Summary

From Market Penetration to Vehicle Scrappage. The Movement of Li-Ion Batteries through the Norwegian Transport Sector

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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.

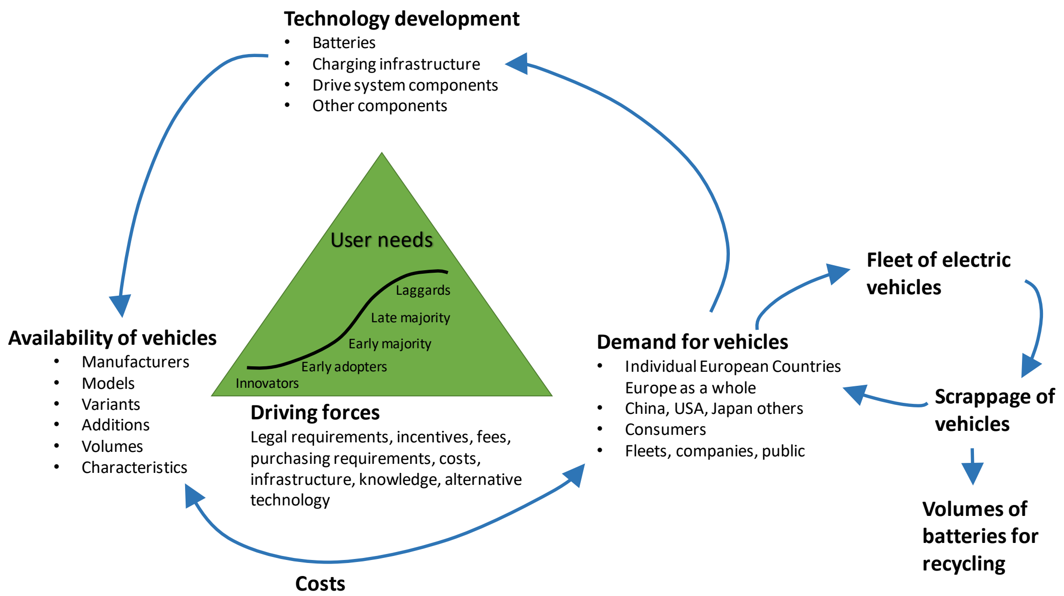

Figure S1: Elements that affect the ability to reach the zero emission vehicle targets in the Norwegian National Transport Plan (NTP).

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.

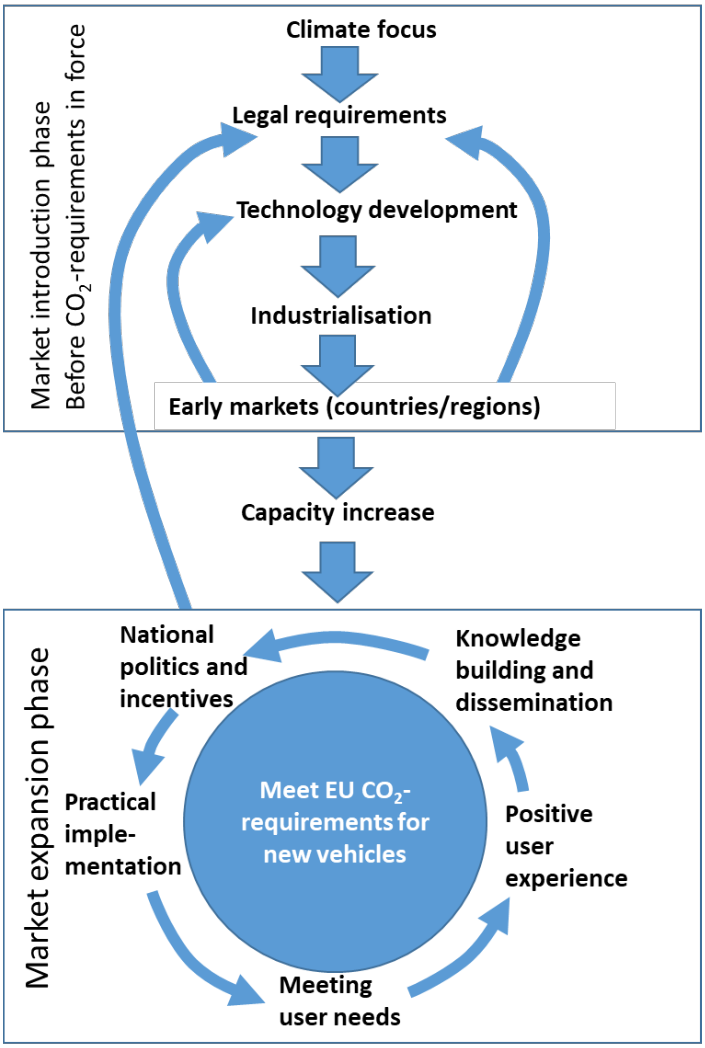

Figure S2: The dynamics that the EU requirements for new vehicle CO_2 emission limits create in the zero emission vehicles markets.

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.

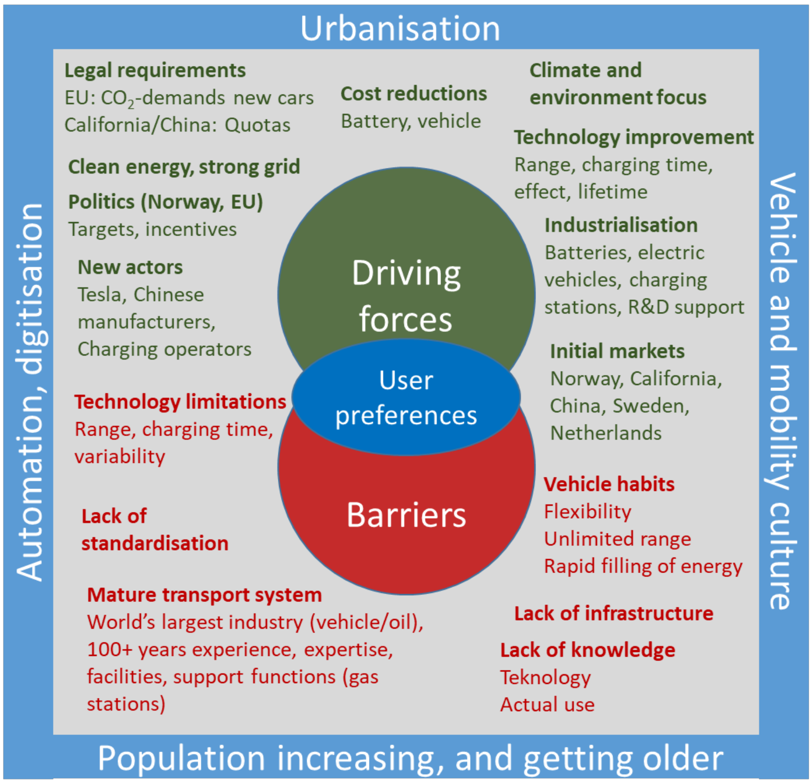

Figure S3: Drivers and barriers to a market dominated by zero emission vehicles.

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.