the limited range and the charging process. It gave users a good feeling that the BEV was environmentally friendly, and they eventually identified themselves as a BEV owner.

Home - the primary charge location with low cost electricity

Home charging is by far the most important. For Norway, Figenbaum and Kolbenstvedt (2016) and Figenbaum and Nordbakke (2019) found that it is almost a prerequisite for buying an BEV. Over 90 per cent charge their BEV at home in their own parking space. Access to home charging has thus been one premise for the purchase (Figenbaum and Nordbakke, 2019). It is also seen as a great BEV advantage, because of access to cheap energy. In cold climates it is beneficial to put the car on charge at home to keep the battery warm so that it does not lose the ability to deliver energy and power (Figenbaum and Kolbenstvedt, 2016; Figenbaum and Nordbakke, 2019). The second most important charge location is jobs, while public chargers are the least important, with the exception of those who support charging close to where people live. Hardman et al. (2018a, 2018d), found these results to universally applicable across nations and continents.

Chakraborty et al. (2019) found that price determines where BEV owners charge. Increased charging interoperability and compatibility can in themselves promote electric vehicle distribution by reducing the complexity of owning an BEV.

Increased distribution of BEVs will have little impact on electricity prices as consumption will be low in relation to total electricity consumption. Challenges with local power grids, was found by NVE (2016) to be less likely for Norway.

To be able to reach the target of only selling BEVs in Norway from 2025, charging solutions for people living in dense parts of cities with on-street parking being the only available option, needs to be developed further. In addition, charging for people living in flats must be further developed (Figenbaum 2018a).

From range to charge anxiety

As BEVs get long enough range to cover daily needs, and are increasingly used for longer trips, the fast charging infrastructure becomes more important. Figenbaum (2019a) found that there are four typical users of fast chargers;

1. Infrequent and random use users charging to solve a problem on the go
2. Local users who occasionally recharge to solve daily transport needs
3. Long distance users using fast chargers to support long journeys
4. Frequent users who may lack home charging, or professional users, e.g. craftsmen.

One-car households were relatively satisfied with the Norwegian fast-charge offer in 2018, but said that charging queues can be stressful (43% agree fully/partially). Somewhat fewer said that they often had range anxiety (31% agree fully/partially) (Figenbaum and Nordbakke, 2019).

Limited range and charging challenges can mean that you do not go on a long journey with the BEV (31% agree fully/partially (Figenbaum and Nordbakke, 2019).

Users can experience charging queues in several parts of the country, both in daily traffic in their own municipality, and when driving on longer trips (Figenbaum 2019a). Charging queues can be more frustrating for car owners than charging itself because one has to sit in the car while waiting to get charged. Figenbaum (2018a) has calculated that BEV owners can benefit greatly from using BEVs locally. However, on long journeys there is an expense associated with the fact that it takes longer to complete the journey due to the need to recharge along the way, and due to queues.

The 2018 survey shows some acceptance among BEV owners for charging stops and queues on busy travel days. Charging time is spent using the charging station's facilities, take a walk, or read e-mails, etc. (Figenbaum and Nordbakke 2019).

There is uncertain data on how many quick chargers are needed per BEV. One estimate may be 1 charger per 100 BEVs in the car fleet Hardman et al. (2018a, 2018d), but there are few data that can substantiate a real estimate. The need may also be another with increasing charge speed (km range/min) (Figenbaum, 2018a).

Longer range means more frequent long distance trips

Everyone wants longer range because it presents fewer challenges and reduced travel time on long journeys, due to less needs to stop to recharge. In 2018, 40% of BEV owners said they could cope with 300 km winter range in winter. A winter range of 400 km increased the share to 66%. If those who have the longest travel needs during the major holiday periods (Easter, summer holidays, autumn holidays, winter holidays) choose BEVs with long range, the challenges can be more easily handled (Figenbaum 2018a, Figenbaum and Nordbakke 2019).

BEVs have been less used for long trips than other cars, due to these limitations as most BEV households also have a petrol or diesel car, and many BEVs are small. However, there is an increasing tendency for BEVs to be used on more and more of these trips, with longer range and improved charging infrastructure for long journeys.

The summer traffic peak may not be the most problematic. Among those who have such journeys, even an E-Golf with 230 km range can cover 40 percent of the range requirement for longer journeys in the summer, and 50 percent in the Easter vacation with one fast charge on the way (Figenbaum and Nordbakke, 2019).

58 percent of BEV owners have access to a cabin. Of these, 65 percent can charge there. Of petrol / diesel car owners, 51 percent have access to a cabin, and 35 percent of these have electricity available near enough to be able to charge an BEV. The average length of the cabin among the BEV owners was 163 km and among ICEV owners 145 km, with some variation between counties (Figenbaum and Nordbakke, 2019). Tesla owners and other long range BEV owners use their BEV to get to their cabins, whereas owners of small BEVs use their ICEV (Figenbaum and Nordbakke, 2019).

In 2016, it was asked how long range is needed in winter to make more people interested in buying BEVs. 300 km was the median for ICEV owners while the median for BEV owners was approx. 250 km (Figenbaum and Kolbenstved, 2016).

Daramy-Williams et al. (2019) found, through a more thorough analysis of 75 of 6,492 references on user experience with electrified cars, that the range of the BEV was not a deterrent, i.e. that BEVs can fit into people's lives.

Professional users have specific needs

BEV experiences in 14 inland municipalities in the Innlandet county were explored by Ydersbond (2018). She found that the municipal staff users say that BEVs are comfortable, easy to drive and economical in use. Use is promoted with political signals, enthusiasts in the administration, that BEVs range is increasing and BEVs has a better standard, and can thus more easily meet the transport needs, while being economical to use. Barriers are the lack of 4-wheel drive, users' range anxiety, lack of expertise and that leasing agreements prevent the VAT exemption from being realized. Long distances and harsh climatic and topographic conditions can be barriers in sparsely populated municipalities (Ydersbond, 2018).

Figenbaum (2018) found a large potential for electrification of light commercial vehicles used in craftsmen and service enterprise fleets if the winter driving range could be increased to at least 120 km all year. The vast majority could replace their entire fleets with battery electric versions if the winter range would increase to 200 km. Given the increased range for small and compact battery electric passenger cars, it can be assumed that to the extent such fleets use passenger cars, range is not a barrier anymore.

Utility of use build loyalty to battery electric vehicles

The majority of both BEV and ICEV owners said they would choose the same car type also next time. BEV owner loyalty increased from 89% in 2016 to 94% in 2018, while the loyalty of ICEV owners was reduced from 63% to 55% (Figenbaum and Kolbenstvedt, 2016; Figenbaum and Nordbakke, 2019).

Over half of the ICEVs owners, who said they would not buy a petrol or diesel car again, said that they would rather buy a BEV, and that environmental quality was a major reason. The major challenge ahead in the diffusion process will be to find strategies to influence the 55% who will still hold onto their ICEV (Figenbaum and Nordbakke, 2019), and those who are unsure of what they to do.

10.1.3 What users want

National and international research on BEV users (Figenbaum et al. 2019, Figenbaum 2018a, Figenbaum and Nordbakke 2019, Bjerkan et al. 2016, Ryghaug and Toftaker 2016, Hardman et al. 2019a) shows that user needs are quite similar across nations.

Cost equivalence and economy in terms of car ownership are the most important factors for consumers when choosing an BEV over another car. Reduced energy costs have an independent effect on BEV sales and are important for users, whereas environmental commitment is not a trigger for BEV purchases. However, as users gain experience two-thirds cite environment as an important advantage.

Infrastructure development has in all the studies been shown to have a positive effect. The opportunity to charge at home is also very important for BEV owners and potential buyers, because it makes life with an BEV easier and cheap electricity will be available. Range is no longer an unsurmountable obstacle to BEV adoption, as BEV owners has proven to be able to use their cars as intensively as other motorists do (Figenbaum 2018a, Figenbaum and Nordbakke 2019).

If even wider user groups are to be reached in Norway, BEVs must become more practical while remaining economically favorable, and more models must become available on the market (Fearnley et al., 2015; Figenbaum and Kolbenstvedt, 2016; Figenbaum, 2018a, Figenbaum and Nordbakke 2019), and in the most popular models/segments (Ryghaug and Toftaker 2016). The availability of models will increase significantly in the coming years and the driving range will increase while charge time will decrease, as seen in Chapter 6. Yet, current non-users say that they would ideally want even more range than the 250-300 km winter range that seems to be the new norm from small and compact vehicles (Chapter 6 and Figenbaum and Nordbakke 2019, Figenbaum and Kolbenstvedt 2016). Convenient, sufficient and efficient fast charging options will therefore need to be in place, as the fleet expands (Figenbaum 2019a,b, Figenbaum and Nordbakke 2019). In other countries it will be equally important to reduce purchase prices (Fearnley et al., 2015), through the introduction of purchase incentives for BEVs or increased taxes for ICEVs, to be able to speed up the adoption rates.

Liao et al. (2015) found that more attention should be directed at understanding how consumers make decisions under uncertainty, such as when facing uncertainty about the future second hand value of a BEV or the life of the vehicles battery. This concern seems appropriate for other countries less advanced in the adoption of BEVs than Norway.

10.1.4 Speeding up the diffusion process through policies

Economy of use and environment most important

BEV owners and owners of ICEVs had quite different opinions about how important various car properties were to their purchase. In the 2018 survey, they were asked to consider which car-related features were the most crucial to the purchase decision. The economy of use was the most decisive factor for BEV buyers, mentioned by 57 per cent in 2018 (Figenbaum and Nordbakke, 2019) and it was also very important for users in the 2016 survey (Figenbaum and Kolbenstvedt, 2016). However, as people take the BEV into use, the reduced environmental impact of BEVs is also valued highly (Figenbaum and Nordbakke, 2019). They are also concerned with reliability, good driving characteristics and driving range. Improving the quality of new BEVs in these areas must therefore be used in strategies to motivate current non-users to make better environmental choices. (Figenbaum and Nordbakke, 2019; and Figenbaum 2018a; Bjerkan et al., 2016). ICEV buyers emphasized that the car needed to be practical (38%), reliable (32%) and safe (15%), while the environment was mentioned by 1% (Figenbaum and Nordbakke, 2019).

Anfinsen et al. (2019) conducted 47 in-depth interviews with BEV owners about purchase motivation and how the BEV was perceived and worked for the household's transport needs. They found that men paid most attention to technology and women most to the environment, and that both were involved in the buying.

Orlov and Kallbekken (2019) found that in a sample of 1033 households who had bought a new car or are thinking of doing so within 12 months, risk taking willingness increased the likelihood of buying an BEV. Environment was of little or no importance, while funding could be a barrier that hindered adoption. Many are still skeptical about the cost savings of BEV use and uncertain about their reliability.

Olson (2018), unsurprisingly, through analysis of a small number of BEV owners who responded to a survey in Norway and California, found that politics and incentives drove BEV adoption in both countries. Limited range and high price were limiting factors. Olsen's selection was motivated more by the environment than by the economy. He also found that without price parity it will not help to remove range barriers, and that traditional marketing will have limited effect.

National and local incentives work best together

The fact that the economy is so crucial in BEV adoption is because the cars are more expensive to produce. Good national and local economic incentives for BEVs offset this in Norway. The national incentives, i.e. lower one-time tax and VAT exemption are important as BEVs price becomes competitive to ICEVs (Figenbaum 2018a).

Local incentive policies changed between 2014 and 2019. In 2014 there was free public parking and charging, free toll roads, cheaper ferries and access to bus lanes. In the fall of 2017, the Parliament (Stortinget) decided that BEV owners may have to up to 50% of what ICEV owners pay for parking, ferries and road tolls.

Accessible capacity in the actual bus lanes determine the type of access BEVs have. From the South-West and South-East into Oslo, there is a requirement that a passenger in the BEV must be present when using the bus lane during rush hour. The toll road rates have increased in Oslo and rush hour fees have been introduced in several places, but also more toll road projects have been introduced. Overall, the value of the local incentives has been reduced between 2016 to 2018 (Figenbaum and Kolbenstvedt, 2016, and Figenbaum and Nordbakke, 2019). The average value of local incentives per BEV owner in 2018 was NOK 14,150 per year. The 20th percentile was NOK 3450, the median value was 11,500 and the 80th percentile was SEK 24,235.

Mersky et al. (2016) isolated the effect of local incentive by using regional socio-demographic data (assumed from Statistics Norway), linked to data on BEV sales (divided into cars with short and long range), the size of local incentives (toll money and bus lanes) and the number of charging stations, to calculate geographical sales differences. They found that the access to charging stations was important at the regional level and that at the municipal level, household income was an important factor. The analysis was sensitive to proximity to large cities, an indicator of access to bus lanes, toll road exemptions and other savings.

Zhang et al. (2016) found that technology development was more important for market development than socio-demographic inequalities and local incentives, and that reduced toll fees and access to charging stations had an effect on sales of BEVs. In their survey, access to the bus lane access was not so important for private individuals, as they may think that the benefit will be lost eventually.

Nayum et al. (2016) found that BEV owners had a different socio-psychological profile than other car buyers. They are not as concerned with comfort and performance as ICEV buyers, perhaps because most also owned an ICEV. Although many people were concerned about environmental issues, it did not affect their car purchase. Incentives are important in making people choose an environment friendly car that is more expensive to buy, but it must meet user needs to speed up sales.

10.1.5 Potential undesirable effects of the diffusion of BEVs

Norway aims to curb the vehicle based traffic growth in cities by increasing the modal shares of public transport, bicycle and walking. BEVs can increase the risk of not reaching that goal. Figenbaum and Nordbakke (2019) found that a transition to BEVs can give about 2.4% increased driving per car among those who replace an ICEV with a BEV. There is a risk that up to 10% percent more BEVs end up as an additional car in household than when an ICEV is bought. On the other hand, 80 percent of BEV owners said the BEV replaced another car, most of them an ICEV, thus making a major contribution to reducing greenhouse gas and local emissions (Figenbaum and Kolbenstvedt, 2016; Figenbaum and Nordbakke, 2019).

The surveys in both 2016 and 2017 show that BEV buyers have a longer distance to work, more children and more reasons to buy an additional car than ICEV buyers. It is thus good reason to assume that they could have bought a petrol or diesel car if there was no suitable BEV in the market.

10.1.6 Can other countries reach Norwegian diffusion rates?

The Norwegian experience shows that BEVs can make a big impact on the market and function reliably in practice for many different types of users and applications when costs are competitive compared to diesel cars, infrastructure is available and reliable information on how the cars work is available. Almost all BEV owners, under these conditions, want to continue to be BEV owners, and new buyers can be convinced. It is easy to dazzle with the good user experience and positivity of Norwegian BEV owners. However, this is context-specific and related to the history of Norway's well-developed incentives and the development that has taken place over a period of almost 30 years. Competence has been built up among industry players that could be used to contribute to the big market introduction leap after 2010, and among potential buyers. The population has gradually been expecting BEVs to be on the market. BEVs have been well visible with EL signs (later EK, EV and EB) and permission to drive in public areas. The fact that most Norwegians know a BEV owner, that 1 in 3 have driven a BEV and another 1 in 3 have been passengers in a BEV makes sales easier (Figenbaum 2018a). Nevertheless, Norwegian experience may be relevant to assessing what other countries, where the BEV is hardly known, should do to accelerate BEV sales and the effects of it.

The BEVs in use in Norway have largely functioned reliably and solved users' transport needs. Incentives have created a competitive price and annual cost of use. The owners have learned to live with range restriction and long charging time. Surveys show that they drive as much yearly as other car owners. More than 90 percent of electric motorists in Norway want to continue as electric motorists. This will be important in other countries as well. Early users communicate practical experiences with electric vehicles in real traffic to their friends and acquaintances and influence their purchasing behavior. It is important that they become buyers. To get a basic positive overall user experience for the first BEV owners must also be at the bottom of other countries' work to bring up the BEV sales.

In other countries, fewer people have access to their own parking and the infrastructure will not be as well developed. In addition, there will be far fewer incentives, see Chapter 9, which can make up for the fact that BEVs are usually much more expensive than petrol and diesel cars. Fewer will be multi-car owners than in Norway. One-car owners in other countries will have to plan more and more thoroughly than the Norwegian BEV owners need to find quick chargers they can use along the way. In countries with less extreme temperature variation between summer and winter than in Norway, the real year-round range may be longer. Higher speeds on motorways are heading in the opposite direction.

10.2 LCVs

Little research has been done on the primary users of small and medium-sized LCVs, i.e. craftsmen and service companies. Some more research has been done in other countries on the use of such vehicles by large fleets of vehicles.

10.2.1 Technical approach

In Norway, Denstadli and Julsrud (2019) have researched organizational factors that influence the adoption of electric LCVs in craft and service companies. A survey of 264 executives in such companies in 2015 showed that 25 percent of companies considered using electric LCVs in the next 2 years and a further 27 percent within the next 5 years. They also found that the first companies to use electric LCVs had typically purchased a smaller number of electric LCVs to test how they worked in practice. Costs and reliability are highly valued by these users when choosing a vehicle, but environmental properties are also important. They can create a green image for the company and make the transport part of the company meet the requirements for environmental certification. The choice of an electric LCV was often promoted by a person with private experience of using a BEV.

Figenbaum (2018b) found that first generation electric LCVs could work for only a small proportion of Norwegian craft and service companies. The usage characteristics of first generation electric LCVs with approximately 140 km range (in the WLTP test) were slightly too short to meet their needs. The proportion that could use electric LCVs would increase if it were possible to recharge during the day or redistribute the transport needs between cars, so that diesel LCVs could take the longest trips and electric LCVs the shortest. Craftsmen found it challenging to use the cars as "craft cars" because they became less flexible to take on assignments during the day; the cars were therefore widely used by supervisors who drove between workplaces. The service companies are a little better off because they often drive shorter lengths per day and have a more repetitive usage pattern. It is also easier for them to find places to recharge during the day.

10.2.2 User experiences

Figenbaum (2018b) analyzed the usage pattern of 115 LCVs from seven companies in the Oslo area using GPS data over 14 days. The days with the maximum mileage were plotted on the y-axis and the annual mileage estimate on the x-axis (based on the two-week average), see Figure 6.12 in Chapter 6. The result indicates a techno-economic potential for replacing diesel LCVs with electric LCVs. Redeployment of the fleet or missions, charging during the day and longer-range LCVs can increase the proportion of LCVs that can be electrified. A 50 per cent increase in range increases the proportion that can profitably be electrified from 5 per cent to approx. 30 percent. Charging during the day can further increase the proportion up to 50 percent. Users even say that with a range of 200 km year-round, all cars can be electrified. In this way, they have a lower need for range than passenger car owners. The users also said that the substitution potential has been limited by the lack of larger LCVs and LCVs that can pull trailers on the market (Figenbaum, 2018b).

In addition to craftsmen and service companies, there are other vehicle fleets that use electric LCVs. The Norwegian postal service has a strategy to electrify as much of their business as possible and has put electric LCVs in the final distribution to the users along with smaller types of electric vehicles such as Paxster. The employees are said to be satisfied with the cars, but there have been some issues with respect to range during the winter (Hovi et al., 2019a). Wolff and Madlener (2019) found that postal workers at Deutsche Post accepted BEVs as a complete and partly better means of transport 3-4 years after Deutsche Post started the introduction of electric vehicles. Electric vehicles lead to perceived energy efficiency for drivers in commercial businesses, and perceived satisfaction with the cars leads to acceptance to their introduction into the business.

Globisch et al. (2018) found that the most important reason for BEVs being implemented in vehicle fleets was the personal interest in technology of people in senior positions. It can thus be worthwhile to find these persons and give them the responsibility of electrifying the vehicle fleet. Other factors include how innovation-oriented the company is, the expected environmental benefits and employee motivation. Fears that mobility may be curtailed and that the cars are less reliable can prevent new businesses from electrifying, but are not seen as challenges among those who have already electrified. Test programs, where companies can test the cars for a while, can thus increase the likelihood of adoption.

10.2.3 Potential for use

LCVs are a segment that is suitable for electrification. The cars are used by companies that respond more easily to costs than private individuals do. The need for range is slightly less than for passenger cars. 200 km year-round range may be enough (Figenbaum, 2018b), while consumers prefer to have 300-400 km and sometimes even longer range.

The first LCVs had too short a range to work for many businesses' needs. The generation of light LCVs available now can meet the needs of 30-50 percent of users, depending on whether it is possible to charge during the day. In 2 years, the next generation will have sufficient range to satisfy almost every use of light and medium-sized LCVs. All the LCVs will have the capability to fast-charge and most of them will be able to pull trailers.

Conditions for the full electrification of light LCVs from 2025 will, from the users' perspectives, be:

- at least 200 km year-round range,
- competitive total costs,
- ability to pull a trailer,
- access to charging where the cars are parked,
- fast-charging capability.

For heavy LCVs, the same conditions apply, but here the NTP target is 2030. The first heavy LCVs that use the battery and drive systems from light LCVs are such a limited range that they cannot meet many of the sector's needs, see Chapter 6. Considering the fact that heavy LCVs are lagging far behind the light LCVs in the development process, further developments will show whether the goal is achievable or not.

10.2.4 Summary

Up until 2018, BEVs had too short a range for large groups of users. They were only used to a small extent by companies with less intensive transport use, and by individual companies with driving patterns that were compatible with the limited range. Some LCVs available in 2019 have up to 150 km year-round range, and a significantly greater scope of application based on how users say they use cars and what real driving data shows. The sales statistics also show that market shares have increased (Figure 13.32). A further increase in the range to 200 km year-round, and the capacity to tow a trailer, will in principle open almost the entire LCV market to electrification, given that the costs will be competitive. This will also require that the large LCVs that come on the market eventually get a longer range.

Depending on local conditions, charging infrastructure can be a barrier for individual businesses, especially if the entire fleet of vehicles is to be electrified. Costs must be sufficiently competitive. While BEV use has been profitable in the passenger car segment for private owners since 2012, there has barely been cost equivalence for LCVs (Figenbaum, 2018b). Strengthening the market requires stronger incentives. Enova has therefore introduced a new support program for electric LCVs, which began in the autumn of 2019.

10.3 Trucks

The electric truck market is in many ways similar to the situation for electric passenger cars in the 1990s and up to 2008 (Figenbaum 2017). It took almost 20 years of niche market experimentation until the full-scale industrialization of BEVs for the passenger car market started. The BEVs that have launched since 2010 have been reliable and robust, and worked well for the users. The electric truck market may seem to be going through the same pattern. The first users have bought remodeled cars and several start-up companies are developing electric and hydrogen trucks.

However, there is reason to believe that developments in the truck market will go much faster than for cars. The technology is far better developed in 2019 than it was from 1990-2010 in the passenger car market, and the technology can also easily be transferred from the passenger cars. It is thus perfectly possible to make functioning, robust and reliable electric and hydrogen trucks already, albeit with limitations in terms of range. Therefore, the user experience so far need not be relevant to new and better products. The EU's CO_2 requirements for trucks for 2025 and 2030 entail a need to produce and sell electric and hydrogen trucks, see Chapter 11.

There are several start-up companies developing electric trucks, including Tesla and Nikola, and hydrogen trucks, including Nikola, but none of these can currently deliver products onto the market. Several of the major manufacturers are working on electric versions of their trucks, including Volvo, Scania, MAN and Mercedes. Therefore, it is assumed that future generations of electric trucks will be robust and reliable

10.3.1 Technical approach

The truck market responds to price signals to a greater extent than the passenger car market does. As soon as the solutions become cheaper for the users, are able to resolve transport needs and function reliably, one can expect them to be used in the trucking industry.

The main drivers in this sector are costs, profitability over time and strategic considerations, and that the companies have promoters that can keep the process moving until acquisition and implementation in day-to-day operations is achieved. For some companies, public tenders trigger the use of BE-trucks. In part, the process is also initiated by the company providing transport services based on public tenders where environmental factors are considered to be crucial.

For companies that use BE-trucks, the situation becomes easier when the products become available through the ordinary supply chains. Then access to spare parts will be much better and technical follow-ups can happen much quicker when problems arise.

The process of starting to use BE-trucks may in principle be similar to companies using BE-LCVs, see Chapter 10.2. But as the technology is lagging, the BE-trucks are not currently being used for normal operation. They are tested in demo and pilot projects, often initiated by someone internal to the company who is passionate about electrification (Hovi et al., 2019a), and it is the belief that this will be profitable for the company that is decisive. There is also a belief that investing in greener transport solutions over time will pay off, and that this will increasingly become a competitive advantage in tendering processes.

10.3.2 User experiences

There are few user experiences of operating electric trucks both in Norway and in Europe as a whole. This section is based on interviews conducted by Hovi et al. (2019a).

The traditional manufacturers have not made BE-trucks because they have felt that the technology has not been good enough for this segment. The few experiences that exist are therefore based on trucks that have been converted to electrical operation by independent companies that rebuild some tens or hundreds of trucks. The trucks have been tested in pilot programs and on various niche markets to a very small extent. The user experiences must be viewed in light of this.

Those who have tested BE-trucks in Norway are fundamentally positive to the technology and believe that these BE-trucks can be used for part of the transportation in their companies. Many have based this on knowledge they have accumulated as electric motorists in their private BEVs.

Currently, BE-trucks work best for companies with fixed driving patterns such as companies within waste management and for mass transport between nearby terminals etc. The cars themselves have in some cases worked well. In other cases, there have been 'growing pains' that have caused the trucks to be unreliable and sometimes have shorter and longer downtime. There have also been stops while driving on the roads. One challenge has been the underdeveloped supply chains, including a lack of Norwegian distributors, long delivery times and poor access to spare parts and personnel who can repair the cars. The companies have dealt with this because they have known that this is new technology and that the lessons learnt over time will push the technology further.

Drivers are satisfied that the BE-trucks are comfortable with little engine noise and no engine vibrations, but some experience the limited range as stressful. Winter driving has worked reasonably well without the range being significantly reduced according to the companies. This may be because the BE-trucks use year-round tires and that heating the interior of the cabin represents a much smaller proportion of total energy consumption than for passenger cars or buses. The companies have partly had to change routes or driving patterns to make the electric trucks work optimally to meet the needs of the company.

10.3.3 Potential for use

A large proportion of the truck transport (vehicle and tonne-km) are carried out by heavy trucks with large engines, which often pull trailers, and run over long distances. The truck owners usually transport goods on contract for carriers and companies. A smaller proportion is transportation activities where the carrier or the company that wants goods transported owns his own trucks. The most suitable applications in the start-up phase will be urban logistics, waste collection and handling, and other transport operations where neither a long range nor a powerful engine is required. This constitutes a small proportion of the number of trucks and an even smaller proportion of the transport work (4 per cent is carried out by trucks with less than 500 kW motor and maximum 200 km driving distance). If the range can be increased to 300 km and the engine power to 600 kW, this will theoretically allow the electrification of over 50 per cent of the truck transport in Norway. The assumption is that this can be done in a way that is profitable for the truck owner (Hovi et al., 2019a).

There are also some practical barriers, such as the fact that a large proportion of truck owners are contracted to drive by others, may have multiple clients throughout the year, and have relatively few trucks in the fleet (Hovi et al., 2019a). How fast charging and night charging will take place in this market is also far from clear, especially for trucks that do not have a fixed base. There are major costs associated with keeping the car stationary, in the form of direct expenses tied to the car's depreciation, the driver's salary and in the form of lost revenue. There is also a risk that the cargo cannot be delivered at the agreed time, which might be a breach of contract. Charging queues could therefore have major consequences in this market. Charging during the imposed rest period or during loading and unloading will be most optimal for this sector.

10.3.4 Summary

The use of BE-Trucks is in the early stages and few user experiences are available. Users report some early problems and that some trucks have been operating unreliably, but also that BE-Trucks can operate even with limited range for specific applications, currently in urban areas for local transport. To some extent, they have had to change routes and transport to achieve this. They report that it might be financially beneficial to use more electric trucks in the long term, but they first want the car manufacturer to have Norwegian representatives, a good service network, and many would still prefer to buy from the traditional suppliers. The drivers feel like they have a good working environment, but they sometimes experience range anxiety. The cars are bought, in part, to win tenders that emphasize environmental factors and also to ensure that the company is testing new technology relatively early on.

However, more testing of electric and hydrogen trucks is needed so that a real operating experience in Norwegian conditions can be established. How does it work in practice when electric and hydrogen powered long haul trucks have to drive across mountain crossings in winter weather, in extreme cold, while waiting for column driving etc.? Can goods be delivered on steep routes? Getting answers to questions such as these requires that the cars be tested in practice first.

10.4 Buses

There are currently no battery electric or hydrogen powered long distance buses on the market. It is thus only possible to look at user experiences with city buses.

10.4.1 Technical approach

Electric buses and hydrogen buses are used in closed transport systems where the buses travel along fixed routes. For electric buses, charging takes place overnight in the depot, and possibly during the day, either with visits to the depot in the middle of the day or from fast charging stations located at bus stops or end stops. The hydrogen buses for Ruter in Oslo are filled at the bus depot from a separate filling station.

Buses for urban use are purchased by bus operators who put the buses into routes that are run on public tenders, that is, county municipalities (Hovi et al., 2019a). The user can thus be defined either as the public transport company for which the bus operator tenders, i.e. Ruter, Kolumbus etc., or the bus operator itself, i.e. Unibuss, Nettbuss etc. In this report, the user is defined as the one who actually operates the bus, i.e. the bus operator.

City buses reflect a market that is almost 100 per cent controlled by the public tenders. By weighting the environment highly or requiring zero emissions, they can de facto push towards a 100 per cent electrification of the bus fleets in Norwegian cities. This requires that there are sufficient suppliers of electric and hydrogen buses on the market for proper bidding and procurement processes to be carried out by the public transport companies and the bus operators. Thus, it is technological development, experience-building and access to series-produced models that are the most crucial factors for achieving the 2025 goal.

However, user experiences are nevertheless interesting because one can uncover barriers to adoption. It might be shown through practical testing that the technology must be further developed to make it possible to electrify all the bus routes in all Norwegian cities. Barriers that must be removed in order to meet the 2025 goal for city buses might also be uncovered. At the same time, we are testing today's technology. Technology will have developed significantly by 2025, and its development will have taken the experiences of the first users into account.

A major challenge in this sector is how to get enough electricity to charge all the buses at the depots at night and who will own and install the infrastructure being used.

10.4.2 User experiences

Experience has been limited so far. Hovi et al. (2019a) have looked at user experiences with Norwegian electric buses. Operators who have electric buses in operation have been interviewed about how the buses have worked in Norwegian cities. The text here is based on that report.

In several of the cities, there have been delays in the early phase related to the delivery of buses and the establishment of charging infrastructure. The operators who were supposed to establish fast charging at the end stop in highly urban areas have found it difficult to get permission to set up a charger at the end stop in the middle of Oslo city center. Furthermore, another fast charger located in the port area of Oslo has been knocked over by trucks. The buses in Oslo have thus ended up as rush hour buses that charge overnight and in the middle of the day during the low traffic period.

The buses are purchased for specific routes where the required battery size can be calculated. In order to meet the heating demands in the winter (which then accounts for half of an electric bus's energy consumption because the doors open frequently and let the heat out) the bus must either have a very large battery, recharge during the day, or have a combustion heater that uses diesel/biodiesel. Different solutions have been chosen in the different cities to meet this challenge. Some operators have experienced major discrepancies between stated and actual range, which is partly due to the thermal energy needed to keep the bus heated in winter. Without heating, city buses use approx. 1.0-1.5 kWh/km, while heating with electricity from the battery can increase consumption by up to 1.2 kWh/km.

The design of the bus has been acceptable, but one operator felt that the increased roof height created challenges on a route where a low bridge under the railway had to be passed. Although they tried to lower the bus and use the "Geo-fence" function to lower the bus air suspension when passing under the bridge, they were not allowed to drive under the bridge. Another challenge has been that 15 meters long buses have not been available on the market nor class 2 buses (seat belt requirement), although this is not an issue anymore in 2020. This bus type is widely used in Norway, and it is therefore of great importance that such bus types now are available in the market.

The engine power has been acceptable for the city buses, but a challenge has been a type of mini-buses where the drivers have barely managed 40 km/h in steep uphill slopes. This creates stress for the driver. Some drivers feel range anxiety, and are anxious for the bus to stop between stops for energy. The comfort is better than in a diesel bus due to the absence of engine noise and vibration. The number of seats is about the same as in a diesel bus according to the operators, but the number of standing spots might be somewhat less. This may lead to a need to run more buses to carry out the same transportation work, which will affect costs.

Battery life is expected to be the same as the bus life, but the operators currently have very little experience. One type of minibus has had challenges to do with battery life. To some extent, the battery risk can be eliminated through agreements with the provider of the bus.

Charging takes place overnight in depots and in part for some buses at the bus stop and end stop with the "OppCharge" pantograph connection. There have been no particular challenges in establishing depot charging in the limited tests that have been carried out with only a few buses by each operator. When fully rolled out, large charging systems are needed. These can be more challenging to establish, depending on where the depot is in relation to available network capacity. Charging infrastructure becomes a key factor in electric bus introduction. It is conceivable that infrastructure costs will be so high that electric bus operation becomes too expensive in some places.

The buses have had some 'growing pains' and there have been challenges to do with service and repairs that have taken a long time to complete. The operators are looking forward to the ordinary suppliers beginning to supply electric buses so that this part of the electric bus operation becomes more predictable. In all bus operations, there is a need to have a certain proportion of spare buses. In the electric bus tests there have been so few buses that the spare buses have been diesel buses.

Electric bus operation is a new mode of operation that requires adjustments to the route operation and organization. Several of the operators had to change their route plans somewhat in order to use the electric buses for routes other than those originally planned. This is primarily due to challenges in establishing the charging infrastructure. The electric buses must to some extent follow a specific charging pattern, especially during the start-up phase, in order to extend the battery life.

Hydrogen buses have also been tested in Oslo. This has consisted of the pilot testing of prototype buses. Experience has been mixed with many technical challenges and long periods where the buses have been out of service due to missing spare parts.

10.4.3 Potential for use and summary

The technology provides electric city buses with properties that in principle might allow all diesel buses to be replaced with electric buses in Norwegian cities. Local conditions will have different consequences in relation to the choice of charging solution, battery size and whether more buses are needed to deliver the same transport work. These are also factors that affect costs. The biggest barriers will be extreme winter conditions in some places in Norway, the ability to heat the buses, charging infrastructure and the fact that the cost of public transport might increase.

There is currently little real operating experience with electric buses in Norway; only a few short demonstrations with variable results. This will change quickly. In several cities, regular scheduled buses have started running. It is only when the results of these are available that one can comment on how the aforementioned factors affect market development.

11 Analysis of driving forces

In this chapter, additional factors along with driver and barrier forces that can influence the situation are analyzed. Finally, these forces are considered together.

11.1 Framework

The discussion in Chapter 10 shows that battery electric vehicles are meeting an increasing number of user needs, thanks to the technological improvements discussed in Chapter 5, and the large-scale product development and industrialization that is underway, as shown in Chapter 6. Chapter 7 highlighted that there is a great need for more infrastructure, and Chapter 8 that the countries have different prerequisites for introducing BEVs. The costs, which are described in Chapter 9, have fallen rapidly since 2011 and will probably become so low by 2030 that BEVs can become competitive with ICEVs without purchase incentives. Even so, there will be challenges related to a full switch away from fossil fuel to electricity and hydrogen.

The main challenges of a full transition to zero emission mobility and zero emission freight transport can be summarized as follows:

> <u>Vehicle buyers have a well-functioning, existing means of transport in today's internal combustion engine-based vehicles. These vehicles enable traveling and the carrying out of transport assignments anytime and anywhere supported by the existing vast refueling infrastructure. Vehicle buyers, if society does not act, can continue using these vehicles as before without inconvenience. However, society needs to change its purchasing behavior so that zero-emission technology is chosen. Taking care of society's needs can bring about disadvantages for the users, while society benefits. A key question is therefore: How can the disadvantages be reduced so that the car buyers make the right choices so that, in turn, the benefits can be reaped?</u>

The vehicle buyer is influenced by internal driving forces and preferences in the process of vehicle selection, and external driving forces or framework conditions. This chapter focuses on the latter; the drivers and barriers behind the development in the supply of vehicles, the market, politics and incentives, and technology for zero emission vehicles on a global level, in Europe, and at national, regional and local levels in Norway. The market may also be affected by exogenous trends such as urbanization, automation, digitization, changing car habits, and changes in the population structure. The vehicle buyer's choice occurs at the intersection of the driver and barrier forces as shown in the framework for the assessment of driving forces in Figure 11.1.

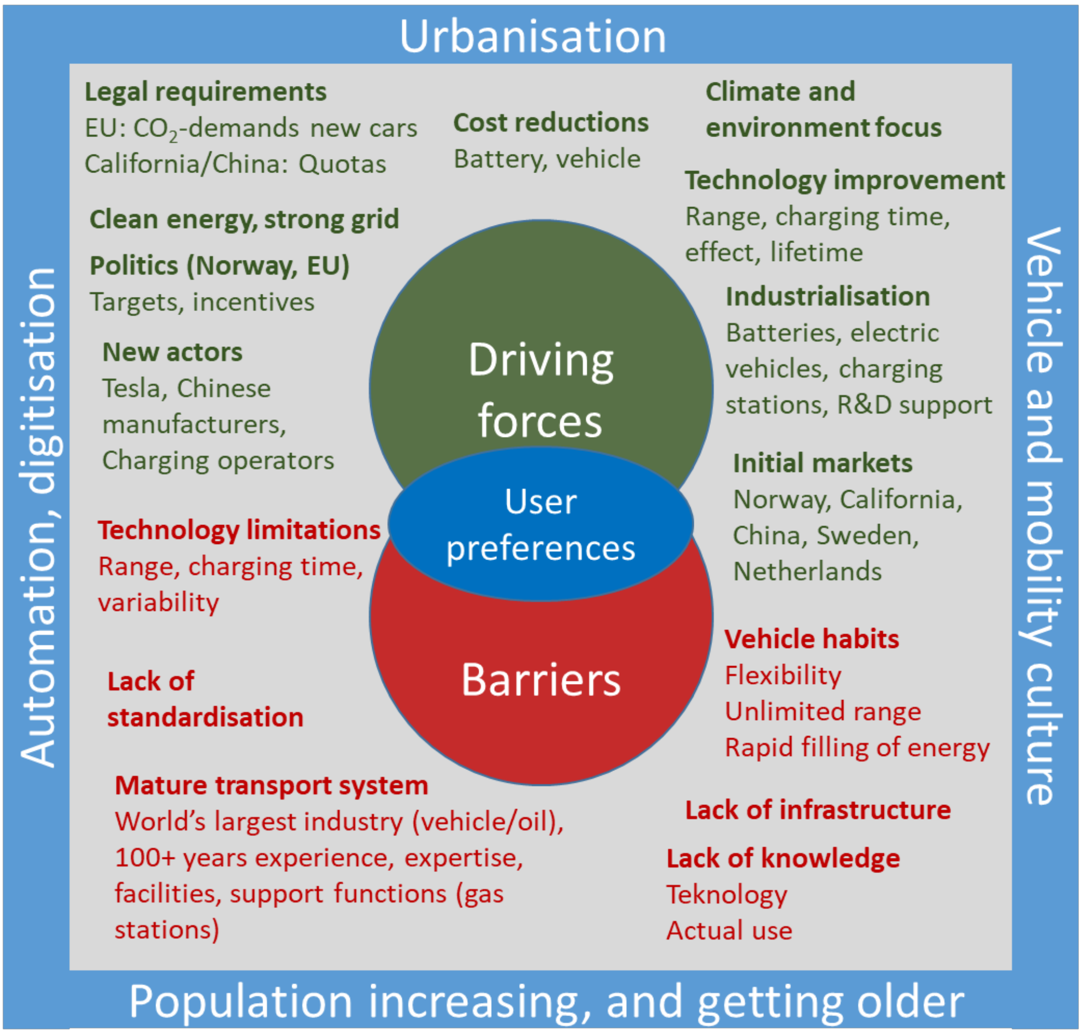
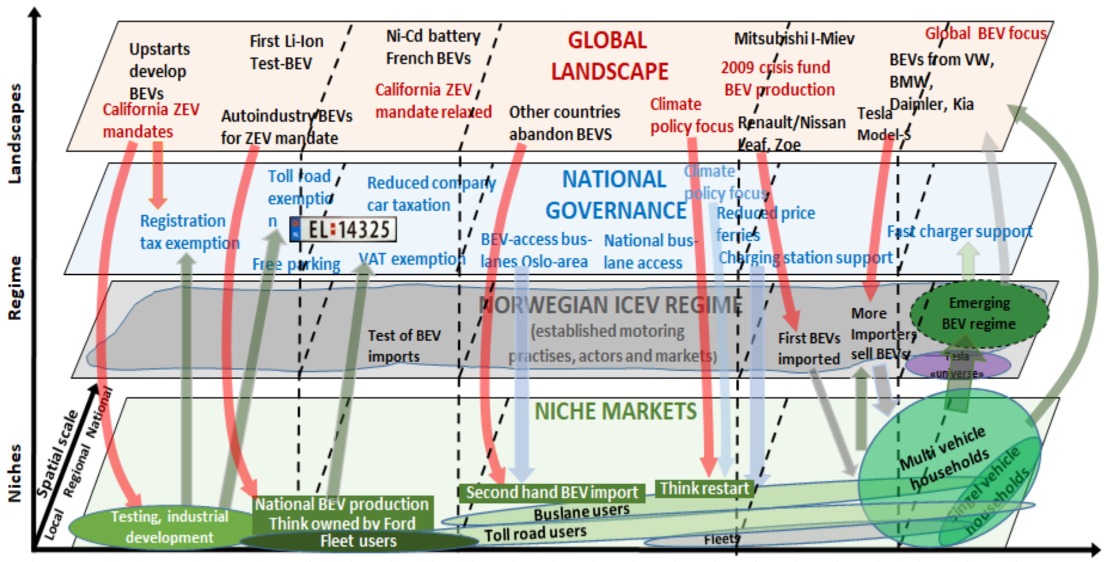


Figure 11.1: Framework for analysis of driving forces. Source: Own analysis.

11.2 The transition to battery electric and hydrogen solutions will take time

The barrier forces shown in Figure 11.1 are about barriers to change, that is, the existing system is well functioning and difficult to change. It is not impossible to make changes, but the experience of the introduction of BEVs in Norway indicates that it will take time in other countries that are lagging, and large incentives and a long-term policy will be required. Other barrier forces are technical limitations in the early phase of introducing a new technology, such as reduced range or increased time to fill energy, and a lack of standards or insufficient build out of infrastructure.

Using Geels' (2012) Multi-Level Perspective Framework (MLP), Figenbaum (2017) found that the BEV development in Norway has taken place through a complex interaction between international politics and technological development, the car regime (car manufacturers, car importers, car dealers), motorists' car use habits etc., and experimentation in niche markets. This interaction has taken place with stable framework conditions over a period of almost 30 years. The result is the establishment of a BEV regime assimilated into the ICEV regime of the existing players, as shown in Figure 11.2.



1990 1995 1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
BEV percentage of total fleet	0.03	0.03	0.05	0.06	0.06	0.07	0.08	0.09	0.11	0.12	0.15	0.23	0.4	0.8	1.6	2.7%	**4%**
BEV percentage of new vehicle sales											0.3	1.4	2.9	5.6	12	18%	**16%**

Figure 11.2: A multi-level perspective on BEV development in Norway from 1990-2016. Source: Based on Figenbaum (2017).

The experimental phase

Inspired by the trend of BEV requirements in California (requirements that meant a minimum share of zero-emission cars had to be sold within a given year), Norwegian pioneers began testing BEVs in niche markets in the early 1990s. The exemption from the registration tax from 1990 onwards made this possible, and also led to the attempts to industrialize BEVs in Norway throughout the 1990s. Think developed a full electric passenger car and, after a bankruptcy in 1998, was bought by Ford who needed a cheap BEV they could sell in California to meet the legal requirements there. The Think factory opened outside of Oslo in 1999. Several new incentives were then introduced to develop a Norwegian domestic market for BEVs, thus supporting Think and Ford. Particularly important was the VAT exemption from 2001 and the exemption from toll road fees from 1997. In 2002, the California requirements were changed, Ford no longer had to sell BEVs there and sold Think. BEV production stopped in Norway (and other countries), but the Norwegian incentives remained and stakeholders could continue experimenting with niche markets. They were aided by the fact that BEVs, from 2003, were allowed to drive in bus lanes. In this way, the BEV expertise and the BEV market were slowly building up in Norway until 2010.

New windows of opportunity with increased global focus

The global climate focus increased significantly in the period 2007-2010, especially around the UN Climate Summit in Copenhagen in 2009 (COP 2009). This resulted in new enthusiasm towards developing BEVs on the part of the major traditional car manufacturers, and several of them began BEV production. Politicians in different countries supported the new development by introducing production and purchase incentives for BEVs.

By 2010-2011 vehicle manufacturers had developed and started to produce BEVs. The Norwegian importers seized the window of opportunity that arose and started selling BEVs, with immediate success. Mitsubishi was first, followed by Peugeot, Citroën and Nissan. From 2013 onwards, more and more models came from other car manufacturers.

The cars gradually improved with longer range and faster charging. Prices fell to a level where the cost disadvantage could be eliminated in Norway, thanks to tax exemptions and local incentives. The development of fast chargers enabled longer journeys and created a local safety net. Thus, the BEV has, for ever larger groups, emerged as a product that addresses their transport needs, and offers relative advantages over gasoline and diesel cars in terms of cost, despite some user disadvantages when it comes to range and charge time. Incorporation into the existing car regime made the transition much faster due to their vast available resources in terms of dealerships and service networks.

Using Roger's theory of the diffusion of innovations as a framework (see chapter 10), Figenbaum and Kolbenstvedt (2015), and Figenbaum (2018a) found that BEVs first came into use in cities and around cities where the relative advantage of buying and using BEVs and the revenue and educational level is highest. Thereafter, the BEVs gradually spread out to a larger surrounding area that has grown into continuous regions. The development is due to a mix of incentives that have given the BEV owners relative advantages, the fact that knowledge about BEVs has spread in the population, and that the local incentives have spread BEVs to new places faster than would otherwise have happened.

Lessons from Norway?

The analysis referred to above was made to understand the BEV development in Norway, but is also relevant to other countries. The Norwegian tax system has given Norway great freedom to "filter out" cars that are unwanted on the market (have large emissions), and support those that have been wanted (BEVs and cars with low emissions), with the result that BEVs have become very attractive on the market. Local incentives have contributed to the geographical spread, especially the exemption from road tolls. This is not the case in most European countries where there is less freedom to impose incentives because they have to take into account their own car manufacturers (for example in Germany and France), or because they are more dependent on income from car taxes and energy taxes.

Other relevant lessons are that changes take a long time and take place through complex processes that one cannot always predict the outcome of. A success factor in Norway has been the fact that the engagement was built up from below by players who have experimented in niche markets. As soon as electric vehicles became available, the traditional players took advantage of this opportunity using their marketing and customer expertise, as well as their dealer networks, causing developments to accelerate rapidly.

Internationally, the situation in 2019 is such that the attempts to establish the BEV market through pressure from above have been met without any commitment from the bottom up, and sufficient knowledge and competence have not had the time to become established, neither in the car industry, among infrastructure players or among consumers.

Relevance for LCVs and trucks?

Although Figenbaum's analysis was made for the passenger car market, the results also have relevance for the LCV and truck markets. For LCVs, developments have taken place in parallel with passenger cars. However, LCVs have not fully met user needs and they have been less profitable to use because the most important incentive, the VAT exemption, has zero effect in this market (Figenbaum 2018b). Denstadli and Julsrud (2019), and Julsrud et al. (2016), found that this type of user advocates using electric vehicles in the company as a result of positive private experiences with BEVs, customer needs, or requirements to reduce emissions as part of environmental certification schemes.

The market for electric trucks is in its early stages and there is experimentation in niche markets as was the case for passenger cars in the period 1990-2010. There are players that re-build diesel trucks to battery electric version of variable quality. These electric trucks are being used and tested by innovative transporters who want to increase the use of new, more environmentally friendly technologies in the sector. This experimentation builds up engagement and interest from below.

Start-up companies such as E-Moss, Tesla and Nikola can aid in the development of niche markets for battery-electric or hydrogen trucks, but if the market is going to fully develop, as for passenger cars, the big manufacturers and their resources will be needed. These resources can be mobilized quickly when products first come on the market (Figenbaum 2017). Several of the major traditional manufacturers have announced that they will start production of electric trucks in the period 2020-2022, as shown in Chapter 6, and there is a strong political focus on finding solutions to reduce the climate gas emissions from trucks. Thus, it will hardly take as long as it did for passenger cars to get this market going.

11.3 Buying and using a car is increasingly complicated

BEV purchase and use has become more, not less, complex in recent years. From a fairly homogeneous car type, BEVs are now a very heterogeneous product, unlike traditional cars where you mainly can only choose between gasoline and diesel models and engine size.

The BEV buyer must consider that different BEVs have very different driving ranges with different options for the size of the battery. There are three different charging standards (Chademo, CCS, Tesla), two main types of normal charging cables (Schuko and Type 2, with the latter coming with different power ratings), and different sizes of chargers in the car (3.6-22 kW, which also complicates the choice of the home charging box or wall mounted Electric Vehicle Supply Equipment, EVSE). The cars also have very different fast charging power capabilities, ranging from 50-350 kW, which affects how long the charging takes. At the fast charge station there may be several types of fast chargers to choose from with different power ratings, and if you choose the wrong type of charger, the costs can be high as it costs more to charge from a high power charger than a standard 50 kW charger. The picture is further complicated by the fact that the cars cannot be charged with as much power as the charger actually can deliver and that the deviation varies considerably between cars and seasons (Figenbaum 2019b). The energy consumption and the range also vary substantially between seasons. In the winter, the range can be reduced by 30-50 per cent, due to the need to heat the interior and the increased driving resistance. Driving on highways at 110 km/h or higher also leads to a high energy consumption. This variability in energy consumption and range is much greater than for gasoline and diesel cars and is much more problematic because fast charging takes a long time.

Cars with a large battery take longer to charge using 50 kW fast chargers than those with smaller batteries. Fast charging can also take different lengths of time for different models that have the same size of batteries, due to differences in the battery's cooling/heating system, differences in the charging state of the cars and the battery temperature at the start of charging. It thus becomes difficult to know how long the cars in front in a charge queue will spend charging. The charging queue time thus becomes unpredictable and more stressful for users.

Other complicating factors are other possible technology choices a car buyer can make, such as continuing with petrol or diesel cars, or choosing another alternative such as a PHEV or hydrogen car. It can also be difficult to find BEVs capable of towing a trailer.

TØI's user surveys, discussed in Chapter 10, show that the buyer initially emphasizes economic factors and may be somewhat concerned about range and charging when purchasing a BEV. After driving an BEV for a period of time, range and charging seem to become minor challenges, and the emphasis is on environmental benefits, and the comfort of charging at home.

Almost all existing BEV users say they would re-purchase a BEV. For the current hesitant ICEV owner, the increasing complexity and unpredictability will not warm them up for BEVs.

11.4 EU legal requirements foster technology and market development

The EU work on imposing requirements for CO_2 emissions from vehicles and facilitating better infrastructure for electric and hydrogen vehicles is explained by the need to reduce greenhouse gas emissions. In addition, the EU is also concerned with the future competitiveness of Europe's automotive industry.

On a global level, car manufacturers regulate the total production volumes of zero-emission cars according to where there are regulatory requirements with quotas for the sale of such cars. Such regulations can be found in California and China, as well as in the EU. The EU CO_2 requirements for vehicles are part of a larger package of measures and instruments as shown in Figure 11.3. For this report, the effects of the EU CO_2 requirements will be evaluated.

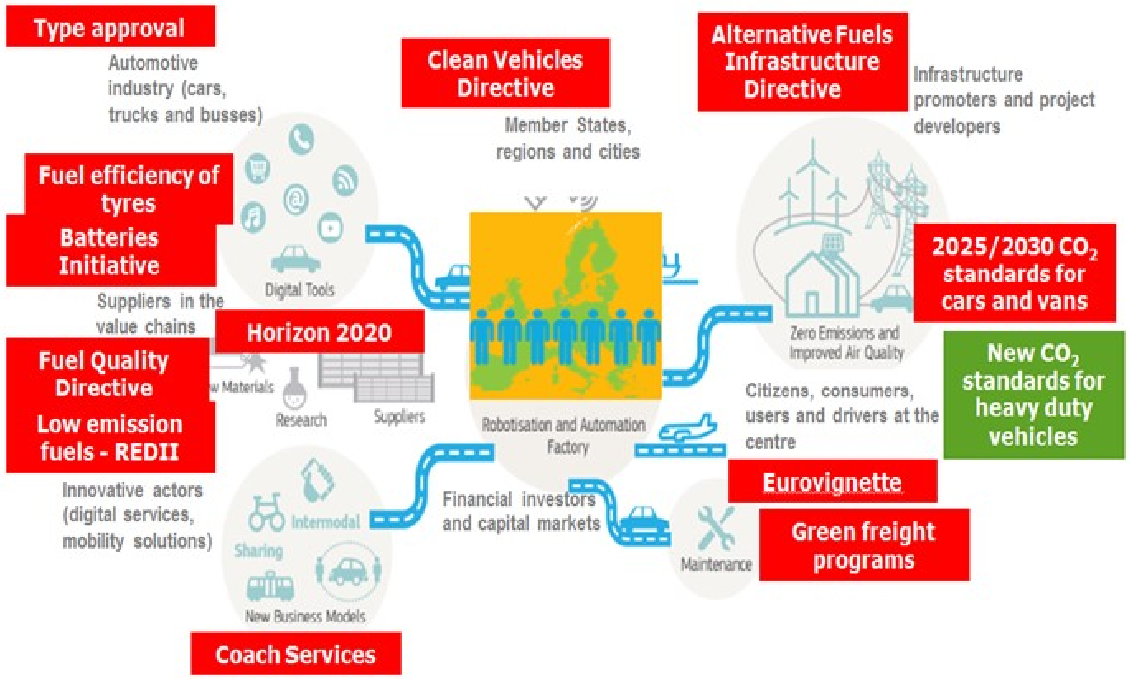


Figure 11.3: Overview of EU transport policy measures. Source: EU Commission 2018.

The EU has set targets for CO_2 emissions reductions from new vehicles between 2020 and 2030 which in practice mean that zero- and low emission vehicles must be sold in increasing numbers. Vehicle manufacturers are fined if these requirements are not met. EU Regulation 2019/631 regulates CO_2 emissions from passenger cars and LCVs. The Regulation is effective from January 2020. The targets are set out in Table 11.1, which are based around the years 2025 and 2030. The targets are set as percentage reductions, with 2021 as the base year. The targets are set based on an average value for all newly registered cars, LCVs and trucks in the EU vehicle fleet.

Table 11.1: EU legal requirements for reducing new vehicle CO_2 emissions 2020-2030.

Vehicle type	EU regulations for reducing new vehicle CO_2 emissions	Reference
Passenger cars	The EU's goal was that in 2015, the average CO_2 emissions from new cars should be a maximum of 130 g/km (Regulation 443/2009). From 2021, but phased in from 2020, emissions from the average car will drop to a maximum of 95 g CO_2/km. Super credits are granted for low-emission cars (<50 g/km), in the period 2020-2022 and there is a 5% flexibility for 2020. The targets that have been set for 2025 and 2030 (Regulation (EU) 2019/631) involve a reduction in emissions from the 2021 level of 15% CO_2 reduction in 2025 (to 80 g/km) and 37.5% from 2030 (to 60 g/km). The fine for not meeting the requirement is 95 Euro/g/km/car.	https://ec.europa.eu/clima/policies/transport/vehicles/cars_en https://ec.europa.eu/clima/policies/transport/vehicles/regulation_en
LCVs	CO_2 requirements for new LCVs were introduced in 2011 (Regulation 510/2011), and will average down to 175 g/km for 2017 and 147 g/km CO_2 for 2020. Regulation (EU) 2019/631 currently sets the targets for after 2020 as a percentage reduction from the 2021-level of 15% CO_2 in 2025 (to 125 g/km) and 31% from 2030 (to 101 g/km) The fine for not meeting the requirement is 95 Euro/g/km/car	https://ec.europa.eu/clima/policies/transport/vehicles/regulation_en https://theicct.org/sites/default/files/publications/ICCTupdate_EU-95gram_jan2014.pdf
Trucks	A new EU Emissions Regulation (Regulation (EU) 2019/1242) entered into force from Aug 2019 for heavy duty vehicles. The CO_2 targets are expressed as a percentage reduction of emissions in relation to the reference period July 2019 to July 2020. From 2025 emissions will be reduced by 15% and from 2030 by 30% in relation to the reference period. The requirements initially apply to large trucks, but may in the future also apply to smaller trucks, city buses and coaches/long-distance buses. The fine for failing to meet the requirement is 4250 Euro/g/ton-km/car in 2025 and 6800 Euro/g/ton-km/car in 2030.	https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en
Electric vehicles generally	The regulatory requirements described above also include other elements that incentivize the introduction of zero-emission vehicles.	

The emission requirements for the various vehicle manufacturers can be slightly adjusted (until 2024: by a factor of 3.33 g/km per 100 kg weight difference between the weight of their vehicles and the EU average). If the targets are not met, the car manufacturer will be fined. From 2020, violations of the regulations will be penalized €95 for each g/km (per newly registered vehicle) that deviates from the target. Compliance with the targets is tested through the type-approval test for new vehicles. In addition, from 2021, data will be collected from the vehicles fuel gauge (OBFCM). It will then be possible to detect any differences in the car manufacturer's stated CO_2 emissions in the type-approval test and the vehicle's emissions in real traffic.

To promote the phasing in of zero and low emission vehicles (ZLEV), car manufacturers can receive deductions in the CO_2 requirement provided they reach specified target figures for sales, which are:

- For passenger cars: A share of 15 per cent ZLEV by 2025, and a share of 35 per cent ZLEV by 2030.
- For LCVs: A share of 15 percent ZLEV by 2025, and a share of 30 percent ZLEV by 2030.

ZLEVs are defined as vehicles with CO_2-emission of 0-50 g/km. The ZLEV factor will range from 1.0 to 1.05. That is, a car manufacturer can receive a deduction of up to 5 percent in the CO_2 requirement for other vehicles provided that the sales share of ZLEV vehicles is 5 percentage points or higher than the target stated above. When calculating the ZLEV factor, the different ZLEV vehicles are weighted differently depending on actual

CO_2 emissions. Since the lowest ZLEV factor is 1.0 - this means that car manufacturers are not penalized if they do not reach the ZLEV target figures. In the period 2020-2022, a "super-credit" system will be available for ZLEV. This system assumes that when the average CO_2 emissions are calculated, the ZLEV vehicles count more:

- ZLEV counts as 2.0 vehicles in 2020
- ZLEV counts as 1.67 vehicles in 2021
- ZLEV counts as 1.33 vehicles in 2022
- ZLEV counts as 1.0 vehicle in 2022

EU Regulation (EU 2019/1242) regulates the emission of CO_2 for heavy vehicles, emission reduction targets are set for 2025 and 2030, see Table 12.1. Initially, the requirements will only cover vehicles in the N2 (trucks weighing 3,500-12,000 kg) and N3 (trucks weighing over 12,000 kg) classes. The use of the vehicle could affect the target number, for example some types of special vehicles are exempt from the requirements. When the Regulation is to be revised in 2022, buses may also be covered by the Regulation. Target achievement is recorded both in the type-approval test and when data is obtained on the vehicle's fuel consumption.

If the requirements are not complied with, the vehicle manufacturer can be fined. The fines per vehicle are €4250 per g/tkm from 2025 and €6800 per g/tkm from 2030. As is the case for light vehicles, the Regulation contains incentives to promote the phase-in of ZLEV vehicles. A "super-credit" system is valid for the period 2019-2024. From 2025, this system will be replaced with a system based on target achievement. If the target of 2 percent sales share of ZLEV vehicles is achieved, it will be possible for the vehicle manufacturer to deduct any excess emissions in the emissions from the other heavy vehicles. The ZLEV factor for heavy vehicles will range from 1.0 to 1.03. In other words, the EU does not expect a comprehensive electrification of trucks in the period leading up to 2025.

Both EU Regulation 2019/631 for passenger cars and LCVs and EU 2019/1242 for heavy vehicles contain requirements for large reductions in CO_2 emissions. In addition, a tightening of rules on the testing routines has been introduced to verify that manufacturers comply with their emission reductions and high fines for violating the regulations have also been introduced. The regulatory incentive system for zero- and low-emission vehicles can make it more attractive for vehicle manufacturers to intensify production of these types of vehicles. The fines greatly exceed the cost of meeting the original requirement, which explains the huge development in the number of models that are coming onto the market, and the large volumes of electric vehicles that are planned to be sold.

11.4.1 CO_2 requirements cause the rapidly increasing electrification of passenger cars

In the passenger car market in Europe, the EU requirement for reduced CO_2 emissions from new cars is the biggest driver of development. Vehicle manufacturers will be able to meet these requirements by following a suit of strategies. Better gasoline and diesel engine technology and hybridization may reduce emissions somewhat, but is far from enough to reach the goals for passenger cars (Fritz et al., 2019; Plötz, 2019). Failing to fulfil the requirements is hardly a sustainable option for the car manufacturers due to the fines.

In practice, the EU requirements therefore require that a certain proportion of BEV, PHEV and/or FCEVs will have to be produced and sold in the 2020s. The statutory requirement will thus help to ensure that these types of cars become available in greater quantities over the next decade. Car manufacturers are, as a result of this legislation, likely to increase their production of different types of electric vehicles faster than they would otherwise, and prices for the different types of vehicles will at the same time fall faster because large-scale production can be reached sooner.

Where the cars end up in Europe and which technologies get the greatest market share will be determined by:

- Where the strongest purchasing and user incentives are
- The structure of the incentives
- The extent to which petrol and diesel cars are «punished»
- How well the countries have adapted to BEVs or hydrogen
- How much the relevant user groups know about the technologies
- The size of the markets

All car manufacturers are working hard to meet the requirements. They implement measures across their entire product range, from terminating certain models with high emissions or small cars that can't adapt to new technology (Autonews, 2019c), to streamlining and hybridizing petrol and diesel cars, and developing and selling BEVs in different variants and segments, as documented in Chapter 6. Those who do not meet the requirements can enter into a partnership with others and their volumes will be assessed together, as Fiat has done with Tesla. Fiat avoids fines, but must pay Tesla hundreds of millions of Euros for this "service" (Reuters 2019b).

BEVs are expected to grow the most by far of the three alternative main technologies. The new generation of PHEVs will also be able to take a share of the market in Europe because they will get a significantly longer range than before, and more models are coming on the market. FCEVs are considered by the authors to remain a niche product until at least 2025, and there are few car manufacturers focusing on the technology. Only a handful of FCEV models will be available on the market up to 2025 (Chapter 6). Looking towards 2030, the situation is more uncertain, and the development of FCEVs will likely depend on whether the BEVs have been a hit or not. If the BEVs are a hit, there is little evidence to suggest that FCEVs could reach any major breakthrough in Europe.

By 2030, BEVs and to some extent FCEVs will become more and more competitive with gasoline and diesel cars, and perhaps become a more profitable car choice in relation to annual costs, even without incentives, as shown in Chapter 9. At this point, EU emission standards and the national incentives may become less important. The market forces will take over and the most effective measure to speed up the transition to zero-emission vehicle purchases in the transport sector will probably be to impose or increase the taxes on the technology that one wants to phase out. There are also discussions in some EU countries about future bans of ICEVs from being sold. Such bans are currently not possible due to EU regulations on free trade and the free movement of goods between the EU member states.

As the regulations allows car manufacturers to partner with others to meet the CO_2 requirement and BEVs are still more expensive than petrol/diesel cars, while there are large fines for not meeting the requirement, it is reasonable to assume that the sales volumes of pure BEV manufacturers (Tesla and various Chinese manufacturers coming to Europe 2020-2030) will be deducted from the volume that European manufacturers must supply to meet the CO_2 requirement. This will be the case until BEVs and PHEVs become so competitive that sales volumes can be achieved by each manufacturer without incurring costs higher than the price they have to pay to form a partnership with a car manufacturer that only produces BEVs. Regardless of this, manufacturers may find it more appropriate to develop and sell this type of car themselves, given that the legislation is becoming more and more stringent over time.

11.4.2 The extent to which the EUs requirements can be satisfied by BEVs

A key question is how much of the CO_2 reduction requirement can be met by reducing emissions from ICEVs and how much must be met by selling BEVs and PHEVs.

Figenbaum et al. (2013) analyzed the possibilities of reaching the Norwegian 85 g/km target for average CO_2 emissions from new passenger cars from 2020. They found that it would require that a certain proportion of BEVs or PHEVs be sold, as it was not realistic that ICEVs could have average CO_2 emissions down to 85 g/km. This would have required extreme alignment of the car model range in the direction of aerodynamic hybrid cars (a la the Toyota Prius). Car manufacturers are unlikely to want this, as it is the variation in the market itself that makes them the most money, in recent years especially on SUVs of all size classes. SUVs will not come close to 85 g/km even with full hybridization.

Transport & Environment (T&E 2019) and Fritz et al. (2019) have performed analyses of the consequences of the EU 2025-2030 CO_2 emission requirements for new passenger cars. Both, with slightly different methods, arrive at similar results. Fritz et al. (2019) estimate that the maximum cost-effective (technology cost) potential to reduce internal combustion engine emissions is down to a level of 80-90 g/km. From the analysis of Figenbaum et al. (2013), this is not achievable without a simultaneous extreme alignment of the market, which may have additional costs (as discussed above). Fritz et al. (2019) assume that PHEVs can emit an average of 31 g/km in 2025 and 28 g/km in 2030. They find that a selection of the largest car manufacturers must then sell either about 26-31 percent BEVs by 2030, or 37-46 percent PHEVs, if internal combustion engines are at 85 g/km on average. In 2025, approx. they must sell 5-7 percent BEVs in the same scenario. However, within that time, automakers are less likely to be able to reduce all their internal combustion engine emissions to such an extent that these sales targets can be achieved. This means that a much higher proportion of BEVs will be needed in 2025 or that a significantly increased number of PHEVs will have to be sold.

Transport & Environment (T&E 2019) found in their analysis that the BEV share in 2025 must be higher in 2025 than that what Fritz et al. (2019) propose. They estimate that a mix of 9 percent BEVs and 6 percent PHEVs must be sold ± approx. 20 percent in 2025, depending on how much ordinary car emissions can be reduced. By 2030, they estimate that BEVs can have a market share of 21 percent and PHEVs 12 percent. Thus, they estimate that at least 1.4 million BEVs and 0.9 million PHEVs will be sold in the EU in 2025 and 3.2 million and 1.8 million respectively in 2030.

Table 11.2 shows the authors' scenario for how the CO_2 requirement can affect sales of BEVs and PHEVs. In this scenario, a total of 15,624,500 passenger cars are sold in Europe (EU28 + EFTA), which is unchanged from 2018. Emissions from ICEVs fall to 95 g/km by 2025 and are held constant after that. It is further assumed that Tesla and Chinese BEVs make up 5 percent of BEVs sold in 2025 and 10 percent in 2030. It is not expected that Chinese manufacturers will sell PHEVs in Europe. It is assumed that twice as many BEVs are sold as PHEVs (they will be more economical for users, see Chapter 9, and more BEV models are being developed, see Chapter 6). In total, approx. 12 percent BEVs and 6 percent PHEVs will then need to be sold in 2025. By 2030, 28 percent BEVs and 14 percent PHEVs will be sold. Sales are distributed according to the manufacturers' market shares in 2018. Even with such a high proportion of PHEVs, there will be sold approx. 1.9 million BEVs in 2025 and 4.4 million in 2030 in Europe. Norway's car market will constitute, respectively, approx. 8 percent and 3.5 percent of these BEV volumes, if BEVs are the only vehicles sold in the new car market in Norway in 2025 and 2030.

Table 11.2: Minimum sales of BEVs for various car manufacturers in the EU and EEA countries in 2025 and 2030. Assumptions 2025: 12 percent BEVs, 6 percent PHEVs and in 2030: 28 percent BEVs, 14 percent PHEVs. ICEVs 95 g/km CO_2 in 2025-2030. Source: ACEA (2019b) for 2018 and Bestsellingcars (2019), and own assessments.

Car Make	Minimum sale BEV 2025	Minimum sale PHEV 2025	Minimum sale BEV 2030	Minimum sale PHEV 2030
VW Group	425 611	224 006	940 824	522 680
VOLKSWAGEN	199 746	105 130	441 545	245 303
SKODA	83 132	43 753	183 764	102 091
AUDI	82 555	43 450	182 490	101 384
SEAT	51 570	27 142	113 998	63 332
PORSCHE	8 037	4 230	17 767	9 871
OTHERS	570	300	1 259	700
PSA Group	284 946	149 971	629 880	349 933
PEUGEOT	110 744	58 286	244 802	136 001
OPEL/VAUXHALL4	100 823	53 065	222 872	123 818
CITROEN	68 201	35 895	150 760	83 756
DS	5 178	2 725	11 446	6 359
RENAULT Group	187 092	98 469	413 571	229 762
RENAULT	126 059	66 347	278 656	154 809
DACIA	60 220	31 695	133 119	73 955
LADA	591	311	1 307	726
ALPINE	222	117	490	272
BMW Group	117 787	61 993	260 372	144 651
BMW	92 930	48 911	205 425	114 125
MINI	24 857	13 083	54 947	30 526
FCA Group	116 429	61 279	257 370	142 984
FIAT	81 086	42 677	179 244	99 580
JEEP	19 229	10 120	42 506	23 614
ALFA ROMEO	9 455	4 976	20 901	11 611
LANCIA/CHRYSLER	5 569	2 931	12 311	6 840
OTHERS	1 090	574	2 409	1 338
FORD	113 361	59 664	250 588	139 216
DAIMLER	110 601	58 211	244 487	135 826
MERCEDES	99 319	52 273	219 548	121 971
SMART	11 282	5 938	24 939	13 855
TOYOTA Group	86 648	45 604	191 537	106 410
TOYOTA	81 325	42 802	179 770	99 872
LEXUS	5 323	2 802	11 767	6 537
HYUNDAI	61 935	32 598	136 910	76 061
KIA	56 351	29 658	124 565	69 203
NISSAN	56 300	29 632	124 453	69 141
VOLVO CAR CORP.	36 488	19 204	80 658	44 810
JAGUAR LAND ROVER Group	24 417	12 851	53 975	29 986
LAND ROVER	14 862	7 822	32 853	18 252
JAGUAR	9 555	5 029	21 122	11 735
HONDA	15 457	8 135	34 167	18 982
GM	376	198	832	462
OTHERS (MAZDA, SUZUKI etc)	83 851		437 486	
TESLA, CHINESE EVs	87 393	45 997	193 185	107 325
TOTAL	1 865 044	937 470	4 374 860	2 187 430

Other combinations of BEV sales and sales of PHEVs will also be possible as shown in Figure 11.4. For every 5 g/km deviation from the assumption that gasoline and diesel cars can average 95 g/km in 2025-2030, the BEV market shares changes by approx. 3-4 percentage points and PHEV share with approx. 1.5-2 percentage points. If the emissions stagnate at 100 g/km, the proportion of BEVs and PHEVs sold must increase to approx. 15 percent BEVs in 2025 (2.3 million) and approx. 7.5 percent PHEVs (1.2 million).

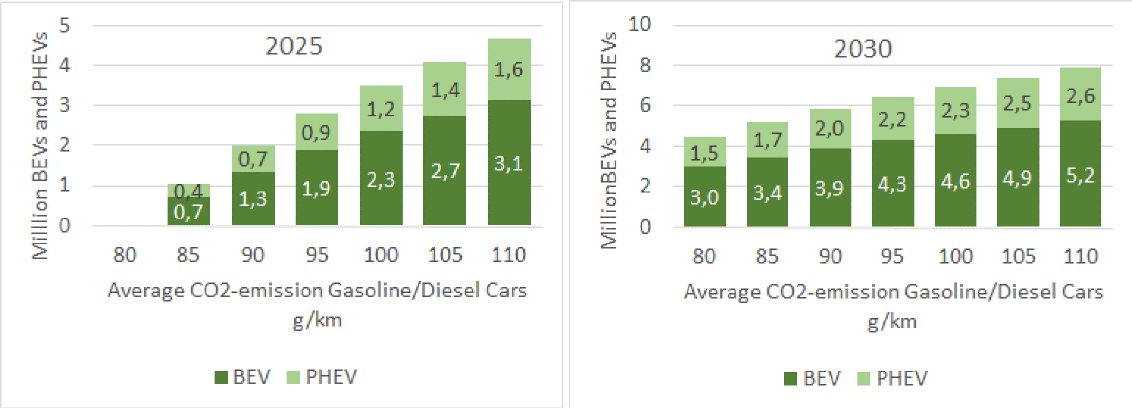


Figure 11.4: Number of BEVs and PHEVs that must be sold as a function of the CO_2 emissions for gasoline/diesel cars. Source. Own calculation.

The EU CO_2 requirements, along with the Chinese and Californian quota requirements, drive multinational car manufacturers towards full-scale electrification. The EU requirement on its own will have the following effects (author's assessment):

- Making ICEVs more energy efficient, including:
  - Micro hybridization with start-stop systems
  - 48V hybrids (greater CO_2 reduction than micro hybrid, relatively low cost)
  - Optimize and increase efficiency of engines and other systems
- Termination of engine variants with high emissions, and models with high emissions and low sales volume
- Car manufacturers must make BEVs to meet the requirements and sell them in large volumes. This will both give lower prices, and they will get more attractive features to appeal to wider consumer groups.
- Car manufacturers' and parts suppliers' research and development is shifting from internal combustion engines to batteries, electric drive systems and other new components. New and better battery technology and drive systems are being developed
- Battery production is industrialized on a large scale with large cost reductions
- A wide range of series-produced BEVs of all sizes and segments are being developed
- Car factories across the world are prepared and modified for BEV/PHEV production
- Car manufacturers must actively market BEVs/PHEVs to meet the CO_2 requirements
- The requirements become more stringent over time, which makes it worthwhile to invest widely early in order to more easily achieve long-term goals
- Major investments are being made in global and European BEV/PHEV production.

A key question is whether car manufacturers will have incentives to produce more BEVs than are needed to meet the CO_2 requirement. There are three possible outcomes:

1. If the cars can be sold at a price that corresponds to the car manufacturer's costs and normal overhead and profit, there will be no volume restrictions in the market. Norway can then get enough cars to meet the 2025 goal of only selling zero-emission cars, regardless of what happens in other countries.
2. If the cars have to be sold at the marginal cost of production, with no (or a very small) contribution to overheads and profits, there will in principle also be no volume restrictions, unless the car manufacturers withhold the BEV production volume to sell ICEVs that generates higher profits. Here, the outcome for Norway will be uncertain, but if it is easiest to sell the BEVs in Norway, the volumes will be available to Norway.
3. If the cars are sold at below marginal production cost, the car manufacturer must cross-subsidize between the models sold, and the volumes will probably be limited to the minimum level of the EU requirement. In this case, Norway must compete against the other countries for the best incentives and where it is easiest to sell the cars.

Outcome 3 is considered to be the least likely since many countries have different incentives for BEVs. It is also reasonable to assume that outcome 1 is also unlikely to be fully achieved by 2025, as some volume limitations may exist because of bottlenecks for instance related to the production of batteries, although such issues will likely be temporal.

Many EU countries have ambitious goals for the electrification of their fleet. These goals will have little impact on Norway's ability to achieve its goals. The goals of the other countries can only be achieved if they introduce sufficiently strong incentives. If they do, it will be easier for car manufacturers to sell BEVs in more countries. Development will go faster than it otherwise would have done, and costs will be lower. The incentives will boost the economy in BEV production, so car manufacturers can invest more in further development. However, if car manufacturers fail to scale up production quickly enough, delivery restrictions may arise that can also affect the Norwegian market. As long as Norway continues to have the best incentives and the best functioning market, as per the situation in 2019, there is no reason to believe that the goal of only selling zero emission cars in 2025 will be at risk due to a scarcity of cars for the Norwegian market.

11.4.3 Requirements for CO_2 emissions also lead to the industrialization of electric LCVs.

The CO_2 requirements for LCVs lead to a significant electrification of this vehicle category. The car manufacturers can and do use the same electric drive systems and batteries as in the passenger cars in small LCVs. They are thus easy to electrify, and the process can happen quickly. The batteries, drive system and the other components will then be produced in large volumes at a low cost due to the passenger car market needs.

As shown in Chapter 6, electric versions of many LCV models are already sold, and several models are under development. By 2022, there will be electric versions of over half of the LCV models on sale. The rapid development of electric LCVs by all major manufacturers is an indication that the EU CO_2 requirements are driving forward electrification also in this segment. The EU's CO_2 requirements specify a 15 per cent reduction from 147 g/km by 2025 as they do for passenger cars, and a 31 per cent reduction by 2030, which is slightly lower than for passenger cars. Emissions will then be 125 g/km in 2025 and approx. 101 g/km in 2030.

With a few exceptions, only BE-LCVs are being developed. Ford has developed a plug-in hybrid variant of the Transit LCV and are also coming with a battery-electric version, and London taxi manufacturer LMC is coming with an LCV with a plug in hybrid solution. Renault offers a hydrogen fuel cell range extender for 2 of its BE-LCVs.

In reality, emissions reductions from diesel versions and the introduction and sale of battery electric versions will be required to be able to reduce emissions from this vehicle segment sufficiently by 2025 and 2030. In Europe, 2.13 million LCVs were sold in 2018, of which 35,800 were sold in Norway (ACEA, 2019c). Emissions in 2018 were well above the requirement for 2021, 158 g/km. Assuming that emissions are reduced by 10 per cent by 2025, it will fall to approx. 142 g/km. The rest of the emission reduction down to 125 g/km, which is the required level for 2025, must be achieved with BE-LCVs which must therefore amount to approx. 12 percent of sales. In 2025, approx. 0.26 million electric LCVs will thus need to be sold in Europe, increasing to approx. 0.64 million in 2030, provided that the same number of LCVs are sold in Europe in the future as in 2018.

The distribution of large and small LCVs in total sales in the EU and EEA countries is not known. In Norway, the light LCVs amount to approx. half of sales. Thus, the Norwegian market will need approx. 18,000 BE-LCVs to meet the NTP target of selling only light zero emission LCVs from 2025. This will amount to approx. 6 per cent of the estimated number of BE-LCVs to be sold in total in the EU + EEA countries, while Norway's share of Europe's total LCV sales was only 1.7 per cent in 2018. Norway may thus need to have better incentives than other markets to be able to reach the target.

Part of the reduction target can be achieved by making further improvements to diesel LCVs, including increased hybridization and efficiency improvements. However, this segment is particularly well suited for battery electric propulsion, as discussed in Chapter 10. It is thus possible to envisage that most of the reduction target can be met with BE-LCVs, even though car manufacturers will probably use the most cost-effective CO_2-saving technologies to reduce emissions from diesel LCVs.

11.4.4 CO_2 requirements for new trucks lead to the development and sale of electric trucks

For trucks, the EU CO_2 requirements for trucks over 16 tonnes total weight require such a rapid reduction in emissions that they will trigger an introduction of electric and hydrogen solutions as early as 2025. Figure 11.5 shows this from Daimler's point of view.

However, there are also many options for reducing CO_2 emissions from diesel trucks as shown in Figure 11.6. Energy consumption is however already an important cost factor for heavy cars and car manufacturers have been constantly working to reduce the energy consumption. Figure 11.5 shows that average CO_2 emissions, which are proportional to energy consumption, have decreased by approx. 1.1 per cent/year for the period 1996-2019 for Daimler’s trucks. If one assumes 1.1 per cent/year in the future, emissions from diesel trucks will decrease by approx. 6 per cent until 2025 and approx. 11 percent in 2030. A gap of approx. 9 percent in 2025 and approx. 19 percent in 2030 is left, which must either be filled with more sophisticated solutions to reduce emissions from diesel trucks or with the sale of zero-emission trucks.

The EU's CO_2 requirements will move the cost curve of the average vehicle upwards so that several types of energy-saving technologies can be used. However, it is natural to imagine that at least half the difference between today's trend and the future need to reduce emissions is likely to come from the sale of zero-emission trucks. This means that sales of electric trucks can reach 5-9 percent in 2025 and 10-19 percent in 2030 in Europe. In 2018, approx. 312,000 heavy trucks over 16 tonnes were sold in the EU, which means that approx. 16,000-28,000 electric trucks can be sold in Europe in 2025 and approx. 32,000-60,000 in 2030.

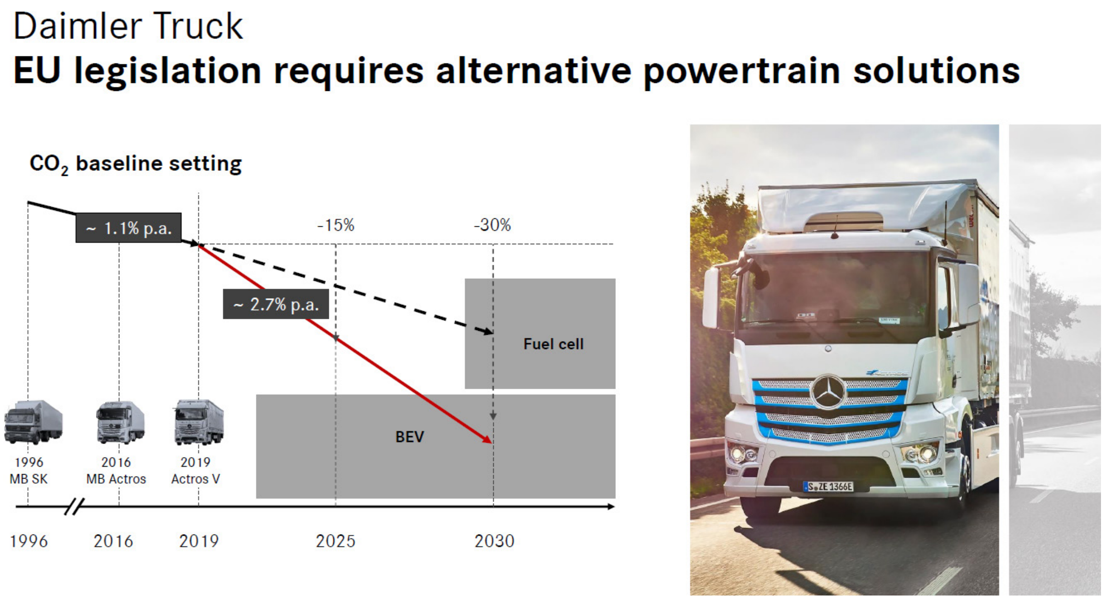


Figure 11.5: Reduction of CO_2 emissions due to EU requirements for alternative drivelines. Source: Daimler 2019.

The barriers to use for electric trucks are greater than for battery electric cars and LCVs due to range limitations and charging time. On the other hand, the energy cost savings will weigh more heavily in the calculation because trucks have a high utilization rate and a long annual mileage. Some applications can be electrified relatively quickly, such as urban logistics, renovation and other trucks used in cities and geographically restricted areas (Hovi et al., 2019a).

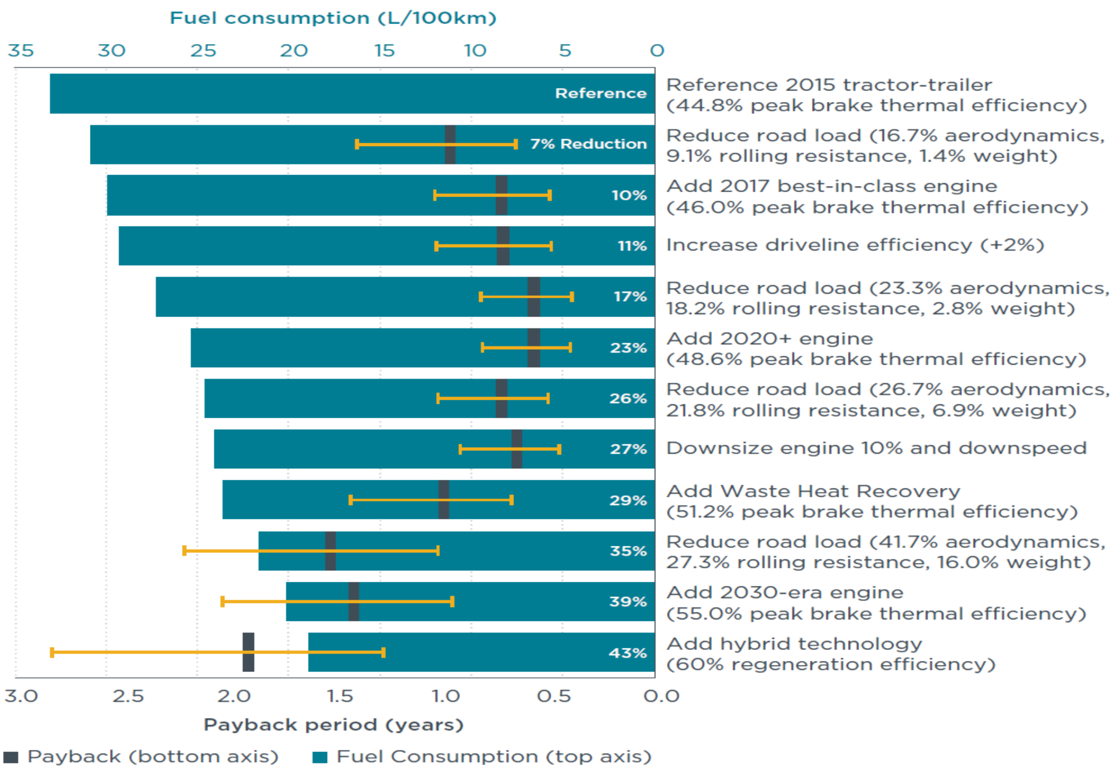


Figure 11.6: Cumulative emission reductions (green) from top to bottom when introducing several types of energy-saving technologies in diesel trucks. The bottom axis (and dash) shows how many years it will take to repay the extra cost of the technology. The percentage rate indicates the percentage reduction from a standard truck. Source: ICCT 2018.

In the initial phase, this vehicle category will need assistance in the form of incentives to get the market going. From 2020, the major truck manufacturers will come with the first series-produced electric trucks, including Volvo and Renault, and from 2022 the Daimler group will start series production. It is also believed that Scania, Man and Iveco will be on track with serial production before 2025. Several start-up companies such as E-Moss (delivers already BE-trucks converted from diesel trucks), Tesla and Nikola will launch products in the years leading up to 2022.

Which countries the trucks sold in Europe will end up in will depend on the policy and incentives in the different countries. In this area, Norway has currently no specific advantages in policy formulation or in the incentive structure in relation to other countries. In fact, the demanding Norwegian topography, road conditions and climate may pose higher barriers to adoption than in for instance France or Germany.

The cost calculations carried out in Chapter 9 give indications as to how the new technologies can compete in the market and the level of incentives that will be needed.

11.4.5 EU Directive for public procurement will push the BE-bus market

The EU directive (see link) [11] on public procurement of vehicles applies to passenger cars, LCVs, buses and trucks. The requirements for different countries are shown in Table 11.3.

In terms of buses, the directive specifies that in countries such as Sweden, Denmark and Germany at least 45 per cent of the buses procured will have to be zero-emission or use biofuel with low ILUC (Indirect Land Use Change) factor by 2025. At least half shall be zero emission (electricity or hydrogen). It is assumed that, if the Directive is incorporated into the EEA Agreement, Norway may have a minimum equivalent requirement like these countries. The requirements for the purchase of trucks are significantly lower, with 10 per cent for Western and Northern European countries in 2025 and 15 per cent in 2030.

For passenger cars and LCVs, the requirements are similar for 2025 and 2030 and is, for most countries, set at 36-38 per cent. In general, for all types of vehicles, the requirements are slightly lower for Portugal and Greece and significantly lower for Eastern European countries.

For passenger cars and the LCV market, the Directive will be of little importance, besides ensuring a minimum introduction of BEVs in all EU countries. The total required number of cars in each country will be low as these public fleets of cars and LCVs are small. For the truck market, the effect will also be limited, beyond a smaller number of refuse collection trucks, mail service trucks and certain types of courier services.

However, the Directive will create a sharp increase in demand for zero-emission buses. This can lead to long delivery times up to 2025, especially if many bus operators are late to purchase at the beginning of the period (2 Aug 2021 to 31 Dec 2025), and therefore need to increase purchases by the end of the period. If this is the case, capacity challenges may arise in the bus industry. There is thus a risk that the 2025 target will not be reached even if the conditions are otherwise favourable.

[11] https://www.europarl.europa.eu/news/en/agenda/briefing/2018-11-12/8/plans-for-cleaner-trucks-more-electric-buses-by-2030, https://www.euractiv.com/section/electric-cars/news/europe-agrees-sales-targets-for-clean-buses-in-cities/ , https://www.transportenvironment.org/press/eu-deal-will-see-roll-out-cleaner-public-buses-faster-uptake-zero-emission-technology-needed, https://www.eumonitor.eu/9353000/1/j4nvk6yhcbpeywk_j9vvik7m1c3gyxp/vl04czyb9kzs, https://www.eumonitor.eu/9353000/1/j4nvk6yhcbpeywk_j9vvik7m1c3gyxp/vl04czyb9kzs, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32019L1161

Table 11.3: Minimum share of zero emission vehicles or biofuel (with low ILUC potential) in public procurement of vehicles in EU countries. Zero emissions vehicles shall account for at least half of the purchases. Source: EU Clean Vehicles Directive.

States	Passenger cars and LCVs		Trucks		Buses	
	2. Aug 2021 to 31. Dec 2025	1. Jan 2026 to 31. Dec 2030	2. Aug 2021 to 31. Dec 2025	1. Jan 2026 to 31. Dec 2030	2. Aug 2021 to 31. Dec 2025	1. Jan 2026 to 31. Dec 2030
Sweden, Germany, Italy, The Netherlands, Belgium, Ireland, Austria, Malta, Luxembourg, United Kingdom	38.5%	38.5%	10%	15%	45%	65%
Denmark, Finland, Spain, France	37.4-38.5%	37.4-38.5%	9-10%	14-15%	41-45%	59-65%
Cyprus, Portugal, Czech Republic	29.7-31.9%	29.7-31.9%	810%	11-13%	35-45%	51-65%
Greece, Slovenia, Estonia, Slovakia, Lithuania, Latvia	25.3%	25.3%	8%	10%	33%	47%
Slovenia, Estonia, Slovakia, Lithuania	20.9-23.1%	20.9-23.1%	7-8%	9%	28-42%	40-60%
Croatia, Romania, Bulgaria	17.6-18.7%	17.6-18.7%	6-7%	7-8%	24-34%	33-48%

It can be concluded that for city buses, almost 100 per cent transition to electricity or hydrogen can be ensured through purchasing requirements provided that the buses otherwise have satisfactory usage characteristics for the individual countries, and that a somewhat higher cost of bus operation can be accepted.

11.5 EU Directive requiring an action plan for infrastructure

The EU Directive for the deployment of alternative fuel infrastructure requires the EU and EEA countries to develop action plans for the establishment and expansion of charging infrastructure. In the EU Directive (Platform electromobility 2018) the goals indicated for charging infrastructure for BEVs are that:

- There should be maximum 10 BEVs per charging station, and that
- there should be at least one fast charger per 60km along main roads

In a meta-analysis of what countries say they will do, it is pointed out that some countries have an unrealistic sales target, causing there to appear to be more BEVs per charger than the EU's proposed norm (Platform electromobility 2018), as shown in the review in Chapter 7. With more realistic estimates of how big the BEV fleet can be, the number of BEVs per charger will fall to a reasonable level (about 15). In total, the plans indicate that there will be approx. 10 BEVs per charger in Europe, but that there will be a regional imbalance within this figure.

It is problematic that some countries have low aspirations for chargers and BEV sales because this may inhibit an adequate pan-European network of chargers that can enable travel across Europe (Platform electromobility 2018). This issue is also relevant for Norwegian BEV owners who may wish to go on holiday trips to European countries.

Based on Norwegian conditions, one fast charger per 60 km seems very unambitious. The strategy in Norway is a minimum deployment of two fast chargers per charge station, and in addition two semi-fast 22 kW AC chargers.

11.6 National incentives determine where BEVs will be sold

The policy of introducing electric vehicles in different countries is governed by the need to reduce greenhouse gas emissions. The transport sector is not part of the EU greenhouse gas emission trading system and is a significant source of emissions in all countries.

A key question is in which countries the zero emission cars, sold as a result of EU CO_2 requirements, will actually end up in. This depends on how effective the different countries' policies will be. An overview of the current and planned policies and incentives in selected EU countries (and China) presented in table 11.4. It shows that:

- Most countries have targets for climate gas emission reductions and greening of electricity by 2030. Climate neutrality by 2050 is the overall target for most countries.
- Countries using coal for electricity production are planning a phase out by 2030 and a ramp up of renewables in the electricity production.
- Most countries have targets to eliminate sales of ICEVs over varying time horizons.
- Many countries have introduced substantial BEV and PHEV incentives, mostly for cars, although nowhere near the level of Norway as was presented in chapter 2.
- Germany, France, Sweden and the Netherlands all have substantial incentives, yet the market shares of BEVs and PHEVs differs widely but all are increasing.
- All countries tend to have targets for public procurement of zero- or low-emission vehicles, especially for the procurement of zero-emission or carbon-neutral city buses, for which also various support programs seem to be available in several countries.
- Enterprises are in most cases mentioned as an important buying group.
- Sweden and Germany seem to be the only countries to have developed policies and put in place incentives for battery electric or hydrogen fuel cell heavy duty trucks.

The policies and incentives have evolved over time. For some countries the framework has been very unstable, whereas in other countries stable frameworks have emerged.

- Denmark and the Netherlands are examples of countries with an unstable policy with frequent and substantial changes to the incentives for BEVs and ICEVs. These earlier policy changes are not shown in the table which displays the current status.
- Sweden has earlier had a government support program for purchase of BEVs and PHEVs that required release of government funding. When the budget had been spent no support was available for the rest of the year. Moving to a bonus malus system provides a much more stable framework. The bonuses for buying BEVs are paid for by the maluses that buyers of ICEVs pay, and the system can be designed to be revenue neutral. France has had a similar system for many years. Temporary imbalances in such systems may occur if there are large shifts in the demand for BEVs vs ICEVs.
- Germany introduced their purchase bonus program in 2019. Before that few incentives were available. In November 2019, it was decided to increase the bonus to 6,000 Euros for BEVs costing less than 40,000 Euros, and to 5,000 Euros for those costing 40,000-50,000 Euros. It was alse desided to extend the bonus program to 2025, and continue the 50/50 cost split between the government and the industry (DW 2020).

It is likely that as battery electric and hydrogen fuel cell LCVs, buses and trucks comes on the market, more countries will develop policies and introduce incentives to support their introduction., if they are serious about meeting their targets to reduce greenhouse gas emissions.

Table 11.4: Incentives, BEV sold 2019, national targets, typical buyer groups, national vehicle producers in selected countries in Europe. Source: Adapted from Figenbaum et al.2019 and expanded.

Country	Denmark	Finland	France	The Netherlands	Sweden	Germany	Austria	China
BEVs/PHEVs sold 2019[12]	5,532 / 3,882	1,897 / 5,966	42,827 / 18,592	62,056 / 4,901	15,596 / 24,810	63,491 / 45,348	9,261 / 2,156	Lack of data
BEV/PHEV share of sales 2019[Feil! Bokmerke er ikke definert.]	2.5% / 1.7%	1.7% / 5.2%	1.9% / 0.8%	13.9% / 1.1%	4.4% / 7.0%	1.8% / 1.3%	2.8% / 0.7%	
Climate and energy sector targets	2030: 100% renewable electricity 2050: Climate neutrality	2030: Coal phased out from power production 2035: Carbon neutrality	2025: Reduce nuclear power share to 50%. 2030: Reduce climate gas emission by 40% 2050: Carbon neutrality	2025/2030: Coal phased out from power production 2030: Reduce climate gas emission by 49% compared with 1990	2040: 100% renewable power production 2045: Carbon neutrality	2030: 65% of brutto electricity production from renewables 2030: Reduce CO_2 emissions by 55% compared with 1990 2050: Carbon neutrality	2030: Coal phased out from power production 2030: Reduce climate gas emission by 36% compared with 2005	2030: Climate gas emission shall have peaked.
Tranport sector targets General		2020: 20% biofuel share	2025: All public procured vehicles shall be low emission.	2025: 30-40 low and zero emission zones 2050: Zero emission sector	2045: Fossil free vehicle fleet		2030: 33% reduction in climate gas emissions 2050: Road transport shall be CO_2-neutral	2020: 2 produce and sell 2 million new energy vehicles (cars, buses, trucks) 2025: sell 7 million new energy vehicles 2050: Be a transport super-power.
Tranport sector targets Passenger cars	2020: 200,000 BEVs 2030: End sales of ICEVs 2035: End sales of PHEVs	2020: 20,000 BEVs, 95 g/km new cars 2030: 250,000 electric vehicles and 50,000 vehicles on gas in fleet Proposal to end sales of ICEVs by 2035	2020: 2 million EVs in the fleet 2040: End sales of ICEVs	2020: 200,000 EVs on the road 2025: Half of all vehicles sold can be externally charged 2030: Sell only zero-emission vehicles	2020: 600,000 BEVs and PHEVs 2030: No sales of ICEVs	2020: I million EVs in the fleet 2030: Only zero-emission passenger vehicles approved, 7-10 million electric vehicles in the fleet (incl. PHEVs) 2050: All passenger cars shall be electric	2020: 250,000 EVs in the fleet	
Tranport sector targets Buses, LCVs, HD Truck	2020: All new buses CO_2-neutral 2030: All buses and taxis CO_2-neutral		2025: All public procured buses shall be low emission.	2025: New buses zero-emission 2030: All buses zero emission	2030: Fossil free public transport			2025: Public services to use new energy vehicles

[12] Source: ACEA 2020.

Country	Denmark	Finland	France	The Netherlands	Sweden	Germany	Austria	China
Important incentives Passenger cars	Exemption from registration tax for BEVs costing< 400,000 DKK Reduced imposed benefit tax	Low registration tax 2000 Euro in purchase support	Bonus-malus, 6,000 Euro bonus for BEVs. ICEV tax on emissions. 2 500 Euro scrappage premium when buying a BEV	Exemption from registration tax. Reduced imposed benefit tax: 4% vs. 22% on cars costing <50,000 Euro	Bonus-malus, up to 60,000 SEK bonus for BEVs. Reduced imposed benefit tax: 40% of ICEV rates	6,000 Euro purchase bonus for cars costing less than 40,000 Ero and 5,000 for cars costing 40-60,000 Euro Reduced imposed benefit tax: ICEVs: 1% of price. BEVs: 0,25%	Purchase support of 3,000 euro for cars costing <50 000 Euro Reduced imposed benefit tax:	
Important incentives Buses, LCVs, HD Truck					Support for battery electric, plug-in hybrid and hydrogen buses, and zero-emission trucks available	Until 2021: Support of 12,000 Euro for small trucks, 40,000 Euro for large trucks. Support for up to 700 buses has been given	20,000 Euro for small buses, 100,000 for large buses	Purchase support buses
Future incentives		Committe evaluates if taxation shall be based on CO_2-emission		Proposal to gradually reduce the electric vehicle advantage in imposed benefit tax	Stricter rules for environmental zones from 2020. Increased support for charging infrastructure	National transport sector emission quota trading system Reduced electricity price	Cars costing 40-60,000 Euro to get 5,000 Euro rebate, cars costing <40,000 Euro get 6,000 Euro	
Buyer groups	Increased demand from businesses	Mostly businesses	No data	Businesses (98%)	Mostly businesses	No data	No data	
National car and LCV producers	None	Valmet Automotive (Components, contract production)	Citroën, Renault, DS Automobiles, Peugeot	Tesla has a facility	Volvo, NEVS[13]	Mercedes-Benz, BMW, Ford-Werke, Volkswagen, Porsche, Audi, Opel	Component industry, Magna-Steyr vehicle assembly line	BYD, SAIC, BAIC, and others. European and Japanese OEM production
National bus and truck producers			Renault, Heuliez	E-Moss	Volvo, Scania	Daimler/Mercedes, MAN, Setra, Neoplan and others		Byd and others

[13] National electric vehicle Sweden. BEV only manufacturer, selling in China, based on the remains of SAAB.

To consider the efficiency of different countries' policies and incentives, it is necessary to define indicators of what an effective policy is. The International EV Policy Council, with leading international BEV researchers, has looked at exactly this in 6 policy briefs and 2 reviews. The Council consists of researchers (from California, Norway, Germany, Sweden, the Netherlands, the United Kingdom, France, Canada, Australia, etc.) who are all experts in electric vehicle user studies and analysis of the BEV markets. The group is led and managed by UC Davis. Based on this work, ten criteria have been drawn up by the authors, as shown in Table 11.5, to assess the effectiveness of BEV policies and policy instruments in different countries.

Table 11.5: Criteria for effective policies and policy instruments to increase acceptance of electric vehicles and thereby increase the market share of electric vehicles. Source: Own analysis based on policy briefs for passenger cars from the International EV Policy Council (Hardman et al., 2019a, 2019b, 2018a, 2018b, 2018c, 2018d, 2018e, 2018f, 2017, Turrentine, 2018, Hardman, 2019). The authors consider that the criteria for cars are also relevant for heavy duty vehicles.

Criterion no.	Content of criterion
Criterion 1:	The policy leads to a significant forced phase-in of electric vehicles
Criterion 2:	The policy is long-term and the objectives are clearly communicated to buyers and actors
Criterion 3:	The policy that is pursued is proportionate to the objectives pertaining to the sale of electric vehicles.
Criterion 4:	The policy puts user needs into focus. Users need: o Cost effective, safe and reliable transport o Access to charging where the vehicle is parked and other places it travels o Access to fast chargers that enable longer journeys and provides security locally o More knowledge about charging and how range limitations can be resolved
Criterion 5:	The policy mobilizes necessary actors and fosters their innovation and development
Criterion 6:	The policy is designed so that different levels of government and private actors play in teams and so that barriers to the use of electric vehicles are removed.
Criterion 7:	The policy contributes to systematic national knowledge building on the advantages and disadvantages of BEVs, how they can be used most effectively, and how different barriers to purchase and use can be eliminated.
Criterion 8:	Policy changes are clearly signaled in good time. Incentives are reduced slowly.
Criterion 9:	The policy consists of a policy package where the policy instruments are complementary and have an effect in the widest possible geographical area. Users are fully compensated for the cost disadvantage of electric vehicles, so that the total cost of ownership (TCO) is equal to that of ordinary vehicles. Alternative policies consist of requirements for new cars' average CO_2 emissions or that a certain proportion of zero-emission vehicles must be sold.
Criterion 10:	Local user incentives to accelerate the market in cities and regions must be transparent, clearly communicated, users must know how long they last, and they should be paired with purchase incentives for increased overall impact.

With the exception of Denmark, all the countries have a substantial automotive industry which would benefit from policies and incentives to ease the market introduction of battery electric and hydrogen vehicles. The criteria presented in Table 11.5 can be used to assess the different countries' policies on BEVs summed up in Table 11.4, and compare them to Norway's policies, to look at the likelihood that the Norwegian market will be given priority by the vehicle manufacturers when volume availability is determined. The situation for passenger cars is shown in Table 11.6. Norway has received a yellow score on criteria 8 for passenger cars due to going back-and-forth with incentives for biofuels. This also conveys a risk that the BEV incentives can also change abruptly. The other yellow score is for the lack of systematic knowledge building.

Based on this overall analysis, there is reason to believe that Norway will have sufficient access to passenger cars to be able to meet the 2025 target, given that the conditions are otherwise suitable. In addition to the 10 criteria, the size of the car markets in the different countries is also important for them to be able to reach the overall EU CO_2-targets for their European activities.

Table 11.6: Evaluation of BEV policy for passenger cars in Norway and some EU countries. Source: Own analysis based on criteria in table 11.4, data on policies in table 11.5 and chapter 2 and other information.

Country/Region	Criteria 1	2	3	4	5	6	7	8	9	10	Rank
Norway											1
Sweden											2
Denmark											8
Finland											5
Germany											6
France											4
Netherlands											3
Austria											7

For trucks, much less information is available, as shown in Table 11.4 (and presented in more detail in Figenbaum et al. 2019). This is because electric trucks have not yet been sold other than by rebuilders who convert diesel trucks into electric trucks in very small numbers. Hydrogen trucks are not yet available for purchase from any supplier. Therefore, few countries have developed policies and incentives for the electrification of trucks or the use of hydrogen. A table like the one for passenger cars could therefore not be developed.

Norway has no advantage over other countries in relation to the politics for the introduction of electric or hydrogen trucks. There are incentives in some countries, e.g. support for the purchase of electric trucks, as shown in Table 11.4 for Germany and Sweden. Norway also has some support through ENOVA, but has no special advantage over other countries, besides the fact that we have renewable electricity and a strong power grid. This market will therefore depend on general European developments. The situation is likely to change when major truck manufacturers launch electric trucks from 2020-2022. When this happens, more policies will probably be developed to get electric trucks on the roads in Europe. Sweden and Germany are researching the development and demonstration of electric roads, where electric trucks are charged while driving (VTI 2018). Test sections have been built.

11.7 Market size affects the priorities of car manufacturers

The total car sales in the EU + EFTA were 15.6 million cars in 2018. Sales per country are shown in Figure 11.7, where one can see that the three car markets in Germany, the UK and France account for more than half of total European sales. Five other countries account for another 30 per cent.

As shown in Figure 11.8, the distribution of BEV sales differs significantly from the total sales. There were particularly high BEV shares in Norway and the Netherlands in 2018.

It is likely that the markets will eventually pick up in several countries. It is unlikey that the vehicle manufacturers will limit sales to the minimum required to meet the EU CO_2 requirement, as long as the car sales price covers the variable cost of manufacturing the vehicles. It is assumed that this will be the case based on the assessments in Chapter 9 and that there is thus no great risk that the volumes coming to Norway will be too low to meet the Norwegian 2025 target.

Norway has 1 percent of the total European car fleet, and 1 percent of all the cars that are 0-5 years old, but 23 percent of total BEV sales in 2018 (Source Eurostat 2019b and ACEA, 2019d). This situation also means that it will be easier to sell BEVs in Norway than in other countries also in the coming years as buyers, dealers and importers have gained knowledge about BEVs already, and basic investments in the education of service and sales personnel has already been made.

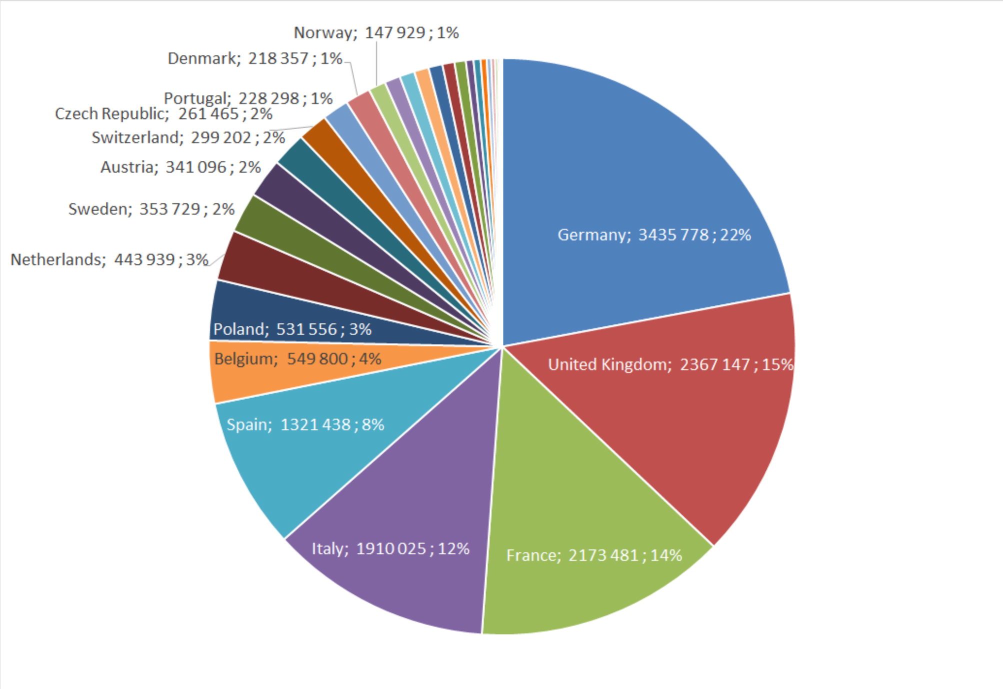


Figure 11.7: Total passenger car sales in the EU and EEA countries in 2018 broken down by country. Source: Eurostat 2019b, and ACEA, 2019b.

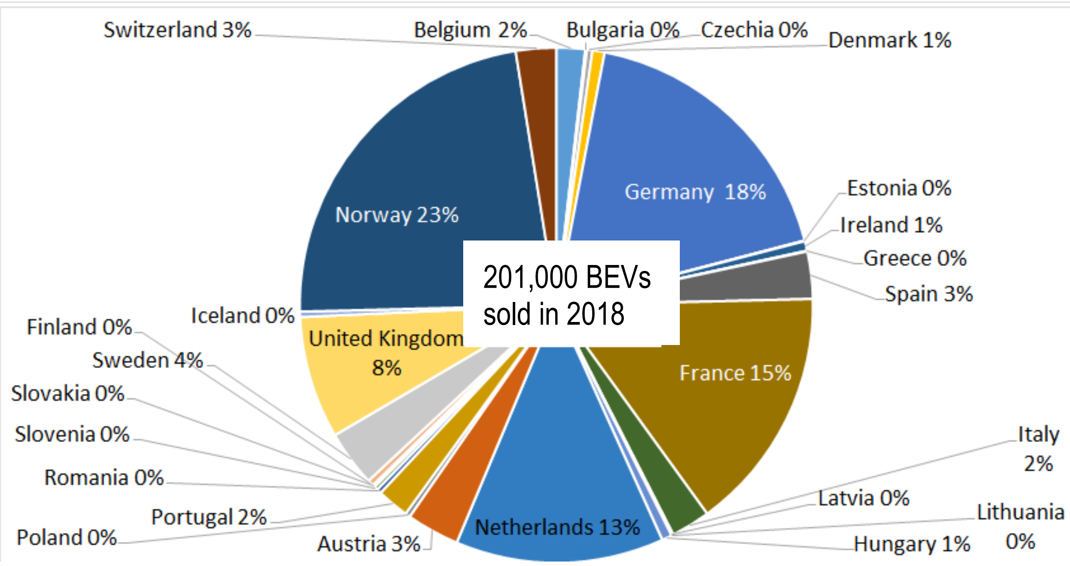


Figure 11.8: EU and EEA countries' share of total BEV sales in Europe. Source: Eurostat 2019b, and ACEA, 2019d.

11.8 Megatrends will not reduce car sales until 2030

Megatrends such as population growth, urbanization and new mobility services could potentially change how the population drives and selects whether to buy a car, and which car to buy.

11.8.1 Population growth, increased urbanization and aging population

As part of the work on the National Transport Plan for 2022-2033, estimates are being made for future transport demand (NTP 2019a, b). In this work, growth is expected to continue in car driving and in the proportion of transport work that is done with private cars on both short and long journeys. This is mainly due to assumptions that the Norwegian population is expected to increase from 5.3 million in 2019 to around 6 million in 2030, that cars through electrification will become cheaper to operate, road infrastructure in the country is improving, and that GDP will continue to increase by 0.8 per cent per year until 2030 (and the population's disposable real income by 0.9 per cent). Most of the population growth will take place in densely populated areas. As an isolated factor, the aging population is expected to contribute to reduced transport demand, but nonetheless one expects annual growth in passenger traffic of approx. 1.3 percent towards 2030 (NTP 2019a, b). Increased urbanization, on the other hand, will mean that a larger proportion of the population will live in places with relatively good public transport and shorter distances to the places important in daily life.

In this report, it is assumed that these trends do not affect the choice of car or the total sales of cars in any specific direction. In TØI's surveys of BEV, PHEV and ICEV owners (Figenbaum and Kolbenstvedt, 2016; Figenbaum and Nordbakke, 2019), the older population appears to be more conservative when it comes to choosing new car types. This may mean that they are more skeptical to BEVs. On the other hand, more and more elderly people have tried BEVs, and those that are middle aged and own BEVs will likely continue with this option, as most BEV owners state that they will buy a BEV again (Figenbaum and Nordbakke 2019, Figenbaum and Kolbenstvedt 2016).

11.8.2 Automation, digitzation and changed car use

Automation (fully or partially self-driving cars), digitization and car sharing can have a positive or negative impact on new car sales.

Full automation for use on public roads, that is, robot taxis, self-driving trucks and the like, can have an impact on car purchases and car use in the future (Ekspertutvalget, 2019). However, there is little evidence that full self-driving will be achieved under Norwegian conditions within the time horizon of the NTP targets for zero-emission vehicles in 2025 and 2030. Car manufacturers are increasingly saying that this will be more difficult to realize than expected, especially in narrow European cities (Autonews, 2019b). In Norway, there are also major challenges associated with narrow roads with no line down the middle, and difficult driving conditions in the winter. If self-driving cars are to be sold to a greater extent, a value chain must be built up for the delivery of sensors and other necessary equipment, and the car manufacturers will test the technology in small volumes of vehicles in an initial phase. The introduction of self-driving cars will therefore take a lot of time, particularly in a country like Norway where driving conditions are especially demanding. All these factors suggest that self-driving cars will not have any significant impact on car sales in Norway in the years leading up to 2030.

Partial automation is also a growing trend because these technologies are being developed in the process of developing a fully automated car. This equipment, such as adaptive cruise control, lane assist etc., is already available in many new cars, and simplifies driving. Driving thus becomes safer and more relaxing. These vehicles features will therefore provide an incentive for increased, not reduced car ownership (Ekspertutvalget, 2019).

Digitization could mean that the fleet utilizes existing road capacity better than before. Digitization will lead to more cars being accommodated for and provide better accessibility. This will probably stimulate growth in the car park, as opposed to a reduction, heading towards 2030 (Ekspertutvalget, 2019). Digitization will also provide better information systems and tools for selecting the form of daily transport. These are useful tools for those living in the largest Norwegian urban areas where the goal is that all growth in transport volumes should be taken by public transport, cycling or walking (Meld. St. 33 (2016-2017)).

The car culture and attitudes to car ownership and use can also change as a result of new environmental requirements and experience with new car types. It is not a given that those who buy a BEV will also have a spare non-BEV moving forward since the range and charging time of the BEVs is rapidly improving. It is also not a given that everyone wants to own their own car in the future. Incentives favoring company-registered BEVs, like in Sweden (see Chapter 9), and different car sharing variants may change this. Car sharing can improve access to cars, which can increase car traffic. However, it can also contribute to somewhat reduced car ownership (Ekspertutvalget 2019), in the sense that some will sell their car or refrain from buying their own car, especially in the cities.

Car sharing has only been electrified to a small extent, partly because leasing costs have been high for BEVs, and partly due to challenges in ensuring that the cars have been recharged when users come to pick them up (Elbil.no 2019c). There are also other forms of car sharing such as "Nabobil" where one can rent a car from private individuals. This generates revenue for the car owner who thus has an incentive to keep the car. Anyone who rents a «neighbour's car» can access a car without owning one. The net effect depends on what either party would have done had the service not existed. The cars used for these mobility variants make up only a minimal part of the car fleet.

It is assumed in this report that these trends will not affect car choices in any specific direction heading towards 2030. It is possible to automate all types of cars regardless of the type of drive system they have. It is also possible to use digitization to make car driving more efficient for all car owners, but BEV owners may experience greater advantages from digitization due to the need to find available chargers and to streamline travel routes. Car sharing can be more demanding to electrify than other uses, and the market is currently relatively small and limited to cities.

11.8.3 The Chinese are coming and Tesla strengthens its footing

For Chinese car manufacturers, the EU CO_2 requirements are a good opportunity to establish themselves in the European market with the sale of electric vehicles. Norway is the most attractive market for electric vehicles in Europe, and 4-6 Chinese manufacturers are already entering the Norwegian market with BEVs and electric LCVs (see Chapter 6). Several of them are also establishing operations elsewhere in Europe. The first Chinese electric buses (Yutong) have also been purchased for use in Norway, in Bergen (Yrkesbil, 2019), and BYD buses will be taken into use in Oslo and other cities (Zero 2019).

Car importers who import traditional car brands that cannot supply BEVs may be interested in bringing these Chinese cars into the market, and they have sufficient resources in the form of dealers and workshops to make it happen. It is also expected that more Chinese manufacturers of electric buses, electric LCVs and electric trucks will come to Norway in the next few years.

Tesla has had one of its main markets in Norway, but will face increasing competition in light of the flood of BEV models coming onto the market in 2020-2022. It is no longer necessary to buy a Tesla to get a long-range BEV. However, Tesla already has a large customer base and high production volumes, and are coming with a minivan in 2021, a pick-up and a semi-trailer, probably in 2021-2022. In addition, they have a well-functioning super-charger network in operation (Figenbaum 2018a, Figenbaum and Nordbakke 2019).

11.8.4 New actors provide the necessary infrastructure and components

Electrification and hydrogen operations mean that a number of new actors are involved in the transport sector.

The foremost new actors within electrification are manufacturers of batteries, electric motors and power electronics, as well as different types of charging infrastructure providers and operators.

The battery market is dominated by a few large manufacturers. Most of the battery cell production is currently in Asia, but there is an increasing establishment of battery production in Europe (McKinsey 2019b). The car manufacturers themselves are responsible for the assembly of battery cells with other components into complete battery packs for their vehicles. Both battery and car manufacturers are investing large sums in expanding production capacity.

The drive systems are either manufactured internally by the car manufacturer or purchased from subcontractors. There are no specific challenges with this type of technology other than raising volumes and optimizing solutions for each model. Larger volumes will reduce costs and enable greater optimization. By standardizing motors and electronics across models and brands (for manufacturer groupings), large costs can be saved.

Traditionally, vehicle manufacturers have produced vehicles and oil companies have supplied the energy used by the vehicles and the infrastructure for this. Different strategies are used to develop charging infrastructure for BEVs. Tesla has set up its own charging infrastructure that can only be used by its cars. Several car manufacturers have joined forces within Ionity to finance and commission a European supercharger network for charging up to 350 kW. This network will be open to all BEV owners. Other charging infrastructure is set up by private charging station operators, partly with support from national, regional and local authorities, and partly in collaboration with retail and restaurant chains and local landowners (Figenbaum, 2018a). Increasingly, gas stations are installing fast chargers and becoming energy stations (CircleK, 2019), and some are removing fuel pumps to accommodate more fast chargers (Elbil, 2019b).

A fast growing industry produces chargers and entrepreneurs specialize in installing and operating chargers.

For trucks, this is more unclear. To the extent that they can be recharged in their own depots overnight, the charging infrastructure will be installed by the owner of the truck, just as a homeowner installs a charging point in a detached house. Fast charging can take place at depots, at rest areas, and elsewhere along the way. This infrastructure outside of the depots must be owned and operated by companies other than the truck owners. At present, this type of infrastructure for trucks does not exist.

For buses, most of the charging will take place at bus depots and to some extent along the routes or at the terminals. As bus operations are out on tender every 7-10 years, the users of depots and charging stations might change over time. The ownership of the infrastructure must then be clarified through the tendering contracts.

For hydrogen the picture is less complex as hydrogen will be delivered to users from central filling stations that can be established as part of regular gas stations or as separate units. For passenger vehicles, the main strategy by the few vehicle manufacturers that aim to put FCEVs into use, is to develop the fuel cell system in-house. For larger vehicle this is more open.

11.9 Politics made Norway and other countries early markets

Up to and including 2019, the BEV markets in Europe were incentive driven. Automakers developed BEVs and put them into more or less limited production to gain real average customer user experience with the technology. This makes them better prepared, and able to more clearly define how the cars must be developed to be sufficiently marketable to meet the EU's CO_2 requirements for new cars.

Globally, Norway is the most interesting market, with a BEV fleet approaching 10 per cent of the total passenger car fleet, and where BEVs are spread geographically across the country. Other global early markets have been California and China, while in Europe Iceland, Sweden and the Netherlands are nations where the BEV share of new car sales has been high the last couple years (see Chapter 2). Developments in these markets have shown that BEVs can meet sufficient user needs, and that they are marketable in volumes large enough for full-scale series production to be initiated. Strong incentives have been needed to accelerate sales in these early adopting countries.

The EU legal requirements for CO_2 emissions from new cars formalize this by making it necessary for car manufacturers to sell BEVs in significant volumes in the European market from 2020, and increasingly so until 2025 and 2030, to avoid fines. The volume constraints in the production of cars are thus likely to disappear from 2020-2022, and the policies in the early markets will work more and more efficiently in increasing the proportion of BEVs sold.

11.10 Market and technology are established, ready for market expansion

From the analysis in Chapters 5 and 6, it is clear that electric vehicles are increasingly meeting the needs of users, as discussed in Chapter 10. In Chapter 9, it was calculated that electric vehicles will also become competitive in the market in Norway and several other countries, with today's policies, as presented in this chapter. Chapters 7 and 8 show that countries have different starting points that determine how well BEVs fit into their respective transport sectors, which can affect which EU countries the BEVs are sold in.

There will be two main stages in the development of an electrified transport sector. The first, the market establishment phase, is about to end for passenger cars, LCVs and city buses. The market for these vehicle types is going to move into a market expansion phase as the production capacity and model availability is increased, as shown in Figure 11.9.

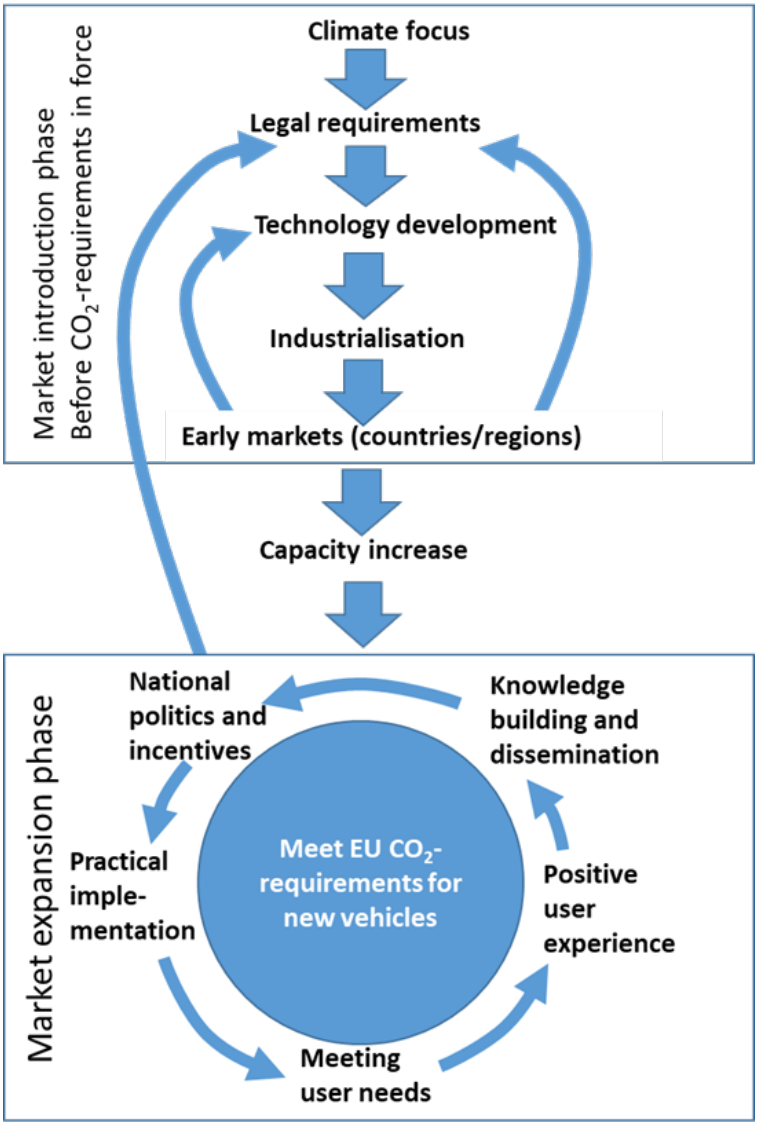


Figure 11.9: Driving forces on the road towards an electrified transport sector. Source: Own analysis.

The market establishment phase lasted until 2019. The driving force for the development in this phase has come from climate policy, which is the political foundation for the requirements for reduced greenhouse gas emissions from vehicles in the EU. The regulatory requirements have a long lead time and give vehicle manufacturers time to develop technologies and vehicles that can meet the requirements. In order to be able to test the technology in early markets and get to know the market in preparation for the market expansion phase, vehicle manufacturers have industrialized electric vehicles, and have launched small and medium-sized series production. Prices have been relatively high and volumes limited, but vehicle manufacturers have gained knowledge of how vehicles are used and applied this to gradual improvements of vehicles introduced regularly in the market. Experience from these early markets has probably also affected how stringent the regulatory requirements that have been enacted for future years have become, as EU legislators have seen that electric vehicles can work for users' needs in practice in countries that have had high sales volumes in this early phase.

The market expansion phase will start from 2020 when the EU CO_2 requirements become mandatory, and there will be major fines for not meeting the requirements. Then production capacity must be increased so that enough BEVs can be sold per year for the legal requirement to be met, and fines to be avoided. This seems to be so important to manufacturers that some of them seems to have postponed vehicle deliveries from 2019 to 2020 to meet the requirement (Motor, 2019). In addition, BEVs in the small car and compact car segments will, entering this phase, receive a proper technological boost with 40-100 percent increased range depending on the model, with a few exceptions.

The CO_2 requirement will become more stringent over time and will gradually lead to increased sales volumes. The proportion of the total volume that will end up in each country will depend on national policy and how effective it is in relation to other countries, how well the countries prepare for electric vehicles, and the extent to which these factors taken together meet the needs of users. The circle ends with positive user experiences that both encourage others to become users and lead to repurchases from the existing users. The countries that make this most efficient will have the highest BEV market shares and will be prioritized by car manufacturers when production volumes are handed out.

The development would not have moved as fast as it is without the EU introducing the CO_2 requirements, and the large fines for non-compliance. Gradually, regulatory requirements will be revised based on marketing experience in the 2020s. This may result in changes that increase or decrease the number of electric vehicles being produced.

Based on the evaluation of the countries readiness for BEVs and the effectiveness of their policies, countries can be divided into four waves of adoption in the market expansion phase at the European level (authors' assessments), as seen in Figure 11.10.

- The *first wave* will be the Nordic countries, that are well adapted to BEVs, have an efficient policy, clean electricity and high purchasing power.
- The *second wave* will be other northern and central Western European countries, such as Germany, France, Belgium, Austria and the UK. They are somewhat less suited for BEVs, but have an automotive industry and policies will eventually promote BEVs.
- The *third wave* will be the remaining Western and Southern European countries, Italy, Spain, Portugal and some Balkan countries. These countries have weaker policies than the first two groups and are a little less suited to BEVs, with lower purchasing power, and hot summers that affect battery life.
- The *fourth wave* will be the other Central European and Eastern European countries and the Baltic States, which will not see high uptakes of BEVs until the costs without taxes and incentives reach equivalence with petrol and diesel cars in around 2030. In these countries, purchasing power is clearly lower than in the rest of Europe and car ownership is also lower.

Figure 11.10: Waves of adoption of BEVs.

Countries can jump on an earlier wave by introducing a more powerful policy.

The city BE-bus market will spread geographically across Europe as a result of the EU's pan-European public procurement requirements, but Eastern and Southern European countries have received slightly less ambitious requirements than the western and northern countries. They are therefore likely to introduce lower proportions of BE-buses.

The truck market is lagging behind the other transportation segments and is at the start of the market establishment phase. The EU's emission reduction requirement for 2025 and 2030 has however given car manufacturers a clear message that it is smart to develop and deploy zero-emission solutions already from the early 2020s. The strong EU framework will make developments in the truck market faster than was the case for passenger cars so far. The market expansion phase for trucks is therefore likely to be reached before 2025 in order to achieve the emission reduction targets in 2025 and 2030.

12 The flow of Li-Ion batteries through the passenger vehicle fleet

12.1 BEVs the source of recyclable Li-Ion batteries up to 2030

It is primarily passenger BEVs that will generate significant volumes for recycling of Li-Ion batteries by 2025 and large volumes by 2030. In this report, the calculation of the number of batteries entering the fleet and later becoming available for recycling is therefore limited to the passenger vehicle market. This means that the volume is somewhat underestimated as batteries from scrapped PHEVs and BE-LCVs will also be available in the coming years to 2030.

Nevertheless, the volumes of scrapped PHEVs and BE-LCVs are assumed to be relatively insignificant compared to BEVs up to 2030. This is because PHEVs came on sale later than BEVs, so the oldest ones will only be 15 years old in 2030. In addition (compared to BEVs), PHEVs have much smaller batteries, have been sold in smaller numbers, and will likely have a longer life because they are in general larger vehicles, are more expensive, and still will be functional even with a degraded battery. The incentive to keep them on the road is therefore large. Similarly, up to 2020, the volume of BE-LCVs has been small with only approx. 7300 in the fleet at the beginning of 2020 (market share of 6% in 2019). Although BE-LCVs have a shorter life span than BEVs because of more intensive use, by 2030 there will still be far fewer BE-LCVs delivered for recycling. Larger volumes of batteries from these types of cars will therefore probably only come to recycling in the years after 2030.

12.2 Basic facts about the vehicle fleet

Figure 12.1 shows a breakdown of the Norwegian vehicle fleet as of 2018, according to SSB data (2019c). For this year, there were 195351 passenger BEVs, with in addition:

- 5314 electric vans
- 13 electric trucks
- 42 electric buses
- 92 electric tractors
- 22 electric crane trucks
- 1385 electric mopeds
- 81 electric light motorcycles
- 1545 electric heavy motorcycles

Considering electric vehicles alone, this means that 96 % of the total were passenger BEVs. In terms of annual sales, data obtained from OFV (2019b) shows that 2000 passenger BEVs were sold in 2011, rising to over 46000 in 2018 (Figure 12.2). Data on the age of BEVs at scrappage is not available, but the average scrappage age for all passenger vehicles in 2018 was 18.1 years (SSB, 2019c).

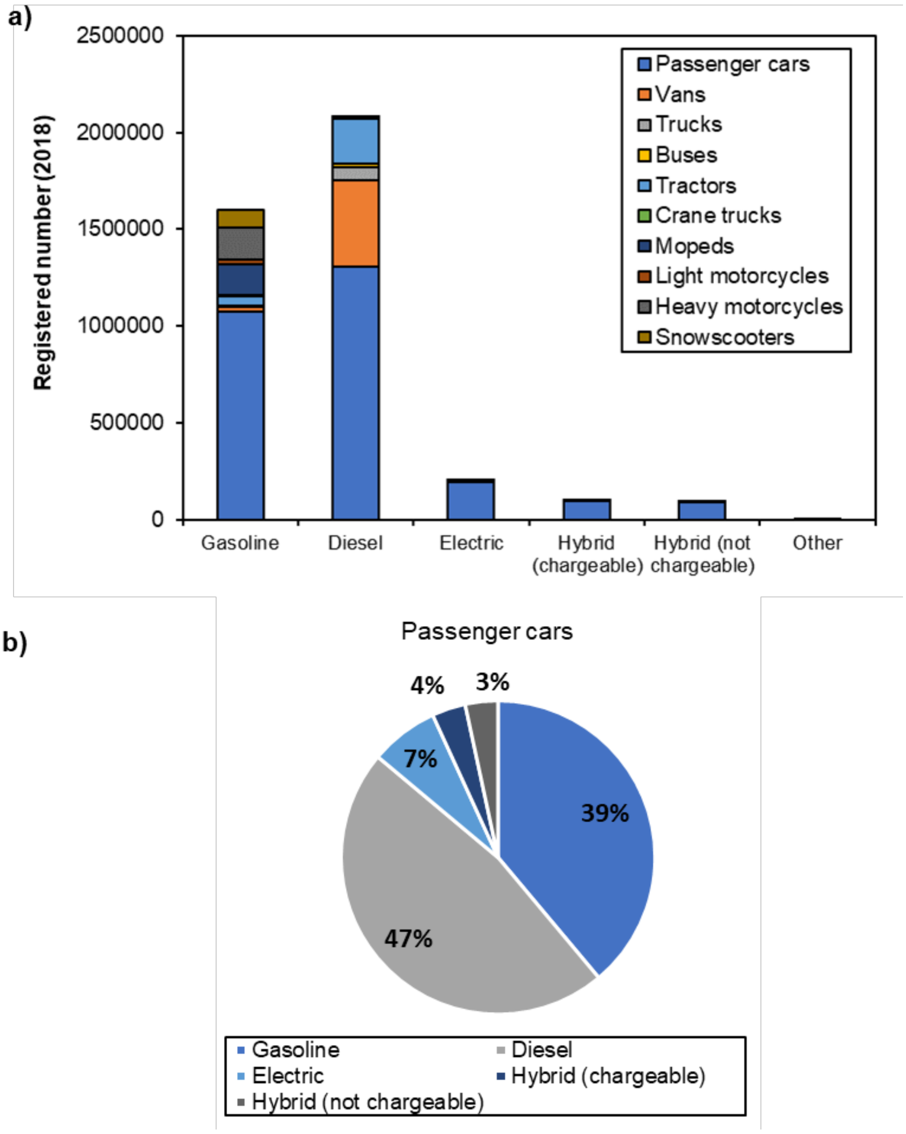


Figure 12.1: Breakdown of propulsion technology for a) all vehicle types, and b) passenger cars, for the Norwegian fleet in 2018. The statistics include all registered vehicles as of 31 December 2018 according to SSB (2019c).

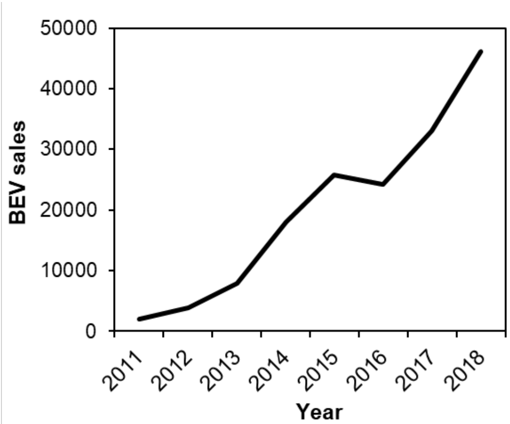


Figure 12.2: The number of passenger BEV sales per year between 2011 and 2018. Data is purchased from OFV (2019b).

12.3 Stocks and flows cohort model

Annual results until 2030 from the stocks and flows cohort model of total new electric passenger vehicle sales, and stock change from the Norwegian electric passenger vehicle fleet (for vehicles older than 1 year), are shown in 12.3. These results are based on the conservative implementation of electric vehicles according to the scenario of sales in "Perspektivmeldingen" (Norwegian Government 2019), an account of likely future societal and economic developments in Norway developed every fourth year by the Ministry of Finance. Fridstrøm (2019) constructed a slightly modified scenario which was used for the calculations; in this scenario the sales of BEVs reach 74.3% in 2030, and about 70% already by 2025. Up to and including 2018, actual data on the number of vehicles of different technologies that have been registered each year has been used, based on data from the national vehicle register.

According to the model estimates for new BEV sales (Figure 12.3a), 57555 new vehicles were sold in 2018, which will rise to 163534 in the year 2030 (sales here are summed for all weight categories), and BEVs will then account for 74.3%. Figures related to a single age class should be interpreted with caution, since the survival rates for vehicles older than 3-4 years rely on a relatively small number of cases meaning there is a considerable error involved. When aggregated across age groups (cohorts), uncertainty is lower.

Model estimates for new BEV sales for the years 2011 to 2018 were compared to historical BEV sales data in the OFV (2019b) dataset (Table 12.1). As can be seen, modelled new vehicle sales are ~10-25 % higher than new vehicle sales registered by OFV. Higher modelled results are expected when comparing with OFV data, since the stocks and flows cohort model also includes the second-hand import of (almost) new vehicles, many of which have already been registered abroad once before during the same year[14].

When considering the model output for total stock change from the Norwegian electric passenger vehicle fleet (Figure 12.3b), the model estimates a total vehicle stock change of -1328 vehicles in 2018, rising to -51667 in 2030. The numbers here represent the net stock change per year of electric passenger vehicles <u>older than 1 year</u>, i.e. not including new vehicle sales for that year. It is thus the net stock change of the vehicles that were already in the fleet each year, exluding new vehicle sales that year. This means that e.g. for the year 2018, the 'net vehicle stock change' represents the sum of the change in vehicle stocks for all classes of vehicles produced prior to the year 2018 (production year ≤ 2017). When the number is negative, as here, it is assumed that net vehicles of all prior production years are removed from the fleet by being scrapped, deregistered or exported. For the calculations done in this chapter, the assumption is that they are scrapped in Norway. Historically this has been the case due to the high taxes on passenger vehicles (cars) compared to other countries, which make old used vehicles more valuable in Norway than in other countries. BEVs do not have purchase taxes so they could potentially be exported to other countries but the user demand for BEVs is much higher in Norway than elsewhere, which makes it reasonable to assume that they will be scrapped here as well. For battery electric trucks and buses the situation may be different.

[14] Almost new BEVs have been imported second hand due to the high demand for some popular models in Norway, that have not been available in sufficient volumes. In some cases, they have been registered in an EU country for just a day to be counted towards the EU CO_2-requirement before being exported to Norway.

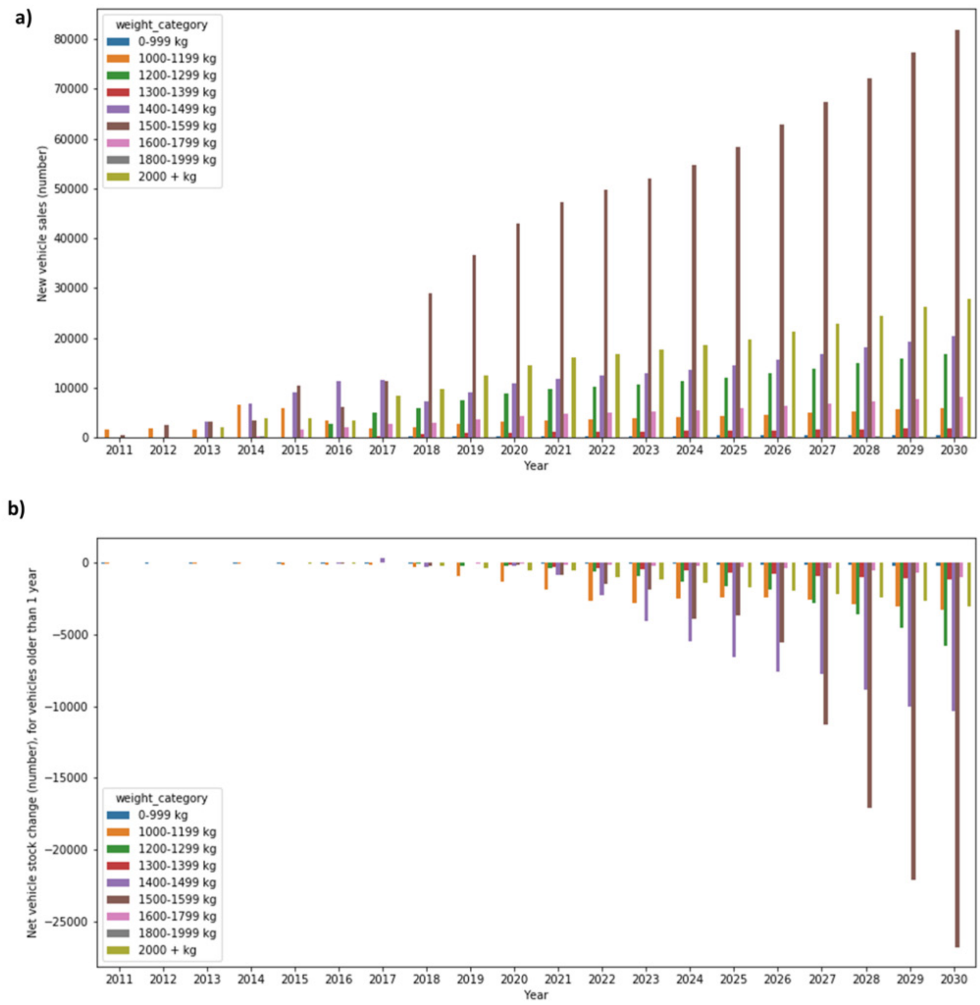


Figure 12.3: The estimated amount of a) total new electric passenger vehicle sales, and b) stock change from the Norwegian electric passenger vehicle fleet (for vehicles older than 1 year), annually until 2030.

Table 12.1: Comparison of the registered (OFV) and modelled number of first time registration of battery electric passenger vehicle (sold new and second hand imported) in Norway, between 2011 and 2018.

Year	New vehicle sales (OFV)	Second hand imported (OFV)	New registrations (modelled, stocks and flow cohort, new and second hand imported vehicles)	Change (%) BIG model vs OFV new+second hand imported vehicles
2011	2000	78	1988	-4
2012	3951	314	4231	-1
2013	7882	2086	9884	-1
2014	18081	3063	21055	0
2015	25777	5122	30758	0
2016	24217	5281	28936	0
2017	33025	8558	41423	-2
2018	46069	11899	57555	-1

Although no splitting is made in the model of vehicles leaving the fleet due to scrappage, de-registration (and re-entry to the fleet later) and second-hand export, most vehicles being removed from the fleet can be assumed as scrappage. However, for younger vehicles (especially vehicles <5 years old), these figures may be more highly influenced by second-hand import and export. Comparisons were therefore made of the total net vehicle stock change estimated by the model for all categories/ages (older than one year)/types of vehicles for years 2010 to 2018 with annual scrappage numbers from SSB (2019d). Results (shown in Figure 12.4) are comparable. Scrappage data specifically for passenger electric vehicles in Norway was not available for detailed comparisons.

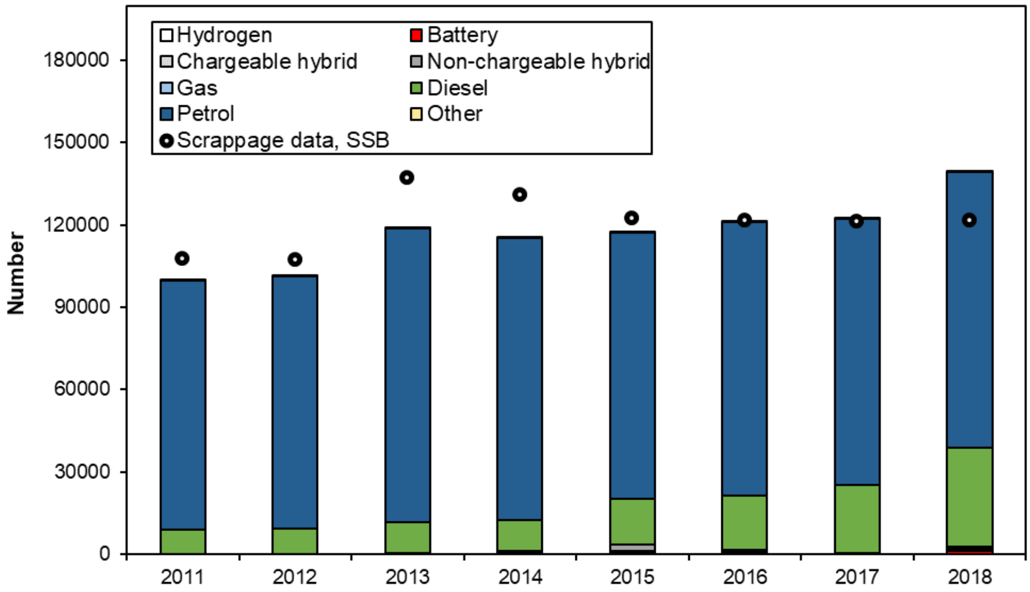


Figure 12.4: The modelled net vehicle stock change data (for vehicles older than 1 year) of all passenger vehicle types, compared with actual scrappage numbers for years 2010-2018 (black, open circles). Vehicle types included in the model results here include hydrogen, battery elecrtric, plug in hybrid, non-chargeable hybrid, gas, diesel, petrol and 'other'. Historical scrappage data was obtained from SSB (2019d).

12.4 Assessment of electric vehicle battery characteristics

Summarised background data of battery type and size for different vehicle makes/models is shown in Table 12.2 (Kelleher Environmental, 2019, Wagner et al., 2019, EV Database, 2019). This was combined with historical electric passenger vehicle sales data from OFV (2019b) to give estimates of the amount of type of batteries introduced into the Norwegian passenger vehicle fleet between 2011-2018, for both each year and weight segment (Figure 12.5).

According to these estimates, NCA and NMC are battery types currently used in greatest amounts, with around 0.7 million kWh and 0.9 million kWh used in new electric passenger vehicle sales in 2018, respectively. There is also a division of battery types by weight category evident, with NCA in use for heavier weight categories and LFP and LMO/NMC in use for lighter weight categories (a very small amount of LFP is in use and is consequently not viewable on the figure).

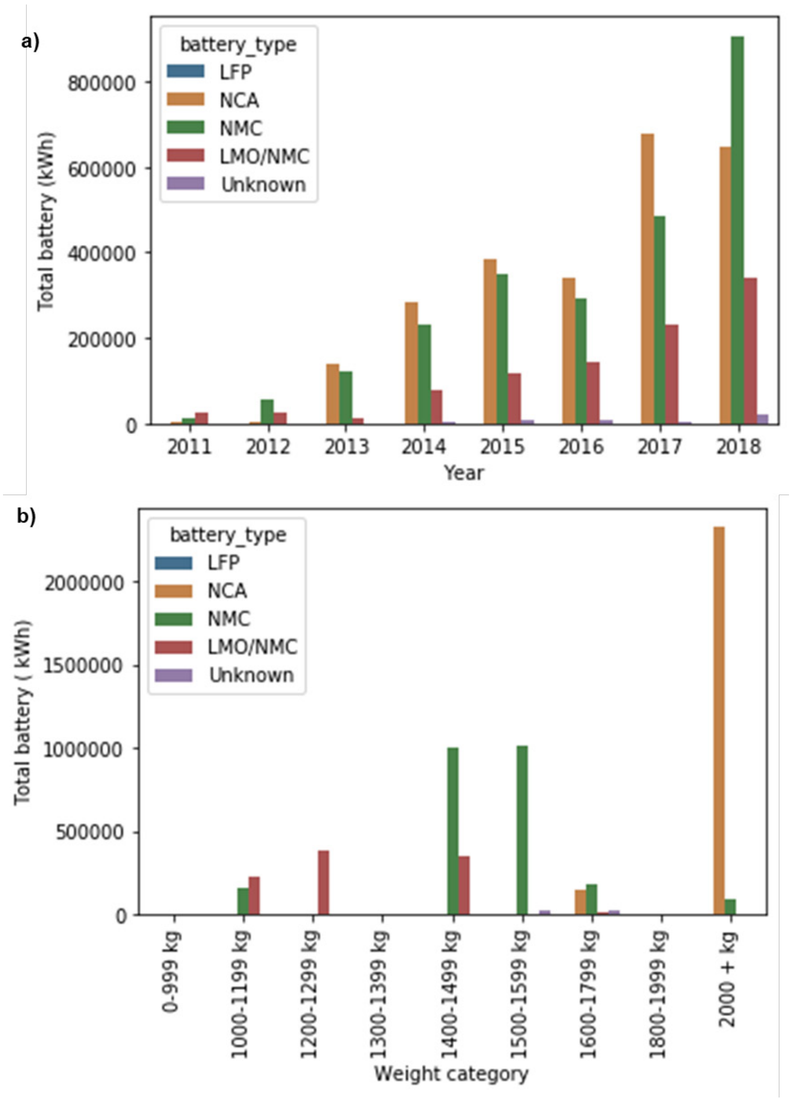


Figure 12.5: The estimated amount of total battery (kWh) introduced to the Norwegian electric passenger vehicle fleet, a) annually between 2011-2018 and b) by weight category (for all years), based on historical sales data (OFV, 2019b) and background battery characteristics data. 'Unknown' refers to unknown Li-ion type (Kelleher Environmental, 2019, Wagner et al., 2019, EV Database, 2019).

Table 12.2: Example background data used in the analysis, of battery type and size for different vehicle makes/models (Kelleher Environmental, 2019, Wagner et al., 2019, EV Database, 2019). 'Unknown' refers to unknown Li-ion type.

Full make/model	Nominal battery size (kWh)	Battery type
Audi e-tron 55 Quattro	95.0	NMC
BMW i3 120 Ah	42.2	LMO/NMC
Chevrolet Bolt	60.0	NMC
Citroen Berlingo Multispace	22.5	Unknown
Citroen C-Zero	16.0	LMO/NMC
FIORINO 40 KW	18.0	Unknown
Fiat 500	24.0	Unknown
Ford Focus	33.5	LMO/NMC
Hyundai IONIQ Electric	38.3	NMC
Hyundai Kona Electric 64 kWh	67.1	NMC
JAC iEV7S	39.0	Unknown
Jaguar I-PACE	90.0	NMC
Kia e-Niro 64 kWh	67.1	Unknown
Kia Soul EV	33.0	NMC
Mercedes B-Klasse Electric Drive	31.0	NCA
Mercedes EQC 400 4MATIC	85.0	NCA
Mercedes SLS AMG	60.0	Unknown
MG ZS EV	44.5	Unknown
MIA VE79	12.0	LFP
Mitsubishi I-MiEV	16.0	LMO/NMC
Nissan e-NV200	40.0	Unknown
Nissan Leaf	40.0	NMC
Nissan Leaf e+	62.0	NMC
Opel Ampera-e	60.0	NMC
Peugeot iOn	16.0	LMO/NMC
Peugeot Partner Tepee Electric	22.5	Unknown
Renault Kangoo Maxi ZE 33	33.0	Unknown
Renault Zoe ZE50 R110	55.0	LMO/NMC
Renault Fluence Z.E.	22.0	Unknown
Seat Mii	36.8	Unknown
Skoda Citigo	36.8	Unknown
Smat EQForFour	17.6	NMC
Smart ForFour	17.6	NMC
Smart ForTwo	17.6	NMC
Tazzari EM1	12.3	Unknown
Tazzari Zero	15.0	Unknown
Tesla Model 3 Long range performance	75.0	NCA
Tesla Model S Long range	100.0	NCA
Tesla Model X Long range	100.0	NCA
Tesla Roadster	200.0	NCA
Think City	24.0	NMC
Volkswagen E-Golf	35.8	NMC
Volkswagen E-up!	18.7	NMC
Volvo C30	24.0	Unknown

Combining OFV sales data with data on the type and size battery each vehicle contains, gives estimates of battery quantity for different production (sales) years and weight categories (see Appendix 1, Table A1 of Figenbaum et al. 2019).

12.5 New batteries and net annual change until 2030

Output from the stocks and flows cohort model was combined with estimates of the types of batteries used in electric passenger vehicles in Norway 2011-2018 to estimate the amount and type of batteries introduced through new vehicle sales, and net battery stock change, of the Norwegian fleet annually to 2030. Battery types and sizes for 2019 were assumed the same as 2018, whilst production years 2020-2030 were estimated by assessing known BEV models arriving on the market from 2020. Since very little concrete data is publicly available about the type of Li-ion batteries future BEV models will utilize, all were assigned as unknown Li-ion type. The batteries sizes were in general assumed to be increasing between 2019 and 2020 and onwards as seen in table 12.3.

Table 12.3: Actual battery sizes for BEVs in 2018 (used also for 2019) and assumed battery sizes from 2020 and onwards. Size is given in kWh per weight segment. Source for 2020+ data: Own assessment based on known characteristics of BEVs available from 2020.

Weight class in BIG model	Nominal battery size 2018-2019 (kWh)	Battery chemistry 2018-2019	Assumed Nominal battery size 2020 and onwards (kWh)
0-999 kg	No models	No models	No models
1000-1199 kg	16	LMO/NMC	37.00
	18	NMC	37.00
1200-1299 kg	33	LMO/NMC	40.00
1300-1399 kg	No models	No models	40.00
1400-1499 kg	44	LMO/NMC	45.00
	27	NMC	45.00
	39	Unknown	45.00
1500-1599 kg	34	NMC	45.00
1600-1799 kg	23	LMO/NMC	60.00
	31	NCA	60.00
	62	NMC	60.00
	34	Unknown	60.00
1800-1999 kg	No models	No models	75.00
2000 + kg	75	NCA	90.00
	90	NMC	90.00

Results are shown in Figure 12.6, with an in-depth summary of annual net stock change for the years 2017 to 2025 given in Figure 12.7. As before, the annual net stock change numbers represent the net stock change of batteries from electric passenger vehicles older than 1 year (not including new vehicle sales for each year), where a negative number is assumed to be (mostly) attributed to scrappage (end-of-life). The large increase in battery capacity entering the fleet between 2019 and 2020 is due to the large increase in assumed battery sizes in many weight classes, as seen in table 12.3. Figure 12.7 thus represents the Norwegian window of opportunity for use of end-of-life BEV arising towards 2025.

According to these results, total battery amount used in new vehicle sales across all vehicle categories and battery types is estimated to be 2.4 million kWh in 2018, rising to

~8.5 million kWh in the year 2030. The net battery stock change from all contributions (i.e. assumed end of life battery quantity from BEVs older than 1 year) is estimated to be around -0.6 million kWh in 2025, and - 2.2 million kWh in 2030. These batteries could potentially feed ~70000 and ~271000 typical home/cabin battery energy systems of 8 kWh in 2025 and 2030, respectively (Alternativ Energi AS, 2020), although it may be more economical to recycle them. No net battery stock change of Li-ion batteries is estimated prior to 2011 since these vehicles were assumed for simplicity to either be registered as non-passenger type or to contain other batteries than Li-ion. Due to the very small numbers of vehicles involved, this added uncertainty to the analysis is small.

Summed results from the model are shown in Table 12.4. Comparisons of the model estimates of the amount of batteries assumed going (mostly) to scrappage with other datasources are not yet possible due to a lack of data.

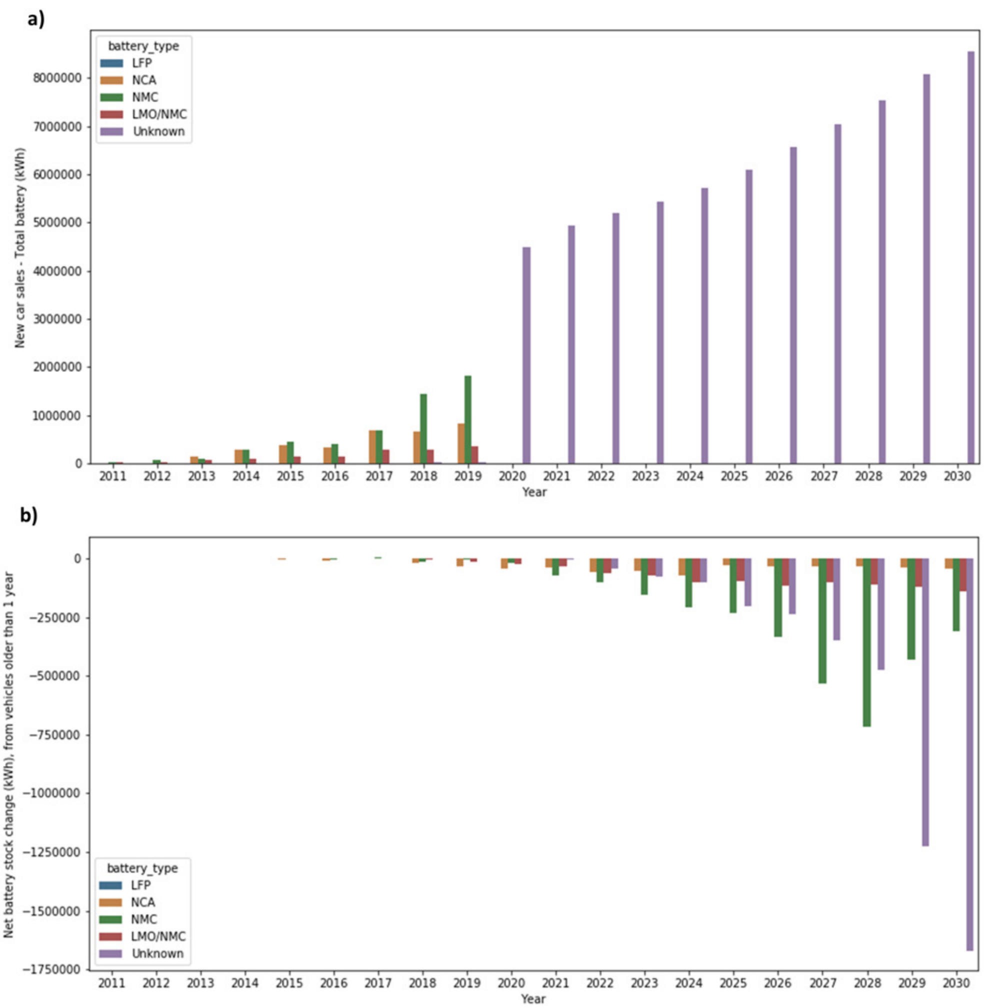


Figure 12.6: The estimated amount of a) total battery (kWh) introduced to the Norwegian electric vehicle fleet through new electric passenger vehicle sales, and b) battery stock change (kWh) from the Norwegian electric passenger vehicle fleet (from vehicles older than 1 year), annually until 2030. 'Unknown' refers to unknown Li-ion type.

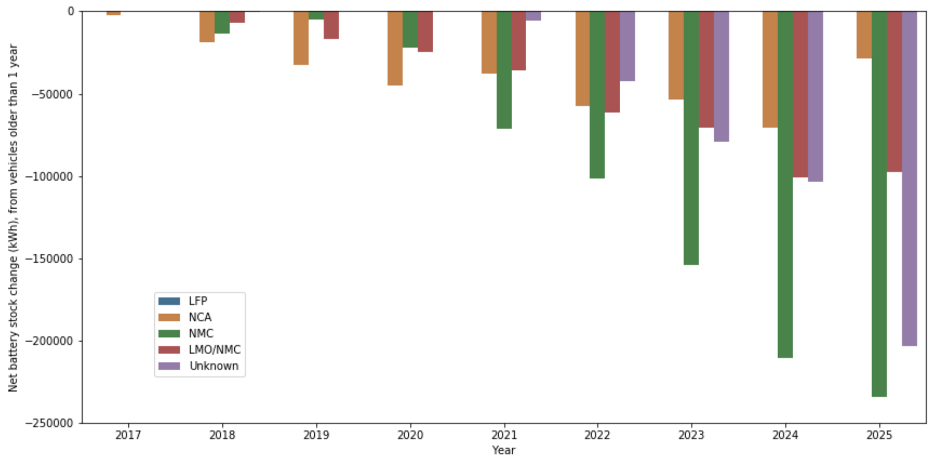


Figure 12.7: Close-up of the battery stock change (kWh) from the Norwegian electric passenger vehicle fleet (from vehicles older than 1 year), between 2017 and 2025. 'Unknown' refers to unknown Li-ion type.

Table 12.4: Modelled results of batteries entering (sum of new BEV sales and second hand imported BEVs registered first time in Norway) and leaving the fleet (battery stock change).

Year	New batteries from vehicle sales (kWh)	Battery stock change estimate (kWh)
2011	37181	0
2012	88873	597
2013	312524	-257
2014	663482	-637
2015	976254	-6687
2016	896311	-13607
2017	1672547	4302
2018	2382616	-39361
2019	3027149	-54664
2020	4496541	-91357
2021	4930404	-150092
2022	5192541	-262237
2023	5439499	-358159
2024	5722762	-485860
2025	6082541	-563632
2026	6553494	-726837
2027	7038081	-1018365
2028	7543683	-1338499
2029	8075702	-1814301
2030	8556837	-2164519

12.5.1 Uncertainties

Uncertainties in this analysis are large, and stem largely from 1) uncertainties in the estimation of the stocks and flows of vehicle numbers towards 2030, and 2) uncertainties in the assumptions of the battery size of vehicle models towards 2030. Due to the almost complete lack of supporting data for the latter (aside from for vehicle models available at the start of the 2020s), this factor was chosen for study in a sensitivity analysis. In this analysis, the battery size in vehicles produced from 2020 was varied +/- 15 % for each weight segment in a low and high scenario. Summarised results of total kWh from new vehicle sales and net stock change for the BEV fleet, for years 2020 to 2030, are shown in Table 12.5.

According to these results, the total quantity of battery entering the fleet in new BEV sales in 2030 ranges from 7.2 million to 9.8 million kWh, whilst the net stock change of the fleet in 2030 ranges from -1.9 to -2.4 million kWh. The resulting quantity of battery sales (kWh) between 2020 to 2030 correlates directly with the battery size values utilized in the model, but the net change figures are more complex due to interaction of older vehicles in the fleet (i.e. those produced before 2020).

Table 12.5: Sensitivity analysis - Summary results of total amount of battery (kWh) in new BEV sales and net stock change for the fleet for years 2020 to 2030, with variation of -15 % and +15 % of assumed battery size in vehicle models available between 2020 to 2030 ('low', "main" and 'high' scenario, respectively).

Year	Low scenario		Main scenario		High scenario	
	Sales (kWh)	Net stock change (kWh)	Sales (kWh)	Net stock change (kWh)	Sales (kWh)	Net stock change (kWh)
2020	3822059	-91357	4496541	-91357	5171022	-91357
2021	4190843	-149324	4930404	-150092	5669964	-150859
2022	4413659	-256414	5192541	-262237	5971422	-268059
2023	4623574	-346713	5439499	-358159	6255424	-369604
2024	4864347	-470897	5722762	-485860	6581176	-500822
2025	5170160	-533842	6082541	-563632	6994922	-593423
2026	5570470	-691842	6553494	-726837	7536518	-761832
2027	5982369	-966510	7038081	-1018365	8093793	-1070219
2028	6412130	-1267853	7543683	-1338499	8675235	-1409146
2029	6864347	-1630568	8075702	-1814301	9287058	-1998034
2030	7273311	-1914541	8556837	-2164519	9840362	-2414497

13 International market prospects

This chapter gives an overview of international studies on the potential for electrification of vehicles of various types.

13.1 New vehicle sales

In 2018, around 2 million BEVs and PHEVs (passenger vehicles) were sold worldwide. BloombergNEF (2019a) estimates that this figure will increase to 56 million by 2040 (see Figure 13.1). It is expected that ICEVs will constitute a high proportion of new car sales for several years to come. Overall, the Nordic countries have the third largest market share of global BEV sales, after China and the USA (IEA, 2018).

In 2025, BloombergNEF (2019a) expects that 48 per cent of all BEVs and PHEVs are sold on the Chinese market, and by 2040 this percentage is expected to be reduced to 26 per cent (BloombergNEF, 2019a).

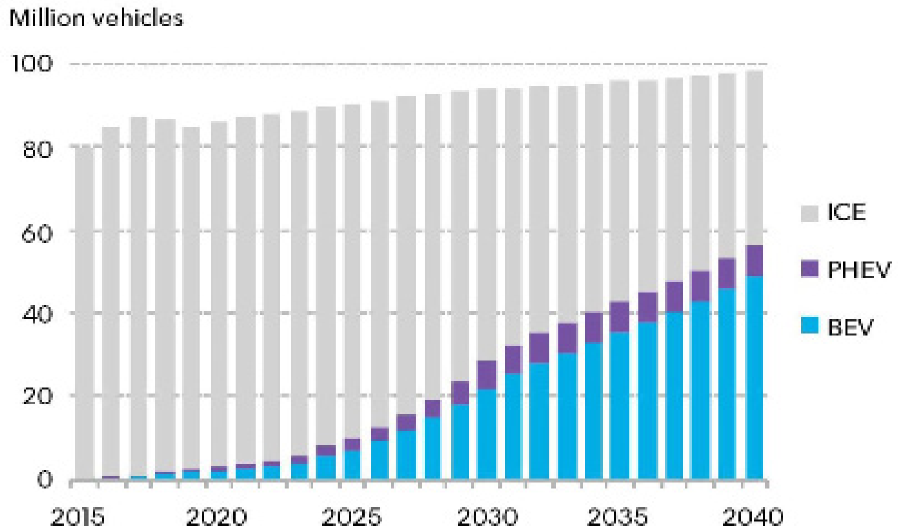


Figure 13.1: Expected global development in sales of passenger cars (BEVs, rechargeable hydride cars and combustion engine cars). Source: BloombergNEF (2019a).

The International Energy Agency (IEA 2019a) estimates that half of all vehicles sold in Europe in 2030 will be Plug-in electric vehicles (BEVs and PHEVs). Bloomberg (2019a) expects the electric vehicle market (BEVs+PHEVs) share to exceed cars with internal combustion engines for new cars worldwide by 2040. DNV GL (2019) expects BEVs and FCEVs to reach 50 percent of the market share for new car sales around 2035, and around 2038 for battery electric and hydrogen fuel cell utility vehicles, see Figure 13.2 and Figure 13.3. China and Europe are expected to reach 50 percent market share of new car sales slightly earlier than the rest of the world (DNV GL, 2019). In Norway, BEVs and PHEVs had a market share of 46 per cent of new car sales in 2018 (IEA, 2019b).

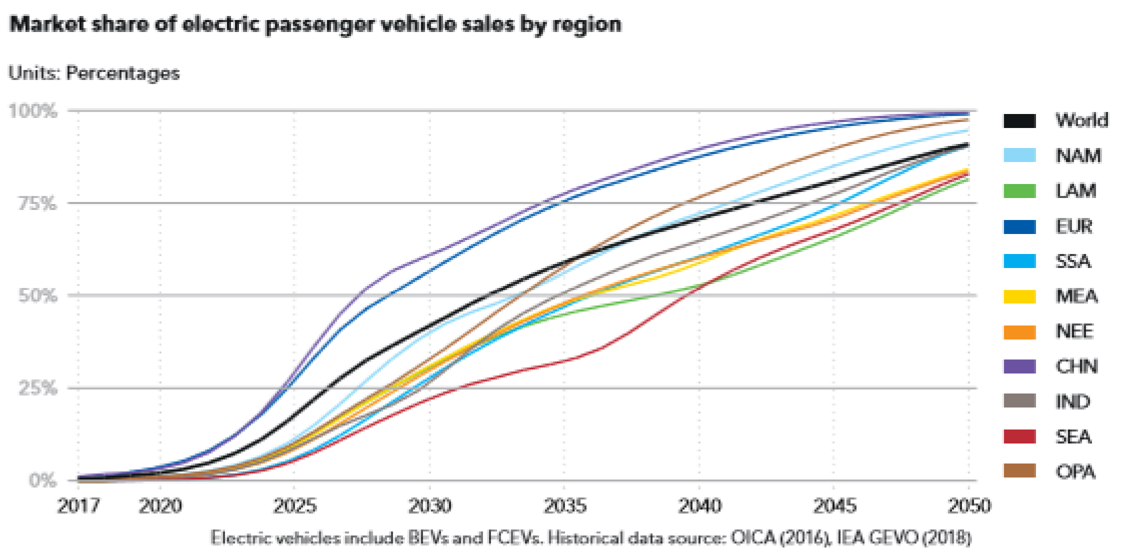


Figure 13.2: Expected global development in sales of passenger cars (BEVs and FCEVs). Percentage of passenger cars sold by region[15]. Source: DNV GL (2019).

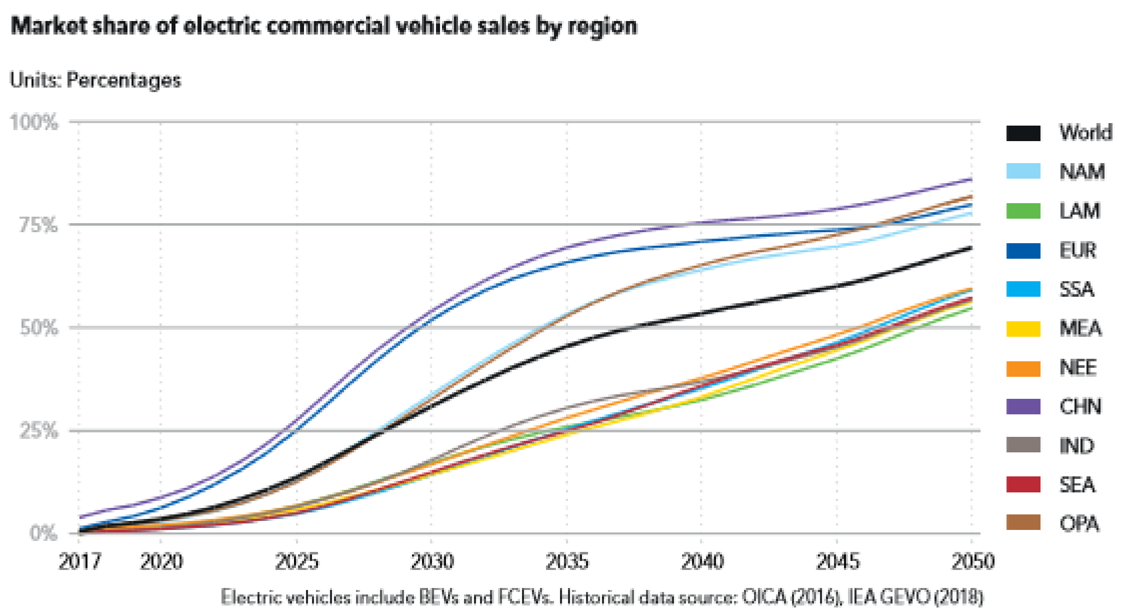


Figure 13.3: Expected global development in commercial vehicle sales (battery electric and hydrogen fuel cell). Percentage of vehicles sold by region. Source: DNV GL (2019).

13.2 The vehicle fleet

According to the International Energy Agency (IEA 2019a), in 2018 there were just over 5 million BEVs and PHEVs, 260 million electric two-wheelers, 460,000 battery electric buses

[15] NAM-North America, LAM-Latin America, EUR- Europe, SSA-Sub-Saharan Africa, MEA-Middle East and North Africa, NEE-North East Eurasia, GHN-China, IND- Indian subcontinent, SEA-South East Asia, OPA-OECD Pacific

and 250,000 BE-LCVs worldwide. Electric trucks are currently not widely used and there were only sold around 1000 - 2000 worldwide in 2018 (IEA, 2019b).

BloombergNEF (2019a) expects that by 2040 there will be around 500 million BEVs and PHEVs, and around 40 million battery electric commercial vehicles worldwide. In its two scenarios for future development, the International Energy Agency (IEA 2019a) estimates that there will be in the range of 130-250 million electric vehicles (battery electric and plug-in hybrids) by 2030 (excluding two-wheelers).

At the end of 2018, there were just under 13,000 fuel cell vehicles globally (IEA Advanced Fuel Cells, 2019). Around 1,400 (11 percent) of these were in Europe, the rest were in the United States (46 percent), Japan (23 percent) and China (14 percent).

Although fuel cell vehicles are not yet widespread, some have set ambitious goals/visions for them (IEA Advanced Fuel Cells, 2019; Reuters, 2019a), for example:

- California vision of 1 million vehicles in 2030
- Japan vision of 800 000 vehicles in 2030 (currently: 3 400)
- China goal of 1 million vehicles i 2030 (2018: 1 800)[16]
- South Korea goal of 850 000 vehicles in 2030 (currently: 900)
- France goal of 20-50 000 vehicles in 2028 (2018: 324).

The proportion of vehicles with internal combustion engines in the vehicle park will be high for many years to come. BloombergNEF (2019a) expects 30 percent of the global passenger car fleet to be electric (BEVs and PHEVs) by 2040 (see Figure 13.4). DNV GL (2019) estimates that half of the global road-based vehicle fleet will consist of electric vehicles (battery electric and hydrogen fuel cell) by 2035 (including 2 and 3 wheelers).

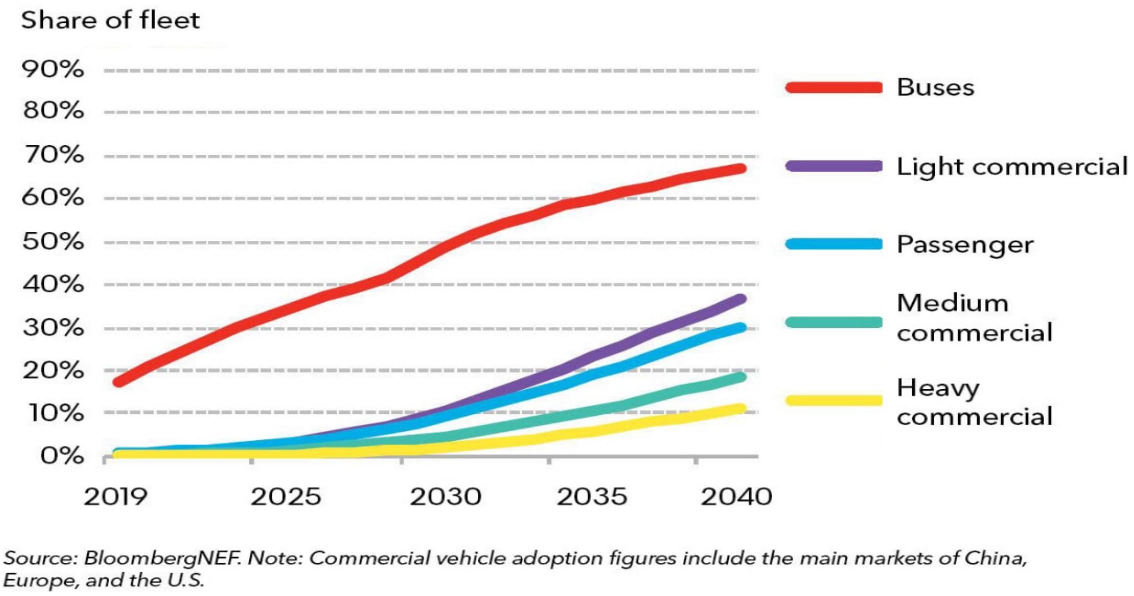


Figure 13.4: Expected global development in the proportion of electric vehicles (battery electric and plug in hybrid) of different types. Share of vehicle fleet. Source: BloombergNEF (2019a).

Figure 13.5 shows a projection of the world's road-based vehicle park for the period 1980-2050. The overview includes battery electric vehicles, fuel cell vehicles and registered two-wheelers. Despite an increase in car sharing and automation, DNV GL (2019) estimates a 75 percent increase in the number of passenger cars by 2050.

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[16] Mainly buses

DNV GL (2019) expects fuel cell utility vehicle sales to rise by 2030, and by 2050, they estimate that up to 17 percent of the electric utility vehicle fleet (as defined in Figure 13.5) in China and in the OECD countries will be fuel cell vehicles. Sales of passenger cars with fuel cells are not expected to have the same growth as commercial vehicles, partly due to energy efficiency, price and the range of new BEVs (DNV GL, 2019).

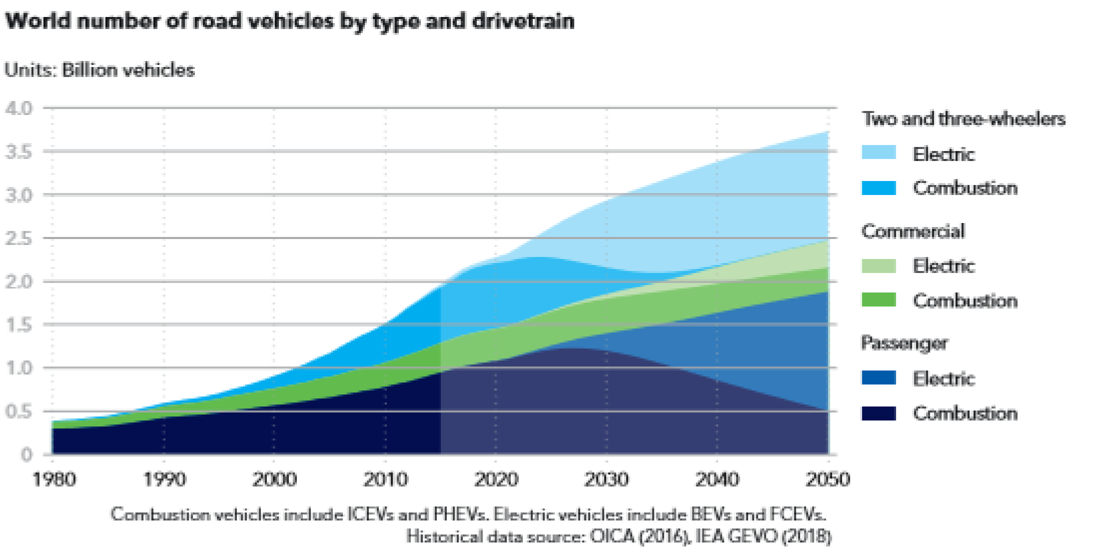

Figure 13.5: Development of the global vehicle fleet until 2050. By type of vehicle and fuel. (Electric = BEV and fuel cell, Combustion = internal combustion engine and PHEVs). Source: DNV GL (2019).

In 2017, there were just under 250,000 BEVs, PHEVs and FCEVs in the Nordic countries. The number of BEVs and PHEVs is expected to increase to around 4 million by 2030 (IEA, 2018), see Figure 13.6. Norway is the country with the most BEVs in the Nordic countries, and it is expected that this will continue to be the case in 2030 even with a growing BEV fleet in Sweden (IEA, 2018).

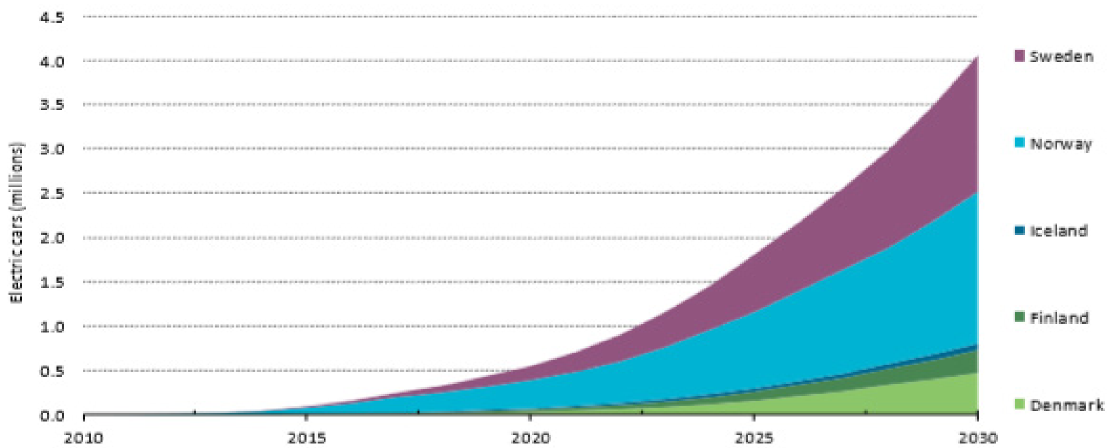

Figure 13.6: Expected development of the vehicle fleet of BEVs and PHEVs (passenger vehicles) in the Nordic countries by 2030. IEA (2018).

There are a number of different projections of the trend in the proportion of electric vehicles, and these vary, in part, in terms of how optimistic they are about the growth of electric vehicles in the various markets. BloombergNEF projections are more optimistic than, for example, OPEC and EXXON (BloombergNEF, 2019a; Coren, 2019). Many have also adjusted their projections annually in a more positive direction. But the uncertainty regarding the growth in market share of electric vehicles remains high. Today's forecasts are partly based on expectations of continued sharp reductions in the price of batteries and expected demand. Many of those who purchased electric passenger cars early had good finances, had a private home with access to charging at home, and often had access to more than one car in the household (see Chapter 10 and Coren, 2019). It may be more difficult to "sell" BEVs to other groups in the population before price, range, charging speed and access to chargers become better. Changes in incentive schemes can also cause major changes in demand. In the case of FCEVs, the uncertainty in the forecasts is greater than for BEVs.

13.3 Batteries

BloombergNEF (2019a) expect a rapid growth in the demand for lithium batteries by 2030 (see Figure 13.7). By 2030, BloombergNEF expect a demand of around 1,748 GWh for use in electric vehicles.

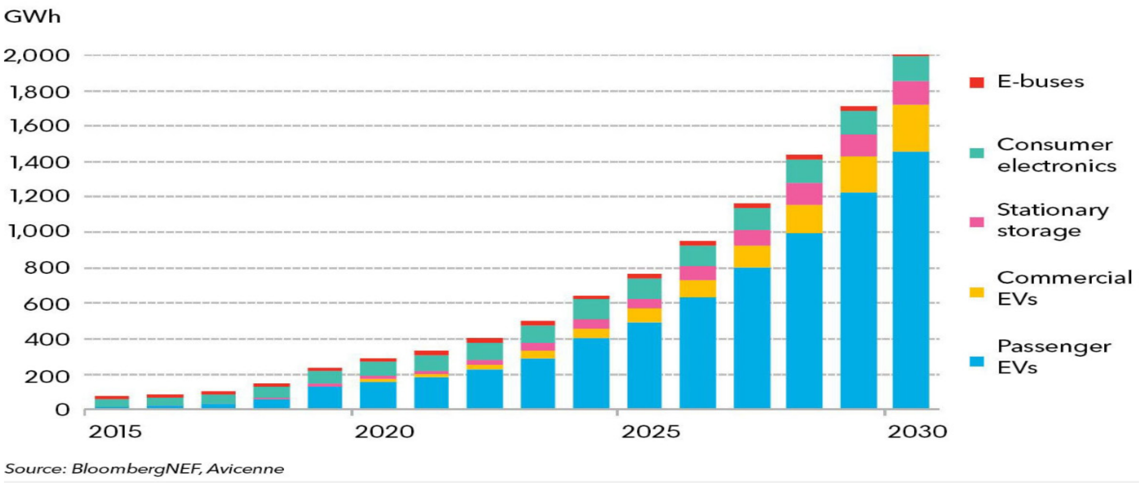

Figure 13.7: Expected global development in the demand for lithium batteries for various purposes. Source: BloombergNEF (2019a).

13.4 Infrastructure

The International Energy Agency (IEA 2019a) estimates that by the end of 2018, there were around 5.2 million charge points for passenger cars/LCVs, of which around 540,000 were publicly available. In addition, there were around 157,000 fast chargers for buses.

In 2017, there were around 264,000 charging points for electric vehicles in the Nordic countries, 16,000 of which were publicly available (IEA, 2018). Given the expected development of BEVs in the Nordic countries, there are expected to be 290,000 publicly available charging points by 2030 (IEA, 2018). But these projections contain great uncertainty.

According to IEA Advanced Fuel Cells (2019), there were 376 hydrogen filling stations worldwide at the end of 2018, 172 of which were in Europe. The 376 filling stations were a combination of both private and publicly available stations.

Europe has a target of at least 747 hydrogen filling stations by 2025 (IEA Advanced Fuel Cells, 2019).

Furthermore, others have the following goals/visions for the number of filling stations (IEA Advanced Fuel Cells, 2019):

- Japan 2025: 320 filling stations (100 in 2018)
- France 2028: 400-1000 filling stations (23 in 2018)
- Germany 2030: 1000 filling stations (69 in 2018)
- California 2030: 1000 filling stations (63 in USA 2018)
- China 2030: 1000 filling stations (15 in 2018)
- South Korea 2040: 1 200 filling stations (14 in 2018).

13.5 Energy

In 2018, the energy consumption of the world's electric vehicles (including two-wheelers) was around 58 TWh (IEA, 2019a). The International Energy Agency (IEA, 2019a) estimates that the energy needs of the world's electric vehicles will be in the range of 640 - 1,110 TWh by 2030.

DNV GL (2019) expect that the total energy demand for the road-based vehicle park will increase until 2027-2030, and then be reduced by 2050 (see Figure 13.8). The reduction is largely due to the fact that the electric vehicles are more energy efficient than combustion engine vehicles. Strong demand for electricity is expected, and some growth in demand for hydrogen is also expected. DNV GL (2019) however expect hydrogen demand to constitute only around 3 per cent of the total energy demand for road transport worldwide by 2050. Hydrogen demand is expected to be higher in Europe than the world as a whole, with demand in excess of 10 per cent by 2050. DNV GL (2019) estimate that the annual hydrogen demand for trucks and buses in Norway will be up to 36,000 tonnes in 2030.

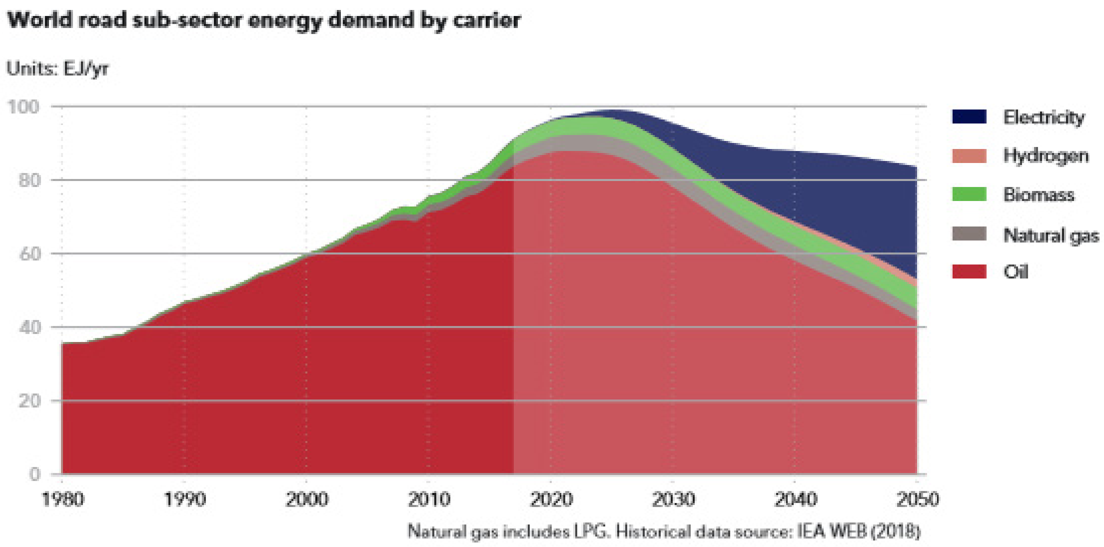

Figure 13.8: Future energy demand (EJ[17]/year) for transport purposes (road-based) worldwide, by energy source. Source: DNV GL (2019) and International Energy Agency (IEA 2019a).

[17] 1EJ = 277,8 TWh

In 2017, the energy consumption of electric vehicles in the Nordic countries was around 500 GWh (IEA, 2018). In Norway, the energy consumption of electric vehicles corresponded to around 0.14 per cent of national energy demand in 2017 (IEA, 2018). Given that there will be around 4 million electric passenger cars in the Nordic countries by 2030, this will result in an energy demand of around 9TWh. This is expected to amount to approx. 2-3 per cent of the region's energy needs in 2030 (IEA, 2018).

Although the energy requirements of electric vehicles constitute a small proportion of energy production, capacity problems may arise in parts of the energy grid. This will apply in particular:

- in the grid's outer edges,
- in areas that are frequently travelled through or visited on holidays or excursions,
- in areas with a lot of fast chargers (e.g. bus charging stations),
- at times when power consumption is otherwise high (morning, afternoon and on cold days)

NVE (NVE, 2016) state that if power consumption increases by around 5 kW per household, around 30 per cent of the transformers in Norway will be overloaded. The average age of the distribution transformers in Norway is around 30 years (lifetime of 40-50 years), which means that many of the transformers must be upgraded soon anyhow (NVE, 2016).

Nordic Energy Research (2019) have developed a scenario for the possible development of total energy production in the Nordic countries. They expect a growth in energy produced by wind power. Energy from fossil fuels/gas/coal is expected to be phased out by 2050 (see Figure 13.9), provided that politicians choose to follow a policy aimed at realising a carbon neutral society.

In Norway, almost all electrical consumption is based on renewable energy. At the Nordic level, this share was just over 70 per cent in 2016 (Nordic Energy Research, 2019).

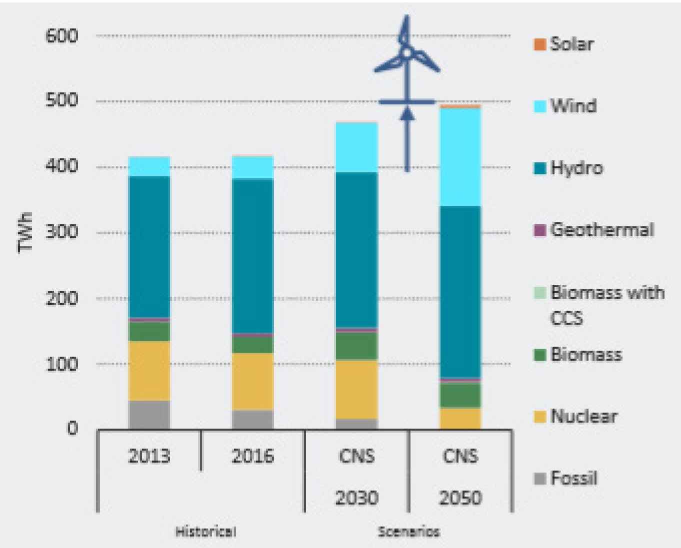

Figure 13.9: Development in Nordic energy production (TWt). Scenarios for 2030 and 2050 (based on the NETP-CNS scenario). Source: Nordic Energy Research (2019).

14 Discussion and Conclusion

14.1 Technology, politics, supply, demand, user experiences and needs coincide in the diffusion of electric vehicles

In the previous chapters, the various sub-factors affecting the BEV market have been discussed and evaluated. Together, as shown in Figure 14.1, they constitute the framework for understanding the possibility of achieving Norway's goal of reducing greenhouse gas emissions from the road transport sector, as defined in the National Transport Plans (NTP) targets for the introduction of zero-emission vehicles in the transport sector.

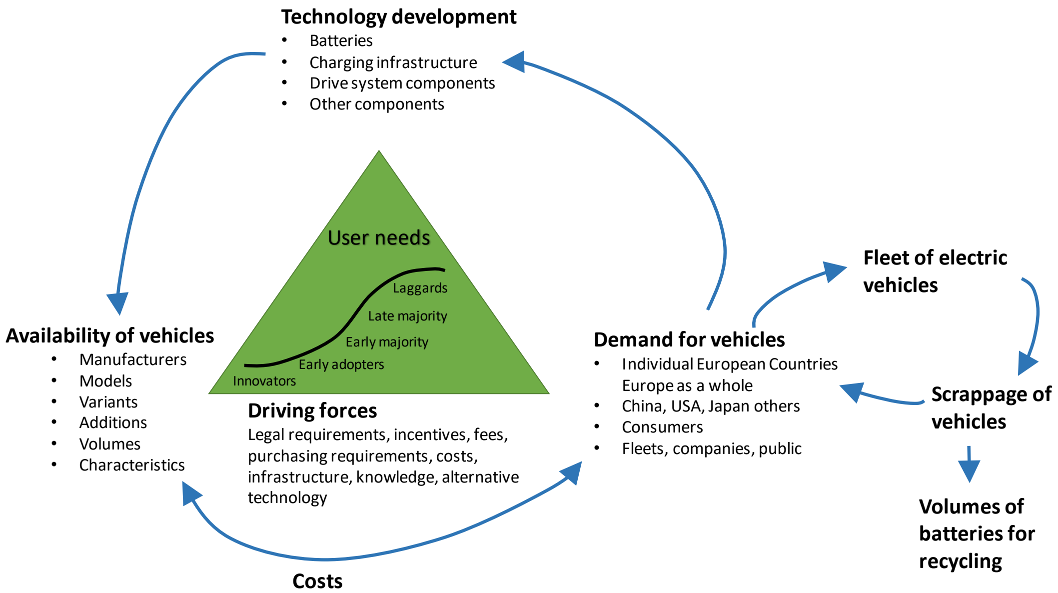

Figure 14.1: The complex interaction of factors affecting the diffusion process of electric vehicles and the availability of batteries for recycling. Own analysis.

The NTP goals are ambitious and demanding to achieve and will lead to significant volumes of battery electric vehicles using Li-Ion batteries being introduced into the vehicle fleet. At the end of the vehicle lifetimes, their batteries become available for recycling. Due to the ambitious targets in Norway, this process will go faster in Norway than elsewhere, leading to opportunities for Norwegian companies to take early leading positions in the recycling of automotive Li-Ion batteries. The national targets are that:

- By 2025, all new passenger cars will be zero emission vehicles
- By 2025, all new light LCVs will be zero-emission vehicles
- By 2025, all new city buses will be zero-emission vehicles, or use biogas
- By 2030, all new heavier LCVs will be zero emission vehicles
- By 2030, 75 percent of new long-distance buses will be zero-emission vehicles
- By 2030, half of new trucks will be zero-emission vehicles.

These targets are potentially achievable because EUs requirements to reduce the CO_2-emissions from new vehicles forces the whole automotive industry to industrialize BEVs and PHEVs.

The needs of users, and the ability to meet these needs, must be the focus when trying to understand whether the goals are achievable. Vehicle users have at the outset a well-functioning means of transport with ICEVs supported by a well-developed "ICEV regime" (Figenbaum 2017), and do not need to change technology to fulfill their transportation needs. Users mainly want to buy a vehicle that meets their needs at a price they can afford. This applies to both individual consumers, businesses and publicly owned companies. One key issue, therefore, is how to get users to change purchasing behavior towards zero-emission technologies instead of continuing with today's technology, so that society's need to reduce CO_2-emissions can be met.

Vehicle manufacturers, subcontractors and start-up companies are developing the technologies needed to produce the vehicles that the market demands. Only when a technology is sufficiently mature and there is a demand in the market will manufacturers begin production on a larger scale.

For zero-emission vehicles, incentives have the effect of moving market introduction to an earlier date. As the market develops, costs go down, policies and incentives begin to take effect, and demand increases. Research on the early users of zero-emission vehicles provides knowledge that supports further development and improvements. Eventually, vehicle manufacturers will launch models with better features that increase demand, competition and lower prices. However, this will take time. Vehicle models can last on the market for 5-8 years and the automotive industry tests new technology very thoroughly before starting serial production to avoid costly recalls.

In the passenger car market, Norway has had an active BEV policy that enabled experimentation with BEVs long before the first modern fully-fledged BEV was launched in 2010. It was from that point onwards that the BEV became as reliable and comfortable as other vehicles.

The Norwegian BEV market was developed (from the bottom-up) in the early 1990s through niche markets, and with a practical and facilitating policy design. Through a complex interaction between international development, Norwegian politics and BEV incentives, the long-standing experimentation in niche markets and car importers who saw opportunities, the path was open for a rapidly increasing market share of BEVs in the Norwegian car market from 2011. Since then, the driving range has increased substantially, the speed of charge has also increased and the cost has gone down, leading to a reduction of purchase barriers and an expanding market.

To some extent this situation is now spreading to the light commercial vehicle sector, with interest simultaneously increasing in the truck sector. Private use of electric vehicles among company leaders appears to increase the likelihood that they will also introduce electric vehicles in their business. It will be difficult for cities and counties to continue with diesel buses when private cars are replaced by BEVs on a large scale. The environmental image of public transport should be further developed in the direction of zero-emission solutions, and accordingly, this is now underway in several Norwegian cities.

In other countries there is now strong pressure from politicians (through incentives and policies, and EU targets and requirements) to introduce BEVs into a passenger vehicle market that is not, initially, particularly interested in BEVs, and where consumers and the industry have little knowledge of the product. Time may also be required to build up sufficient expertise and capacity in various support functions, where these are lacking; this applies to charging infrastructure operators, the vehicle industry and consumer organizations. In Norway, the BEV association represents a well-organized and important source of information for consumers and for politicians about the need for incentives, but such a powerful and competent organization does not yet exist in other countries. In order to achieve effective diffusion of innovations, information and communication are crucial in the initial phase (an early-user market developing to the "early majority"). Therefore, there will likely be a period of time in other countries where consumers gradually become increasingly familiar with BEVs before the market can rapidly develop further.

In Norway, user experiences with battery BEVs and BE-LCVs have largely been positive. The cost disadvantages have been eliminated since the tax system in Norway has compensated for additional costs and the risk of new technology. BEVs have mostly been used in multi-car households that have few barriers to BEV purchases; these households have had few challenges associated with the use of BEVs since they also have another car. Almost all electric motorists want to continue to be electric motorists (Figenbaum and Nordbakke, 2019). The LCVs that were available until 2018 had a limited driving range, but some companies that started using them still had positive experiences. However, for one of the main user groups (craftsmen), although they could be used in some niches the range was short relative to their main transport needs, (Figenbaum, 2018b). For service companies, the range was not so restrictive and there are companies that have replaced all their cars with BEVs.

The experience with battery electric trucks and buses is also positive, although very limited, and somewhat variable as this market is at an early stage. The trucks in use have been rebuilt from diesel operation by small independent companies, and the reliability has been somewhat variable. Electric buses are produced in series, but there have been some minor run-in challenges, including establishing charging infrastructure and planning of operations. Nevertheless, users of electric buses and electric trucks are positive that electrification is a real alternative to solving transport needs in Norway and envisage increased use in the future.

A key trend in all vehicle categories is that the electrification technology is now in place, vehicle range and model numbers are increasing, and the charging time and prices are decreasing. Combined, this allows far more user needs to be met, and will enable the electrification of increasing vehicle types and areas of use, and expand BEV markets across Europe. Vehicle manufacturers that have long been negative to BEVs, such as Toyota and Fiat, will also launch BEVs in the coming years.

Incentives, regulatory requirements and policies that favor zero-emission vehicles and compensate users for the extra cost, can help create an early market among innovators and early users. EU CO_2-requirements will push vehicle manufacturers to develop and sell light and heavy electric vehicles in increasing numbers throughout the 2020s, to avoid paying large non-compliance fines to the EU. It is up to the manufacturers to determine how to sell these electric vehicles in Europe. The number of electric and hydrogen vehicles that must be sold depends on the extent of emissions reductions in petrol and diesel cars. The CO_2-requirements will probably mean a need to sell more than 1.9 million BEVs and 0.9 million plug-in hybrid cars in Europe in 2025, and 4.4 million BEVs and 2.2 million plug-in hybrid cars in 2030. A minimum of 0.26 million battery electric light commercial vehicles in 2025 and 0.65 million in 2030 will probably also have to be sold. In the truck market, manufacturers will most likely need to sell 16000-28000 and 32000-60000 battery electric or hydrogen trucks in 2025 and 2030 respectively.

The incentives in different countries will largely control where in Europe these vehicles end up. There are currently no CO_2-requirements for the bus market, but from 2022 they may be included in the directive governing the new heavy-duty truck CO_2 emissions. Prior to this, the bus market will mainly be governed by purchasing requirements (public tender processes), specifying that a minimum proportion of buses bought should be zero-emission. Technically, up to 100 per cent of city buses can be replaced by electric buses, but this will in the short term incur additional costs for the operators. These costs will be passed on to the public authorities in the form of increased subsidy requirements for public transport.

The vehicle manufacturers (especially in Germany) are investing heavily in the development of BEVs and plug in hybrid vehicles, and modify their car factories so that they can produce them in high numbers. For Norway, this will probably mean that volume restrictions on BEVs will largely cease over the next few years, but it will depend on what price the car manufacturers can charge for BEVs. Investments in the development of the car models and factories have already been made to be able to reach the EU CO_2-requirement and will be written off regardless. In principle, car manufacturers therefore only need to cover their marginal production costs. This cost includes all materials and parts costs, labor in the factory, warranty and costs for distributing the vehicles to dealers. As long as the BEVs can be sold from the factory to the car importers or dealers for a price higher than the sum of these costs, it will always be profitable for the manufacturer to sell another vehicle. The importer and dealer must also have their costs covered. As long as Norway has a tax system and a policy that allows BEVs to be sold for more than marginal production costs, plus the margin needed by importers and dealers, the vehicles will probably be available for sale in Norway in unlimited volumes. However, there may be periods when bottlenecks in the manufacturer value chains (of both the vehicle and the battery) limit the availability of some models. Theoretically, manufacturers may also have an interest in limiting BEV availability to the level that is most profitable to meet EU demand levels in a transitional phase. This would potentially allow them to sell more petrol and diesel vehicles that they have in stock.

The Norwegian vehicle sector has already taken part of the costs of the transition to electrification of passenger cars and LCVs. For example, dealers and workshops have been trained and they have invested in chargers and other necessary equipment. These costs are already distributed among large sales volumes.

If a situation persists where manufacturers only cover marginal costs for the sale of BEVs in Europe, it is conceivable that the pace of development will decline, that the model range will be smaller and that the models will be upgraded less frequently. BEVs can then be relatively less attractive compared to conventional vehicles, and the situation may then be that the total volume of vehicles in the EU will only be what is required to meet the EU legal requirements. One policy principle should therefore be that the importers and dealers in Norway, as well as manufacturers, should have a normal return on BEVs, so that it will be attractive to further develop this market.

Passenger vehicles are leading the electric vehicle development together with LCVs, which largely use the same technology and drive systems. The driving range for BEVs has increased, and the charging time has been reduced, and this trend will continue leading to the further reduction of barriers to BEV purchases. The availability of models is increasing drastically, so that by 2025 30-60 percent of all passenger car models will be available as battery-electric variants. The typical range for the smallest BEVs will be 250-400 km, for compact 300-450 km and for the largest the range will be 450-600 km. The electric light commercial vehicle supply is also increasing rapidly and by 2025 there will be battery-electric variants of more than half of all models. The driving range will reach 200 km in winter as well, which means that most professional user needs can be met.

Within the heavy-duty segment, city buses are likely to be electrified the fastest. The range of electric buses is increasing rapidly and they are now taken into use in several Norwegian cities. All bus manufacturers offer (or will soon offer within one to two years) electric buses for urban use. Elsewhere, the heavy-duty truck market is lagging behind. Hydrogen can compete more evenly with electrification in long haul transport. It is currently therefore an open question which technology will dominate, or if there will be a combination. Electric trucks can have a reduced payload as a result of electrification (although an EU directive is introduced to reduce this barrier), and the charging speed is low in relation to filling diesel or hydrogen. Long-distance buses and coaches will have the same technology, barriers and opportunities as long-distance trucks, with the exception of express buses that run on fixed routes. For these, it will be relatively easy to set up charging or filling infrastructure. For urban logistics there are few barriers to battery-electric solutions, which will probably end up being the preferred solution over hydrogen.

Hydrogen is far behind in the development of passenger vehicles. Only a few models are available (or will be available) by 2025. Therefore, in relation to the 2025 NTP target, hydrogen can only have a marginal role. With a significantly increased range in the all-electric driving mode of the plug-in hybrid cars coming on the market in 2020, an average of 70 percent reduction in greenhouse gas emissions could be possible in real traffic compared to ICEVs. The marginal utility of developing hydrogen as a new fuel alternative for passenger cars will then be small. Hydrogen is also of little relevance for light commercial vehicles. They are used in limited geographical areas and do not need as long a range as passenger cars. Hydrogen may have better opportunities for use in trucks used for long haul transport. A comprehensive infrastructure for heavy duty vehicles must be developed whether they run on electricity or hydrogen. Electrification can pose infrastructure challenges as the market expands rapidly, but in the start-up phase it will often be possible for companies to charge a few electric trucks or light commercial vehicles at no great investment cost by using existing electricity infrastructure.

If electrification breaks through in all vehicle segments, there may be challenges in battery availability. This is because it takes a long time to develop mines that can extract more of the materials used in the batteries, and there may also be other bottlenecks in the value chains for battery production. Passenger vehicles and LCVs have come the furthest in terms of market introduction, and manufacturers are securing long-term battery supply contracts for these vehicle categories. The city buses will follow close behind, while the industrialization of electric trucks is lagging. It is therefore likely that a limitation in the availability of batteries will first and foremost affect the possibilities of electrifying the trucks. This potential issue could point in favor of hydrogen as an alternative for trucks.

Bloomberg NEF, DNV GL and IEA all propose scenarios for the introduction of electric vehicles. These scenarios all show significant growth in electric vehicle sales, but differ in terms of how large the market shares will actually be. It is not surprising that sales are partly driven by incentives and partly by demands. Sales beyond the minimum legal requirements will thus be very difficult to estimate because the policies and incentives can change quickly.

Vehicle manufacturers are investing over €300 billion (of which 45 per cent is in China) in technology development and mass production capacity for electric vehicles ranging from passenger cars to heavy-duty trucks, and together plan to launch a wide range of products. Due to having invested so much to meet the EU CO_2-directive for new vehicles, they are therefore dedicated to the launch of electric vehicles. Resultingly, they and the countries in which they are based, now need electric vehicles to be a success. They will therefore probably use their large available resources to get the market started; through their dealer network, they can disseminate knowledge to customers and assist them in assessing whether electric vehicles can be a good alternative for them. In addition, they are concerned that sufficient measures are implemented that will make it easier for consumers and professional users to buy the electric vehicles. This includes, for example, support for the development of charging stations, and the introduction of incentives that can reduce the initial cost disadvantage of the vehicles. These support measures will reduce the burden for vehicle manufacturers of launching the technology.

In some areas, Norway is better adapted to electric vehicles than many other countries. Norway has clean electricity production, which makes electrification very favorable in terms of reducing national greenhouse gas emissions. Norway also has a strong power grid extending to consumers who use electricity for heating in homes as well as for businesses, meaning that users have the power they need available to charge electric vehicles. Norwegian households, with the exception of those living in dense cities, also have good access to parking and charging at home. Companies mostly have their own parking for the vehicles they use and should be able to install charging outlets to charge them.

The substantial BEV incentives in the passenger car market have made BEVs seem cheap to buy, own and use. There have been some challenges associated with the second-hand value of the vehicles, in part due to falling new car prices in periods, but customers have largely been satisfied. Almost all of the existing owners want to buy a BEV again. This is despite the harsh climatic conditions during the winter, which has resulted in a significantly reduced range and slower fast charging.

Several countries have introduced relatively strong incentives for BEVs, including Sweden, France and Germany. However, most countries are far behind Norway's sales figures, mainly because the overall conditions are less favorable than in Norway. There will be several waves of countries in the market expansion of electric vehicles at the European level (the authors' assessments), based on the assessment of policies and other conditions (countries can jump on an earlier wave by introducing more powerful policies):

- The first wave will be made of the most northern countries, especially Norway, Sweden and Iceland, because they are well organized, have efficient policies, clean electricity and purchasing power is high.
- The second wave will be made up of other northern and central Western European countries, including Germany, France, Belgium, Austria and the United Kingdom, which are slightly less well-suited to BEVs than the countries in the first wave and have weaker policies.
- The third wave will be the remaining Western and Southern European countries, Italy, Spain, Portugal, and the Balkans, which have weaker policies and are less suited.
- The fourth wave will be the other Central European and Eastern European countries and the Baltic States that are unlikely to receive high uptake of BEVs until the costs become more comparable to the alternatives.

These waves of adoption will propagate through the vehicle fleets and lead to four waves of batteries becoming available for recycling when the vehicles reach their end of like. The differences in the average age of vehicles across Europe, as seen in Figure 14.2, and export of secondhand vehicles between Western and Eastern Europe will influence the flow of batteries that becomes available for recycling in each country, and when they become available.

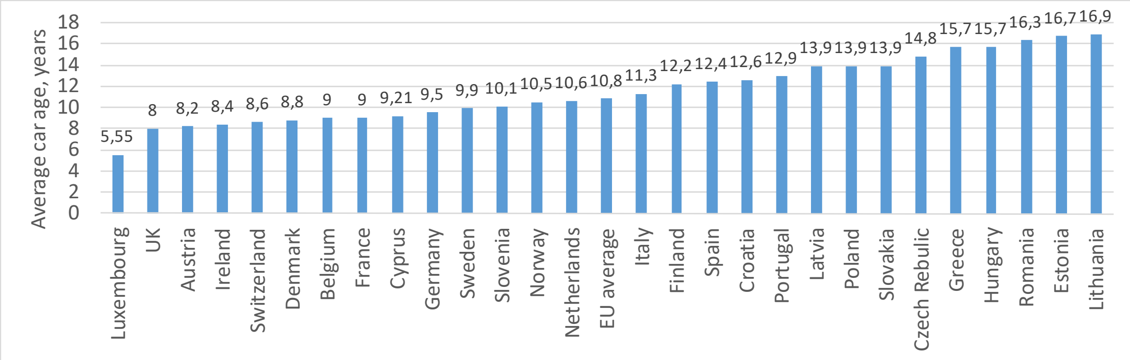

Figure 14.2: Average vehicle age across Europe (Mainly 2018). Source: EEA 2020, AUT 2020.

One challenge for electric vehicle manufacturers is that they do not have full control of the development of charging infrastructure. Most manufacturers leave the infrastructure to charge operators and thus have no control of this key element. Although, Tesla develop the charging infrastructure itself, it would not be sustainable if all car manufacturers were to do the same. In some countries this split responsibility has had a negative impact on the perceived quality of electromobility. Infrequently used infrastructure tends to be less reliable and the user experience can be poor. One experience from Norway is that the infrastructure should be expanded in line with the fleet expansion to ensure that there are regular users of the infrastructure. A specific challenge as the market takes off is to avoid charging queues that can give negative user experiences.

The Heavy-Duty Truck market is much less developed and few countries have introduced policies for this market. The charging infrastructure for trucks has for instance not been developed and few countries have any strategy for how to solve this.

14.2 The battery volume for recycling increases towards 2030

The calculation of the number of batteries entering and leaving the fleet is limited in this report to the passenger car market and BEVs. This means that the volume of batteries is somewhat underestimated as volumes of batteries from PHEVs and BE-LCVs will be available for recycling in 2030. Nonetheless, these are estimated to constitute relatively small volumes compared to BEVs since amongst other factors, up to 2020, the volume of BE-LCVs has been small with only approx. 7,300 in the fleet at the start of 2020 against 260,600 BEVs. PHEVs are sold in much smaller numbers, have much smaller batteries and are mainly larger vehicles with a bit longer life expectancy than smaller vehicles.

To estimate the amount and type of batteries introduced through new vehicle sales, and net battery stock change of the Norwegian fleet annually to 2030, output from a stocks and flows cohort model was combined with estimates of the types and sizes of batteries used in electric passenger vehicles in Norway 2011-2018. Battery types and sizes for 2019 were assumed the same as 2018, whilst production years 2020-2030 were estimated by assessing known BEV models arriving on the market from 2020. Since very little concrete data is publicly available about the type of Li-ion batteries future BEV models will utilize, all were assigned as unknown Li-ion type. The annual net stock change numbers represent the net stock change of batteries from electric passenger vehicles older than 1 year (not including new vehicle sales for each year), where a negative number is assumed to be (mostly) attributed to scrappage (end-of-life).

According to these results, total battery amount used in new vehicle sales across all vehicle categories and battery types is estimated to be 2.4 GWh in 2018, rising to ~8.5 GWh in the year 2030. The net battery stock change from all contributions (i.e. assumed end of life battery quantity from BEVs older than 1 year) is estimated to be around -0.6 GWh in 2025, and - 2.2 GWh in 2030. These batteries could potentially feed ~70000 and ~271000 typical home/cabin battery energy systems of 8 kWh in 2025 and 2030, respectively. No net battery stock change of Li-ion batteries is estimated prior to 2011 since these vehicles were assumed for simplicity to either be registered as non-passenger type or to contain other batteries than Li-ion. Due to the very small numbers of vehicles involved, this added uncertainty to the analysis is small.

No calculation has been made for Europe as a whole. An overview of the total EU+EFTA market and for Norway, and Norway's share of that total market is seen in figure 14.3. Two calculations are shown. The first shows new registrations per year. The second adjusts for Norway's second hand import (assuming it all comes from EU+EFTA countries). The graphs indicate that the volumes becoming available for reuse or recycling elsewhere in Europe could be about 2 times the Norwegian volume in 2025 and about 4 times in 2030.

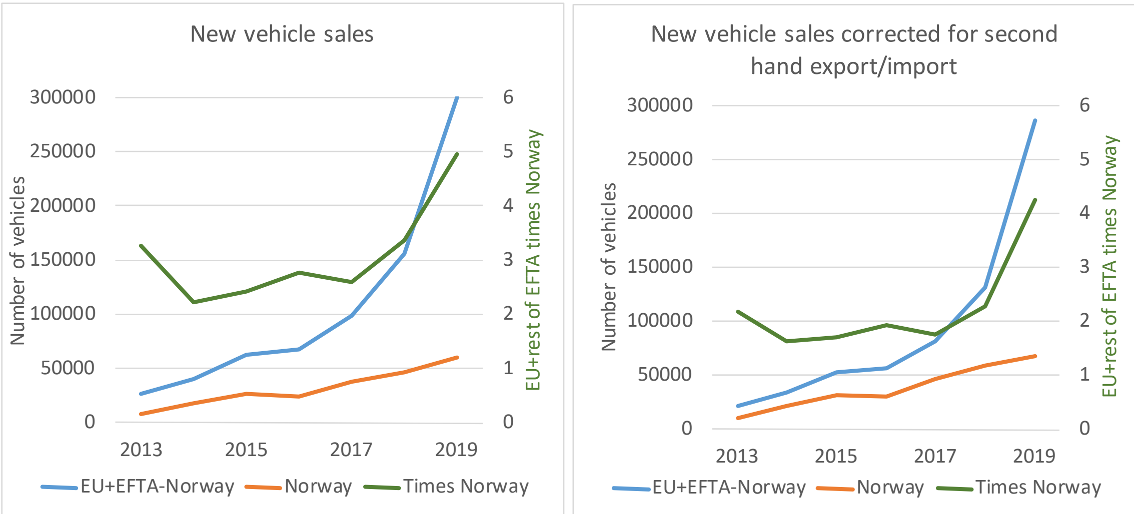

Figure 14.3: Volumes of vehicles sold in Norway and EU+rest of EFTA, with and without correcting for the flow of second hand vehicles (all second hand vehicles coming to Norway assume to come from EU/EFTA countries), and how large volumes in Europe are outside of Norway relative to Norway. Source ACEA 2020, and own analysis.

After 2030, volumes for reuse/recycling should grow much more rapidly outside of Norway as the market is expected to increase faster in other EU-EFTA countries from 2020 onwards than in Norway (due to the already high market share). The EU CO_2-requirement will lead to rapid increase in the overall volumes of vehicles entering the Norwegian market. Norway could stand for 8% of the market in 2025 and 4% in 2030. That would lead to a very steep ramp up of reuse/recycling volumes in Europe, which could be approaching 10 times that of Norway sometime between 2035 and 2040, and 20 times higher 5 years later.

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