TØI report 1734/2019

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Mobility Zero Emission Energy Systems

# User experiences from the early adopters of heavy-duty zero-emission vehicles in Norway. Barriers and opportunities

TØI-rapport
1734/2019

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## Barriers and opportunities

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**Sammendrag:**

Norges ambisiøse klimamål krever store utslippskutt og storskala innfasing av nullutslippsteknologi også i tungbilsegmentet innen 2030. En overgang, fra dagens dominans av forbrenningsmotorer og fossile drivstoff, vil kreve innovasjon i teknologi og systemer på mange nivåer. Formålet med rapporten har vært å innhente erfaringer fra de første brukerne av batterielektriske busser og lastebiler i Norge. Viktige problemstillinger har vært å kartlegge barrierer og muligheter for batterielektrisk fremdrift innenfor disse to segmentene. Rapporten oppsummerer brukererfaringene i en tidlig fase (fra intervjuer), teknologisk modenhetsnivå, pågående innfasing av elektriske kjøretøy i Norge og utlandet. Det er utarbeidet anslag på potensiale for elektrifisering av godstransport på kort og lang sikt, og eierskapskostnader for ulike fremdriftsteknologier ble sammenliknet under ulike forutsetninger om teknologisk modenhetsnivå.

**Summary:**

Norway's ambitious climate objectives require large GHG-emission reductions and a large-scale adoption of zero-emission HDVs, by 2030. A transition, from today's dominance of internal combustion engines and fossil fuels, will require technology and system innovations at many levels. This report gathers experiences from Norwegian early users of battery-electric buses and trucks. Important objectives were to map barriers and opportunities for electrification within these two vehicle segments. The report summarizes results from early phase user experiences (interviews) and technological maturity and adoption of electric vehicles at the Norwegian, European, and global level. We further assess the potential for electrification of freight transport in a shorter and longer term, and compare TCO for different propulsion technologies under different assumptions on technological maturity.



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# Preface

This report has been prepared in Research Area 4 for MoZEES, Mobility Zero Emission Energy Systems, a Norwegian Centre for Environment-friendly Energy Research (FME), led by the Institute for Energy Technology, co-sponsored by the Research Council of Norway (project number 257653) and 40 partners from research, industry and public sector. In MoZEES, basic research is carried out on batteries and hydrogen fuel cell technology for heavier applications such as buses, lorries and vessels.

The purpose of this document is to provide an overview of technology status, user experiences from the first adopters of battery-electric vehicles, and the potential for the operation of battery-electric heavy-duty vehicles in Norway. In addition, an overview is given of the barriers and measures for achieving the increased phase-in of such vehicles.

The case study was led by Chief Research Economist Inger Beate Hovi, and the work was carried out in collaboration with Erik Figenbaum, Daniel Ruben Pinchasik and Rebecca Thorne. Daniel Ruben Pinchasik has written most of chapter 1, 2, 6, 7, 8, 9 and 11, while Rebecca Thorne has written most of chapter 3, 4, 5 and 10. Inger Beate Hovi and Erik Figenbaum have guided the work, completed the interviews, designed most of the analysis and contributed to the writing, analysis and discussions. Secretary Trude Kvalsvik has been responsible for the final finishing of the report for publication, while Deputy Managing Director Kjell Werner Johansen has had the final quality assurance responsibility.

We would like to thank our MoZEES research partners for comments and input to the report. However, any remaining errors or omissions are TØI's responsibility.

Oslo, November 2019
Institute of Transport Economics

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# Content

**Summary**

# User experiences from the early adopters of heavy-duty zero-emission vehicles in Norway

*TØI Report 1734/2019*
*Authors: Inger Beate Hovi, Daniel Ruben Pinchasik, Rebecca Thorne and Erik Figenbaum*
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*User experiences from the first Norwegian pilots with battery-electric buses and trucks have largely been positive. However, there is still a considerable way to go before zero-emission propulsion technologies can become a full-fledged alternative for HDVs. Although technological progress has so far been larger for busses than for trucks, cost premiums versus ICE vehicles are still high. Other barriers for the phasing in of zero-emission solutions include limitations to driving range and payload, long charging times, and lacking access to public charging infrastructure. Further, financial incentives for HDVs, and particularly trucks, are much weaker compared to incentives for passenger cars. This illustrates the importance of predictable framework conditions and financial incentives to accelerate the phase-in of electric propulsion solutions in the HDV-market.*

## Introduction

Heavy-duty vehicles (HDVs), such as buses and trucks, cause substantial $CO_2$ emissions. Norway's ambitious climate commitments, combined with transport-political objectives from e.g. Norway's National Transport Plan, however, require large emission reductions and a large-scale and rapid adoption of zero-emission heavy-duty vehicles by the year 2025 or 2030 (dependent on segment). Such a transition away from the currently dominant use of fossil fuels and internal combustion engines (ICE) in the transport sector will require technical and system innovations at many levels.

In this report, we describe the status and prospects for alternative, zero-emission propulsion HDVs (with particular focus on battery- and hydrogen-electric solutions), both globally and from a Norwegian perspective. Primarily, our discussion revolves around 1) technology status and prospects, 2) user experiences, 3) potential for use in Norway and 4) costs for these alternatives.

## Technology status and prospects

Generally speaking, zero-emission vehicles have many advantages compared to vehicles with ICE. Battery-electric vehicles are more efficient than ICE vehicles and have good acceleration and low operation costs. Hydrogen-electric vehicles with fuel cells also yield efficiency gains (albeit less than battery-electric vehicles) and have long driving ranges and short filling times. However, important challenges for battery-electric vehicles, particularly in the case of HDVs, relate to limited driving ranges, high battery weight (reducing transport capacity) and charging time and infrastructure requirements. Key challenges for hydrogen-electric vehicles revolve around commercialization, including unit durability and performance, hydrogen infrastructure, and storage and safety issues.

The market for both battery-electric and hydrogen-electric HDVs is maturing, with an increasing number of models operated. However, purchase costs are considerably higher than for vehicles with ICE, and with both technologies the market for HDVs lags behind zero-emission passenger vehicles. For battery-electric buses and trucks, the price difference is becoming smaller as the technology matures, and with expected progress in battery technology over the next decade. The main reason for this is that batteries themselves are a major cost driver.

Several manufacturers have announced to start small-scale series production of battery-electric buses/trucks in the next few years. Production of hydrogen-electric (heavier) vehicles is still relatively immature with limited production plans yet announced for HDVs. The number of pilots using hydrogen-electric propulsion is much lower than for battery-electric vehicles. Nevertheless, fuel cell technology is showing year-on-year growth, with an increasing number of prototypes (albeit most focused on passenger vehicles).

Although technological progress, more mature production phases, and significant cost decreases are expected for the future, hydrogen-electric technology is expected to lag behind production and adoption rates of battery-electric HDVs. Nevertheless, specific advantages compared to battery-electric vehicles in some use cases (e.g. long-haul transport) might nevertheless open for a market.

## User experiences

Until recently, Norway counted only a small number of electric HDVs. Although the phase-in of electric solutions has started to accelerate for Norwegian city buses, this has not yet been the case for trucks. The main reason for this is that demand and production of E-buses is moving from trials to small-to-medium scale series production, driven by requirements set in public transport procurements. This is coupled with a more suitable use case than for E-trucks, due to fixed routes and charging opportunities both at depots and through fast charging, also in central areas. E-trucks, in turn, are still largely only available as vehicles rebuilt from diesel engines, have less suitable use cases, and are more technology demanding.

For this report, we analyzed experiences from small-scale pilots with E-buses and E-trucks in Norway, based on a case study using semi-structured interviews with bus and truck operators. In addition, relevant policy-associated institutes and manufacturers were interviewed.

### Buses

The interviews showed that E-buses are ideally suited for operation in city centers or other urban areas where zero-emissions are required, which has led to extensive plans being made by city transport authorities across Norway. However, results showed that efficient operating schemes for E-buses are highly important due to recharging requirements during working days, which can be longer than 18 hours. Unless routes and charging times are carefully optimized, this implies that more buses (5-10 %) are needed to achieve the same passenger transport volume. There are also major issues with installing streetside charging infrastructure within urban areas, and although increased E-bus operation is a political objective, the municipal administration does not yet facilitate the establishment of stations for fast charging. Unless these issues are resolved, E-buses will be most appropriate where there is a short distance to the bus depot. Another key challenge relating to E-buses is their high upfront cost compared to diesel buses.

Nevertheless, bus operators are in general optimistic when considering the future of electric buses, although many agree that a mixture of different propulsion technologies will be optimal for buses in the foreseeable future. Whilst E-buses are ideal to use in city center areas, hydrogen-electric (fuel cell) vehicles may be more suitable where a longer range is important, highlighting a complementarity between technologies. Crucially, the higher the number of E-buses in a fleet, the more careful planning is required to adapt.

Table S.1. gives a technical summary of vehicles used in the trials with battery-electric buses upon which interviews were based.

*Table S.1: Electric bus (E-bus) trials beginning 2017/2018 in the Oslo region, that interviews were based on. Trials (columns) listed in the table are ordered after vehicle length, with subsequent analysis of operators given in a randomized order for anonymity. Source: Autosys (NPRA, 2018) and interviews with the operators. *Based on average driving distance of a corresponding ICE-bus. **Based on planned operation hours/average speed. ***Twincharger. ****Charger use was planned at the time of the interview.*

| | Oslo Taxibuss | Taxus | Norgesbuss | Unibuss | Nobina |
|---|---|---|---|---|---|
| Type of bus | Mini bus | Mini bus | City bus | City bus | Articulated bus |
| Manufacturer | Iveco | Iveco | Solaris | Solaris | BYD |
| Model | El-bus | El-bus | Urbino 12 Electric | Urbino 12 Electric | El-bus |
| Expected driving range (km/y) | - | 12-13 000 | 74 000-87 000** | 60 000 | 110 000* |
| Range on full charge (km) | 150 | 160 | 240 | 45-50 | 180 |
| Number tested | 4 | 10 | 2 | 2 | 2 |
| Registration year | 2018 | 2017 | 2017 | 2017 | 2017/2018 |
| Length (m) | - | 7.13-7.33 | 12 | 12 | 18 |
| Battery technology | Sodium-nickel chloride ($Na\text{-}NiCl_2$) | Sodium-nickel chloride ($Na\text{-}NiCl_2$) | Lithium-titanate (LTO) | Lithium-titanate (LTO) | Lithium-iron phosphate (LFP) |
| Battery capacity (kWh) | 82 | 90 | 127 | 75 | 300 |
| Depot charging (kW) | 22 | 11 | 80*** (250****) | 80*** | 80*** (300****) |
| Opportunity charging (kW) | | | 400 | 300 | |
| Charge time (hours) | 8 (over night) | 4 (day time) | 1/0.1 (slow/fast-charging) | 8/0.1 (slow/fast charging) | 3.5 |

## Trucks

In general, experiences from operation with battery-electric trucks were positive (particularly for waste and recycling companies), with comments relating to good working conditions, energy savings, and lower operating and maintenance expenses. However, major technical issues were experienced by several other operators. As with E-buses, purchase costs of electric propulsion vehicles were reported to be an issue.

Looking to the future, feedback from operators was that if a transition to electric heavy-duty transport is to be made, charging infrastructure must be further developed, possibly with help from authorities. Interview results also showed that it is important to keep incentives such as ENOVA[1] subsidies to encourage further diffusion of E-trucks, as well as free toll-road passing and access to bus lanes. In addition, demand for zero-emission trucks must be created through requirements set in public and private tenders.

Operators interviewed were positive to meet the emission requirements in the years to come and in general expect to expand the use of E-trucks. This means that further orders have been made, or plans will be made for purchasing more E-trucks when these become

[1] ENOVA is a Government organization tasked with supporting the introduction of climate friendly solutions within the industry, energy, household and transport sectors.

available in series-production. For operators with the latter perspective, the view was that larger scale production of E-trucks is required for many issues to be solved.

Table S.2. gives a technical summary of vehicles used in the trials with battery-electric heavy-duty trucks upon which interviews were based. Trials were carried out in the South Norway, within food distribution, refuse collection and recycling businesses.

*Table S.2: E-truck vehicle trials beginning 2017/2018 in Norway, that interviews were based on. Trials (columns) listed in the table are ordered after total vehicle weight, with subsequent analysis of operators given in a randomized order for anonymity. Source: Autosys (NPRA, 2018) and interviews with the operators. *Average value for the fleet, with large variation. **For a similar (existing) ICE vehicle in the fleet. ***At the time of the interview, the operator did not yet have their vehicles in regular operation, but had experience from a test-vehicle. ****Actual km/y driven at time of interview.*

| | Nor Tekstil | BIR | Renovasjonen | ASKO | Norsk Gjenvinning | Ragn-Sells | Stena Recycling*** |
|---|---|---|---|---|---|---|---|
| Sector | Manufacturing | Waste collection | Waste collection | Freight transport | Waste collection | Waste collection | Recycling |
| Vehicle type | Heavy van | Truck (waste) | Truck (waste) | Truck (freight) | Truck (waste) | Truck (waste) | Tractor (recycling) |
| Manufacturer | Iveco | DAF/Emoss/ Geesinknorba | DAF/Emoss/ Geesinknorba | MAN/Emoss | Dennis Eagle/PVI (Renault) | MAN/Emoss/ Allison | MAN/ Emoss/ Allison |
| Expected driving range (km/y) | 30 000 | 20-26 000** | 16 800** | 50 000* | 18 000**** | 80 000** | 120-130 000 |
| Range on full charge (km) | 160 | 120-130 | 100-140 | 180 | 140 | 200 | 178 |
| Number of vehicles tested | 5 | 1 | 1 | 1 | 2 | 1(+1) | 2 |
| Registration year | 2018 | 2018 | 2018 | 2016 | 2018 | 2018(2019) | 2018 |
| Total weight (t) | 5.6 | 12.0 | 12.0 | 18.6 | 26.8 | 28.0 (50.0) | 40.0-45.0 |
| Payload (t) | 2.6 | 3.5 | 3.5 | 5.5 | 9.7 | 18-19 | 15-20 |
| Length (m) | 7.2 | 7.0 | 7.0 | 9.0 | 9.5 | 7.8 | 7.4 |
| Battery technology | Sodium nickel chloride ($Na\text{-}NiCl_2$) | Lithium-ion (LIB) | Lithium-ion (LIB) | Lithium-ion (LIB) | Lithium-ion (LIB) | | Lithium-ion (LIB) |
| Battery capacity (kWh) | 80 | 120 | 130 | 240 | 240 | 200(300) | 300 |
| Depot charging (kW) | 22 | 22/44 | 44 | 2 x 43 | 44 | 44 | 44 |
| Opportunity charging (kW) | | | | | | 150 | 2 x 150 |
| Charge time (hours) to 80 % | 8 | 2-8 | 3.5 | 5 | 8 | 4.5 (to full charge) | 4-6/0.3 for slow charging/fast charging |

## Potential for electrification from a use pattern perspective

### Buses

The potential for E-bus use might be high in areas where buses drive locally in a closed system. Across the European region, E-buses have been increasingly used for testing, pilot studies and regular operation, and predictions are that the EU E-bus share will reach 50 % by 2030. In Norway specifically, there is a National target in the National Transport Plan 2018-2029 for 100 % of all new city buses to be either zero-emission (battery- or hydrogen-electric) or using biogas, by 2025, and there are multiple plans at a regional level set by local transport authorities towards these targets.

## Trucks

Both the literature and trial experiences indicate that important obstacles for the market introduction of battery-electric trucks stem from limitations to cargo capacity, driving ranges, and engine power. In this light, we assessed the potential for electrification for Norwegian commercial vehicles from the perspective of user patterns for different categories of vehicles, using base data from the Norwegian public vehicle registry and Statistics Norway's survey of trucks.

Today, the majority of total mileage for newer trucks is driven using trucks with engines over 500 Horsepower (HP), and for which a major supplier indicates that there are currently few alternatives to diesel. Trucks with smaller engines, for which electrification in a shorter term is most likely, however, make up only a fraction of total mileage conducted with newer trucks. Within this segment, trucks with closed chapel constitute the largest group of vehicles, followed by special trucks such as refuse collection vehicles. This indicates a need both for more powerful battery-electric motors and longer driving ranges than is the case today. These needs are amplified by the fact that a large share of driving is done with trailer attached (requiring engine power) and that such trips are also longer on average than when not using a trailer. A number of these findings are illustrated in Figure S.1.

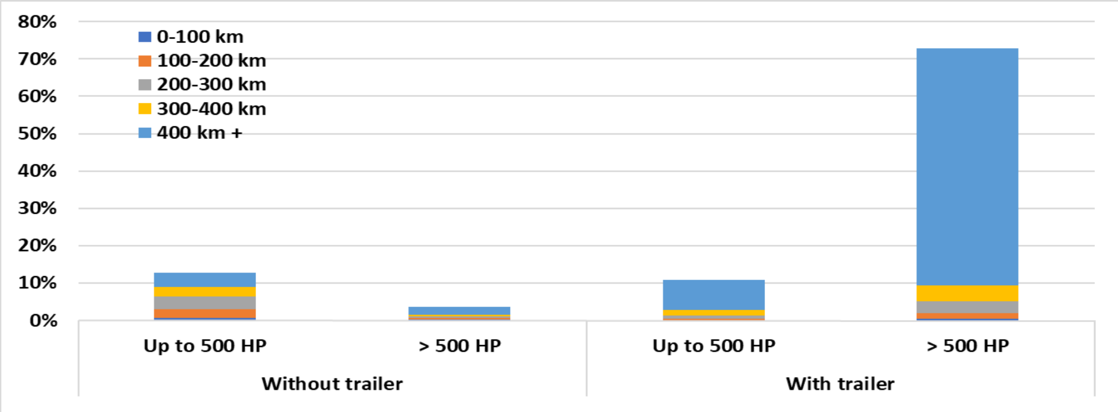


*Figure S.1: Distribution of daily mileages for trucks of up to 5 years old, for engine power below and over 500 HP, and for driving with and without trailer attached. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

In a longer term, firms owning multiple trucks might be able to redistribute transport routes between vehicles, and thereby increase potential for electrification. Specific characteristics of the transport industry, such as the large fragmentation and differences between own-transport and hire-transporters, make it difficult to quantify this potential. Our findings suggest that own-transport is to a larger degree using smaller vehicles and covering shorter mileages making them more suitable for electrification, but at the other hand, such vehicles are older on average, which works in the opposite direction.

If the engine power of available E-trucks increases to 600 HP and driving ranges to 300 km, this could in a longer term allow for the electrification of a large share of transport in Norway.

We find that vehicle capacity on trips with cargo is often not fully utilized with respect to weight. Underutilization rates suggest that for a large share of transports, vehicles could have considerable room (often several tonnes) for the extra weight of a battery, without violating vehicle weight restrictions. Whether this is also the case in practice depends on whether some trucks are always driven with spare capacity, whether there are parts of distribution routes that have less weight, and whether our data sufficiently identifies variation in transport volumes throughout the year. At the same time, it can be noted that e.g. European Parliament, in April 2019, adopted a proposal that opens for up to 2 tonnes of additional total vehicle weight for zero-emission trucks. Given current battery technology, this could negate the weight of about 200-300 kWh of batteries, which is equivalent to a driving range of ca. 150-200 kms for trucks.

## Costs of ownership

### Buses

A favorable comparison of Total Costs of Ownership (TCO) with both ICE-buses and other low/zero-emission technologies is of key importance to E-bus uptake, although authorities at the regional level may decide to accept higher costs to get to a zero-emission bus fleet. Information obtained from interviews was thus used to calculate E-bus TCO for the current year and 2025, which was compared to other technologies ($H_2$-, Biodiesel- and ICE-buses).

The results indicate that although E- and $H_2$-buses currently have higher TCO than ICE-buses running on diesel or biodiesel (mostly due to the high vehicle capital costs for these technologies), by 2025, TCO is more comparable. These figures also account for an additional 10 % E-buses that may be needed in the fleet to deliver the same level of transport service as an ICE fleet. The charging strategy for the modelled E-bus was assumed to be based on depot charging, due to the difficulties experienced by operators (at present) in installing opportunity charging in city centers, and was based on the number and type of chargers/buses used by one operator interviewed.

Key parameters were varied as a sensitivity analysis. If an optimistic value is considered for the E-bus vehicle investment cost in 2025, TCO in 2025 is directly comparable with an ICE bus at around 10 NOK/km for both options. In contrast, if a less optimistic E-bus investment cost is considered, E-bus TCO in 2025 is 19 % higher than for an ICE-bus. The charging strategy chosen also has an effect on TCO. With projected optimizations, either depot charging and opportunity charging alone represent the charging solutions with the lowest TCO, with both of these solutions giving comparable TCO to that of an ICE-bus. Depot charging alone allows the use of chargers with relatively low cost, whilst for an optimized opportunity charging solution, the high cost of opportunity chargers at endstops is offset by the high number of buses that may use them. Where a mix of depot charging and opportunity charging is used, the high cost of the opportunity charging points is not offset over a high number of buses. However, these solutions also come with varying practicalities; where an opportunity charging solution alone is chosen, the buses may not be preheated before use.

Due to the variation of TCO with input parameters, results have high associated uncertainty, but it is nevertheless clear that the potential is high for competitive E-bus TCO compared to other technologies in future. This is with upcoming larger scale production of E-buses and a projected decrease in investment costs. The charging solution chosen must be carefully dimensioned and planned, and will be route dependent.

### Trucks

With regard to the costs of ownership for trucks using alternative propulsion technologies versus ICE vehicles, we carried out comparisons for several scenarios of production maturity (and investment cost decreases) for electric heavy-duty vehicles. This included the current early stage, small-scale serial production, and mass production scenarios. Cost comparisons were based on a relatively detailed decomposition of cost drivers, with cost parameters stemming from interviews and base parameters from the National Freight Model for Norway, alongside a number of validations from different literature sources and assumptions on reductions in production costs in more mature phases of production.

Our cost analysis shows that in the current, early stages of production, larger battery-electric vehicles cannot compete on costs with vehicles using diesel, biodiesel, or biogas, unless significant incentives are available. The main cause for this is the large cost premium of investment for battery-electric trucks.

When this cost premium decreases, as assumed in the scenario with small-scale serial production, battery-electric vehicles may become competitive versus diesel vehicles at annual mileages of between ca. 43 000 km (tractors) and 58 000 km (heavy distribution trucks). Data on vehicle usage shows that such mileages are currently not at all unusual for newer ICE vehicles.

Provided that battery-electric alternatives provide comparable driving ranges, cargo capacity, engine power, etc., they could thus become a cost competitive alternative. Other barriers that must be overcome are related to amongst others the development of infrastructure for fast-charging, knowledge gaps about operational characteristics, and the development of a second-hand market.

In turn, small- and medium-sized vans have already reached a stage of small-scale serial production, and can already be considered cheaper in operation than (bio)diesel or biogas vehicles from relatively short annual mileages, especially in light of annual mileages that are typical for newer vehicles in these van segments.

Finally, in the scenario with mass production of battery-electric vehicles, we find that HDVs become cost competitive versus diesel vehicles already from relatively low annual mileages of between 19 000 – 23 000 km, depending on the vehicle segment. The main reason for this is the low energy cost when operating on electricity. Compared to biodiesel and biogas vehicles, the break-even point is even lower.

Battery-electric vans, in turn, are found to become cost competitive already from mileages of around 1 000 km in the mass production scenario given the current battery sizes used in these vehicles. Future battery-electric vans are likely to be equipped with larger batteries and longer range, but will probably remain highly competitive with regards to cost. Even when such vehicles would lose advantages such as toll exemptions/discounts, it therefore seems likely that they will remain a competitive alternative from an economic point of view. However, factors such as range limitations and charging time, as well as a somewhat smaller flexibility in vehicle use, may for the time being still slow down the adoption and diffusion of these vehicles.

## Barriers

Although rapid developments are taking place in the market for battery-electric passenger cars, and to a lesser extent also for vans, there is still a considerable way to go before zero-emission propulsion technologies can become a full-fledged alternative for HDVs. This applies particularly for trucks.

Despite the fact that pilots with battery-electric trucks and buses have so far been ongoing for only a relatively short time period, the first experiences have predominantly been positive, as stated by the users themselves. Despite some teething problems and downtime of individual vehicles, most operators are positive and hopeful about the future adoption of more battery-electric vehicles.

However, there are also a number of challenges that need to be addressed to diminish barriers to investing in battery-electric vehicles for day-to-day operation within trucking and bus companies:

- High upfront cost of battery-electric HDVs. Although operation and maintenance costs are already comparable (or lower), especially for buses, total ownership costs are currently higher than for ICE-based vehicles.
- Limitations in range and cargo capacity, engine power, and access to charging/filling infrastructure. In a shorter term, uncertainty and knowledge gaps may also form barriers.

From our cost comparisons, we found that in current, early stages of production, larger battery-electric vehicles (buses and trucks) cannot compete on costs with vehicles using diesel, biodiesel, or biogas, without incentives. When cost premiums decrease, in scenarios of small-scale series and later mass production, however, battery-electric solutions could become cost competitive on their own at realistic annual mileages.

Cost competitive prospects are better (and production maturity already more advanced) for battery-electric vans.

## Policy measures

All in all, however, the adoption of zero-emission heavy-duty vehicles does not happen automatically. An important barrier is formed by high upfront investment costs due to limited demand and production scales. To speed up the start-up of series production of battery-electric vehicles, and particularly trucks, demand can be created through requirements set in tenders. Especially for buses and waste collection trucks, zero-emission technology can be phased in through new tenders and/or change orders to existing contracts.

Further, predictability in the framework for ownership and operation is important. Because incentives through policy instruments such as purchase tax or VAT exemptions, are much weaker for vans, buses and trucks than for passenger cars, other incentives are needed. For HDVs and enterprises, main policy instruments for encouraging the uptake and further diffusion of zero-emission technology are support through the ENOVA scheme and 'zero-emission fund'. Further support schemes include the Pilot-E and Klimasats programs.

Local incentives such as free or reduced road tolls or access to bus lanes will also foster increased adoption of E-trucks and E-buses. In light of high upfront investment costs, changes in tax deduction regulation for battery- and hydrogen-electric vehicles may also improve incentives for adoption.

**Sammendrag**

# Erfaringer fra tidlige brukere av nullutslippsløsninger for tunge kjøretøy i Norge

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*Forfattere: Inger Beate Hovi, Daniel Ruben Pinchasik, Rebecca Thorne og Erik Figenbaum*
*Oslo 2019 130 sider*

*Brukererfaringer fra de første norske pilotprosjekter med batteri-elektriske busser og lastebiler har i hovedsak vært positive, men det gjenstår innovasjon av teknologi og systemer på mange nivåer før nullutslippsløsninger vil være et fullverdig alternativ til kjøretøy med forbrenningsmotor. Selv om teknologisk utvikling så langt har kommet mye lenger for busser enn for lastebiler, er merkostnadene ved investering fremdeles høye. Andre barrierer for innfasing av nullutslippsløsninger gjelder bl.a. begrensninger på rekkevidde, nyttelast og lang ladetid ved dagens teknologi, samt manglende tilgang til offentlig ladeinfrastruktur. For tunge kjøretøy generelt og for lastebiler spesielt er det dessuten mye svakere økonomiske virkemidler sammenliknet med det en har gjennom kjøpsavgifter for personbiler. Dette illustrerer at det er viktig med forutsigbare rammebetingelser og økonomiske insentiver for å få fremskyndet innfasingen av elektriske løsninger i tungbilsegmentet.*

## Introduksjon

Tunge kjøretøy, som busser og lastebiler, står i dag for betydelige utslipp av klimagasser. Norges ambisiøse klimamål, kombinert med transportpolitiske mål som f.eks. fra Nasjonal Transportplan 2018-2029, krever imidlertid store utslippskutt og en storskala innfasing av nullutslippsteknologi i tungbilsegmentet, innen hhv 2025 og 2030 (avhengig av kjøretøysegment). En slik overgang, fra dagens dominante bruk av forbrenningsmotorer og fossile drivstoff, vil kreve innovasjon av teknologi og systemer på mange nivåer.

Denne rapporten beskriver status og prognoser for alternative nullutslippsteknologier for tunge kjøretøy (med spesielt fokus på batteri- og hydrogen-elektriske løsninger), fra både et globalt og et nasjonalt perspektiv. Vår diskusjon dreier seg primært om 1) teknologistatus og forventet teknologiutvikling, 2) brukererfaringer, 3) potensiale for bruk og elektrifisering i Norge, og 4) eierskapskostnader ved disse alternative teknologiene.

## Teknologistatus og -prognoser

Generelt sett har nullutslippskjøretøy mange fordeler sammenliknet med kjøretøy med forbrenningsmotor. Batteri-elektriske kjøretøy er mer energieffektive enn biler med forbrenningsmotor, og har i tillegg god akselerasjon og lave driftskostnader. Hydrogen-elektriske kjøretøy med brenselceller gir også effektivitetsgevinster, men mindre enn for batteri-elektriske kjøretøy, og har lang rekkevidde og korte fyllingstider. Betydelige utfordringer for batteri-elektriske kjøretøy, og tungbilsegmentet spesielt, er rekkeviddebegrensninger, høy batterivekt (som reduserer lastekapasitet), lang ladetid, og krav til infrastruktur.

For hydrogen-elektriske kjøretøy er det i dag i hovedsak kommersialisering, herunder tilgjengelighet, driftssikkerhet, ytelse, hydrogen-infrastruktur, og lagrings- og sikkerhetsspørsmål, som byr på utfordringer.

Markedet for både batteri-elektriske og hydrogen-elektriske tyngre biler begynner å bli mer modent, og antallet kjøretøy som er på veien øker. Dette gjelder primært for busser, mens lastebiler ligger et stykke bak i kommersialiseringen. I dag er anskaffelseskostnaden for slike kjøretøy betydelig høyere enn for biler med forbrenningsmotor. For batteri-elektriske busser og lastebiler antas det at prisdifferansen kontra dieselkjøretøy vil reduseres på grunn av mer moden teknologi og framskritt som forventes på batteriutvikling over det kommende tiåret, siden selve batteriene er en svært viktig kostnadskomponent. Videre har flere produsenter annonsert (småskala) serieproduksjon av batteri-elektriske busser og lastebiler med forventet oppstart i de kommende årene.

Produksjonen av (tyngre) hydrogen-elektriske kjøretøy har ikke kommet like langt, og det er færre annonserte produksjonsplaner enn for batteri-elektriske kjøretøy. Også antallet pilotprosjekter har vært mye lavere enn for batteri-elektriske kjøretøy, selv om brenselcelle-teknologi har vokst år for år, og det har kommet flere prototyper (selv om dette i hovedsak gjelder personbiler).

Til tross for forventet teknologisk utvikling og forventninger om mer modne produksjons-faser og med det betydelige kostnadsreduksjoner, antas hydrogen-løsninger å henge bak produksjon og innfasing av batteri-elektriske tunge kjøretøy. Et antall spesifikke fordeler ved hydrogendrift i f.eks. langtransport, der det ellers er nødvendig med svært tunge batterier, vil likevel kunne gi et potensielt delmarked.

## Brukererfaringer

Inntil nylig var det kun et fåtalls elektriske tunge kjøretøy som ble testet eller brukt i Norge. Selv om innfasingen av elektriske løsninger har økt for norske bybusser, har dette så langt ikke vært tilfellet for lastebiler. Hovedgrunnen til dette er at etterspørselen etter og produksjonen av elbusser har utviklet seg fra en fase med pilotprosjekter, til små- og mellomstor-skala serieproduksjon, bl.a. fremskyndet av krav satt i offentlige anbudsutlysninger for kollektivtransport. Videre er også elbussens anvendelsesområde bedre enn for elektriske lastebiler, ettersom busser har faste ruter og lademuligheter både i depot og gjennom hurtiglading, også i sentrale områder. Elektriske lastebiler derimot, har så langt nesten bare vært tilgjengelig som (dyre) konverteringer fra dieselkjøretøy. I tillegg er lastebilene mindre egnet for elektrisk drift, og teknologikravene er høyere enn for busser.

### Busser

Tilbakemeldinger fra intervjuene tyder på at elbusser er godt egnet for bruk i bysentra og andre (by)områder hvor nullutslipp er viktig eller der det stilles krav om dette. Dette har også ført til innfasingsplaner hos kollektivselskaper i flere norske byer og regioner. Intervjuene tydet imidlertid også på at for innfasing av elbusser er det svært viktig med effektiv ruteplanlegging på grunn av krevende ladebehov, særlig fordi driftsdøgnet kan være opptil 18 timer. Med mindre ruter og lading er nøye optimalisert, er det behov for flere busser (5-10 %) for å dekke det samme servicetilbudet som en tilsvarende bussflåte med forbrenningsmotor. Det foreligger også betydelige utfordringer når det gjelder installasjon av ladeinfrastruktur i urbane strøk (f.eks. ved endeholdeplass), og selv om innfasing av flere elbusser er et politisk mål, fasiliterer kommuneadministrasjonen i f.eks. Oslo foreløpig ikke etablering av hurtigladestasjoner. Med mindre disse utfordringene håndteres vil elbusser foreløpig være best egnet på ruter der det er kort avstand til depot. En annen stor utfordring er elbussenes høye investeringskostnader sammenliknet med tilsvarende busser med forbrenningsmotor.

Til tross for ovennevnte utfordringene er bussoperatørene generelt optimistiske om videre innfasing, selv om mange er enige i at det i nærmeste framtid vil være optimalt med en blanding av ulike fremdriftsteknologier. Mens batteri-elektriske busser er godt egnet for bruk i urbane og sentrumsområder, vil hydrogen-elektriske busser kunne være mer egnet på ruter der det er behov for lang rekkevidde. Dette tyder på en viss komplementaritet mellom teknologiene. En viktig observasjon er videre at jo flere elbusser en operatør har i sin flåte, desto viktigere blir det med nøye ruteplanlegging.

Tabell S.1 oppsummerer elbussene/pilotprosjektene som brukerintervjuene er basert på.

*Tabell S.1: Norske pilotprosjekter med elektriske busser med start i 2017/2018 og som intervjuene var basert på. Pilotprosjektene (kolonnene) er rangert etter kjøretøylengde. Kilde: Autosys (NPRA, 2018) og operatørintervjuene. *Basert på gj.snittlig kjørelengde for en tilsvarende buss med forbrenningsmotor. **Basert på planlagte driftsskjema, timer/gj.snittlig hastighet. ***Dobbeltlader. ****Lader var planlagt på intervjutidspunktet.*

| | Oslo Taxibuss | Taxus | Norgesbuss | Unibuss | Nobina |
|---|---|---|---|---|---|
| Type buss | Minibuss | Minibuss | Bybuss | Bybuss | Leddbuss |
| Produsent | Iveco | Iveco | Solaris | Solaris | BYD |
| Modell | El-buss | El-buss | Urbino 12 Elektrisk | Urbino 12 Elektrisk | El-buss |
| Forventet kjørelengde (km/år) | - | 12-13 000 | 74 000-87 000** | 60 000 | 110 000* |
| Rekkevidde på full lading (km) | 150 | 160 | 240 | 45-50 | 180 |
| Antall kjøretøy som ble testet | 4 | 10 | 2 | 2 | 2 |
| Registreringsår | 2018 | 2017 | 2017 | 2017 | 2017/2018 |
| Lengde (m) | - | 7.13-7.33 | 12 | 12 | 18 |
| Batteriteknologi | Natrium-nikkel-klorid (Na-NiCl$_2$ | Natrium-nikkel-klorid (Na-NiCl$_2$) | Litium-titan (LTO) | Litium-titan (LTO) | Litium-jern-fosfat (LFP) |
| Batterikapasitet (kWh) | 82 | 90 | 127 | 75 | 300 |
| Depotlading (kW) | 22 | 11 | 80*** (250****) | 80*** | 80*** (300****) |
| Hurtiglading (kW) | | | 400 | 300 | |
| Ladetid (timer) | 8 (om natten) | 4 (på dagen) | 1/0.1 (sakte-/hurtiglading) | 8/0.1 (sakte-/hurtiglading) | 3.5 |

## Lastebiler

Tabell S.2. gir en oppsummering av pilotprosjektene med batteri-elektriske lastebiler som dannet grunnlaget for intervjuene. Pilotene pågår i Sør-Norge, hos operatører innenfor matdistribusjon, renovasjon, og gjenvinning.

Generelt er erfaringene fra pilotprosjektene positive (spesielt innenfor renovasjon og gjenvinning), bl.a. når det gjelder arbeidsmiljø, energibesparelser, og lavere drifts- og vedlikeholdskostnader. Noen av operatørene har også erfart større tekniske problemer, som f.eks. manglende trekkraft og perioder med driftsstans. Som for elbusser ble også den høye merkostnaden ved investering påpekt som en viktig utfordring. Med tanke på videre innfasing av elektriske lastebiler i fremtiden er det viktig med videreutvikling av ladeinfrastruktur, for eksempel med bidrag fra myndighetene. Intervjuene tydet videre på at det er viktig å beholde insentiver som ENOVA[2]-tilskudd, gratis bompasseringer, og tilgang til kollektivfelt. I tillegg må etterspørselen etter lastebiler med nullutslipp stimuleres gjennom krav i offentlige og private anbud.

Operatørene som ble intervjuet var positive angående oppfylling av utslippskrav i de neste årene, og forventet økt bruk av elektriske lastebiler. Flere av operatørene hadde allerede

[2] ENOVA er et statsforetak som har som formal å bidra til innfasingen av klimavennlige løsninger innenfor nærings-, energi-, husholdnings- og transportsektorene.

bestilt flere elektriske lastebiler, eller planlegger å kjøpe flere når disse blir tilgjengelig gjennom serieproduksjon. Noen av operatørene trakk fram at serieproduksjon av lastebiler er nødvendig for at flere av dagens utfordringer skal kunne løses.

*Tabell S.2: Pilotprosjekter med elektriske lastebiler med oppstart i 2016 til 2019 og som intervjuene er basert på. Pilotprosjektene (kolonnene) er rangert etter kjøretøyenes totalvekt. Kilde: Autosys (NPRA, 2018) og operatørintervjuene. *Gj.snittsverdi for flåten, med stor variasjon. **For et tilsvarende (eksisterende) kjøretøy med forbrenningsmotor i flåten. ***På intervjutidspunktet brukte ikke operatøren kjøretøyene i vanlig drift ennå, men operatøren hadde erfaring fra et prøvekjøretøy. ****Faktisk kjørt distanse (km/år) på intervjutidspunktet.*

| | Nor Tekstil | BIR | Renova-sjonen | ASKO | Norsk Gjenvinning | Ragn-Sells | Stena Recycling*** |
|---|---|---|---|---|---|---|---|
| Sektor | Industri | Renovasjon | Renovasjon | Godstransport | Renovasjon | Renovasjon | Gjenvinning |
| Kjøretøytype | Stor varebil | Renovasjons-bil | Renovasjons-bil | Lastebil (gods) | Renovasjons-bil | Renovasjons-bil | Trekkvogn (gjenvinning) |
| Produsent | Iveco | DAF/Emoss/ Geesinknorba | DAF/Emoss/ Geesinknorba | MAN/Emoss | Dennis Eagle/PVI (Renault) | MAN/Emoss/ Allison | MAN/ Emoss/ Allison |
| Forventet kjørelengde (km/år) | 30 000 | 20-26 000** | 16 800** | 50 000* | 18 000**** | 80 000** | 120-130 000 |
| Rekkevidde på full lading (km) | 160 | 120-130 | 100-140 | 180 | 140 | 200 | 178 |
| Antall kjøretøy som ble testet | 5 | 1 | 1 | 1 | 2 | 1(+1) | 2 |
| Registreringsår | 2018 | 2018 | 2018 | 2016 | 2018 | 2018(2019) | 2018 |
| Totalvekt (t) | 5,6 | 12,0 | 12,0 | 18,6 | 26,8 | 28,0 (50,0) | 40,0-45,0 |
| Nyttelast (t) | 2,6 | 3,5 | 3,5 | 5,5 | 9,7 | 18-19 | 15-20 |
| Lengde (m) | 7,2 | 7,0 | 7,0 | 9,0 | 9,5 | 7,8 | 7,4 |
| Batteriteknologi | Natrium-nikkel-klorid ($Na\text{-}NiCl_2$) | Litium-ion (LIB) | Litium-ion (LIB) | Litium-ion (LIB) | Litium-ion (LIB) | | Litium-ion (LIB) |
| Batterikapasitet (kWh) | 80 | 120 | 130 | 240 | 240 | 200 (300) | 300 |
| Depotlading (kW) | 22 | 22/44 | 44 | 2 x 43 | 44 | 44 | 44 |
| Hurtiglading (kW) | | | | | | 150 | 2 x 150 |
| Ladetid (timer) til 80 % | 8 | 2-8 | 3,5 | 5 | 8 | 4,5 (full lading) | 4-6/0,3 for saktelading/ hurtiglading |

## Potensiale for elektrifisering

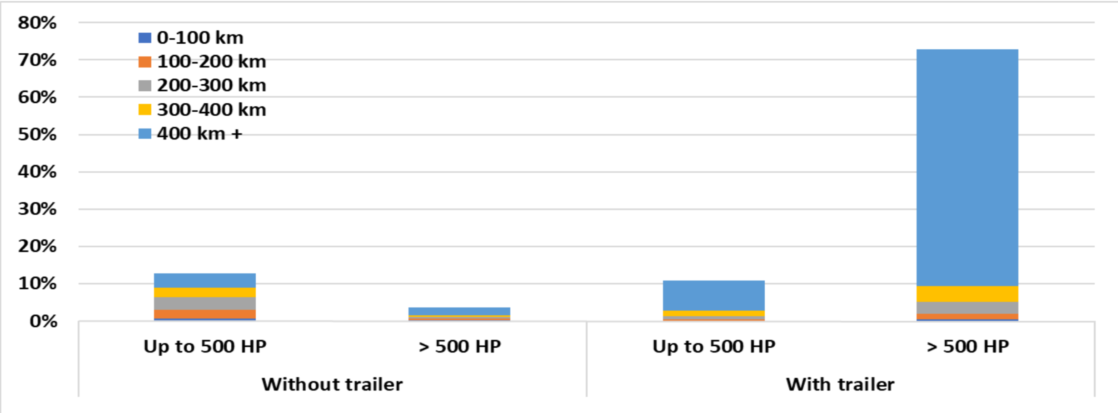
### Busser

Potensialet for bruk av elbusser kan være stort i områder der busser kjører lokalt og i et lukket system. I Europa synes en trend der elbusser i økende grad brukes i tester, pilotprosjekter, og i vanlig drift, og det spås at i EU vil elbussandelen ligge rundt 50 % i 2030. I Norge setter Nasjonal Transportplan 2018-2029 et mål om at innen 2025 må 100 % av nye bybusser være enten nullutslippsbusser (batteri- eller hydrogen-elektrisk) eller bruke biogass. Også på regionalt nivå har forskjellige lokale transportmyndigheter laget planer for å oppfylle dette målet.

## Lastebiler

Både litteraturen og erfaringer fra pilotprosjektene tyder på at viktige barrierer for produksjon og innfasing av batteri-elektriske lastebiler er begrensninger relatert til lastekapasitet, rekkevidde, og motorytelse. I denne konteksten har vi analysert potensialet for elektrifisering av nasjonal lastebiltransport basert på bruksmønstre for ulike kjøretøykategorier fra Statistisk Sentralbyrås lastebilundersøkelse.

I dag står lastebiler med motor over 500 hk for mesteparten av kjøringen med nyere lastebiler, og det er nyere lastebiler som i hovedsak dimensjonerer brukerkrav. Ifølge en stor lastebilprodusent er det pr i dag få alternativer til diesel i dette segmentet. Lastebiler med mindre motorer, og som har størst elektrifiseringspotensiale på kortere sikt, utgjør kun en brøkdel av kjøringen med nyere lastebiler basert på dagens bruksmønster. Innenfor dette segmentet utgjør lastebiler med lukket godsrom den største gruppen, fulgt av spesialbiler (som f.eks. renovasjonsbiler). Observasjonene tyder på at det er behov for både kraftigere elmotorer og lengre rekkevidder enn det som finnes på markedet i dag. Dette forsterkes av at en stor del av kjøringen gjøres med tilhenger (noe som krever høyere motorytelse) og at slike turer i gjennomsnitt er lengre enn turer uten tilhenger. Et antall av disse funnene er illustrert i Figur S.1.




*Figur S.1: Fordeling av daglig kjørelengde for lastebiler mellom 0-5 år, for motorytelse opp til og over 500 hk, og for kjøring med og uten henger. Kilde: grunnlagsdata fra SSBs 'lastebilundersøkelse' for 2016 og 2017, og Autosysregisteret.*

På lengre sikt vil bedrifter som eier flere lastebiler til en viss grad kunne omfordele transportruter mellom kjøretøy, og på denne måten øke elektrifiseringspotensialet i en del av flåten. Noen næringsspesifikke egenskaper (f.eks. fragmentering av transportnæringen og forskjeller mellom egentransport og leietransport) gjør det imidlertid vanskelig å kvantifisere dette potensialet. Våre analyser tyder på at egentransport i større grad utføres med mindre kjøretøy og som kjører kortere distanser og dermed gjør dem mer egnet for elektrifisering enn leietransport. På den annen side utgjør kjøretøy som benyttes til egentransport en større andel av eldre biler, noe som trekker motsatt retning.

Hvis motorytelsen til elektriske lastebiler ville økt til 600 hk og rekkevidden til 300 km pr lading, vil dette på lengre sikt kunne være tilstrekkelig for at en stor andel av godstransporten i Norge kan elektrifiseres.

Når vi ser på i hvilken grad lastebiler har uutnyttet kapasitet til økt batterivekt, finner vi at kjøretøyenes lastekapasitet som oftest ikke er fullt utnyttet. Kapasitetsutnyttelsesrater viser at for en stor del av transportene har kjøretøyene betydelig ubrukt vektkapasitet (ofte flere tonn) for vekten til et batteri, uten at kjøretøyet overskrider vektrestriksjoner. Om dette er tilfellet også i praksis avhenger av om noen lastebiler alltid kjøres med ledig kapasitet, om deler av distribusjonsruter kjøres med ledig kapasitet, og om våre data i tilstrekkelig grad fanger opp variasjon i transportvolum gjennom året. Samtidig kan det nevnes at Europaparlamentet, i april 2019, vedtok et forslag som åpner for opptil 2 tonns ekstra totalvekt for nullutslippslastebiler. Gitt dagens batteri-teknologi tilsvarer dette vekten av rundt 200-300 kWh i batterier, som igjen tilsvarer en rekkevidde på 150-200 km for lastebiler.

## Eierskapskostnader

### Busser

For at elbusser fases inn er det svært viktig at eierskapskostnaden er gunstig sammenliknet med konvensjonelle busser eller/og andre lav- og nullutslippsteknologier, selv om transportmyndighetene kan være villige til å godta høyere utgifter for å oppnå en nullutslippsflåte. Vi har brukt informasjon fra intervjuene til å beregne eierskapskostnader for elbusser for dagens situasjon og for 2025, for så å sammenlikne disse med andre teknologier (hydrogen, biodiesel, og vanlige dieselbusser).

Resultatene tyder på at selv om batteri- og hydrogen-elektriske busser i dag har høyere eierskapskostnader enn busser som bruker (bio)diesel, i hovedsak på grunn av høyere merkostnad ved investering, vil eierskapskostnadene kunne ligge på et mer konkurransedyktig nivå i 2025. I våre beregninger er det tatt hensyn til at det kan være behov for 10 % flere elbusser for å dekke de samme transportvolumene som en flåte bestående av konvensjonelle busser. Ladestrategien i kostnadsanalysen er basert på depotlading (pga utfordringer som operatørene i dag erfarer ved installasjon i sentrumsområder), og er videre basert på antall og type ladere og busser som brukes av en av operatørene som ble intervjuet.

De viktigste parameterne i kostnadsanalysen har vi sett nærmere på gjennom en følsomhetsanalyse. Fra denne finner vi at om det antas en optimistisk verdi på investeringskostnader for elbusser i 2025, vil eierskapskostnaden for elbusser og dieselbusser ligge på omtrent samme nivå, eller rundt 10 kr/km. Om det derimot antas en mindre optimistisk verdi er eierskapskostnaden for en elbuss i 2025 omtrent 19 % høyere enn for en tilsvarende dieselbuss.

Eierskapskostnadene påvirkes også av ladeløsningen som velges. Forutsatt dagens forventninger rundt optimalisering, er eierskapskostnadene lavest ved en løsning med enten depotlading eller hurtiglading, og i begge tilfeller vil elbusser kunne ha tilsvarende eierskapskostnader som dieselbusser i 2025. Når det kun brukes depotlading, kan det benyttes ladere som er relativt billige, mens når det velges en løsning med kun hurtiglading, f.eks. ved endestasjonene, spres høye investeringskostnader pr lader ut over et stort antall busser som kan benytte samme lader. Når det velges en blanding av depot- og hurtigladere blir ikke lenger kostnaden for hurtigladere spredt ut i like stor grad. Valg av ladeløsning har imidlertid også en rekke praktiske implikasjoner. Når det f.eks. velges en løsning med kun hurtigladere, kan ikke bussene varmes opp før bruk.

Ettersom eierskapskostnader i betydelig grad påvirkes av variasjon i usikre inputparametere, må resultatene tolkes varsomt. Det framkommer likevel tydelig at potensialet for konkurransedyktig elbussbruk i fremtiden er høyt, om produksjonsskalaen øker og produksjons- og investeringskostnadene blir lavere. Ladeløsningene som velges må dimensjoneres og planlegges nøye, og vil være ruteavhengige.

### Lastebiler

Eierskapskostnader for elektriske lastebiler, kontra konvensjonelle lastebiler og andre lav- og nullutslippsteknologier, er utarbeidet for ulike grader av teknologisk modenhet og dermed lavere merkostnader ved investering for elektriske lastebiler. Scenarioene inkluderte dagens tidlige fase, småskala serieproduksjon, og masseproduksjon. Analysene er basert på en relativt detaljert dekomponering av eierskapskostnader, med kostnadsparameterne fra intervjuene og fra Nasjonal Godsmodell (Grønland, 2018), i tillegg til en rekke valideringer fra litteratur, og antakelser rundt reduksjoner i produksjonskostnader ved mer modne produksjonsfaser.

Våre analyser viser at i dagens tidlige produksjonsfase er større batteri-elektriske kjøretøy ikke konkurransedyktige sammenliknet med kjøretøy som bruker diesel, biodiesel, eller biogass, med mindre det foreligger betydelige økonomiske insentiver. Hovedgrunnen til dette er dagens høye merkostnad ved investeringen.

Når merkostnaden for elektriske lastebiler reduseres, som vi antar i scenarioet med småskala serieproduksjon, blir batteri-elektriske lastebiler mer konkurransedyktige enn dieselkjøretøy ved årlige kjørelengder over ca. 43 000 km (trekkvogn) og 58 000 km (tunge distribusjonsbiler). Data for kjøremønstre viser at slike årlige kjørelengder er ganske vanlige innenfor dagens bestand av nyere lastebiler.

Gitt at batteri-elektriske lastebiler også oppfyller behovene rundt rekkevidde, lastekapasitet, motorytelse, osv., vil de altså ha potensiale til å bli konkurransedyktige alternativer. Andre barrierer som må løses dreier seg bl.a. om utviklingen til infrastruktur for hurtiglading, kunnskapshull med tanke på driftsegenskaper og etablering av et bruktmarked, som gir bruktbiler en restverdi.

Små og mellomstore varebiler har allerede nå nådd en fase med småskala serieproduksjon, og trenger ikke å ha særlig høye årlige kjørelengder før eierskapskostnadene blir lavere enn for tilsvarende varebiler som bruker (bio)diesel eller biogassbiler. Dette gjelder spesielt når en ser på typiske årlige kjørelengder for nyere kjøretøy innen disse varebilsegmentene.

Til slutt finner vi at i et scenario med masseproduksjon av elektriske kjøretøy, vil batteri-elektriske lastebiler kunne bli konkurransedyktige mot dieselbiler fra årlige kjørelengder på mellom 19 000 og 23 000 km, avhengig av kjøretøysegmentet. Hovedgrunnen til dette er at store besparelser gjennom lavere energikostnader ved elektrisk fremdrift er tilstrekkelig til å dekke merkostnadene ved investeringene. Sammenliknet med biodiesel- og biogasskjøretøy ligger break-even-punktet enda lavere.

Videre finner vi at i scenarioet med masseproduksjon kan batteri-elektriske varebiler bli konkurransedyktige allerede fra årlige kjørelengder på rundt 1 000 km (gitt dagens batteristørrelser i disse kjøretøyene). Fremtidige batteri-elektriske varebiler vil sannsynligvis ha større batterier og lengre rekkevidder, men vil sannsynligvis også forbli svært konkurransedyktige når det gjelder eierskapskostnader. Selv om varebiler ville mistet insentiver som dagens bompengefritak og -rabatter, virker det derfor sannsynlig at de vil fortsette å være et konkurransedyktig alternativ. På kortere sikt vil imidlertid faktorer som rekkeviddebegrensninger og ladetider, samt noe mindre bruksfleksibilitet, kunne bremse innfasingen av disse bilene.

## Barrierer

Selv om utviklingen i markedet for batteri-elektriske personbiler er i rask endring, noe som i noe mindre grad også gjelder varebiler, er det fortsatt en lang vei å gå før fremdriftsteknologi med nullutslipp kan bli et fullverdig alternativ for tungbilmarkedet. Dette gjelder spesielt for lastebiler.

Til tross for at pilotprosjekter med batteri-elektriske lastebiler og busser så langt har pågått i en relativt begrenset periode, har de første brukererfaringene hovedsakelig vært positive. Med unntak av noen barnesykdommer og nedetid for enkelte kjøretøy, er de fleste operatørene positive og optimistiske når det gjelder fremtidig innfasing av flere batteri-elektriske biler.

Det foreligger likevel et antall utfordringer som må løses for å fjerne barrierer mot investeringer i batteri-elektriske kjøretøy som skal brukes i daglig drift hos lastebil- og bussoperatører:

- Høye merkostnader ved investering i batteri-elektriske tunge kjøretøy. Selv om drifts- og vedlikeholdskostnader allerede ligger på et tilsvarende eller lavere nivå enn for konvensjonelle biler (spesielt for busser), er dagens eierskapskostnader betydelig høyere.
- Begrensninger i rekkevidde, ladekapasitet, motorytelse, og tilgang til lade-/fylle-infrastruktur. På kortere sikt vil også usikkerhet og kunnskapshull kunne være barrierer.

I kostnadssammenlikningen fant vi at i dagens tidlige produksjonsfase er ikke større batteri-elektriske kjøretøy (busser og lastebiler) konkurransedyktige sammenliknet med kjøretøy som bruker diesel, biodiesel, eller biogass, med mindre det gis store økonomiske insentiver. Når merkostnaden ved investering går ned, som har vi forutsatt i scenarioene med småskala serieproduksjon og senere masseproduksjon, kan batteri-elektriske løsninger imidlertid bli konkurransedyktige uten slike insentiver, fra realistiske årlige kjørelengder.

Konkurransedyktigheten på kostnadssiden er bedre for batteri-elektriske varebiler, som allerede har oppnådd en mer moden produksjonsfase.

## Virkemidler

Innfasingen av tyngre kjøretøy med nullutslippsteknologi skjer ikke av seg selv. En av de største barrierene er dagens høye kjøpspriser, som følge av begrenset etterspørsel og produksjonsskala. For å fremskynde oppstart av serieproduksjon av batteri-elektriske kjøretøy, og spesielt lastebiler, er det viktig at etterspørsel skapes gjennom krav i anbudsprosesser. Spesielt for busser og renovasjonsbiler kan nullutslippsteknologi fases inn gjennom nye anbudsrunder og/eller endringer i eksisterende kontrakter.

Videre er det viktig med forutsigbarhet i rammebetingelser for eierskap og drift. Etablering av insentiver for lastebiler, gjennom støtte fra ENOVA og nullutslippsfondet vil bidra til innfasing av teknologi og spredning av elektriske lastebiler. Andre støtteordninger er bl.a. Pilot-E og Klimasats. Lokale insentiver som f.eks. gratis eller rabatterte bompasseringer eller tilgang til kollektivfelt kan også bidra til økt innfasing. I lys av høye investeringskostnader på anskaffelsestidspunktet vil også endringer i skattemessige avskrivningsregler for batteri- og hydrogen-elektriske kjøretøy kunne gi insentiver for innfasing.

# 1 Introduction

Norway's National Transport Plan (NTP) for the period 2018-2029 sets ambitious targets for the introduction of zero-emission commercial vehicles as a means to reach goals of reduced $CO_2$ emissions by 2030. By 2025, all new lighter vans are to be zero-emission vehicles. By 2030, the same applies to all new heavy vans and 50 % of new Heavy Goods Vehicles (HGVs) (Norwegian Government 2017).

Unlocking the dominance of fossil energy in the transport sector will require technical and system innovations at many levels. The main motivation of the MoZEES Center is to assist in the design of safe, reliable, and cost competitive zero-emission transport solutions for the future. The work performed in this report is a part of Research Area 4 (RA4) in MoZEES, where the main objective is to identify the market potential, business cases, and policy prerequisites for innovative, energy-efficient transport concepts for all surface transport segments, based on electricity or hydrogen.

Key questions in RA4 are how and when new technology can become competitive in the market and how public and corporate stakeholders can avoid the lock-in effects typical of current technologies and end user habits. Predicting the market for an entirely new mode of transportation is difficult (with high uncertainties), but not impossible. Analysis of international technology development road maps, policy options, incentives, and other governance measures will be required to produce national road maps for how the international and Norwegian value chains for the transport, energy and ICT sectors may undergo stepwise transformation towards 2030. This report is mainly a case study of user experiences from the first adopters that operate battery-electric buses and trucks in Norway.

Technology improvement is a prerequisite for advances in efficiency and greenhouse gas (GHG) abatement. However, equally important prerequisites are market viability and social and political acceptance. New technologies will only be taken into use when a significant amount of decision makers see their interests served by it. Thus, identifying and overcoming barriers is an important part of the technological shift. Market conditions and behaviour must be understood and predicted, and business models must be developed and implemented. Policy regulations and economic incentives are also needed to support the transition phase.

The phase-in of battery-electric solutions has this year accelerated for city buses. At the start of 2019, there were fewer than 20 electric city buses in operation in Norwegian cities, while during 2020 close to 400 electric buses are planned phased-in in eight Norwegian cities. The same pace has not yet been seen for trucks, where the number of electric vehicles in operation in Norway was only 14 in the beginning of July 2019. The main reason for this is that electric trucks are still only available as vehicles rebuilt from diesel engines. In this report, we discuss experiences from pilot-projects with battery-electric trucks in Norway, focusing on purchasing processes, technology, vehicle choices, use, and different performance aspects. Further, we discuss the electrification potential for trucks given typical user patterns, and compare ownership costs vs. trucks with internal combustion engine (ICE) for different technological maturity stages.

The report is structured into 11 chapters, including this introduction. Chapter 2 gives an introduction to Norwegian climate objectives and policy instruments for the phase-in of zero-emission technology in road transport. This is followed by a discussion of the current technology status and prospects for battery-electric and hydrogen/fuel cell vehicles in chapter 3. Chapter 4 describes methodology used in interviews of user experiences, analysis, and limitations.

Chapter 5 discusses experiences from E-bus operation in Norway, based on a set of semi-structured interviews with identified bus operators. In Chapter 6, the same is done for electric trucks. This distinction between vehicle types is made because of the somewhat different challenges and introduction phases of electric buses and trucks.

Based on current operational limitations identified in chapter 3 and the interviews (particularly limited driving ranges), Chapter 7 assesses the electrification potential for Norwegian commercial vehicles from a perspective of typical daily/annual use.

This is followed by a discussion of the costs, and cost differences, between conventional vehicles and vehicles with alternative propulsion systems, predominantly based on information from the interviews and the National Freight Model for Norway (Chapter 8). This chapter also forms the basis for a model-based cost and competitiveness assessment for different vehicle technologies/types in Chapter 9.

In chapter 10, we discuss the potential for electrification of buses in Norway, and present a cost analysis. Finally, in Chapter 11 we present conclusions and discuss our findings and their implications.

# 2 Climate objectives, policy instruments, and implementation

## 2.1 Emission reduction objectives

Norway has committed to the EU objective of reducing total $CO_2$-emissions by 40 % by 2030, compared to 1990 levels[3]. This objective is also incorporated in Norway's 2017 Climate Act. The same Act formalizes the objective to turn Norway into a low-emission society by 2050, and operationalizes this objective as an emission reduction of 80-95 % compared to 1990-levels[4]. For non-ETS[5] emissions (which include emissions from most of the transport sector), Norway's target under the EU's Effort Sharing Mechanism is currently an emission reduction of 40 % in 2030, compared to 2005, but under the Government's so-called Granavolden platform, this is set to increase to a 45 % reduction.

When it comes to approaches to reduce $CO_2$-emissions, the Norwegian Government works towards sector-specific targets, under which much focus is directed at the Norwegian transport sector. The transport sector makes up around a third of Norwegian overall emissions, or about 60 % of emissions from the non-ETS sector. The current objective is to halve these transport emissions in 2030, compared to 2005 levels, through (amongst other factors) improvements in technological maturity in different parts of the transport sector (Norwegian Government 2019a, Norwegian Government 2019b).

## 2.2 Objectives for the phase-in of zero-emission technology in the National Transport Plan

The overall target for the transportation sector is to develop a safe transportation system that promotes economic development, while supporting the transition to a low emission society. Until 2019, the transport authorities, i.e. the Norwegian Public Roads Administration, the Norwegian Railway Directorate, the Norwegian Coastal Administration and national airport operator Avinor worked together when developing a proposal for a National Transportation Plan for Norway[6]. The Norwegian Public Roads Administration led the work, with the Norwegian Environment Agency providing input during the process. Targets and ambitions for the sector were proposed by the transport authorities in the plan document for the NTP, which would then be sent to the Ministry of Transport. The Ministry is then responsible for writing a white paper for the NTP and sending to Parliament for the final approval of the NTP. Once approved, the actual work depends on the annual national budget allocations for investments in the transportation sector.

[3] Norwegian Government has called for increasing this target to 55 %.

[4] Also here, Norwegian Government has announced intentions of increasing targets, to 90-95 %.

[5] ETS = Emissions Trading System

[6] From 2019, the organization of this process has been changed and the Ministry of Transport and Communication is now leading the entire process.

The current NTP for 2018-2029 (Norwegian Government 2017) takes into account the relevant overall national targets, for instance on climate policy, and suggests how these targets can be supported by setting adequate sub-targets for the transportation sector. The NTP further states that the transport sector, in order to contribute a sufficient share towards Norway's 2030 greenhouse gas emission reduction targets, must meet the following ambitions and objectives relevant for this report:

- By 2025, all new city buses are to be zero-emission vehicles or use biogas
- By 2025, all new smaller Light Commercial Vehicles (LCVs or vans) are to be zero-emission
- By 2030, 75 % of new coaches (long distance buses) are to be zero-emission vehicles
- By 2030, all new larger LCVs and 50 % of new HGVs are to be zero-emission
- By 2030, goods distribution in the largest city centres should be virtually emission-free

Some of these goals stemmed from a report from the Norwegian Climate Agency, as follow-up to the 'Climate Cure' investigation[7]. The goals ended up as part of the NTP proposal and in the version of the NTP that was approved by Norwegian Parliament. However, at the time the NTP was published, there were very few electric vans and only one electric truck, which made the targets difficult to defend.

## 2.3 Today's policy instruments for the forced phase-in of zero-emission technology

Norway has particularly strong policies and incentives for the introduction of zero-emission vehicles. These policies and incentives have evolved over many decades (Figenbaum 2017) and currently consist of:

- Exemption from purchase tax
- Exemption from Value Added Tax
- Exemption from toll road charges (will in the future consist of reduced rates, but not exceed 50 % of the rates for ICE vehicles)
- Reduced ferry charges
- Reduced parking fees at public parking spaces
- Access to public transport (bus) lanes (some places)
- Exemption from annual tax (passenger vehicles)
- Reduced annual (weight) fee

However, these policy instruments are significantly stronger for passenger cars than for vans, buses and trucks. This is due to the fact that vans are subject to a reduced purchase tax compared to passenger cars[8]. Heavy vehicles (with total weight >3.5t), in turn, are not subject to a purchase tax (meaning that this exemption does not provide an incentive for

[7] This investigation assessed measures and instruments that could be used for reducing GHG emissions sufficiently in line with adopted Norwegian climate objectives.

[8] In 2019, the weight component of this purchase tax for vans makes up 20% of the level for passenger cars, while the $NO_x$ component is set at 75% of the passenger car level. NB: applies to vans in 'class 2' (green registration plates). Source: https://www.skatteetaten.no/person/avgifter/bil/importere/hvilke-avgifter-ma-du-betale/engangsavgift/

heavy vehicles), while enterprises can subtract VAT on incoming goods/services (meaning that the VAT exemption does not provide an incentive compared to ICE vehicles).

Specifically for zero-emission vans, a new incentive scheme with purchase subsidies was introduced in August 2019 in connection with a new 'zero-emission fund' ('Nullutslippsfondet'), which has a budget of minimum 1 billion NOK until the end of 2020. According to the scheme's administrator, ENOVA, firms can apply for and immediately be granted a purchase subsidy while at the car dealer. The scheme uses three standard subsidy rates depending on the vehicle's engine power, and rates will be decreased over time. Currently, the rates are 15 000 NOK, 25 000 NOK and 50 000 NOK for vehicles with engines of <80 HP, 80-120 HP and >120 HP respectively. After registering the vehicle, an additional subsidy of 5 000 NOK is available for investments in a charger (ENOVA 2019). For the battery-electric van models discussed in this report, this support scheme would reduce the purchase price of a battery-electric version by about 8-9 %, but leaves sizable cost premiums compared to regular diesel versions of the same vans. During a conference in late September 2019, ENOVA announced that within less than two weeks after the introduction of the fund, the fund had already awarded support to a larger number of electric vans than were sold during the whole of 2018. The zero-emission fund also provides subsidies for energy and climate measures in land transport (includes subsidies for gas-powered trucks) and electrification of maritime transport.

For heavy vehicles and enterprises, one of the main policy instruments for speeding up the adoption of zero-emission technology is the ENOVA scheme, which, in certain cases, provides subsidies towards the purchase of zero-emission vehicles and heavier biogas vehicles. Depending on the size of the applicant firm, ENOVA subsidies, subject to EU regulations on state aid, cover a maximum of respectively 40 % or 50 % of the cost premium of the vehicle compared to conventional ICE-vehicles. Costs for charging and/or filling infrastructure can also be considered as part of this cost premium. However, ENOVA is reluctant to provide support towards higher operational costs, as investment projects are meant to be profitable after taking into account the support given towards higher investment costs.

Important eligibility requirements for the ENOVA support scheme are that awarded subsidies have to trigger the investment (i.e. the investment would not have been made and is not profitable without subsidies[9]), and that the investment results in reduced or converted energy consumption (from fossil fuels to electricity, biogas or hydrogen) exceeding a certain minimum of 10 % or 100 000 kWh (or 10 000 liter diesel) each year (ENOVA 2018).

While such ENOVA-subsidies may contribute towards reducing net investment costs, the firms that receive these subsidies will still have to cover a significant part of the cost premium themselves. Furthermore, these ENOVA subsidies do not apply when the purchase of vehicles with alternative propulsion technologies is made in connection with public tenders for transport services (ENOVA 2018)[10]. Infrastructure, however, can in some cases be eligible when installed prior to the tender. ENOVA also has a program for supporting hydrogen infrastructure, with a vision of providing subsidies towards three filling stations a year. However, ENOVA does not provide support to all charging and filling infrastructure initiatives. One strategic decision for example is to support charging

[9] ENOVA does not provide support for investments that are economically profitable. In an interview, an example of small electric vans was given (other than this, trucks and vans are treated equally when assessing applications).

[10] Firms can, however, be eligible for ENOVA support when they want to transition to e.g. zero-emission technology in ongoing tender periods, but this is rare.

and filling infrastructure in national transport corridors, but not in the cities. The latest support programme targets installation of fast chargers in municipalities that lack these.

Further support schemes include the Pilot-E and Klimasats programmes. Pilot-E is a collaboration between ENOVA, Innovation Norway and the Norwegian Research Council. The program supports pilots of new energy and climate technologies through different 'themed' calls, and had a budget of 100 million NOK in 2017. Support is given towards a broader cost base than is usually the case (not just investments), and varies from up to 25 % for larger firms to up to 45 % for small firms (however, ENOVA does not participate in Pilot-T (transport), which has a different focus than energy and climate).

Through the Klimasats programme, in turn, Norwegian municipalities can apply for funds towards projects that focus on reducing GHG emissions and/or the transition towards a low emission society. In 2019, the program's budget is over NOK 200 million, and awarded funds can amongst others be used for planning and assessment of climate measures, e.g. 'extra climate-friendly land use and transport planning'. Projects can be carried out and funded together with non-public parties, but municipalities are required to be an active participant in supported projects, and contribute with material labor effort or funds (Miljøkommune 2019, Norwegian Government 2019c).

Amongst other incentives, it is worth mentioning that in 2019, the annual tax depreciation rate for company-owned trucks, buses and vans is 24 %, while for fully electric vans, an increased rate of 30 % can be applied. As such, a small incentive is present for choosing electric vans. This incentive could be increased by increasing the depreciation rate for electric vehicles, so that a larger share (or all) of the higher investment costs of electric vans can be depreciated for tax purposes already in the year of purchase of the vehicle.

The same incentive could also be extended to apply for other electric vehicles than vans. As long as a firm has a positive income before tax, depreciation rates will affect the amount of taxes that the firm is liable to pay for each year (i.e. the time profile of tax payments is affected). However, profit margins in the transport industry are generally small. This can limit the effect of increasing incentives, especially for vehicles used in hire-transport. For vehicles used for own-transport, the tax situation of the firm that owns the vehicle to a smaller extent depends on profit margins in the transport sector. As such, depreciation legislation may have a larger potential to create incentives.

Further, an 'environmental' scrapping scheme exists for vans up to 3 500 kg. When vans with internal combustion engine are scrapped to be replaced by a new, zero-emission van, a subsidy of 13 000 NOK is available, in addition to the regular scrapping subsidy for vans. (Norwegian Environment Agency 2018b). By the end of August 2019, such subsidies were paid out for 91 vans.

Previously, discussions were held to force the phase-in of zero-emission HDVs/trucks by establishing a so-called $CO_2$-fund (Hovi et al. 2016). An advantage of such a fund for the transport operator, compared to support schemes through ENOVA, would be that ENOVA is bound by rules on government aid, and as such can only provide support up to 50 % of the cost premium of investments, while the fund would be able to provide support to a broader set of measures or investments, and towards a larger share of investment cost premiums. Preparations for such a fund with implementation originally planned from 2021, however, seem to have been ceased.

### 2.3.1 Norwegian vehicle stock

The majority of today's vehicle stock in Norway consists of vehicles with internal combustion engines (Table 2.1). The table illustrates that buses, trucks and vans predominantly use diesel-based propulsion systems, while for passenger cars, regular petrol also makes up a large share. At the end of 2018, 7.1 % of the passenger car fleet were electric, while another 3.5 % were plug-in hybrids.

*Table 2.1: Registered vehicles by fuel type, per 31 December 2018. Source: Norwegian Public Roads Administration (2019).*

| | Number of vehicles | Petrol | Diesel | Electric | Plug-in hybrid | Hybrid | Gas | Other (incl. hydrogen) |
|---|---|---|---|---|---|---|---|---|
| Passenger cars | 2 749 680 | 39.1% | 46.9% | 7.1% | 3.5% | 3.4% | 0.0% | 0.0% |
| Buses | 15 632 | 1.4% | 92% | 0.3% | 0.0% | 1.0% | 5.2% | 0.0% |
| Vans | 476 264 | 5.2% | 93.6% | 1.1% | 0.0% | 0.0% | 0.1% | 0.0% |
| Trucks | 71 877 | 3.1% | 96.3% | 0.0% | 0.0% | 0.1% | 0.4% | 0.1% |

In recent years, however, sales of new electric vehicles have increased markedly. While in 2016, 15.7 % of new passenger cars was electric, this share had increased to 31.2 % of new car sales in 2018 and has so far largely increased further in 2019. The share of electric vans in new sales is lower, but even so, increased from 1.8 % in 2016, to 4.6 % in 2018 (OFV 2019), and also increased significantly in connection with the introduction of the abovementioned subsidy scheme for zero-emission vans.

For heavy-duty vehicles, the adoption process of alternative propulsion technologies is more closely illustrated in Table 2.2, by focusing on vehicle segment and year of registration.

*Table 2.2: Overview of the number of heavy-duty vehicles using alternative fuels/propulsion technology in Norway, by vehicle segment and year of registration. Source: Autosys registry as of April 2018 (NPRA, 2018).*

| | 2010 and older | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | Apr. 18 | Sum |
|---|---|---|---|---|---|---|---|---|---|---|
| Refuse collection trucks | 30 | 1 | 3 | 9 | 17 | 52 | 77 | 83 | 9 | 281 |
| Trucks with closed compartment | 7 | 4 | 7 | 25 | 18 | 3 | 4 | 6 | 1 | 75 |
| Trucks with open compartment | 19 | 1 | | | 1 | | | 2 | | 23 |
| Other trucks | 3 | | | 2 | | | | 1 | | 6 |
| Tractors for trailers | | | 1 | | | | 4 | | | 5 |
| Buses | 107 | 254 | 96 | 105 | 27 | 66 | 76 | 131 | 13 | 875 |

It can be seen that the majority of alternative technology vehicles have been introduced from 2011, starting in the bus segment, and from 2014 also picking up quickly within refuse collection trucks. At the same time, adoption of alternative technologies within other HDV segments has remained limited.

However, of these alternative technology vehicles, the majority were gas-based, rather than battery- or hydrogen-electric. For buses, this can be seen in Table 2.3.

*Table 2.3: Overview of buses using alternative fuels/propulsion technology in Norway, by year of registration. Source: Autosys registry as of April 2018 (NPRA, 2018).*

| | 2010 and older | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | Apr. 18 | Sum |
|---|---|---|---|---|---|---|---|---|---|---|
| Diesel hybrid | | 16 | 13 | | | | | | | 29 |
| Electric | 7 | | | | | 2 | | 18 | 1 | 28 |
| Gas | 99 | 238 | 78 | 105 | 27 | 64 | 76 | 113 | 12 | 812 |
| Hydrogen | | | 5 | | | | | | | 5 |
| Paraffin | | | | | | | | 1 | | 1 |
| Other fuels | 1 | | | | | | | | | 1 |
| SUM | **107** | **254** | **96** | **105** | **27** | **66** | **76** | **132** | **13** | **876** |

With the exception of 12 mini buses and 33 coaches, all buses in this table are city buses. Indeed, up until recently, alternative propulsion on buses was largely limited to (bio)gas operation. However, driven by public tenders and improved driving ranges, the adoption of electric trucks has increased somewhat in recent years. With concrete plans for a large-scale phase-in of electric buses in Oslo, Romerike, Drammen and Trondheim, the market share of electric buses is projected to increase also in the coming years. Hydrogen operation, in turn, has so far been limited to 5 buses that were introduced in Oslo in 2012.

For trucks, Table 2.4 provides a similar overview into the different alternative propulsion technologies.

*Table 2.4: Overview of trucks using alternative fuels/propulsion technology in Norway, by year of registration. Source: Autosys registry as of April 2018 (NPRA, 2018).*

| | 2010 and older | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | Apr.18 | Sum |
|---|---|---|---|---|---|---|---|---|---|---|
| Diesel hybrid | 3 | 1 | 3 | 2 | | | | | | 9 |
| Electric | | | | | | | 1 | | 2 | 3 |
| Gas | 30 | 5 | 3 | 16 | 21 | 53 | 79 | 91 | 8 | 306 |
| Hydrogen | | | | | | | | | | - |
| Paraffin | 15 | | 1 | | 1 | | 3 | 1 | | 21 |
| Other fuels | 11 | | 4 | 18 | 14 | 2 | 2 | | | 49 |
| Sum | **59** | **6** | **11** | **36** | **36** | **55** | **85** | **92** | **10** | **388** |

Here too, it can be seen that the adoption of alternative propulsion technologies has increased in recent years, but somewhat later, and to a lesser extent than for buses, especially in light of the relative sizes of the bus and truck segments. Looking at the few electric trucks, and the lack of hydrogen operation (as per April 2018), the table illustrates that hydrogen trucks also have a lower maturity than buses in this respect.

# 3 Vehicle Technology: Status and Prospects

Having looked at Norway's climate objectives, policy instruments and developments with regard to the vehicle stock, we now turn to a discussion of the global status of different propulsion technologies, as well as their prospects. This chapter serves as an updated technical overview of available technologies, and focuses on the technological readiness of zero-emission battery-electric and hydrogen fuel cell propulsion solutions, particularly applied to the heavy-duty transport sectors (buses and trucks) as studied in MOZEES.

## 3.1 Alternative propulsion technologies available today

In addition to conventional fossil energy deriving from oil and gas production, a variety of alternative vehicle propulsion technologies are available (Figure 3.1). These can be divided into zero-emission propulsion (meaning that the vehicle produces no tail-pipe emissions[11]) and biomass derived propulsion (whereby combustion products are still emitted from the tail-pipe but the net carbon emission is reduced). Besides improvements in efficiency of current vehicles, their combined use contributes to reach national and international climate and emission goals (as detailed in Chapter 2).

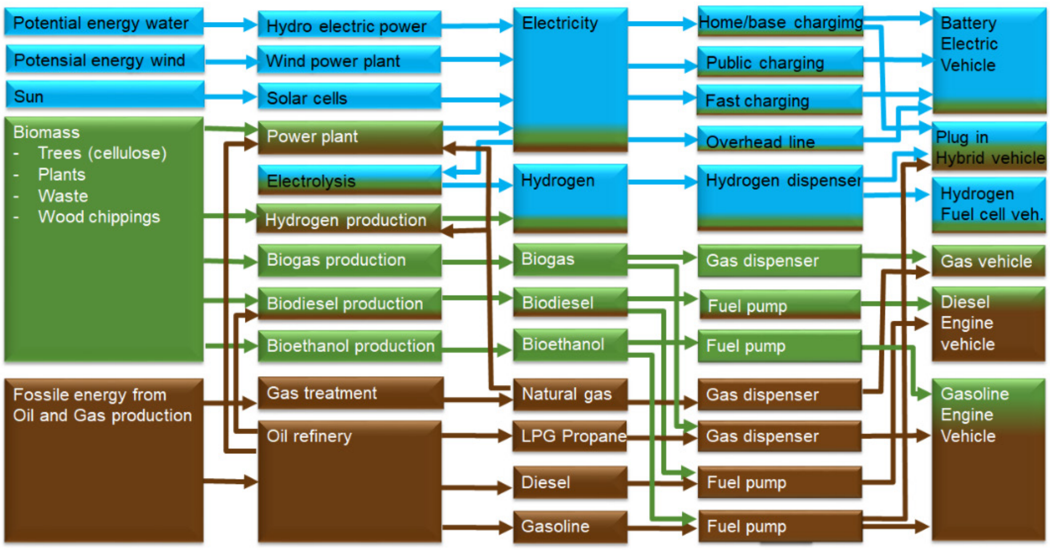



*Figure 3.1: Schematic illustration of different energy carriers available today, and their sources. Source: authors' own analysis. Brown: Fossil fuel/gas based, Green: Biomass based, Blue: Hydroelectric, wind, solar based.*

[11] Water vapor and heat are the only direct tailpipe emissions from hydrogen vehicles. All vehicles also produce secondary particulates during operation (both from dust resuspension and from brake and tyre wear), and have indirect (up-stream and down-stream) emissions associated with manufacturing and end-of-life.

Due to a forecasted increase in the number of passengers, independence needs from oil, complex interactions with other human requirements and local air quality requirements; in the long term zero tailpipe emission technologies may be required. Thus, in-line with the research goals of RA4, zero-emission propulsion technologies (battery-electric and hydrogen fuel cell) will be focused upon in this chapter. These can be thought of as complementary.

## 3.2 Battery-electric solutions

### 3.2.1 Principles

With battery-electric technology, an electric motor (powered by the battery) replaces the fuel tank and internal combustion engine, and the vehicle is plugged into a charger to charge on-board batteries when not in use. The efficiency of the conversion from electrical to mechanical energy is high at between 70-95 % (Andwari et al. 2017) compared to the ~25-40 % for ICE engines. Other benefits are that electric motors may be used as generators during braking to recover energy, thus reducing energy consumption.

Batteries consist of one or more electrochemical galvanic cells that can convert chemical energy to electrical energy (and conversely, act as electrolytic cells when charging). When used in vehicles, batteries are managed in systems within 'blocks' (Figure 3.2) in battery management systems (Hannan et al. 2018). Cells are arranged in parallel and series to meet the needs of the engine, and charge balancing between cells prevents damage and improves lifetime. Interaction of the battery with other vehicle components is shown in Figure 3.3. Discharge and recharge power is kept within allowable values that vary with the state of charge and the temperature of the battery, to increase life expectancy.

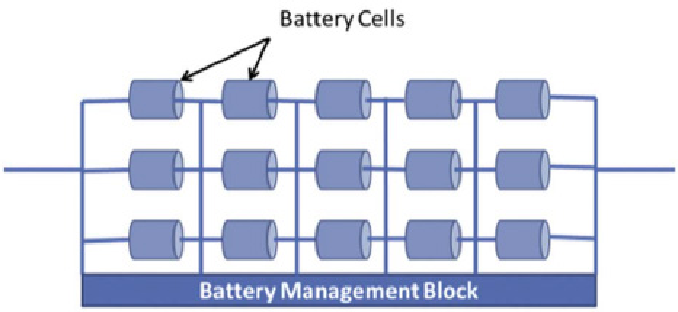



*Figure 3.2: Battery block principles (Andwari, Pesiridis et al. 2017).*

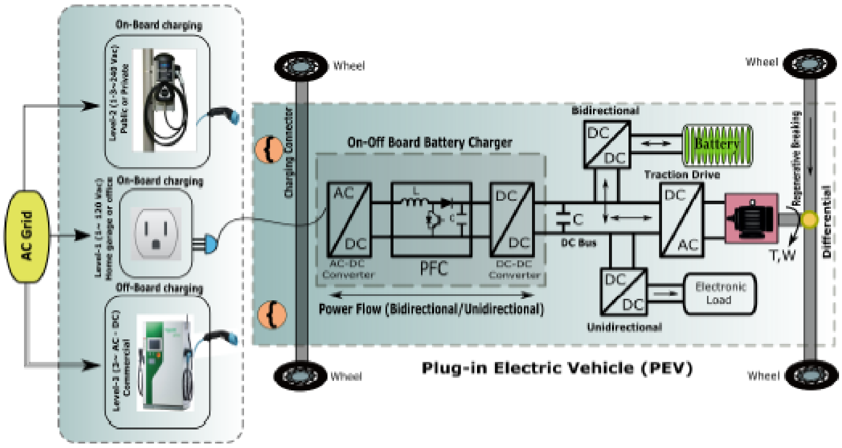



*Figure 3.3: Plug-in electric vehicle operation (Yilmaz et al. 2013).*

### 3.2.2 Technology readiness and challenges

Advantages of battery-electric vehicles are evident, since in addition to being zero-emission, they are efficient, have good acceleration, and can be charged overnight on low cost electricity produced by any type of power station (Andwari, Pesiridis et al. 2017). However, there are also challenges associated with the technology. In addition to required improvements in the batteries themselves (and safety issues), electricity storage is expensive, charging of batteries is time consuming and requires significant infrastructure, some battery elements have led to resource depletion concerns, and there may be damaging impacts on the grid if not managed properly (Andwari, Pesiridis et al. 2017, Golubkov et al. 2018, Hannan, Hoque et al. 2018). There are also challenges with social acceptance due to high capital costs and range anxiety; these should be overcome in order to obtain full market penetration of battery technology.

The performance of a battery depends on the chemistry of the battery, which depends on the electrode materials, separator, electrolyte and binders. Gopalakrishnan et al. (2016) note that for application in hybrid vehicles, the intercalation and de-intercalation of ions should go rapidly, and therefore the surface area of the active material should be significantly higher when compared to BEVs. In contrast, for BEVs, the electrode should be thicker in order to store more energy, and the electrolyte thermally stable (and conductive). Selection of materials (and morphology, structure, microstructure and texture) is thus essential to improvement of the technology.

In brief, principal battery technologies available on the market are lead acid, nickel metal hydride (Ni-MH), lithium-ion (Li-ion) and sodium nickel chloride ($Na/NiCl_2$, Zebra) (Figure 3.4). Li-ion batteries are considered the most promising for BEV use in the near future, due to high energy density, efficiency and long lifespan, with much potential for improvement[12]. Table 3.1 summarizes advantages and disadvantages of various Li-ion technologies; the nominal cell voltage of these ranges from 2.2 V ($LiFePO_4$/graphite) to 3.8 V ($LiMn_2O_4$/graphite) (Gopalakrishnan, Goutam et al. 2016). In practice, the choice of battery types is normally based on the field of application, and the relative importance of each key property. Solid-state batteries are most likely the closest successor to conventional Li-ion batteries in the market (Gopalakrishnan, Goutam et al. 2016). Lead acid and Ni-MH batteries are considered as mature and well-known technologies with relatively low specific

[12] The term Li-ion family encompasses a large number of different chemistries, based on the electrode materials.

energy density, and since potential for improvement is low, they are not considered for future BEVs (Gopalakrishnan, Goutam et al. 2016, Andwari, Pesiridis et al. 2017). $Na/NiCl_2$ batteries have good specific energy (~120 Wh/kg), but low specific power (150 W/kg), and are thus not generally considered for powering BEVs alone[13].

Irrespective of battery type, there are capacity issues with change in temperature due to changes in chemistry (Figure 3.5), safety issues, and in general, the technology has still not met all targets set by the United States Advanced Battery Consortium (USABC) for commercialisation of BEVs (Andwari, Pesiridis et al. 2017). Updated USABC targets are shown in Table 3.2.

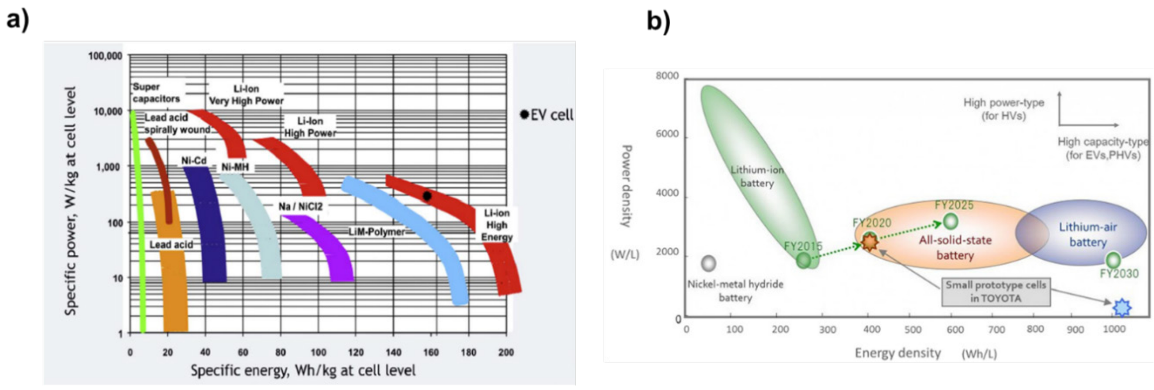



*Figure 3.4: a) Specific energy and power of the main battery technologies (Andwari, Pesiridis et al. 2017), and b) Ragone plot of different battery technology, focusing on solid-state batteries (Gopalakrishnan, Goutam et al. 2016).*

*Table 3.1: Comparison of different lithium-ion battery technologies (Andwari, Pesiridis 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 |

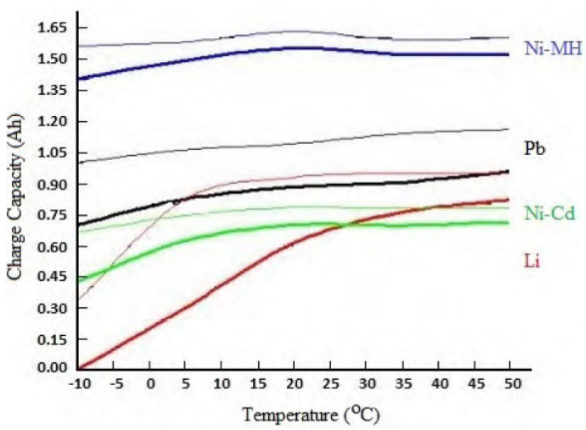



*Figure 3.5: Lithium-ion and other common batteries capacity variation with temperature (Hannan, Hoque et al. 2018).*

[13] Iveco, has however, launched a minibus on the market using these batteries.

*Table 3.2: USABC goals for advanced batteries for EVs – CY 2020 Commercialization (USCAR 2019).*

| End of Life Characteristics at 30°C | Units | System Level | Cell Level |
|---|---|---|---|
| Peak Discharge Power Density, 30 s Pulse | W/L | 1000 | 1500 |
| Peak Specific Discharge Power , 30 s Pulse | W/kg | 470 | 700 |
| Peak Specific Regen Power , 10 s Pulse | W/kg | 200 | 300 |
| Useable Energy Density @ C/3 Discharge Rate | Wh/L | 500 | 750 |
| Useable Specific Energy @ C/3 Discharge Rate | Wh/kg | 235 | 350 |
| Useable Energy @ C/3 Discharge Rate | kWh | 45 | N/A |
| Calendar Life | Years | 15 | 15 |
| DST Cycle Life | Cycles | 1000 | 1000 |
| Selling Price @ 100K units | $/kWh | 125 | 100 |
| Operating Environment | °C | -30 to +52 | -30 to +52 |
| Normal Recharge Time | Hours | < 7 Hours, J1772 | < 7 Hours, J1772 |
| High Rate Charge | Minutes | 80% ΔSOC in 15 min | 80% ΔSOC in 15 min |
| Maximum Operating Voltage | V | 420 | N/A |
| Minimum Operating Voltage | V | 220 | N/A |
| Peak Current, 30 s | A | 400 | 400 |
| Unassisted Operating at Low Temperature | % | > 70% Useable Energy @ C/3 Discharge rate at -20 °C | > 70% Useable Energy @ C/3 Discharge rate at -20 °C |
| Survival Temperature Range, 24 Hr | °C | -40 to+ 66 | -40 to+ 66 |
| Maximum Self-discharge | %/month | < 1 | < 1 |

### 3.2.3 Global use status, with focus on HDVs

Whilst mass production of battery-electric passenger vehicles has already begun, and mass production of battery-electric small vans and buses is expected soon, the market for electric freight vehicles,  – including large vans, distribution and heavy-duty trucks - is still in an early stage (IEA 2017).

When Li-ion batteries are applied in vehicles, several additional challenges to those described in section 3.2.2 have been highlighted. One of the major current issues with battery-electric passenger vehicles (and small vans) is the large variation in energy consumption and range over the year (Figenbaum et al. 2016, Figenbaum 2018). In the worst case (winter driving), Figenbaum and Kolbenstvedt (2016) found that range could be halved for vehicles with relatively short nominal ranges in the old NEDC range test (New European Driving Cycle). The range loss is partly due to the test being unrealistic, so that even under good summer conditions, the range may be reduced by around 25 %. The other main reason for the range loss is the energy consumption used for heating the cabin in the winter (Haakana et al. 2013, AAA 2019), which can add another 30 % range loss. Other factors are the use of winter tyres and the increased aerodynamic drag in low ambient temperatures (thicker air). Larger vans with separate driver cabins (and heavy-duty goods vehicles) will need about the same heat energy for the cabin as a passenger vehicle, but the overall energy consumption for propulsion is higher. The relative derating of range for HDVs in winter should therefore be less, and due to their higher power batteries and motors, there might also be a potential to use surplus heat to heat the cabin. On the other hand, since city buses open their wide doors at all stops, letting the heated air out of the bus and cold air in, variation in range between summer and winter will be very large (although air conditioning on hot summer days will lead to similar but less pronounced problems).

#### Buses

Although trolley buses have been commonplace in cities for a long time, it has only been more recently that plug-in electric and all-electric solutions have been tested for public transport (Cabukoglu et al. 2018, Gohlich et al. 2018, Jordbakke et al. 2018). Market surveys conducted in 2018 by Gohlich et al. (2018) show that battery-electric buses were dominated by standard 12 m buses and 18 m articulated buses. As of 2019, BYD has launched the first 27 m battery-electric bi-articulated bus (Global Energy Today 2019). Battery-electric double decker buses are also available, having been operated by BYD in London since 2016, and are now available from Hyundai (Clean Technica 2019) and Unvi (Motown India Commerical Vehicles 2018).

Various options of bus and charging technologies are available, leading to numerous system solution possibilities (Figure 3.6) (Gohlich, Fay et al. 2018). The key parameters to be selected for an E-bus are the size and the capacity of the battery, since they influence the range between recharges, the recharge time, and thus the charge power, and the capability of carrying passengers (Jordbakke, Amundsen et al. 2018). The typical reduction in theoretical passenger capacity conveyed by the use of batteries in E-buses is shown in Figure 3.7. The reduction is mainly related to the number of standing places in the electric buses because of the weight of the batteries, and the maximum allowed gross weight of the bus. However, in practice (according to a source in the Norwegian bus industry), the total standing places capacity is never fully utilized in diesel buses, so the real passenger capacity is expected to be the same for electric buses. The other part of the equation is the characteristics of the route the buses will be used on, and the manner in which the buses will be recharged. According to Gohlich et al. (2018), lithium-iron phosphate (LFP), lithium-titanium oxide (LTO) and lithium nickel manganese cobalt oxide (NMC) are the most common batteries currently encountered in electric buses.

Around 98 % of the E-buses in use globally for the year 2015 were located in China (about 170 000), and this domination is expected to continue well after 2020 (Jordbakke, Amundsen et al. 2018). Nevertheless, use of E-buses in Europe is increasing. Since 2013, large pilot projects (mainly on inner city lines) where entire bus lines utilize E-buses, have developed from smaller projects involving 1-2 E-buses (ZeEUS 2016, Jordbakke, Amundsen et al. 2018). Use of inner city lines, ranging from between 10-20 km, permits more flexibility in terms of battery capacities and charging options, but may increase the complexity in locating charging infrastructure.

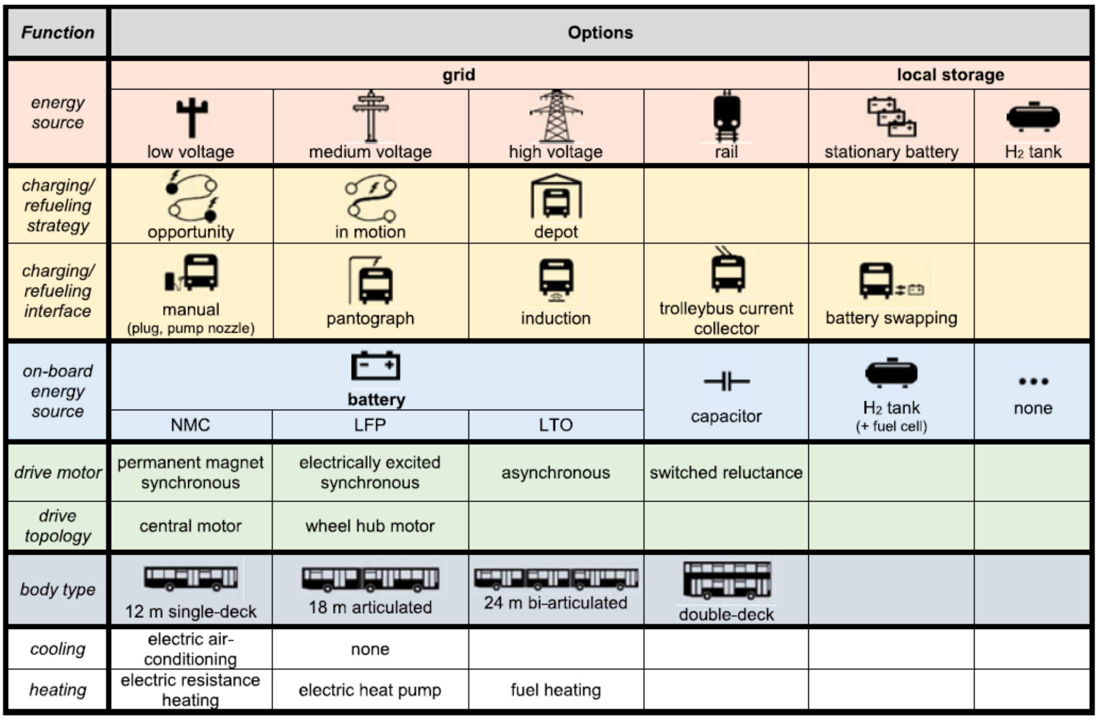



*Figure 3.6: Morphological matrix of available technology options in electric bus systems (Gohlich, Fay et al. 2018).*

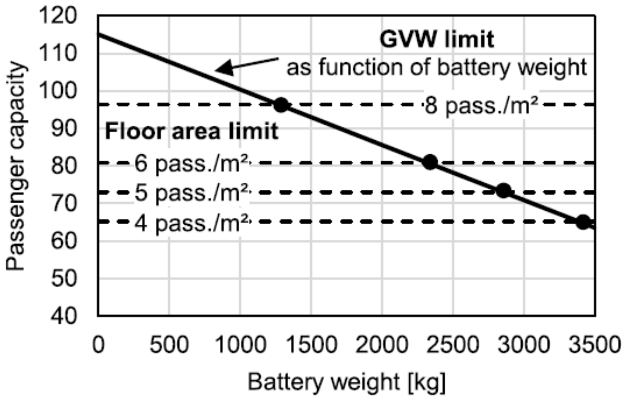



*Figure 3.7: Passenger capacity of a 12 m bus by gross vehicle weight (GVW) as a function of added battery weight (Gohlich, Fay et al. 2018).*

Within Europe, by the end of 2017, fully electric buses totalled 1.6 % (around 1 560) of all municipal buses in use (Jordbakke, Amundsen et al. 2018). Currently, more than 40 European cities have (or are still) testing out E-buses. In 2015, 18 % of the European fleet of E-buses were located in the UK, whilst the Netherlands, Switzerland, Poland and Germany had around 10 % of the European E-bus fleet each (ZeEUS 2016, Jordbakke, Amundsen et al. 2018). An overview of the E-bus models available in Europe (and their characteristics, as of the year 2018) is shown in Table 3.3.

*Table 3.3: Overview of models of electric buses available in Europe and their characteristics, as of the year 2018 (Jordbakke, Amundsen et al. 2018).*

| Bus model | Battery options[14], kWh | Range, km | Gross-weight, tonnes | Year on the market |
|---|---|---|---|---|
| Volvo 7900 Electric (12m) | 150, 200, 250 | <200 | 19 | 2017/18 |
| BYD Ebus K9 (12m) | 324 | 250 | 19 | 2010/13 |
| BYD articulated K11 (18m) | 550 | 275 | 29[15] | 2016 |
| Van Hool CX45E (14m) | | >300 | | 2019 |
| Van Hool Exqui.City (18m) | 215 | 120 | 28 | 2016 |
| Ebusco citybus 2.1 | 311 | 250-300 | 12.3 | 2014 |
| Solaris Urbino (12m) | 240 | | 19 | 2012/16 |
| Solaris Urbino (18m) | 240 | >200 | 28[16] | 2017 |
| VDL Citea electric SLF (12m) | | 40-160 | 19.5 | 2014/15 |
| VDL Citea electric SLFA (18m) | | 40-160 | 29 | 2015/16 |
| Linkker (12m) | 55 | 50 | 16 | 2016 |
| Sileo S12 (12m) | 310 | 400 | 19.5 | 2015 |
| Sileo S18 (18m) | 450 | 400 | 28 | 2016 |
| Irizar i2e (12m) | 380 | >200 | 19 | 2014 |
| Bollore Bluebus (12m) | 240 | 200 | 20 | 2016 |
| Iveco Daily Electric (mini) | 84 | <200 | 5-6 | 2016/17 |
| <u>Trolley buses</u> | | | | |
| Van Hool Exqui.City (18m) | 35 | | 29 | 2014 |
| Solaris Trollino (18 m) | 69 | | 28-30 | 2005 |

[14] For most of the bus models it is possible for the customers to choose between several different battery capacities

[15] 64 600 lbs gross weight

[16] 28 000 kilo curb weight

## Trucks

Use of battery-electric trucks (or E-trucks) has traditionally only been considered feasible for local delivery trucks (and not long-range driving), due to the high energy requirements for long ranges, necessitating a heavy battery with associated payload restrictions (Mareev et al. 2018a). However, with improvements in battery energy density, lithium-ion batteries have now made longer range (full electric) E-trucks more viable, in addition to hybrid vehicles (Svens et al. 2015). According to Talebian et al. (2018), current E-trucks using lithium-ion batteries have a range of 150-400 km, depending on the mass of the battery. A relationship between typical battery capacity and available payload (and maximum range) is shown in Figure 3.8 (Mareev, Becker et al. 2018a).

Commercially available E-trucks include Swiss E-force one, Maschinenfabrik Augsburg-Nurnberg (MAN), Emoss and Terberg, with Mercedes-Benz, Nikola, Volvo, Tesla and Daimler[17] also recently announcing products for the 2020-2022 time frame (Cabukoglu, Georges et al. 2018, Mareev, Becker et al. 2018a, Transport Topics 2019). The truck types vary; e.g. for Maschinenfabrik Augsburg-Nurnberg (MAN) and Tesla's tractor (semi-trailer trucks), MAN's tractor truck is for delivery applications whilst Tesla plans to produce a class 8 truck for long-haul transportation (Mareev et al. 2018b).

Despite these developments, E-trucks are still relatively scarce. Most electric freight vehicle models do not exceed a gross weight of 3.5 t, and the availability and choice of electric freight vehicles is limited. An overview of the heavy good vehicle trucks and tractors currently on the market, and expected to be on the market soon (as of the year 2018) are shown in Table 3.4 and Table 3.5 respectively (Jordbakke, Amundsen et al. 2018). For comparison, an overview of light goods vehicles (vans), currently on the market, and expected to be on the market soon (as of the year 2018), is shown in Table 3.6 and Table 3.7 respectively (Jordbakke, Amundsen et al. 2018).

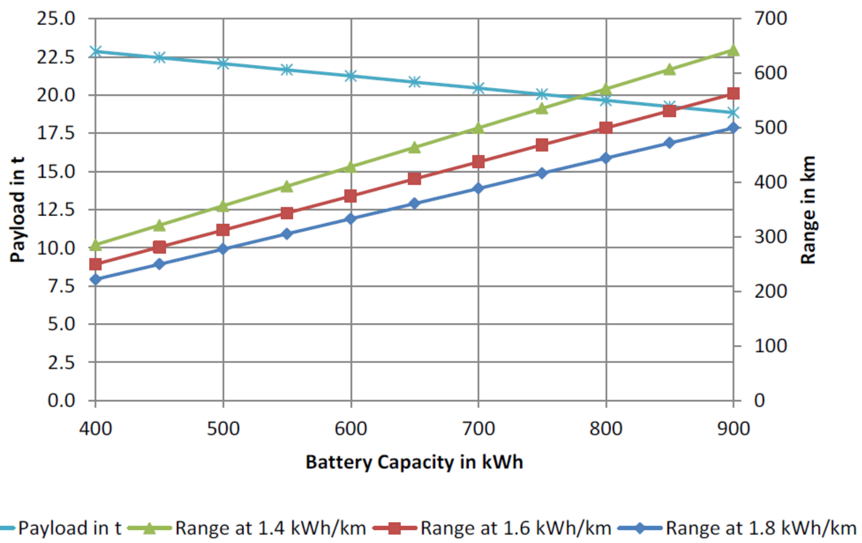



*Figure 3.8: Payload and range of the E-truck depending on the average energy consumption (Mareev, Becker et al. 2018a).*

[17] Daimler furthermore announced to quit the development of natural gas-powered trucks to focus on the development of battery- and hydrogen-electric trucks.

*Table 3.4: Battery-electric heavy goods vehicle (trucks and tractors) on the market, by model, range, capacity, size and year, as of the year 2018 (Jordbakke, Amundsen et al. 2018).*

| 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 |

*Table 3.5: Battery-electric heavy goods vehicle (trucks and tractors) soon to be on the market by model, range, capacity, size, and expected year of introduction (as planned in the year 2018). Adapted from Jordbakke, Amundsen et al. (2018).*

| Vehicle model | Battery kWh | Range, km | Hauling capacity, tonnes | Gross-weight, tonnes | Expected market introduction |
|---|---|---|---|---|---|
| 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 |

[18] Information reported by the operator of the converted truck.

*Table 3.6: Battery-electric light goods vehicles (vans) on the market, by model, range, capacity, size and year. Based on updates of Jordbakke, Amundsen et al. (2018).*

| Vehicle model | Battery options, kWh | Range, km (NEDC) | Cargo capacity, tonnes | Gross-weight, tonnes | Year on the market | 2018 price, kNOK |
|---|---|---|---|---|---|---|
| Ford Transit Connect Electric | 28 | 130 | | 2.3 | 2010 | |
| Renault Kangoo 2012-2017 | 22 | 170 | 0.5 | | 2012 | |
| Renault Kangoo 2017-[19] | 33 | 270 | 0.63 | 1.505-1.735 | 2017 | 250 |
| Citroen Berlingo | 22.5 | 170 | 0.7 | | 2013 | 230 |
| Peugeot Partner Electric | 22.5 | 170 | 0.62 | | 2013 | 235 |
| Mercedes-Benz Vito E-Cell | 36 | 130 | 0.78 | 3.0 | 2013 | |
| Nissan e-NV200 2014-2018 | 24 | 170 | 0.658 | | 2014 | |
| Nissan e-NV200 2018- | 40 | 280 | 0.742 | From 1.498 | 2018 | 284 |
| Maxus EV80 (previously LDV) | 56 | 192 | 0.95 | 2.55 | 2019 | |
| Iveco Daily Electric | 28-85 | 200 | 3 | 5.6* | 2018 | |
| Volkswagen e-Crafter | 36 | 173 | 0.95 | 3.5 | 2018 | 630 |
| MAN eTGE | 36 | 173 | 0.92 | 2.58 | 2018 | 795 |
| Mercedes-Benz eVito | 41.1 | 149-190 | 1.1 | 3.2 | 2018 | |

As of September 2019, the Nissan eNV200 is by far the best-selling electric van, and accounts for almost 60% of all electric vans sold in Norway so far.

[19] Renault has announced a Renault Kangoo Z.E. with 10 kW hydrogen fuel cell as range extender, with expected availability at the end of 2019. Renault claims this increases the driving range (based on the WLTP cycle) from 230 to 370 km.

*Table 3.7: Battery-electric light goods vehicles (vans) soon to be on the market by model, range, capacity, size and expected year of market introduction. Based on updates of Jordbakke, Amundsen et al. (2018).*

| Vehicle model | Battery options, kWh | Range, km | Based on cyclus | Cargo capacity, tonnes | Gross-weight, tonnes | Expected market introduction | Expected in Norway |
|---|---|---|---|---|---|---|---|
| 2T Ford Transit * | 30-90 | 200 | NEDC | | | 2021 | N.A. |
| Renault Master Z.E[20] | 33 | 120 | WLTP | 1.1 | | 2020 | N.A. |
| Mercedes-Benz e-Sprinter | 41/55 | 135 | WLTP | 1 | Depends on type | 2019 | 2019-end |
| StreetScooter Work / Work L Box | 20/40 | 118 | NEDC | 0.72-0.895 | 1.46-1.695 | Available already | N.A., considering Norway |
| Maxus EV30 | 35/52.5 | 225/ 325 | NEDC | 0.855/1.0 | N.A. | 2020 | 2020? |
| Opel Combo | N.A. | N.A. | | N.A. | N.A. | 2019-fall | 2019-fall |
| Fiat Ducato Electric | 47-79 | 220 | NEDC | 1.95 | N.A. | 2020 | 2020 |
| Peugeot Boxer | N.A. | 225 | NEDC | N.A. | N.A. | N.A. | N.A. |
| Citroën Jumper | N.A. | 225 | NEDC | N.A. | N.A. | N.A. | N.A. |
| Volkswagen ABT e-Caddy | 37.3 | 220 | NEDC | N.A. | N.A. | 2019 | N.A. |
| Volkswagen Caddy Maxi | 37.3 | 220 | NEDC | N.A. | N.A. | 2019/2020 | N.A. |
| Volkswagen ABT e-Transporter | 37.3-74.6 | 304 | NEDC | 0.7-1.0 | N.A. | 2019/2020 | 2020? |
| Peugeot Expert | N.A. | N.A. | | N.A. | N.A. | 2020 | N.A. |
| Peugeot Traveller | N.A. | N.A. | | N.A. | N.A. | 2020 | N.A. |
| Citroen Dispatch | N.A. | N.A. | | N.A. | N.A. | 2020 | N.A. |
| Citroen Space Tourer | N.A. | N.A. | | N.A. | N.A. | 2020 | N.A. |
| Opel Vivaro | N.A. | N.A. | | N.A. | N.A. | 2020 | 2020 |
| Opel Vivaro Life | N.A. | N.A. | | N.A. | N.A. | 2020 | N.A. |
| Volkswagen ID. Buzz | N.A. | 548 | NEDC | N.A. | N.A. | N.A. | 2023* |
| Toyota Proace | N.A. | N.A. | | 1.0-1.2 | N.A. | N.A. | 2020 |

### 3.2.4 Technology development pathways

A typical development path for electric HDVs seems to be that after initial development, pilot tests are carried out over a period of months or years to gain practical operational experience before *series* production is introduced. These tests are conducted in fleets of large existing customers to ensure real world use and conditions. In passenger vehicle development, these pilot tests can be done internally by the employees of the manufacturer, as they are also motorists.

An estimated timeline overview of battery-electric technology in different vehicle segments, based on publically available market information and author analysis, is given in Figure 3.9 (Jordbakke, Amundsen et al. 2018). Based on this figure, it seems unlikely that there will be full mass production of electrified large vans[21], distribution trucks or heavy-duty trucks in the near future.

[20] Renault has also announced a Renault Master Z.E. with 10 kW hydrogen fuel cell as range extender. This model is expected to become available in the first half of 2020. Renault claims the hydrogen-based extender increases the van's driving range (WLTP) from 120 to 350 km.

[21] Some semi series production is taking place with 'OEM internal retrofit' schemes (e.g. the Renault Master)

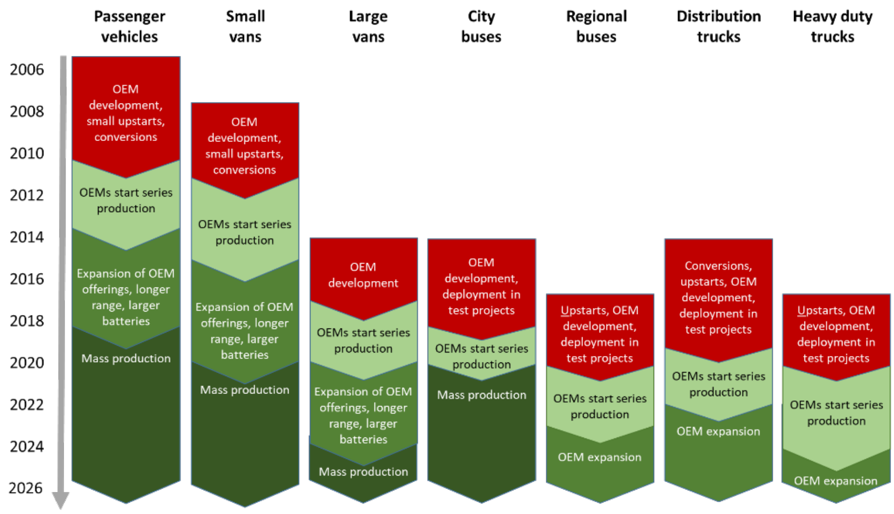



*Figure 3.9: Timeline of introduction of battery-electric versions in different vehicle segments, as of the year 2018. Updated from Jordbakke, Amundsen et al. (2018).*

### 3.2.5 Costs and cost development pathways

Battery-electric vehicles have a higher cost than ICE vehicles, mainly due to the additional cost of the battery. The development in battery costs is thus a key determining factor for the potential of electric vehicles to replace other technologies. However, as battery technologies change rapidly, the rate of production scale increases is uncertain, and the current market is still relatively small (particularly for heavy vehicles), price projections are subject to considerable uncertainty[22]. According to USABC requirements, the battery cost should be less than ~200 USD/kWh for the start of commercialization, as it is for passenger vehicles already (Gopalakrishnan, Goutam et al. 2016, Figenbaum 2018)

Table 3.8 presents projections for the development in lithium-ion battery prices, based on four recent sources that were published in the same year (i.e. 2017), and one updated source for 2019. Battery cost averages for the first four sources are prices of 460[23], 265, 182 and 139 USD/kWh for the years 2015, 2020, 2025 and 2030, respectively[24] (Quak et al. 2017). Cost projections made in 2019 are lower, possibly reflecting the higher maturity of the technology. Although only two of these sources are specifically for the heavy-duty sector, battery packs for HDVs are assumed to use similar technology as for LDVs[25]. Variation is large between sources, even for the starting year. This is due to the differences that can be found within batteries even of the same category (Berckmans et al. 2017). The high costs are mainly due to the materials used, such as cobalt and nickel. Of the lithium-ion battery technologies, LFP based batteries will thus have the lowest cost due to use of iron instead of cobalt (Gopalakrishnan, Goutam et al. 2016).

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22 The cost of the battery is inversely linked with the growth of the electric and hybrid vehicles but the sensitivity of the battery price to sales volume of vehicle is much lower than e.g. fuel cell. The reason is that the battery market is significantly larger than the fuel cell system market.

23 460 USD/kWh is not the 2015 average, but the price that three references were closely grouped around.

24 The battery lifecycle is also expected to increase over the coming years, with an expected cycle life of 3 000 in 2016 and 5 000 in 2024.

25 The ICCT (2017) mention that the assumption is in line with a Tesla statement that the upcoming Tesla Semi will share parts with its electric car production and Toyota's announcement that its Class 8 fuel cell tractor will use its Mirai passenger car fuel cell stacks.

According to the ICCT (2017), reductions in battery costs are due to the replacement of high-cost materials, economies of scale, improvements to battery design, production and manufacturing, and competition among suppliers. A general relation between battery cost and volume production change is described in Equation 1, where $D_o$ is the current battery cost (USD), $E_o$ is the production volume (units/year), D is the future cost of the battery (USD) and E is future production). Hence, an 8 % increase in production volume should result in a 27 % cost decrease (Gopalakrishnan, Goutam et al. 2016). Compared with passenger BEVs produced in numbers above 100 000 per year (2018-2019), pack costs will be higher for HDVs relative to cell cost, due to lower vehicle production volumes.

$$\log\left(\frac{D}{D_o}\right) = -0.15\left(\frac{E}{E_o}\right) \qquad 1)$$

*Table 3.8: Selected projections for the price development of lithium-ion battery packs for the period 2015-2030. Figures in $US/kWh. Note: Original price projection in FREVUE (2017) are in EUR/kWh. As the other sources state prices in $US, we converted FREVUE's estimates to $US for comparability, using exchange rates from Eurostat for 2017 (the report's year of publication). *Price for 2019.*

| Source | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| ICCT (2017) | 326 | 228 | 168 | 120 |
| Quak, Koffrie et al. (2017) | 468 | 336 | 252 | 228 |
| Blackrock (2017) | 450 | 210 | 140 | 110 |
| Berckmans, Messagie et al. (2017) | 466 | 195 | 115 | 75 |
| Bloomberg New Energy Finance (2019) | | 176* | 87 | 62 |

Other additional capital costs for zero-emission heavy-duty vehicles, sourced from the ICCT (2017), are shown in Table 3.9. Regarding repair and maintenance costs associated with the operation of battery-electric solutions, Quak, Koffrie et al. (2017) comment that for passenger cars these are around half of comparable conventional vehicles. Thus, maintenance costs for electric HDVs may also be lower than for conventional vehicles, and also have the potential to decrease further in future years. In practice, the reduced maintenance costs may not be fully realized near term, as vehicle manufacturers will need to invest in tools and training to be able to service these new technology vehicles.

Nevertheless, engine-, engine-after-treatment-, and battery replacement will be expensive (Quak, Koffrie et al. 2017). It is perceived that such investment in (already aged) vehicles is typically not desirable, as such investments will not pay back in the residual value of the vehicle. For a relatively small battery that is recharged during the day, it may however be profitable to replace the battery while the vehicle has not reached its economic lifetime limit.

*Table 3.9: Selected component cost projections for the period 2015-2030 (ICCT 2017). Figures in $US/kWh.*

| Component Costs | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| Battery ($/kWh) | 326 | 228 | 168 | 120 |
| Electric motor fixed cost ($) | 120 | 94 | 85 | 75 |
| Electric motor ($/kW) | 22 | 18 | 16 | 14 |
| Fuel cell system ($/kW) | 240 | 166 | 89 | 59 |
| Additional fuel cell systems ($/kW) | 38 | 34 | 31 | 28 |
| Overhead catenary vehicle grid connection ($) | 71,700 | 49,600 | 21,200 | 21,200 |
| Dynamic induction vehicle grid connection ($) | 16,700 | 11,800 | 11,500 | 10,800 |
| Additional electric vehicle systems ($/kW) | 55 | 52 | 46 | 41 |

*Based on den Boer et al., 2013; Slowik et al., 2016; Wolfram & Lutsey, 2016*

Regarding the total cost of ownership (TCO), Quak, Koffrie et al. (2017) expect the TCO of electric freight (vs conventional freight) vehicles to be comparable or higher at the current time, although it is expected to be lower in the future. TCO also varies with driving behavior (e.g. driving distance) and technology (e.g. battery type and size) (Figure 3.10 and Figure 3.11). However, calculations do not take into account the perceived risk from users of taking new technology into use.

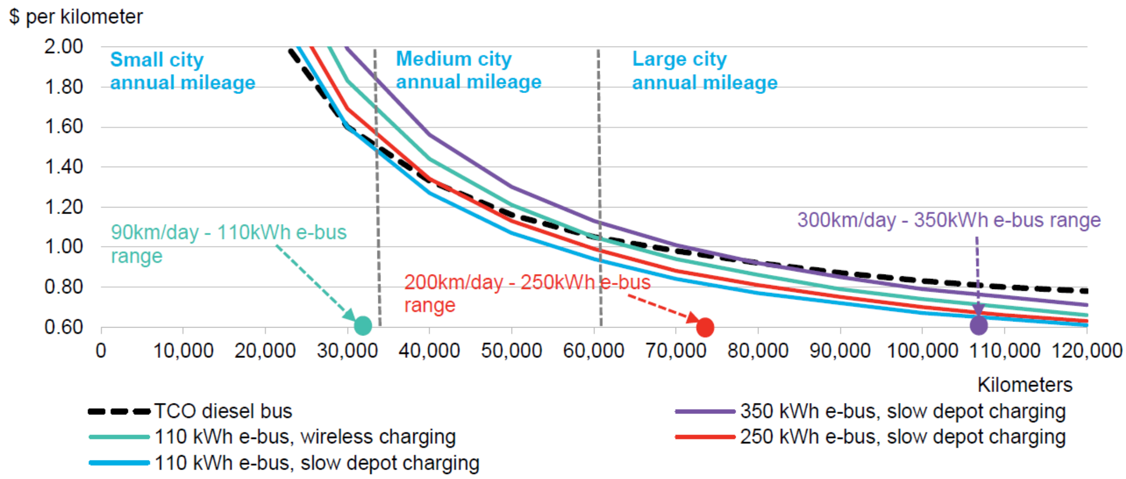



*Figure 3.10: Total cost of bus ownership comparison with different annual distance (Bloomberg New Energy Finance 2018). Notes: Diesel price at $0.66/liter ($2.5/gallon), electricity price at $0.10/kWh, annual mileage – variable. Bus route length will not always correspond with city size.*

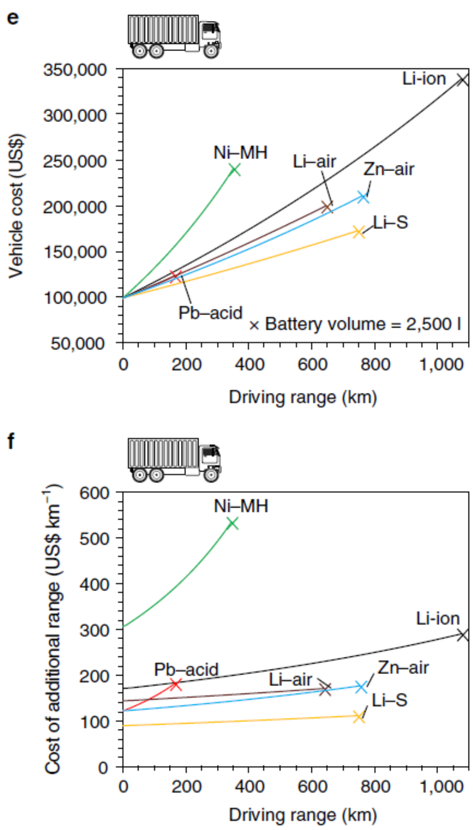



*Figure 3.11: Vehicle cost and cost of additional range as a function of driving range (Cano et al. 2018). Notes: tractor (semi-trailer truck; vehicle cost = 100 000 USD, vehicle mass = 24 000 kg, vehicle energy consumption efficiency = 0.0445 Wh km-1 kg-1.*

## 3.3 Hydrogen/fuel cell solutions

### 3.3.1 Principles

With hydrogen fuel cell technology, an electric motor powered by the hydrogen fuel cell replaces the fuel tank and internal combustion engine. Electricity generated by the fuel cell is then used to drive the vehicle, or is stored in batteries or ultra-capacitors (Alaswad et al. 2016).

A hydrogen fuel cell is a galvanic cell that can convert chemical energy to electrical energy. Unlike a battery, it does not store chemical or electrical energy, but requires a constant external supply of reactants. Fuel cells are classified in relation to the type of their electrolytes and type of fuels as solid oxide fuel cells (SOFCs), molten carbonate fuel cells (MCFCs), phosphoric acid fuel cells (FAFCs), alkaline fuel cells (AFCs), direct methanol fuel cells (DMFCs) and proton exchange membrane fuel cells (PEMFCs)[26]. When used in a vehicle, fuel cells are combined into stacks (Figure 3.12), the core of which is a repeating membrane electrode assembly (MEA). This consists of the proton conducting electrolyte, cathode/anode porous electrodes, anodic/cathodic catalyst layers, and gas diffusion layer (Alaswad, Baroutaji et al. 2016). Interaction of the fuel cell stack with other vehicle components is shown in Figure 3.13.

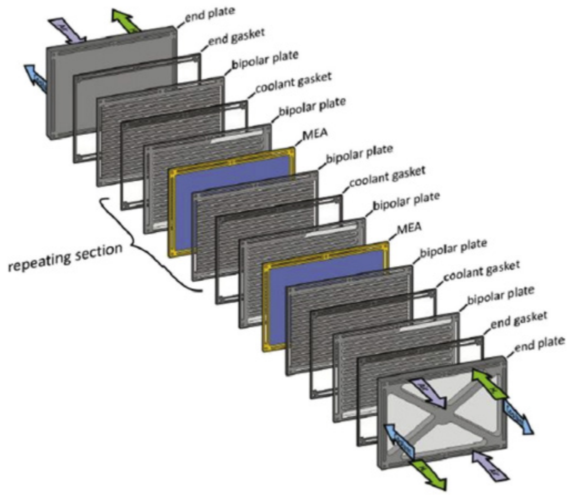



*Figure 3.12: Main components of a PEMFC stack (Alaswad, Baroutaji et al. 2016). Note: Membrane Electrode Assembly (MEA).*

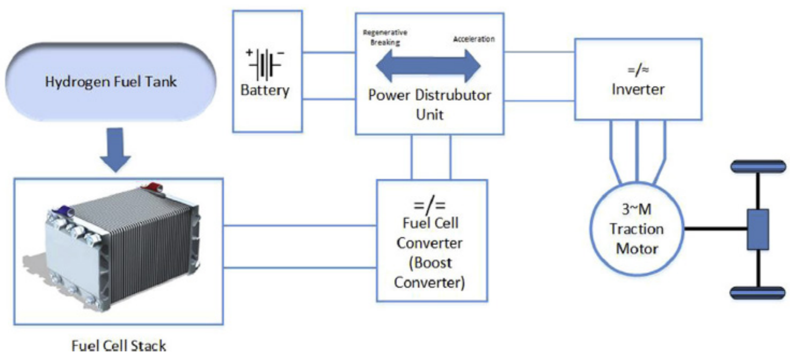



*Figure 3.13: Schematic illustration of a fuel cell electric vehicle (Gurz et al. 2017).*

[26] Alternatively known as the polymer electrolyte membrane fuel cell

### 3.3.2 Technology readiness and challenges

Different fuel cell technologies are suited to different applications; for transport applications, PEMFC are widely adopted due to their high associated power density, high energy conversion efficiency, compactness (and lightness), and relatively low operating temperature (60-80°C) (Alaswad, Baroutaji et al. 2016). However, the high cost of the technology represents the largest commercialization challenge. Other commercialization challenges are the unit durability and performance, hydrogen infrastructure, and storage and safety issues (Alaswad, Baroutaji et al. 2016). In addition, fuel cells become heavy as power demands increase, and have a slow response to instant power demand (and excessive power output in case of sharp acceleration). Use of the fuel cell as a hybrid with a battery or supercapacitor allows some of these negative effects to be overcome, and is the strategy taken in most commercial vehicles[27] (Gurz, Baltacioglu et al. 2017).

According to Chen et al. (2018), fuel cell stacks for commercial vehicles currently fail at lifetime goals, meaning this is a research area currently focused upon, along with development of associated durability testing methods. Technical objectives set by the U.S. Department of Energy (specific for transportation) for transit buses include a 25 000 hour lifetime (Table 3.10). The lifetime should also cover the full range of external environmental conditions, including variable humidity, shutdown/startup, freeze/thaw and subfreezing down to -40°C.

*Table 3.10: Technical targets set by the U.S. Department of Energy fuel cell transit buses (U.S. Department of Energy 2011).*

| Table 3.4.11 Technical Targets: Fuel Cell Transit Buses | | | | |
|---|---|---|---|---|
| Characteristic | Units | 2015 Status | 2016 Targets | 2020 Targets |
| Bus lifetime | years/miles | 0.25–4.9/7,900–117,000[a] | 12/500,000 | 12/500,000 |
| Power plant lifetime[b,c] | hours | 20,000[a] | 18,000 | 25,000 |
| Bus availability | % | 40–92[a] | 85 | 90 |
| Fuel fills[d] | per day | 1[a] | 1 (< 10 min) | 1 (< 10 min) |
| Bus cost[e] | $ | 800,000[f] | 1,000,000 | 600,000 |
| Power plant cost[b,e] | $ | 60,000–120,000[g] | 450,000 | 200,000 |
| Hydrogen storage cost | $ | 100,000[h] | 75,000 | 50,000 |
| Road call frequency (bus/fuel cell system) | miles between road calls | 1,800–6,800/ 9,000–104,000[a] | 3,500/15,000 | 4,000/20,000 |
| Operation time | hours per day/days per week | 7–21/5–7[a] | 20/7 | 20/7 |
| Scheduled and unscheduled maintenance cost[i] | $/mile | 0.54–1.33[a] | 0.75 | 0.40 |
| Range | miles | 240–340[a] | 300 | 300 |
| Fuel economy | miles per gallon diesel equivalent | 5.6–7.7[a] | 8 | 8 |

In addition to challenges for the fuel cells themselves, on-board storage of hydrogen is a major challenge due to the low density of hydrogen, coupled with difficulties of liquefaction (which requires cooling to 22 K (-251 °C)). Different types of transport segments require varying amounts of hydrogen to be stored onboard, to cover their daily range in a single refueling event (Figure 3.14). According to Gurz, Baltacioglu et al. (2017), storage options can be defined as a) storage as hydrogen (by compression in gas form or in liquid form in conjunction with storage using reversible metal hydride and by using carbon

[27] Fuel cell vehicles using a hybridized fuel cell system are obtained in two types; fuel cell electric vehicles (FCEVs) and plug-in extended range fuel cell electric vehicles (PHEVs). The size of the required battery and the power of the used fuel cell system determine the differences (Gurz et al., 2017).

nanofiber); and b) storage using chemical methods (methanol, alkali metal hydrides, sodium borohydride and ammonia). Due to its high potential for low cost and weight storage, research has focused on development of liquid hydrogen storage systems. These are considered in high, medium and low pressure classes (Figure 3.15).

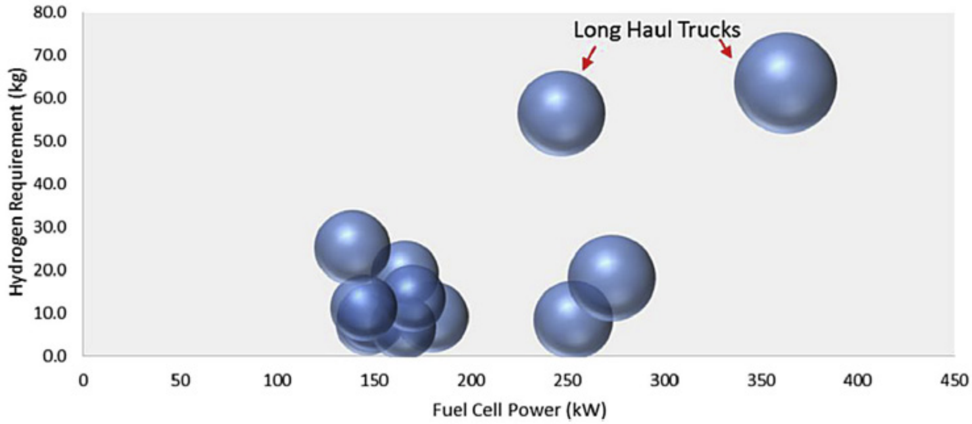



*Figure 3.14: Powertrain component sizing. Area of the bubbles is proportional to motor size (Kast et al. 2017). Various vehicle specifications were included in the analysis, each with its own performance and daily range requirements from a single refueling event.*

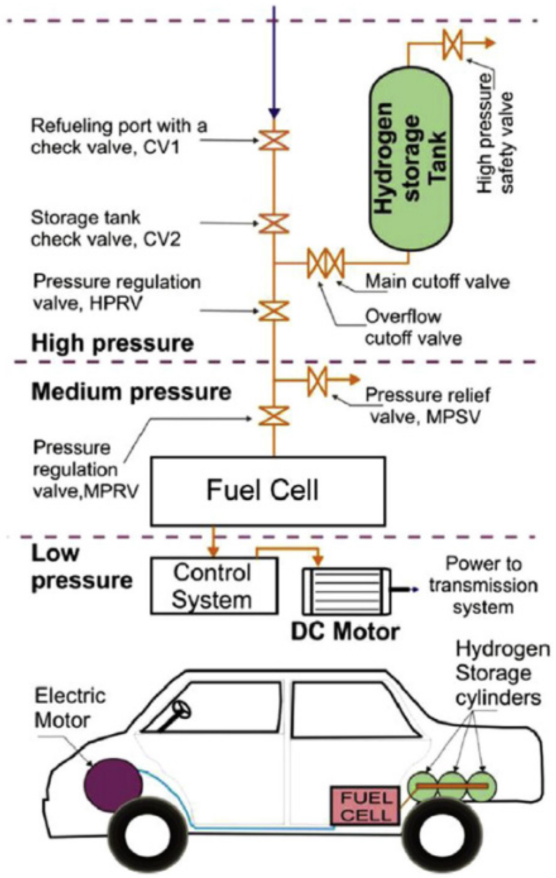



*Figure 3.15: Onboard hydrogen storage systems for fuel cell vehicles (Gurz, Baltacioglu et al. 2017).*

### 3.3.3 Global use status, with focus on HDVs

Fuel cell technology is showing year-on-year growth, with an increasing number of prototypes. Nevertheless, most of the development work on fuel cell vehicles has focused on passenger vehicles, and only three models from Toyota, Honda and Hyundai have reached a small-scale *series* production (thousands) (Jordbakke, Amundsen et al. 2018). Toyota and likely Hyundai will enter a phase with larger-scale (whilst still small) *series* production from 2020, potentially producing 10 000-30 000 vehicles annually.

#### Buses

There are several hydrogen fuel cell buses in pilot operation in different parts of Europe, as seen in the overview (as of the year 2018) in Table 3.11 (Jordbakke, Amundsen et al. 2018). Different versions of fuel cell buses have been tested out for the last 8-10 years. In Europe in 2018, 82 fuel cell buses were being tested out in different pilot projects, and the testing of a further 200-300 was planned. In the U.S., a total of 26 fuel cell buses were in active service in pilot studies (as of Aug 2017), with plans to test a further 42 fuel cell buses (Jordbakke, Amundsen et al. 2018).

*Table 3.11: Fuel cell buses by bus model/brand, range, capacity, size and year, as of the year 2018 (Jordbakke, Amundsen et al. 2018). *The customer can specify the required storage capacity, depending on range needed. **Some producers already offer fuel cell electric buses for sale. But the buses sold now are part of different EU or national test projects.*

| Bus model | Range, km | $H_2$-storage*, kg | Net weight, tonnes | Year on the market** |
|---|---|---|---|---|
| Van Hool A330 (13m) | | 30-50 | 16 | |
| Van Hool Exqui.City (18m) | | 40-45 | | |
| Solaris (18m) | 250-300 | 45 | | 2015 |
| Mercedes/Evobus Citario (12m) | | 35-40 | 13 | 2018 |
| VDL/APTS (18m) | | 40 | | |
| Solbus/HyMove (12m) | 300+ | 30 | | |
| Wrightbus (12m) | 250-300 | 30 | 11 | 2017 |

#### Trucks

All heavy-duty goods vehicles with hydrogen fuel cell systems which have been tested on the road so far, have been test vehicles or converted vehicles produced especially for demo-projects and pilots. The fuel cell power requirements for different classes of trucks vary, as shown in Figure 3.16. Table 3.12 gives a list of the conversion vehicles available. There are even fewer producers that offer light goods vehicles (vans) with hydrogen fuel cell propulsion.

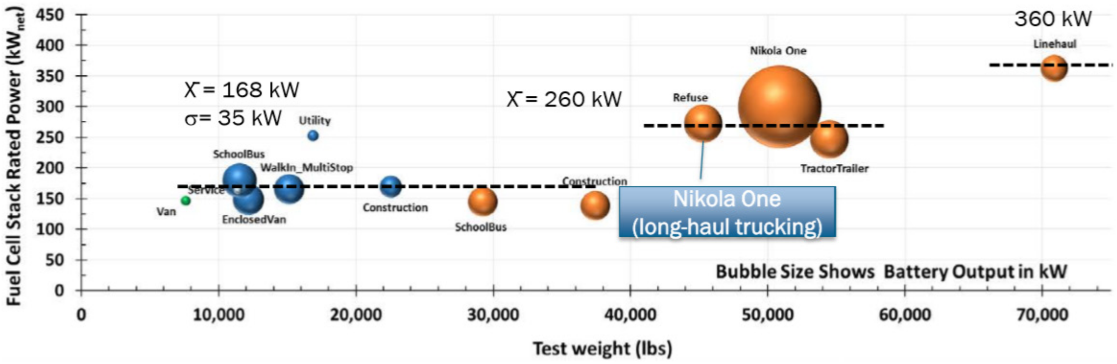



*Figure 3.16: Fuel cell power requirement for various classes of trucks (U.S. Department of Energy 2018)*

*Table 3.12: Hydrogen fuel cell trucks by brand, vehicle model, range, capacity, size and year, as of the year 2018 (Jordbakke, Amundsen et al. 2018).*

| Vehicle model | In use for | Range in km | Load capacity in tonnes | Gross weight in tonnes | Year on the market or road |
|---|---|---|---|---|---|
| Renault Maxity $H_2$ | French post office (La poste) | 200 | 1 | 4.5 | |
| Esoro | Coop Mineralöl, gas station company | 400 | | 34 | 2017 |
| Scania | Asko, Norwegian wholesaler | 500 | | | 2019 |
| Toyota /International Prostar | Test program: port of LA and Long Beach | 320 | 36 | Class 8 | 2017 |
| Kenworth | | | | Class 8 | 2017/2018 |
| US Hybrid /International Prostar | | | | Class 8 | 2017/2018 |
| UPS | UPS | 200 | | Class 6 | 2018 |
| EGEN, Workhorse | FedEx, Delivery in New York | 250 | | Class 5 | 2018 |
| Nikola One | 7 000 pre-orders | 2000 | | Class 8 | 2020 |
| Hyundai | $H_2$ Energy, initially for Swiss $H_2$ Association (1 000 to be deployed) | 400 | | 18 | 2019 |

### 3.3.4 Technology development pathways

An estimated timeline overview of hydrogen fuel cell technology in different vehicle segments, based on publically available market information and author analysis, is given in Figure 3.17 (Jordbakke, Amundsen et al. 2018). From this figure, it seems unlikely that there will be mass production of small or large fuel cell vans (apart from Renaults hydrogen range extender for the Kangoo and Master battery-electric vans), buses, or distribution trucks in the near future.

Instead, most of the published plans for *series* production of fuel cell HDVs focus on long distance trucking. Little information is known about when and even whether mass production of vans, distribution trucks and buses will commence. City buses and city logistics will likely be using battery-electric propulsion combined with charging during the day, but hydrogen could be needed for buses and distribution trucks in sub-urban areas and within long-haul trucking. Buses are an arena where fuel cell hydrogen solutions are tested out on a small scale, but no producers have yet announced plans for regular production.

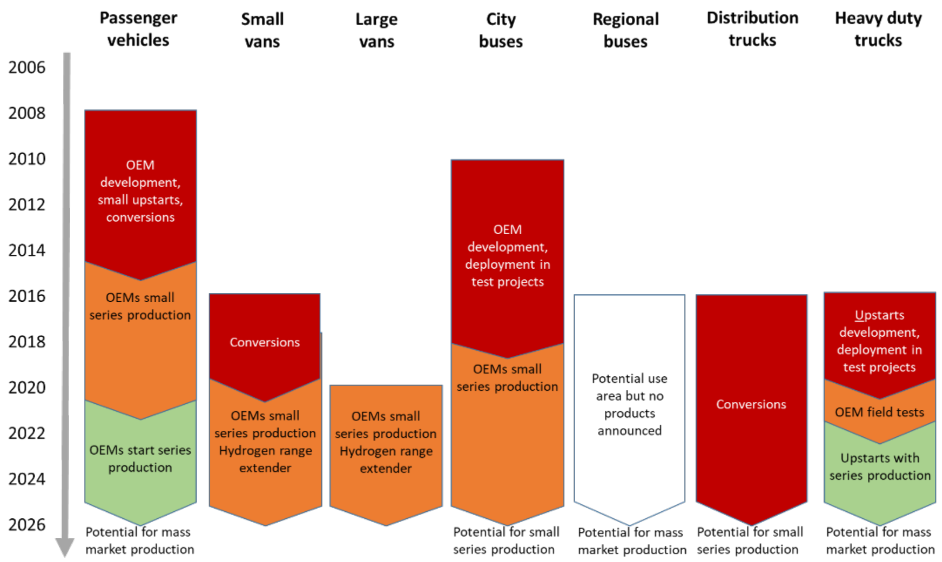



*Figure 3.17: Timeline for introduction of hydrogen versions in different vehicle segments. Updated from Jordbakke, Amundsen et al. (2018). Since the van segment is optimal for battery-electric technology (battery-electric vans will soon be on the market with a long enough range to replace most diesel vehicles), hydrogen is therefore of little interest for this field of application.*

### 3.3.5 Costs and cost development pathways

As with battery-electric vehicles, fuel cell vehicles have a higher cost than ICE vehicles, mainly due to the fuel cell component itself. Fuel cell costs can be broken down into three elements; the material and component costs, labor, and design, fabrication and capital cost of manufacturing (Alaswad, Baroutaji et al. 2016). Cost savings can be achieved by reducing material costs[28], increasing power density, reducing complexity, and improving durability (Alaswad, Baroutaji et al. 2016). According to the U.S. Department of Energy, fuel cells should be mass produced at a cost of $40/kW by 2020, and ultimately $30/kW (U.S. Department of Energy 2012 (Revised 2017))

Material and component costs are dependent on technological innovations and the market, and therefore have an associated uncertainty. A projection of fuel cell cost projection for the heavy-duty vehicle segment, based on a prediction of vehicle production numbers, can be seen in Table 3.13. However, this is based on a study regarding light-duty vehicles (ICCT 2016). Alternatively, the U.S. Department of Energy (2018) identifies system cost drivers for the years 2018, 2020 and 2025, as expressed in Equation 2. The novelty is that the study takes into account differences between fuel cell systems for light-duty vehicles and medium-duty vehicles (for which a baseline was used of a Class 6 vehicle for construction, with a 170 kW fuel cell). 'Platinum loading', for example, was set higher for medium-duty vehicles[29]. The cost calculations further considered technology changes towards 2020/2025.

[28] Material costs can be particularly decreased by reducing platinum content, either by using Pt-alloy catalysts or by applying core shell catalysts.

[29] 0.125 mgPt/cm² for light-duty vehicles vs. 0.35 mgPt/cm² for medium-duty vehicles

*Table 3.13: Fuel cell system cost projections (ICCT 2017).*

| | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| Prediction of vehicle production | 1 000 | 5 000 | 10 000 | 50 000 |
| Fuel cell cost ($/kW) | 240 | 166 | 89 | 59 |

*Estimated Cost = (Material Cost + Processing Cost + Assembly Cost) × Markup Factor.*

Figure 3.18 illustrates the fuel cell system cost as a function of the annual production rates (U.S. Department of Energy 2018). For MDVs, this is illustrated for the years 2018, 2020 and 2025, with production ranging from 200 to 100 000 systems per year), while for LDVs, only the year 2018 is included. The figure shows that the rate of cost reductions is much higher at relatively low levels of production, and declines more gradually at higher levels, implying diminishing returns of scale. Although a comparison between LDVs and MDVs can only be made for 2018, the figure shows that the cost projection paths are different, and the cost reduction rate (as a function of production volume) is lower for MDVs.

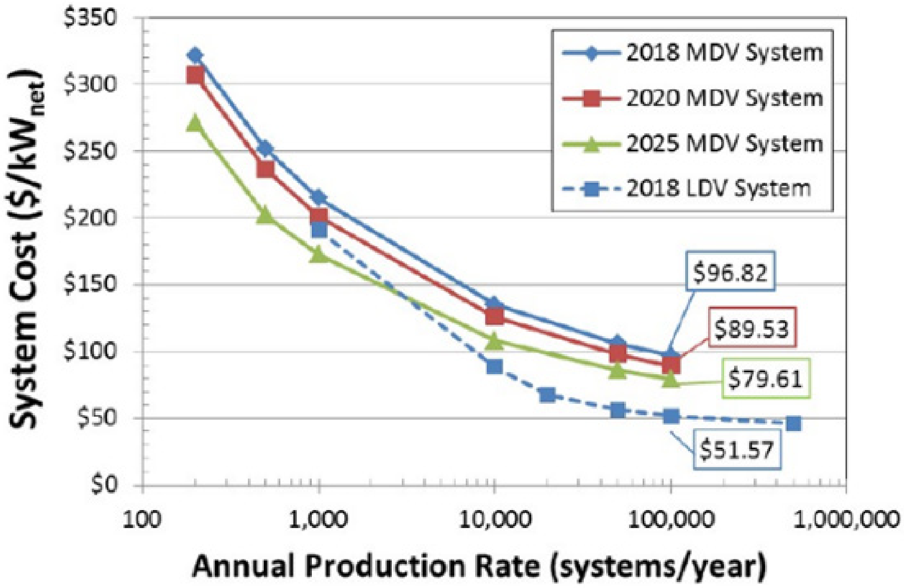



*Figure 3.18: Total fuel cell system cost (U.S. Department of Energy 2018).*

In addition to changes in costs with market size, as with battery technology, costs also vary depending on driving requirements (e.g. required range). Figure 3.19 shows the vehicle cost as a function of driving range for fuel cell electric vehicles, with comparisons to battery-electric vehicles. According to Cano, Banham et al. (2018), costs of fuel cell vehicles are less sensitive to increased driving range, because increasing the range requires only increasing the size, quantity or pressure of hydrogen storage tanks, which are lighter and less expensive than Li-ion battery packs on a per kWh basis. Nonetheless, current conventional fuel cell vehicles are more expensive than battery-electric ones, due to the high present cost of fuel cell systems.

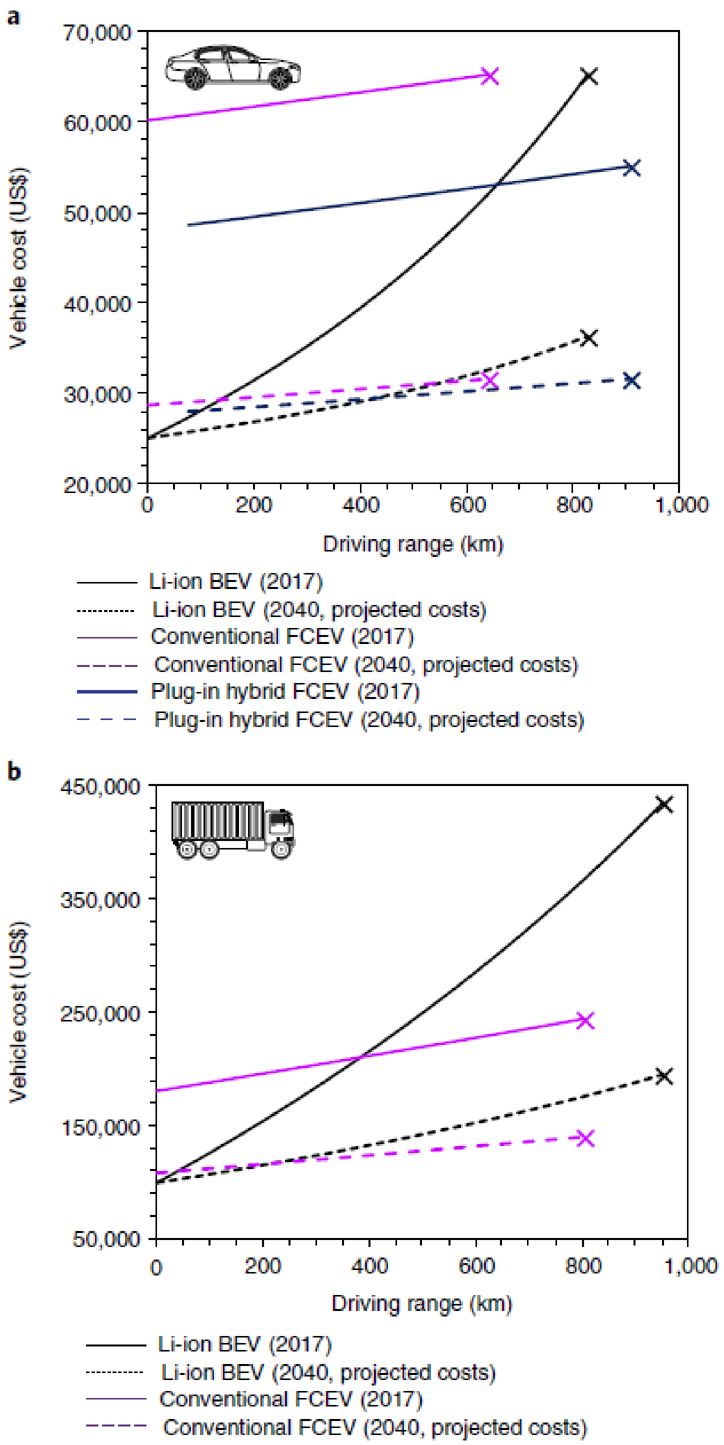



*Figure 3.19: Vehicle cost as a function of driving range for Li-ion battery- and hydrogen fuel cell- electric vehicles (Cano, Banham et al. 2018). Curves for battery-electric and hydrogen-electric vehicles are plotted for (a) mid-size vehicle and (b) tractor (semi-trailer truck).*

# 4 Assessing Current User Experience in Norway

The previous chapters provided an overview of climate objectives and the composition of the vehicle stock in Norway, as well as the global status and prospects of alternative propulsion technologies, with a particular focus on HDV battery-electric and hydrogen vehicles (based on the literature).

The core of the analysis presented in this report, however, is a case study based on semi-structured interviews with bus and truck operators who have experience with operating heavy-duty battery-electric and hydrogen vehicles in Norway. In addition to mapping user experiences, these interviews provide input for two further assessments: one assessment looking at the potential for the electrification of trucks, in light of typical use patterns and cost competitiveness of different propulsion technologies in different scenarios of technological maturity (Chapter 7-9), and one assessment regarding electrification potential and cost competitiveness for buses (Chapter 10).

## 4.1 Interview methodology

In order to carry out a series of semi-structured interviews, a sample of operators utilizing zero-emission HDVs was identified using the Norwegian Public Road Administration's vehicle registry, Autosys, per April 2018 (NPRA 2018), and ENOVA's[30] project list (ENOVA 2018). In addition to operators, relevant policy-associated institutes and manufacturers were interviewed. To summarize:

- Operators contacted included:
    - Asko
    - BIR AS (Bergensområdets interkommunale renovasjonsselskap)
    - Nobina AS
    - Norgesbuss AS
    - Norsk Gjenvinning Renovasjon AS
    - Nor Tekstil
    - Oslo Taxibuss
    - Posten (also representing Bring)
    - Ragn-Sells AS
    - Renovasjonen
    - Stena Recycling AS
    - Taxus AS (representing Nedre Romerike Minibuss/Lillestrøm Minibuss)
    - Unibuss AS

[30] ENOVA is the Norwegian Government Agency for the transition towards a low-emission society

- Government bodies contacted included:
    - Norwegian Public Road Adminisation (Statens Vegvesen[31])
    - ENOVA
- Industrial authorities contacted included:
    - Ruter
- Manufacturers contacted included:
    - Scania
    - Volvo

A summary of the interviews carried out (showing the type of sector and entity in question), is given in Table 4.1. For most entities, one interview was conducted..

*Table 4.1: Summary of the number of interviews conducted.*

| Sector | Individual operator | Government body | Industrial authority | Manufacturer |
|---|---|---|---|---|
| Public transport | 5 | 0 | 1 | 0 |
| Forwarders and freight | 4 | 0 | 0 | 0 |
| Waste collection | 4 | 0 | 0 | 0 |
| Manufacturer | 0 | 0 | 0 | 2 |
| Policy | 0 | 2 | 0 | 0 |
| Recycling | 1 | 0 | 0 | 0 |

Semi-structured interviews were mainly conducted as Skype meetings with persons responsible for the investments decisions of each of the identified organizations. For government bodies, the person in charge of the activity was interviewed. As preparation, subjects were sent a questionnaire in advance of the interview meetings (see Appendix 1 for an example[32]). Framed by this focus of enquiry, the open ended questioning allowed study participants to articulate perceptions freely.

For operators, questions related to the following topics (although specifics varied slightly depending on the company in question):

- The process behind the purchase of the low emission vehicle(s).
- How existing (fossil fuel) vehicles in the fleet are used.
- General information about the low emission vehicle(s) chosen; technology and performance.
- Information about operation of the low emission vehicle(s) and charging infrastructure.
- Information about service and maintenance.
- Decomposed costs connected to investments.
- Driving (distance related) costs.
- Public frameworks, incentives, and dispensation factors that can contribute to faster phasing in of low emission vehicles.

After the meetings, subjects were sent notes from the interview for comments, and to allow for the clarification and correction of any misunderstandings.

[31] Including Vegdirektoratet, which is a part of Statens Vegvesen

[32] Questions are in Norwegian.

## 4.2 Analysis methodology

After finalization of the interview notes, data was analysed in the software suite NVivo (Version 12 Plus). A design framework for the analysis is shown in Table 4.2. Company activity sub-themes included operations, tender process, company strategy, further orders, and future development. Technology sub-themes included manufacturer, charging, battery, hydrogen, maintenance, hybrid and biogas. Performance sub-themes included owners, drivers, public interest, sound, vibrations, vehicle (general), technical, capacity, range, weight, design, energy use, speed, and lifetime. Barriers and enablers sub-themes included barriers to low emission technology and enablers (policy and incentives) to low emission technology. User experience sub-themes included positive and negative categories.

Due to the nature of the semi-open ended questioning, the interview data was partly grouped according to pre-defined formats, but was also thematically distributed. To ensure accuracy, the auto coding features of NVivo were not used. Thus, the qualitative data analysis software was only used as a tool for efficiency and transparency.

*Table 4.2: Design framework for the interview analysis.*

| Data Type(s) | Unit(s) | Variables | Longitudinal study (yes or no) | Themes |
|---|---|---|---|---|
| Interviews | Entities | Entity type (operator/ manufacturer/ authority/government)<br><br>Relevant sector (freight transport/public transport/policy/waste collection/forwarders/manufacture /recycling)<br><br>Vehicle type employed (bus/truck/tractor)<br><br>Technology employed (BEV/ mixed) | No, a snapshot | Broad topic coding:<br>• Company activity<br>• Costs<br>• Technology<br>• Performance<br>• Barriers and enablers<br>• User experience<br><br>Emergent fine coding:<br>• Sub-themes |

## 4.3 Limitations

This study was designed to give a snapshot of current user experiences with zero-emission HDVs in Norway, but it has evident limitations associated. These are mainly related to the fact that currently only a relatively small number of zero-emission HDVs are in use in Norway, meaning there is so far little experience (and no long-term experience). In addition, many operators and/or manufacturers are reluctant to give out information which may be considered sensitive.

In part due to the limited short-term information, and in part due to the fact that there exist many uncertain (global linked) variables, direct comparisons across propulsion technologies are difficult. This is also because answering the question of what is a comparable vehicle is complex.

On many of these aspects, however, improved and more extensive information is expected to become available in the coming years, and this study only seeks to act as a preliminary collection of information.

# 5 Experiences from E-bus operation in Norway

## 5.1 Introduction

In Norway, as of the year 2018, there were practical experiences from operating low emission buses in two cities, Stavanger and Oslo (and its surrounding area)[33]. Of the 30 zero-emission buses in operation in Norway in 2018, 14 were battery-electric minibuses, while there were 11 battery-electric city buses (both regular and articulated city buses). This gives a total of 25 E-buses in 2018 using battery-electric technology, and only five electric buses equipped with hydrogen/fuel cell technology[34]. The object of the present chapter is to present the experiences gained in these E-buses trial operations, focusing on Oslo and surrounding area.

## 5.2 The trials

Table 5.1 summarizes the previous, current and planned E-bus trials in Norway as of the year 2019. A technical summary of the E-bus trial characteristics in the Oslo region that began 2017/2018 (and whose operators formed the core of the interviews) is shown in Table 5.2[35]. By 2020 it is planned that there will be 416 E-buses in Oslo, Bergen, Trondheim, Drammen, Hamar, Haugesund, Bodø, and Ålesund (NRK 2019). Specifically in Oslo, it is planned that there will be an additional 41 E-buses in the year 2020 (23 City buses with Unibuss, and 18 Class 2 E-buses with Vy).

In Oslo, the pilot projects have been run on tenders for Ruter by operators Nobina, Unibuss, Norgesbuss and Taxus. In addition, Oslo Taxibuss also has trials with battery-electric minibuses. In general, all operators aim to deliver the same transport capabilities as with ICE-buses, with scheduled buses typically operated between 05:00/06:00-00:00. For the city buses, this leaves 4-6 hours for depot charging after morning peak time if they should be fully comparable with ICE. Minibuses are typically only operated in morning and evening periods, with good opportunities for charging during the day.

[33] In addition, there are seven trolley buses in operation in Bergen, but these are less relevant in the context of the MoZEES project since they draw power from overhead wires. These include one regular-size city bus from 1957, and six articulated trolley buses from 2003.

[34] Ruter operates five hybrid A350 fuel cell Van Hool city buses around Oslo (170 kW, 13.16 m length). For consistency, these are not further discussed in this chapter.

[35] Trials are listed in the table according to size order, with subsequent analysis of operators given in a randomized order for anonymity.

*Table 5.1: Overview of current electric bus trials in Norway (as of 2019). Year given is the starting year for the trial.*

| Year | Location | Authority | Operator | Bus type | Manufacturer | Number |
|---|---|---|---|---|---|---|
| 2015 | Stavanger | Kolumbus | Boreal (now Norgesbuss) | City | Ebusco | 2 |
| 2017 | Stavanger | Kolumbus | Boreal | City | Ebusco | 3 |
| 2017 | Lillestrøm/Jessheim | Ruter | Taxus | Mini | Iveco | 10 |
| 2017/2018 | Oslo | Ruter | Nobina | Articulated | BYD | 2 |
| | | | Norgesbuss | City | Solaris | 2 |
| | | | Unibuss | City | Solaris | 2 |
| 2018 | Oslo | | Oslo Taxibuss | Mini | Iveco | 4 |
| 2019 | Trondheim | AtB | Tide | City | Volvo | 28 |
| | | | Tide | City | Heuliez | 11 |
| 2019 | Lillehammer | Opplandstrafikk | Unibuss | City | Volvo | 2 |
| 2019 | Drammen | Brakar | Nettbuss | City | Volvo | 6 |
| 2019 | Oslo and surrounding area | Ruter | Nobina | Articulated | BYD | 42 |
| | | | Unibuss | Articulated | VDL Citeas | 30 |
| | | | Unibuss | 12m | VDL Citeas | 10 |
| | | | Norgesbuss | City | Volvo | 27 |

*Table 5.2: Electric bus (E-bus) trials beginning 2017/2018 in the Oslo region, that interviews were based on. Trials (columns) listed in the table are ordered after vehicle length, with subsequent analysis of operators given in a randomized order for anonymity. Source: Autosys (NPRA, 2018) and interviews with the operators. *Based on average driving distance of a corresponding ICE-bus. **Based on planned operation hours/average speed. ***Twincharger. ****Charger use was planned at the time of the interview.*

| | Oslo Taxibuss | Taxus | Norgesbuss | Unibuss | Nobina |
|---|---|---|---|---|---|
| Type of bus | Mini bus | Mini bus | City bus | City bus | Articulated bus |
| Manufacturer | Iveco | Iveco | Solaris | Solaris | BYD |
| Model | El-bus | El-bus | Urbino 12 Electric | Urbino 12 Electric | El-bus |
| Expected driving range (km/y) | - | 12-13 000 | 74 000-87 000** | 60 000 | 110 000* |
| Range on full charge (km) | 150 | 160 | 240 | 45-50 | 180 |
| Number tested | 4 | 10 | 2 | 2 | 2 |
| Registration year | 2018 | 2017 | 2017 | 2017 | 2017/2018 |
| Length (m) | - | 7.13-7.33 | 12 | 12 | 18 |
| Battery technology | Sodium-nickel chloride ($Na\text{-}NiCl_2$) | Sodium-nickel chloride ($Na\text{-}NiCl_2$) | Lithium-titanate (LTO) | Lithium-titanate (LTO) | Lithium-iron phosphate (LFP) |
| Battery capacity (kWh) | 82 | 90 | 127 | 75 | 300 |
| Depot charging (kW) | 22 | 11 | 80*** (250****) | 80*** | 80*** (300****) |
| Opportunity charging (kW) | | | 400 | 300 | |
| Charge time (hours) | 8 (over night) | 4 (day time) | 1/0.1 (slow/fast-charging) | 8/0.1 (slow/fast charging) | 3.5 |

## 5.3 Procurement process

It was generally the operator management teams that made decisions for testing battery-electric technology, in response to public tenders run by transport authorities. These tender periods can be between e.g. 5-7 years. In Oslo, the city buses are part of a seven year trial with Ruter. The trials were intended to be part of existing bus routes (and tender periods), thus a change contract was negotiated. There was no financial risk for the companies, since Ruter covered investment costs and loss in transportation efficiency. The electric minibuses in Romerike were acquired by Taxus AS in connection with a Ruter call for tenders (five years with an optional year extension). Two minibus companies (Nedre Romerike Minibuss AS and Lillestrøm Minibuss AS) are subcontractors. Additional costs for E-buses are partly reflected in a higher hourly rate that Ruter pays for bus operation. Efficient use of the E-buses (and their drivers) is the bus operators' responsibility.

For the Oslo trials, terms were equal for all operators, but operators were free to decide which solutions to test. Technology was tailored by operators to the required topography and operation conditions, and risk and cost benefit analyses were carried out. Drivers were in some cases also involved in the process, e.g. for decisions regarding technical specifications of the buses, and for factory visits where buses were reviewed.

Several E-bus manufacturers were available for city bus operators to choose from. One operator stated they initially discussed with 5-6 manufacturers, where price and quality were crucial for the choice. However, this wide choice was not available for all types of buses, especially if it was preferred to manufacture from scratch around the battery to achieve the best possible battery capacity. Purchasing internationally required closer follow-up at the start, and required type approval for Norwegian traffic. A limited selection was also encountered for minibuses. Electric minibuses were ordered from Iveco, which at the time was the only available provider of electric minibuses that were suitable for use. One explanation for this relatively limited selection of suppliers is that Norway is one of only a few countries to use 17 seater minibuses with ~8 m length.

Operators could collaborate on charging infrastructure at end stations, but the one who established the infrastructure had preferential rights. Access was regulated in the form of agreements, which seemingly works well. In addition, operators have to cooperate with the municipality for land access.

## 5.4 Battery and charger technology

Batteries that were chosen for the E-bus trials were dimensioned based on the route and charging solutions required. Resulting battery capacity utilized by the bus companies ranged between 75 kWh and 300 kWh, with a corresponding range (on full charge) between 45-240 km, given that cabin heating in the winter season is provided by a fuel fired heater system. A summary of the selected battery capacity, associated E-bus range on full charge, and charger solution chosen by the bus operators is shown in Figure 5.1.

The battery technology itself varied, depending on route and operation. Two operators chose lithium-titanate (LTO) batteries, of which 85 % is usable. The advantage with LTO is that it can be rapidly charged (up to 400 kW) and has high efficiency. It can also tolerate more charging cycles than other batteries (10 000 versus 3 000, according to the supplier). For new buses, one operator will also trial lithium nickel manganese cobalt oxide (NMC) batteries, which although can only be charged at maximum 250 kW, have lower costs.

Other buses in the current trials are equipped with sodium ($Na\text{-}NiCl_2$) batteries, with 90 kWh and 82 kWh total capacity per vehicle, respectively. An advantage of this choice is that the operating temperature is 270-320 °C, giving little difference in summer and winter performance of the battery itself. Another operator chose 300 kWh lithium-iron phosphate (LFP) batteries.

Regarding charging solutions chosen, due to challenges with establishing fast chargers in Oslo's city center, most operators charge at the depot, using 11/22 kW or 80 kW fast chargers. Several operators either have or plan to have fast-charging points at end stations also, but one operator rarely uses theirs due to bus-line operational issues. Pantograph charging with the arm raising up from the bus (rather than down) is popular since it is thought to minimize wear.

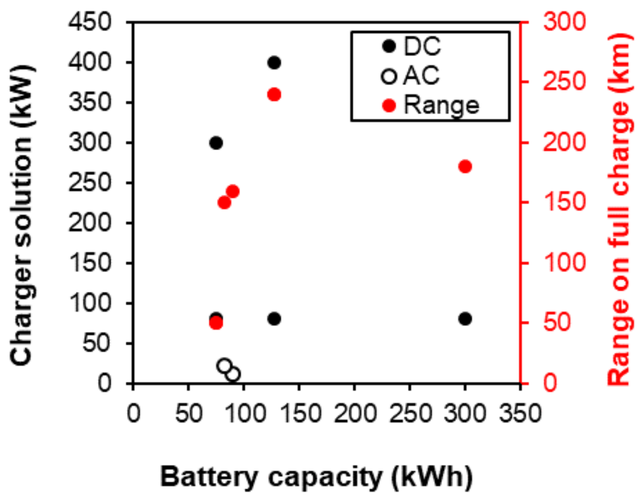



*Figure 5.1: Summary of the battery capacity (kWh) and relating charging solution (AC or DC, kW) used by the E-bus operator. The range on full charge is also shown (red).*

## 5.5 Experience from operation

Table 5.3 summarizes the reported user experiences associated with the vehicles for a range of parameters. Subsequently, each parameter indicated in the table is further described in the sections below.

*Table 5.3: Negative (red), positive (green), neutral (yellow) and mixed experiences (orange) associated with the E-bus trials in Oslo. No color means that no information was obtained in the interview.*

| | Operator 1 | Operator 2 | Operator 3 | Operator 4 | Operator 5 |
|---|---|---|---|---|---|
| Design (5.5.1) | | | | | |
| Owners/drivers/passengers (5.5.2) | | | | | |
| Energy use (5.5.3) | | | | | |
| Range (5.5.4) | | | | | |
| Vehicle performance (5.5.5) | | | | | |
| Charging performance (5.5.6) | | | | | |

### 5.5.1 Design

The general design of the buses used has not been problematic. Nonetheless, for one city bus operator, the added height of the E-bus compared to ICE vehicles caused a specific issue on a line due to low underpasses. Although the E-bus has equipment installed to lower it - via a geofencing system when passing the bridge - permission to drive under this bridge has not been gained. Since the E-bus that experienced this problem was the lowest among the available choices, this highlights a general design issue with the E-buses due to rooftop air conditioning/climatization units and (with the exception of the minibuses) the battery placement. In addition, one street-side upcharge fast-charging station (a fast charge station with pantograph that goes up to the charging cap) used by this bus had to be lowered to less than the maximum height for road-traffic. Resultantly, it has been hit by passing vehicles, resulting in break-down periods and repair costs.

Regarding vehicle capacity, whilst one operator reports a small reduction (two seats) in passenger capacity compared to a regular ICE bus, another states that the capacity is identical for E-buses and buses with ICE. However, more buses are still needed for the same amount of passenger transport on heavy and frequented routes, due to the added time for charging the buses during the day.

It was also noted that (historically) a challenge for regional E-bus operation is access to 15 m E-buses with three axles. This is primarily a Nordic bus size, with therefore low demand in the wider European region. Nevertheless, the situation is changing, with for example operator Vy planning to use Class-2 buses in Oslo, Hamar and Haugesund from 2020 (Unibuss 2019). In addition, another operator noted that little emphasis is currently placed on bus body design.

### 5.5.2 Owners/drivers/passengers

It was widely commented that the E-buses contributed to a better environment for the drivers and for the passengers, and generally, feedback from drivers regarding driving the buses was good. For the minibuses, drivers specifically comment that they are easy to drive and flexible in traffic. The biggest challenge is stress from range anxiety, and some issues with low power on steep gradients (in particular for the minibuses). Some drivers do not cope well with these issues due to concerns for the passengers and/or concern for other road users, and when the driving range indicated is less than required to get to the endstop, may forget that E-buses additionally charge from regenerative breaking en-route. Due to this, not all drivers want to drive E-buses. Additionally, there are challenges with bus types that were previously often parked at the drivers home overnight, while they now have to be parked at the depot for charging purposes.

In a regular operation based on ICE-buses, two drivers are usually dedicated per bus and each driver works around 154 hours per month. Since E-buses require charging, driver utilization is more complicated, and it was discovered that a higher number of drivers had to be used. To optimize E-bus use, there is therefore a need to optimize the routes to allow for a better utilization of the drivers. In addition, extra training is required in order to drive the E-buses, requiring time and money. There are also new routines that are different from a regular ICE bus (particularly charging routines, which must be followed rigorously to allow for optimal bus utilization the following day), and it is not just the new drivers, but the entire organizations that have to get used to the new technology.

Comments were also received from several operators that E-bus interest has been high from passengers, the general public, and the press. It was noted that passengers generally experience improved comfort compared to when using ICE-buses, associated with the reduced noise and vibrations. However, one of the operators reported that there is relatively high noise in the buses (measured at >70 decibels). This is a whining sound from the electric motor which is attempted to be rectified by better insulation of the engine. One other operator reported that other noises, e.g. connected with ventilation systems, are more noticeable. Similarly, another operator had hoped the buses would be even more quiet, and also highlighted the fan noise (ventilation), which they reported is higher than in ICE-buses.

### 5.5.3 Energy use

At 0.6-1.5 kWh/km, E-bus energy use is significantly lower than for comparable ICE-buses (Figure 5.2). It is challenging to compare these values to other studies, but Bloomberg New Energy Finance (2018) estimates that a 110 kWh E-bus uses 0.8 kWh/km. However, energy for heating in winter and cooling in summer may not be sourced from the battery without reducing the driving range. In practice, this means that energy for heating/cooling must come in addition, and since unlike for ICE-buses, no heat comes up through the bus floor, and little heat is produced in the drive system or the battery during operation, this energy requirement may be significant. Around 50 % of the energy for operating an E-bus is related to heating and ventilation, and one operator estimated this additional energy requirement to lie around 1.2 kWh/km. To sort this, operators often install additional burners for interior heating. As these burners are powered by biodiesel (HVO), heating can be classified as carbon neutral (but not as zero-emission). In future, further E-buses from at least one operator will have larger batteries to allow for heating without an additional power source. More frequent charging can also enable electricity to be used for heating and cooling, but the risk is that added charging time requires more buses to run a route and therefore induces higher costs. Other factors that heavily influence energy consumption of E-buses are the topography, road conditions, and characteristics of the route.

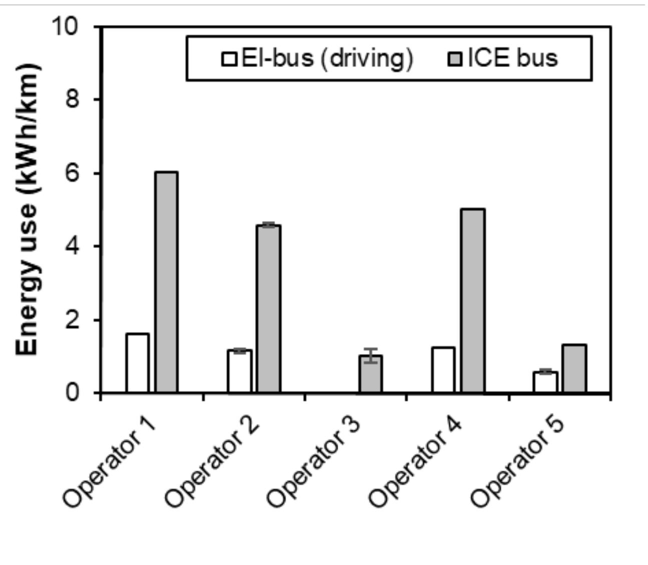



*Figure 5.2: Average energy use reported by the operators per km, for E-buses and buses with ICE. Note: energy for heating the E-buses is additional to that shown on the figure. Energy use for ICE-buses was calculated from the average fuel consumption. Where relevant, error bars show the range reported by operators.*

### 5.5.4 Range/route

E-buses in the pilots were intended to service existing lines, but have primarily been used in peak (rush) hours, because of various practical challenges related to e.g. charging infrastructure and design. Due to this, route arrangements have been optimized, and driving is normally controlled within good margins of distance and range. One operator has 10 suitable routes for electrical operation, and similarly, the city buses have set routes around the city center. According to one operator, 40 E-buses out of a fleet of 200 can be assimilated, and bus operation can be planned so that no additional buses are needed, as long as E-buses are put on carefully selected routes.

Range is also of concern for the operators. Although one operator stated that the vehicle delivers the range that is promised (even though it was the most concerning factor at the start), others comment that the theoretical range varies from the actual range, which means that they have to use the latter one for route planning. This may be due to the parasitic battery energy use from lights and doors, varying route topography, or seasonal variation. Although winter operation was not noted to significantly affect the driving range by one operator, another commented that temperature affected the battery and driving range to a small degree. Both these operators use HVO-based heaters for interior heating.

### 5.5.5 Vehicle performance

When working as they should, feedback was that E-buses have good performance, although some were reported as lacking power for steep gradients. One operator reported that the manufacturer adjusted the engine programming to try to improve power, but this has not yet significantly improved traction.

However, driving performance aside, the E-buses have been driven less than expected due to a suite of technical problems ranging from minor to major, requiring workshop time (Figure 5.3). This was reported as particularly problematic by one operator, since the workshop cannot prioritize extra time to the E-buses.

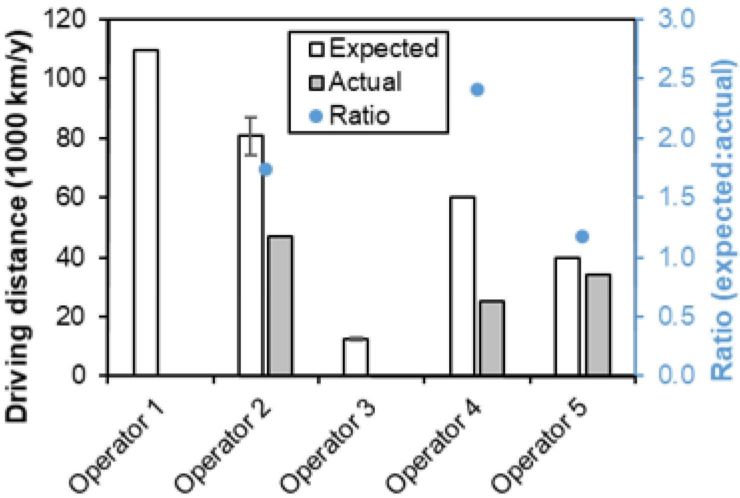



*Figure 5.3: Expected and actual annual driving distances for the E-buses at the time of the interviews (left axis), and the ratio between these parameters (blue, right axis). Note: where relevant, error bars show the range reported by operators.*

Key reasons for reduced operating time are charging problems, reduced range due to winter operation, and a number of issues not associated with propulsion (such as door opening closing, warning lights, etc.). Major technical problems were reported by one operator, resulting in multiple fleet battery changes in the first year. Others also report part changes due to e.g. major faults in the battery module or electric motor. In contrast, another operator only experienced 'teething' problems, which they believe will be sorted out in future production series. Whilst the technical problems have resulted in unforeseen maintenance, it was noted that ordinary services are more straightforward due to there being less brake-wear due to the regenerative braking feature.

The technical issues, as well as other factors related to the technology changes, have led to a decreased driving distance compared to what was originally expected. In the case of one operator, an E-bus had only been driven 5 000 km out of the 60 000 km annual target at the time of the interview (although it was expected it would still reach 25 000 km by the end of the year). For another operator, the E-buses produced half of what they should in the first month.

In general, it is necessary for operators to have access to extra buses regardless of propulsion system, due to extra maintenance needs resulting from the extensive use (and resulting time out of service). This also leads to a need to use reserve ICE buses when E-buses need maintenance. Numbers of these are difficult to estimate, but one operator stated that an extra 10 % buses are needed. However, for E-buses tested in small numbers, reserve E-buses are often not directly available and ICE buses will be the alternative. In addition, feedback was received that for E-buses, an additional 5-10 % are needed in a fleet compared to ICE due to downtime during charging.

### 5.5.6 Charging performance

Several practical (as well as technical) charging issues were reported. A major problem was highlighted relating to difficulties in establishing charging infrastructure in central dense city zones. Reasons for this are 1) the extensive planning and permitting required and 2) the large land-area required (especially for articulated buses). This has resulted in the operators using the E-buses during peak hours and depot-charging them at mid-day, setting limits on which routes can be electrified since there should not be too large a distance to the depot.

Regarding technical issues, one operator commented that the need for a 'balance charger', to slow charge the batteries in order to balance the state of charge of each cell of the battery system, has created operational issues. Other issues reported by operators include problems resulting from a need to transform from 230 V to 400 V 3-phase, and that the power available to them (from the grid) has not been strong enough to charge at double power (22 kW instead of 11 kW). In addition, one operator reported voltage drops in the service battery that cause the bus to stop charging, whilst another noted that power outages, that could result in stranded buses, have not yet posed a problem.

## 5.6 Costs

TCO costs associated with the use of E-buses can be broken down into the following components: 1) vehicle investments, 2) charging infrastructure investments, 3) operating costs (energy) and 4) maintenance costs. In this section, a discussion is presented for each of these parameters based on the operator feedback.

The purchase price of an E-bus was quoted by operators as around twice that of a similar bus with ICE (Figure 5.4) as also revealed from previous data (Hagman et al. 2017, Amundsen et al. 2018). Nevertheless, it was noted that the willingness to pay is often higher for buses than for other types of vehicles, such as trucks. The battery pack makes up a significant part of the cost, with some operators citing it as around half the total vehicle cost. In addition, the larger the battery pack, the greater the likely price (Figure 5.5a) and cost difference vs. an ICE-bus. The investment lifetime was cited by operators as between 5-12 years, with variation due to technology, lengths of bus operation contracts, and operational changes (e.g. battery lifetime can be increased by minimizing fast charging). It was also noted by one operator that the same depreciation period is used for E- and ICE-buses.

Charging infrastructure purchase price is dependent on the solution chosen (Figure 5.5b). Depot charging can be optimal for trial operation, whilst fast-charging may be more economical where there are a higher number of vehicles used. Fast chargers mounted in depots were cited by operators as costing ~0.4-1.4 MNOK respectively (fully mounted). If using pantographs, costs increase by another ~0.2 MNOK (per bus).

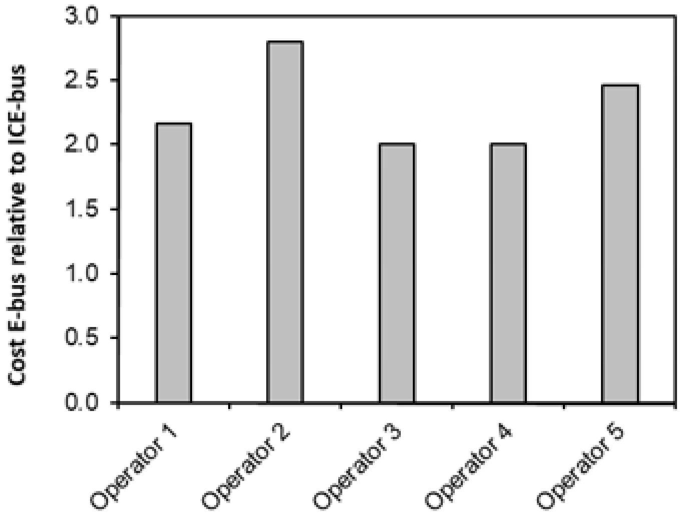



*Figure 5.4: A summary of the investment E-bus costs relative to similar ICE-bus investment costs, as reported by the E-bus operators interviewed.*

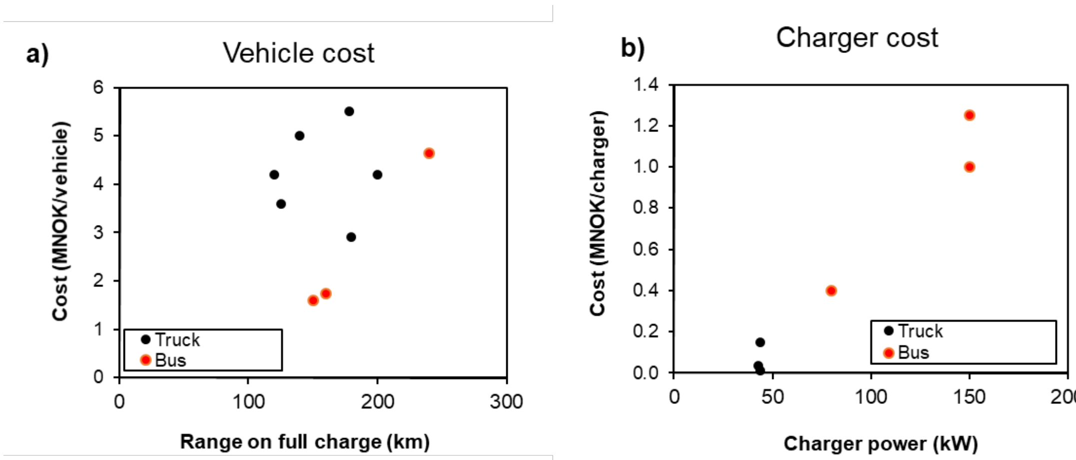



*Figure 5.5: A summary of the investment vehicle (a) and charger (b) costs reported by the operators interviewed. For comparison (and due to the limited data), data gathered for E-trucks, as presented in Chapter 6 is also shown.*

Although the purchase price per vehicle is higher, operating costs are significantly lower for E-buses. Important reasons for this are both that energy consumption is reduced by around 75 % for electric propulsion versus ICE, and that electricity cost (per kWh) may be less than for e.g. diesel fuel. However, one operator added that additional indirect costs have been incurred by them due to the fact that a large reserve of older ICE buses (which would otherwise have been sold) had to be kept as a back-up for periods of E-bus downtime.

Maintenance costs vary depending on whether service agreements are in place, or whether own personnel are used for service and repair. E-buses from international manufacturers are unlikely to have service agreements in place in Norway, meaning that own personnel may be used for service (for everything except for the battery). Regarding maintenance costs, one operator commented that ordinary services are cheaper than for regular ICE-buses, due to the lack of brake-wear and oil changes; although it was too early to know specifically, they believed the costs are around 20-30 % lower than for a similar bus with ICE engine. However, others reflected that although they originally thought that maintenance costs would be lower for E-buses, in practice they are similar to ICE buses, for instance factoring in the risk of battery replacement costs. Due to their considerable cost, the question of whether batteries have to be replaced during bus lifetime is of utmost importance for operators, but little information is available for risk assessment.

## 5.7 Future outlook and discussion

In summary, E-buses are ideally suited for operation in city centers or other urban areas where zero-emission operation is required. This has led to extensive plans being made by city transport authorities across Norway. For example, in Oslo, the transport authority Ruter plans to have transitioned to a fossil-free bus fleet by 2020, while by 2025, 60 % of buses should be battery-electric (Ruter 2017). Buses can be phased in through new tenders. In order to speed up the phase-in, public transport companies can introduce change orders to existing contracts; this was done in the ongoing trial in Oslo and will also be used in the extended trial commencing this year.

Efficient operating schemes for E-buses are even more important than for ICE-buses. This is because E-buses have to be recharged during regular working days, which can be longer than 18 hours. Unless routes and charging times are carefully optimized, this implies that more buses are needed to achieve the same passenger transport volume, than would have been the case with ICE-buses. However, there are major issues with installing streetside charging infrastructure within urban areas. Although increased E-bus operation is a political objective, the municipal administration does not yet facilitate the establishment of stations for fast-charging. Unless these issues are resolved, E-buses will be most appropriate where there is a short distance to the bus depot. These challenges are not to be neglected; bus lines may require two or three buses to fast-charge simultaneously, potentially requiring large amounts of space in dense areas.

The greatest challenge relating to E-buses is their high upfront cost compared to ICE-buses. Although operation-related and maintenance costs are comparable (or lower), TCO is currently higher for E-buses than for ICE-buses. Nevertheless, with upcoming larger scale production of E-buses and a projected decrease in investment costs, TCO is likely to become competitive with other technology in the coming years.

In summary, bus operators are in general optimistic when considering the future of electric buses. Nevertheless, many agree that a mixture of different propulsion technologies will be optimal for buses in the foreseeable future. Whilst E-buses are ideal to use in city center areas, hydrogen (fuel cell) vehicles may be more suitable where a longer range is important, highlighting a complementarity between technologies. Crucially, the higher number of E-buses in a fleet, the more careful planning is required to adapt.

# 6 Experiences from E-truck operation in Norway

## 6.1 Introduction

Whilst series production of electric buses and small vans started some years ago, the first E-truck in Norway became operative as late as September 2016. Correspondingly, the market for heavy vans and trucks is currently at an early (pilot) stage. Of the 13 zero-emission trucks in use in Norway by the end of the year 2018, all utilized battery-electric technology[36]. These vehicles were mostly rebuilt to battery-electric powertrains from standard diesel trucks, although several manufacturers have announced that they will start series production of electric trucks from 2020. The object of the present chapter is to present the experiences gained in these E-truck trial operations.

## 6.2 The trials

Table 6.1 summarizes current and planned E-truck trials in Norway. A technical summary of the early E-truck trial characteristics, whose operators formed the core of the interviews, is shown in Table 6.2[37]. In addition to the truck operators, Posten (and its subsidiary, Bring) were interviewed for comparison. They are primarily light duty battery-electric vehicle operators, with a mixed fleet. No battery-electric HDVs are regularly operated by these companies, although Bring had tested a battery-electric heavy van for 14 days at the time of the interview and Posten has pre-ordered some tractor units from Tesla.

The first E-truck trials were operated in South Norway, and the E-trucks were used for food distribution, household and business refuse collection, and recycling services. The E-trucks operated vary in power and total weight, and were mostly registered in 2018. Most operators wanted to use their E-trucks in the same service as regular vehicles. All trucks operate five days a week and have an expected annual mileage ranging from 18 000 to 120 000 km, divided into about 250 business days per year, and 1 to 3 working shifts per day. Nearly all the operators interviewed said that they want to be among the first actors to test new technology in trucks and be able to highlight that their enterprise has a positive environmental profile.

[36] Asko have since ordered four hydrogen-electric trucks. For consistency, these are not described further in this chapter.

[37] Trials are listed in the table according to size order, with subsequent analysis of operators given in a randomized order for anonymity.

*Table 6.1: Overview of current E-truck trials in Norway (as of 2019). Year given is the starting year for the trial.*

| Reg. Year | Location | Operator | Truck type | Manufacturer | Number |
|---|---|---|---|---|---|
| 2016 | Oslo | Asko | Truck (freight) | MAN/Emoss | 1 |
| 2018<br>2019 | Sarpsborg<br>Kristiansand | Norsk Gjenvinning | Truck (waste) | Dennis Eagle/PVI (Renault)<br>DAF/Emoss | 2<br>3 |
| 2018 | Oslo-region | Stena Recycling | Tractor (recycling) | MAN/Emoss/Allison | 2 |
| 2018 | Oslo | Nor Tekstil | Heavy van | Iveco | 5 |
| 2018 | Lier | Cater | Truck (freight) | Iveco | 1 |
| 2018<br>2019 | Bergen | BIR | Truck (waste)<br>Truck (waste) | DAF/Emoss/ Geesinknorba<br>DAF/Emoss/ Geesinknorba | 1<br>3 |
| 2019 | Stavanger | Renovasjonen | Truck (waste) | DAF/Emoss/ Geesinknorba | 1 |
| 2018<br>2019 | Oslo | Ragn Sells | Truck (waste)<br>Tractor | MAN/Emoss/Allison<br>MAN/Emoss/Allison | 1<br>1 |

*Table 6.2. E-truck vehicle trials beginning in 2016-2019 in Norway, that interviews were based on. Trials (columns) listed in the table are ordered after total vehicle weight, with subsequent analysis of operators given in a randomized order for anonymity. Source: Autosys (NPRA, 2018) and interviews with the operators. *Average value for the fleet, with large variation. **For a similar (existing) ICE vehicle in the fleet. ***At the time of the interview, the operator did not yet have their vehicles in regular operation, but had experience from a test-vehicle. ****Actual km/y driven at time of interview.*

| | Nor Tekstil | BIR | Renovasjonen | ASKO | Norsk Gjenvinning | Ragn-Sells | Stena Recycling*** |
|---|---|---|---|---|---|---|---|
| Sector | Manufacturing | Waste collection | Waste collection | Freight transport | Waste collection | Waste collection | Recycling |
| Vehicle type | Heavy van | Truck (waste) | Truck (waste) | Truck (freight) | Truck (waste) | Truck (waste) | Tractor (recycling) |
| Manufacturer | Iveco | DAF/Emoss/ Geesinknorba | DAF/Emoss/ Geesinknorba | MAN/Emoss | Dennis Eagle/PVI (Renault) | MAN/Emoss/ Allison | MAN/ Emoss/ Allison |
| Expected driving range (km/y) | 30 000 | 20-26 000** | 16 800** | 50 000* | 18 000**** | 80 000** | 120-130 000 |
| Range on full charge (km) | 160 | 120-130 | 100-140 | 180 | 140 | 200 | 178 |
| Number of vehicles tested | 5 | 1 | 1 | 1 | 2 | 1(+1) | 2 |
| Registration year | 2018 | 2018 | 2018 | 2016 | 2018 | 2018(2019) | 2018 |
| Total weight (t) | 5.6 | 12.0 | 12.0 | 18.6 | 26.8 | 28.0 (50.0) | 40.0-45.0 |
| Payload (t) | 2.6 | 3.5 | 3.5 | 5.5 | 9.7 | 18-19 | 15-20 |
| Length (m) | 7.2 | 7.0 | 7.0 | 9.0 | 9.5 | 7.8 | 7.4 |
| Battery technology | Sodium nickel chloride (Na-Ni$Cl_2$) | Lithium-ion (LIB) | Lithium-ion (LIB) | Lithium-ion (LIB) | Lithium-ion (LIB) | | Lithium-ion (LIB) |
| Battery capacity (kWh) | 80 | 120 | 130 | 240 | 240 | 200(300) | 300 |
| Depot charging (kW) | 22 | 22/44 | 44 | 2 x 43 | 44 | 44 | 44 |
| Opportunity charging (kW) | | | | | | 150 | 2 x 150 |
| Charge time (hours) to 80 % | 8 | 2-8 | 3.5 | 5 | 8 | 4.5 (to full charge) | 4-6/0.3 for slow charging/fast charging |

## 6.3 Procurement process

Although the standard operating system for most transport assignments is based on private assignments, many operators who have invested in E-trucks did so after applying for assignments in public tenders. This requires waiting for the correct opportunity where the environment is weighted higher than price. Requirements for new vehicles are often set in the tender, such that all trucks must be replaced at the start of a new contract. Since tender competitions are usually announced only a year before the start of an agreement, initial risks (particularly when trialing new technology) are therefore related to getting vehicles delivered on time.

There is also financial support for testing zero-emission truck technology available from the authorities. Part-financing through ENOVA was the solution taken by operators whose operating system is based on private assignments for companies, or to trial new technology under an ongoing contract (tender period). ENOVA is financed by an energy fund and can provide support for 40-50 % of *additional* costs of the trucks compared to a diesel truck, in addition to the full costs of a charging station, depending on the size of the business applicant. However, this support must be a trigger for the investment, and as a rule, no support is given to vehicles that are purchased due to demands in a call for tenders. Other financing received was derived from the Norwegian Environment Agency's municipality support. Comments were received that there is much to be gained from a more efficient application process around the support schemes, and that it is difficult for operators to orientate themselves in these bureaucratic systems.

The leader groups led decision-making processes to engage in zero-emission technology. This was then communicated to the departments, who received the responsibility to investigate which solutions were possible and come up with possible solutions. In some cases, pilots were run and evaluated. Before the trucks were put in operation, drivers generally participated in courses with the suppliers.

It was not difficult for the operators to find potential suppliers, but according to one operator, the challenge was that these suppliers were outside Norway, without agents in the Norwegian market. This situation contrasts with the electric LDV operators interviewed, who commented that they have a framework agreement with all major vehicle suppliers.

## 6.4 Battery and charger technology

Battery choices by the operators were based on requirements set by the operating purpose of the vehicles. Resulting battery capacity utilised by the truck operators ranged between 80 kWh and 300 kWh, with most vehicles having a battery capacity at the higher end of this range. This corresponded to ranges (on full charge) of between 100-200 km, and contrasted to the LDV operators interviewed, where the battery size was smaller, at 56 kWh. A summary of the selected battery capacity, associated E-truck range on full charge, and charger solution chosen by the truck operators is shown in Figure 6.1.

The battery technology chosen by all truck operators was based on lithium-ion technology. The limited types of battery in use may be due to the limited maturity of the market.

Regarding charging technology and solutions chosen, due to challenges with establishing chargers in urban areas, most operators charge at the depot using 22/44 kW industry plugs with charger in the vehicles. Nevertheless, two operators interviewed utilized 150 kW DC fast chargers at a plant or depot that is at the origin or destination at the route that the vehicle is operating. The LDV operators interviewed utilized 16 A (AC) depot charging.

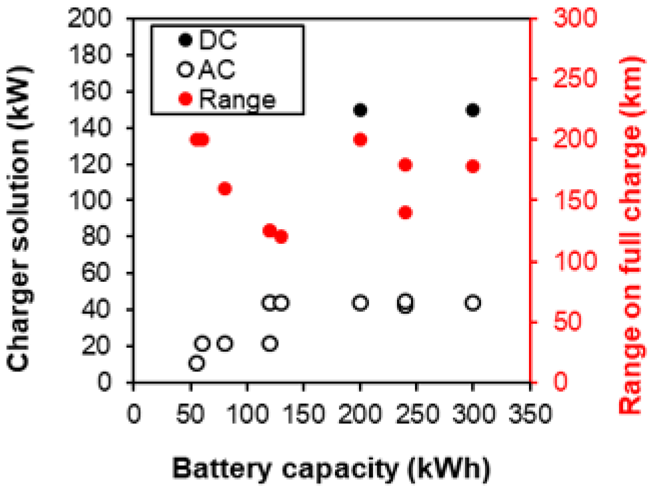



*Figure 6.1: Summary of the battery capacity (kWh) and relating charging solution (AC or DC, kW) used by the E-truck operators. The range on full charge is also shown (red).*

## 6.5 Experience from operation

Table 6.3 summarizes the reported experiences associated with the vehicles for a range of parameters. Subsequently, each parameter indicated in the table is further described in the sections below. LDV operators are included for comparison.

*Table 6.3. Negative (red), positive (green), neutral (yellow) and mixed experiences (orange) associated with the electric heavy-duty vehicle trials in Norway. Whilst representing a mixed fleet (light duty vehicles), other operators interviewed have been included in the table for comparison.*

| | Operator 1 | Operator 2 | Operator 3 | Operator 4 | Operator 5 | Operator 6 | Operator 7 | LDV Operator 1 | LDV Operator 2 |
|---|---|---|---|---|---|---|---|---|---|
| Design (5.5.1) | red | yellow | | yellow | | | | yellow | |
| Owners/drivers/passengers (5.5.2) | orange | green | green | orange | orange | green | green | | |
| Energy use (5.5.3) | green | green | | green | | | | | |
| Range (5.5.4) | yellow | yellow | yellow | red | | | | red | orange |
| Vehicle performance (5.5.5) | orange | orange | green | red | green | green | red | green | green |
| Charging performance (5.5.6) | red | red | green | yellow | | | | orange | orange |

### 6.5.1 Design

Although the design of the E-trucks did not convey major issues, some user comments were made about a lack of focus on (reducing) the specific vehicle weight in the bodywork (and associated weight increases due to battery, cooling aggregate, and insulation). Other comments included the limited availability of different vehicle size alternatives, and that although there are currently opportunities for tailoring vehicles to customer needs, these opportunities may decline when suppliers start with series production. In addition, it was noted that it takes a long time between the initial launch of vehicles designed with new propulsion technology, and these vehicles effectively becoming available on the market.

In general, much of the design knowledge for E-trucks has been transferred from buses, with the most important difference being battery dimensioning due to different possibilities for opportunity charging[38]. This means that the trucks must carry more energy on board (ideally to cover one shift, or about 200 km per day for distribution). A failure in charging e.g. during the night becomes critical for truck operations the following day because of the long charging time.

### 6.5.2 Owners/drivers

Despite initial reservations, both managers and drivers were generally pleased with the trucks. Several operators, in particular for trucks in refuse collection services, commented that the trucks contribute to a good working environment, and when working properly, are pleasant, comfortable and fun to drive. Drivers have been generally happy, and one operator even noted that there is a competition between the firm's drivers to operate the E-trucks. However, the main challenge has been to trust the technology and to overcome range anxiety. Some operators chose to select a few dedicated drivers, to create a sense of 'ownership' of the vehicles and for efficiency, since extra driver training was required (e.g. regarding brake use). Some specific issues for the managers/owners included the fact that one electric vehicle truck model required a different driving license (for HDV) than with the corresponding ICE vehicle, making it more challenging and expensive to find the right drivers. In addition, another noted that their insurance premium doubled compared to their premium on a corresponding ICE vehicle.

In general, the E-trucks are reported to produce less noise and vibrations than regular ICE vehicles, although in some cases, mechanical noise became more noticeable. Reduced noise/vibrations were received positively, both for the work environment of the drivers/refuse collectors, but also because operators recognized a potential for operation during times of day where noise restrictions preclude ICE operation (depending on regulation). However, one operator noted that their trucks were almost too quiet from a safety perspective, although the warning lights and implemented noises when reversing ensured that safety was maintained.

Several operators reported that public interest is high, and that this extends to both customers and media. One of the operators further commented that both they and their client felt a sense of pride and were happy with the chosen vehicle solution.

### 6.5.3 Energy use

The energy use of the E-trucks under real-life conditions (per km) proves significantly lower than for ICE vehicles (~1-1.5 kWh/km vs. ~3-8 kWh with ICE, based on diesel use)

[38] Buses can be charged at the end stop many times a day, while trucks must be recharged less frequently.

(Figure 6.2). This has been received positively by the operators, and the same goes for the ability to generate energy when decelerating. However, comments were also made relating to the fact that energy used for equipment such as waste compressors was sourced directly from the battery and could reduce driving ranges. Also for heating and cooling the cargo and driver's cabin, energy sourced from the battery had an impact on driving ranges. This can particularly be an issue when transporting freight that requires temperature control, and has in some cases been solved using an external HVO-based cooling aggregate. Issues were also reported due to the lack of soft start functions of cooling units, which makes the power load on the battery large when the cooler unit starts.

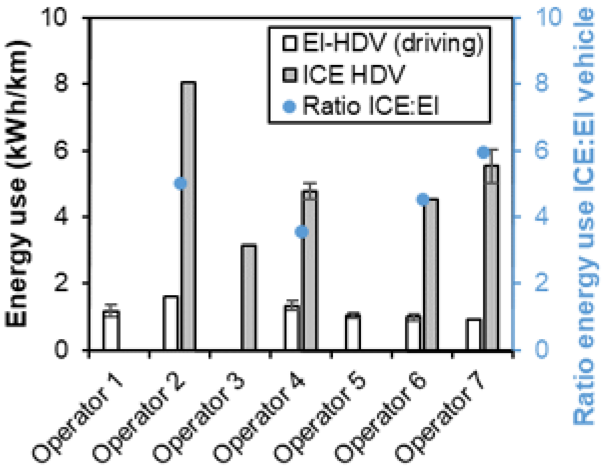



*Figure 6.2: Average energy use reported by the operators per km, for E-trucks and trucks with ICE and ratio energy use for ICE-trucks relative to E-trucks. Note: energy for heating/cooling the E-trucks is additional to that shown in the figure. Energy use for ICE-trucks was calculated from the average fuel consumption. Where relevant, error bars show the range reported by operators.*

As seen from Figure 6.2, ICE-trucks use 4-6 times more energy compared to E-trucks, making the ratio higher than the ratio between ICE-based and electric passenger cars. The highest energy ratio is related to the refuse collection trucks that have a lot of starts and stops. Such operation contributes to high diesel consumption; with electric operation, the trucks regenerate electricity and the electricity consumption is thus reduced.

### 6.5.4 Range/route

Both the vehicle depot locations and daily routes have proven critical in the vehicle trials, and comments were received that extensive route planning is required. Most of the battery-electric vehicles were originally intended to directly replace routes of other ICE vehicles, but in practice, this was not always feasible, particularly where the fleet has varying daily driving requirements. In effect, some vehicles were therefore put in operation in central areas, where topographical differences are small and they are deemed most useful (due to low noise and reduction of local emissions). Other operators used careful planning to optimize routes for charging during pick-up/delivery or breaks.

One operator noted that they avoided starting points at a large distance from the first customers, to avoid too long distances with full-loaded driving and consequent battery-drains. Comments also addressed that when driving patterns vary from day to day, electric vehicles are particularly vulnerable to longer assignments late in the day.

A number of operators further reported that driving ranges did not live up to their expectations; e.g. one operator reported that the range was half of that originally quoted by the manufacturer. Ranges used for planning thus had to be significantly adjusted downwards compared to what was specified by suppliers. Such issues were also reported for LDVs; assumed to be due to the number of stops *en route*, relatively low speed driving, cargo, climatic variations, and route topography.

Different operators also experienced large discrepancies in range between display readings and practice, both positively and negatively. Range differences between summer/winter have so far not been apparent, but there has been little experience with operation during cold days as of yet.

### 6.5.5 Vehicle performance

Experience with the technical/general performance of the trucks has been mixed. One operator reported major technical issues and a lot of downtime. In some cases, troubleshooting/diagnostics and actual repairs took a long time, in part because a service agent was not yet available in Norway. Figure 6.3 summarises the expected and actual driving distances for the E-trucks.

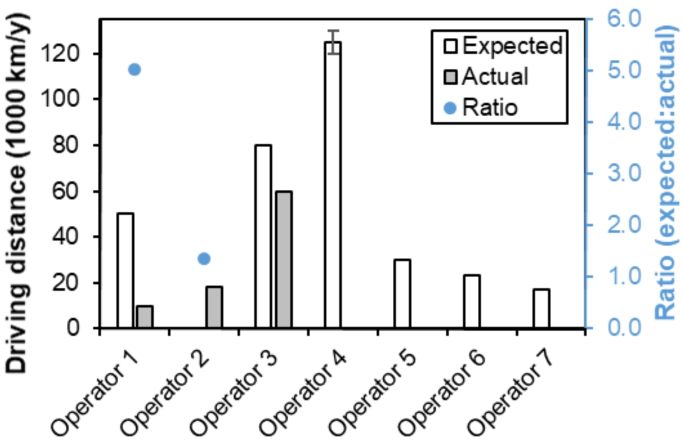



*Figure 6.3: Expected and actual driving distances for the E-trucks at the time of the interviews (left axis), and the ratio between these parameters (blue, right axis). Note: where relevant, error bars show the range reported by operators.*

Extensive technical issues were experienced by one E-truck operator as a result of major stability issues and water leaks. Similarly, another experienced major shutdowns due to circuit board failures and hydraulics challenges, although these were not explicitly linked to the electric motor. Nevertheless, for refuse collection trucks (and LDVs), operators were generally happy with technical performance, and most of the issues reported were relatively minor and attributed to the conversion from diesel to electric powertrains, and teething problems. Examples included warning lights that turned on unexpectedly and a vehicle that stopped several times after washing because of a component that did not withstand water.

Regarding general vehicle performance, noteworthy comments included mixed experiences with vehicle traction (good vs. insufficient power under challenging conditions), and challenges with engine power (on high gradients, this led to a few cases with a vehicle rolling backwards). For some operators, adjustments from the manufacturer improved the engine power and fixed these issues, allowing the vehicle to proceed up steeper gradients, but for another operator it led to a longer period out of service. Braking capacity posed a challenge when batteries were fully charged at the start of a trip from high terrain, and as such did not have capacity to receive regenerative braking current (this was solved by slightly undercharging the vehicle at the depot).

Most operators reported reduced freight capacity for the E-trucks compared to the equivalent ICE vehicles. Reasons given were significant battery weight and in some cases, battery position in the vehicle. In a few cases, reported capacity reductions were so significant that they were considered a bigger issue than range limitations, since some heavy goods types could not be transported and led to limitations in the operation of the vehicle. In other cases, slight capacity reductions were reported, and in one case, it was the volume, rather than the load weight that limited capacity based on current use. Several policy measures and proposals aim to counter capacity reduction challenges by increasing maximum authorized weights for zero-emission vehicles (e.g. European Parliament (2019)).

### 6.5.6 Charging performance

Some operators considered the availability and possibility of daytime charging and the number of stops on the route as the most restrictive factor. In addition, various (sometimes major) technical issues were also reported relating to charging problems and/or lack of experience. Examples include failures with the chargers, difficulties with distinguishing whether problems originate in the vehicle or charging point, and (previously unclear) charging restrictions during a 'run-in' period before putting the vehicle in operation. Some issues were also related to the cold Norwegian winter climate, when one of the vehicles sometimes failed to charge outdoors, necessitating indoor facilities. A number of other, more minor technical issues, were mostly resolved quickly.

For battery-electric LDVs, the operators interviewed mentioned challenging power peaks when charging many vehicles simultaneously. Challenges also occurred relating to the availability of grid power when building new terminals, and incentives for the development of charging infrastructure at rented locations. Some operators called for a form of central coordination for smarter charging for the business sector, because in the long term, when both E-buses and E-trucks become more common, there will be considerable power needs in the grid connected to areas with both bus depots and freight terminals and warehouses.

## 6.6 Costs

As with E-buses, costs associated with the use of E-trucks can be broken down into the following components: 1) vehicle investments, 2) charging infrastructure investments, 3) operating costs and 4) maintenance costs.

The interviews provided detailed information on different cost components, such as battery, chassis, energy, maintenance, chargers, and operation, which were an important input to the work performed in later chapters. One operator notes that early on it was accepted that E-trucks will cost more than ICE, in a start-up and testing phase. Interviews suggested that at current cost levels, battery-electric vehicles were between ~1.5-4x the price of corresponding ICE vehicles, depending on vehicle classes (Figure 6.4), and that for battery-electric vehicles to be chosen, environmental performance has to be emphasized actively (e.g. by including terms and conditions regarding environmental performance in public tenders). The relationship between driving range (on full charge) and total vehicle cost is shown in Figure 6.5a. The battery makes up a large part of total vehicle cost.

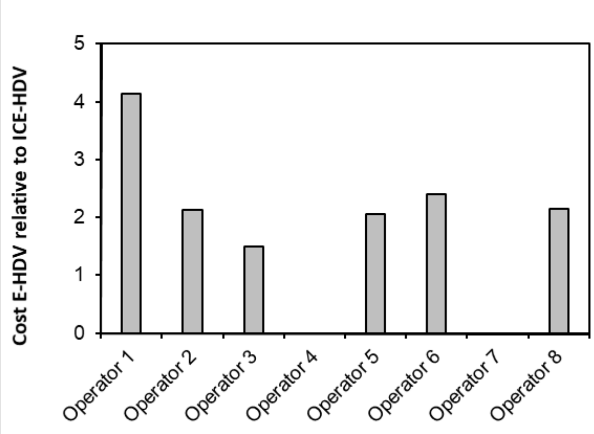



*Figure 6.4: A summary of the total E-truck and similar ICE-truck investment costs reported by the HDV operators. Note: where relevant, error bars show the range reported by operators.*

Operator expectations on the E-truck lifetimes vary, e.g. between 7-10 years. In some cases, this is reflected in how the vehicles are depreciated (either the same or slightly longer write-off periods than ICE trucks since there are uncertainties about the residual value for a rebuilt E-truck). For the battery-electric LDVs, the vehicles are often leased for periods of 4-5 years, since leasing a vehicle eliminates uncertainties about the vehicle residual value for transport operators.

The price of charging infrastructure is dependent on the charging solution selected. Depot charging can be optimal for trial operation, whilst fast-charging may be more economical in cases where a larger number of vehicles is used. Fast chargers (150 kW DC) were cited by operators as costing 1 MNOK, whilst a slow charger (AC) was quoted as costing 0.15 MNOK (or ~0.01 MNOK for a new industry plug at depot) (Figure 6.5b).

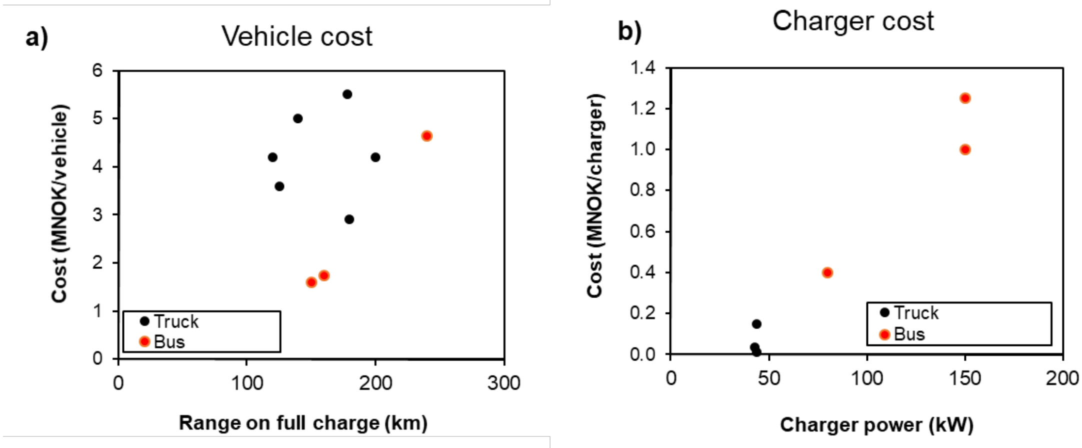



*Figure 6.5: A summary of the total vehicle costs and charger costs reported by the operators interviewed. For comparison (and due to the limited data), data gathered from all types of operators interviewed (as well as E-bus operators) is shown.*

The interviewed operators agree that battery-electric vehicles have significantly lower costs of operation than ICE-vehicles. This is particularly due to savings on energy costs due to higher engine efficiencies and reduced road toll expenses (although savings on energy costs are relatively lower compared to passenger cars because of VAT deductions on energy expenses). Maintenance costs, too, are found to be lower than for ICE vehicles, although estimates of savings vary between the operators (at between 10-70 % lower). Reasons for this are that electric motors have simpler constructions than diesel engines, and that brakes wear less than on corresponding ICE-vehicles, as the engine brake is used more actively.

Maintenance components remaining for the electric trucks are thus primarily related to periodic vehicle controls and brake and light adjustments. It was commented that maintenance expenses are highest if they involve damage to the vehicles, and that in this respect, repair costs between ICE and battery-electric vehicles are similar. Other than this, the largest maintenance costs usually start to occur after 4-5 years, and there is so far no experiences with such old E-trucks.

Battery changes were not expected to be required during the effective vehicle lifetime, but it was noted that such changes could be relatively expensive, both due to battery costs itself and due to complications from impractical placement within the vehicle. Comments were received from several operators that it is usual to enter into a service agreement upon purchase, where service costs are fixed and often based on mileage, but so far, none of the E-truck operators have such agreements in place.

Overall (and despite the lower maintenance and operating costs), some operators still expect that E-trucks will be more expensive over a time horizon of 8 years compared to corresponding ICE trucks.

## 6.7 Future outlook and discussion

In future, Norway has ambitious targets for the introduction of zero-emission commercial vehicles as a means to reach the goal of reduced $CO_2$ emissions by 2030. According to the objectives of the NTP 2018-2029, all new lighter vans are to be zero-emission vehicles in 2025, and by 2030, all new heavy vans, and 50 % of new trucks are to be zero-emission vehicles. This is reflected in the interviewed companies' strategies to meet the emission requirements in the years to come or the visions for the zero-emission operations in the municipalities for which tenders are being submitted, and plans to expand the use of E-trucks with further orders made, or plans for more E-trucks when series-produced E-trucks are available.

The companies feared major challenges with the trucks, but most of them are so far well pleased. Generally good vehicle performance was experienced by the waste and recycling companies, although major issues were reported by several operators. Comments were received that there are two main challenges to investing in battery-electric solutions: 1) general availability of batteries and 2) availability of high quality batteries.

If a transition to electric heavy-duty transport is to be made, charging infrastructure must be further developed. Although currently depot charging is used by most operators, an emphasis is increasingly being placed on fast charging. One operator suggested for example that the Norwegian Public Roads Administration should establish fast chargers for trucks at all its vehicle control stations (weight stations). However, if much of an operators' fleet is converted to vehicles with battery-electric propulsion, this may yield issues regarding total power requirements, when all or many vehicles are required to be charged simultaneously. This issue increases if there are several operators located in the same geographical area that convert from ICE-trucks to E-trucks.

It is important to keep incentives to encourage the uptake of the technology and foster further diffusion of E-trucks, such as ENOVA support as well as free toll-road passing and access to bus lanes. In order to speed up the manufacturers' start-up of series productions, demand must be created through requests in public and private tenders. Emphasis on the environment in public tenders is required to give E-trucks, which may be more expensive, a competitive edge.

# 7 Potential for electrification of trucks in Norway: a use pattern perspective

Both the literature review in chapter 3 and user experiences in chapters 5 and 6 indicated that loading capacity and driving range limitations of battery-electric vehicles are seen as the most important obstacles for their potential market introduction in the short- to medium term. This is particularly the case for trucks, which generally cover larger service areas and have less predictable daily routes than buses, and for which charging during the day can be challenging.

Unlike most passenger vehicle owners, truck owners rely on their vehicles to generate income. Loss of payload capacity in terms of weight or volume, due to the installation of large and heavy batteries, translates directly into cost increases, and will also make that more vehicle-kms are needed to perform the same transport amount. Similarly, added time required for charging during the workday (except for time used for imposed resting and/or lunch), also translates into losses in income and reduced cargo capacity.

In the current chapter, we assess the potential for electrification for Norwegian commercial vehicles from the perspective of user patterns for different categories of vehicles. Hereby, we distinguish between the electrification potential in a short term, and in a long term. For the short term, we particularly focus on how technological limitations such as driving ranges and engine sizes relate to current user patterns and requirements. For the long term, our focus is more on identifying the influence of different vehicle-dependent obstacles for electrification.

## 7.1 Data and methodology

The assessments in this chapter build on base data from Statistics Norway's survey of trucks for 2016 and 2017 (SSB 2019), the Norwegian Public Road Administration's vehicle registry, Autosys (NPRA 2018), and a number of assumptions and criteria for in which cases electric propulsion can be considered a viable alternative.

Statistics Norway's survey of trucks is a sample survey that includes Norwegian-owned trucks with payload above 3.5 tonnes, in which truck operators report all transport assignments for one week for each of their trucks in the sample. The sample is drawn so that all the weeks of the year are represented. Reporting is per trip, and as such, base data for the survey of trucks includes information about, amongst others, daily transport patterns and places of origin and destination (at post code level), for approximately 8 300 trucks and 75 000 trips in sum for 2016 and 2017. The survey does not include trucks older than 30 years.

By connecting vehicle identifiers in the truck survey sample to technical information about each vehicle from the Autosys registry, we constructed a dataset in which data are segmented based on amongst others vehicle category, vehicle age, engine power, use of trailer (during the reporting week), and daily driving distances. Vehicle categories include trucks with platform body, trucks with closed chapel, tank trucks, tractors with semitrailer, and special trucks (e.g. refuse collection trucks, concrete-mixer trucks, and rescue trucks).

Preparing our dataset for analysis further included aggregating data from trip level to daily mileages. User requirements regarding the minimum driving range that electric vehicle alternatives should have to be suitable for the user, are set to each vehicle's maximum daily mileage in the reporting period. In cases where a vehicle has two or more daily trips starting from the same post code, as a proxy for a vehicle returning to a base or terminal where charging is possible, daily mileages are modified to reflect that user requirements with regard to driving ranges will be lower. This approach is an approximation since information about the exact origin and destination address is missing in the survey data, but we assume that there is a certain likeliness that trips starting from the same post code start from the same address.

As the electrification potential within different truck segments depends on user patterns, but also on other factors, we further set a number of viability criteria. To be considered as having (theoretical) potential for electrification in *a short term*, we include trucks that:

- Have a maximum daily mileage that is shorter than the driving range on a fully charged battery
- Have an engine with up to 500 horsepower (HP)
- Are not using trailer (other than for tractor units)

The reason for looking at vehicles with engine power up to 500 HP is that for vehicles with higher engine power, a major vehicle manufacturer stated that today, there are effectively no alternatives to diesel or biodiesel. Further, of electric vehicles currently used or trialed in Norway, none have engines with more than 500 HP. Similarly, the reason for focusing on vehicles driving without trailer attached (except lighter ones), is the higher engine power that is required for driving with heavier trailers.

Further, based on specifications of and pilot experiences with electric vehicle alternatives currently on the market, the driving range on a fully charged battery is assumed to be 150 km at a maximum, given current technology levels. In the short to medium term, practical ranges can increase with technological development and/or if sufficient (public) charging infrastructure is available for daytime opportunity fast charging. However, such fast charging, in particular public fast charging, will be more expensive than slow charging at a privately owned depot.

Finally, we focus on trucks of up to five years old, since it is primarily this segment of the vehicle fleet where user requirements for new vehicle purchases are set. Within our dataset, this yields a sample of 6 150 trucks. As yearly mileages decrease with vehicle age, taking also older trucks into account would have yielded a risk of overestimating the electrification potential of the vehicle fleet.

## 7.2 Potential for electrification in a short term

In light of the above, we first look at the composition of the Norwegian commercial vehicle fleet in terms of age and engine power. Table 7.1 shows the shares of trucks within different segments of the fleet, based on the Norwegian Public Road Administration's vehicle registry Autosys, as of April 2018.

*Table 7.1: Shares of trucks within different segments of the vehicle fleet. Source: Base data from the Norwegian Public Road Administration's vehicle registry, Autosys, as of April 2018. Light lorries have a maximum total weight up to 7.5 tonnes; trucks have total weights of more than 7.5 tonnes.*

| | | Engine power in HP | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Vehicle segment | Vehicle age | 100-200 | 200-300 | 300-400 | 400-500 | 500-600 | 600-700 | 700+ | Unknown engine power | Share within category | Number of vehicles |
| Light lorries | ≤5 years | 16.1% | 5.2% | 0.4% | 0.6% | | | | 0.0% | 22.4% | 2 087 |
| | >5 years | 58.6% | 13.6% | 3.7% | 0.7% | | | | 0.9% | 77.6% | 7 239 |
| Trucks | ≤5 years | 0.6% | 5.4% | 4.9% | 8.7% | 20.8% | 2.5% | 3.7% | 0.0% | 46.8% | 19 383 |
| | >5 years | 1.4% | 9.4% | 9.8% | 17.8% | 10.6% | 3.3% | 0.6% | 0.3% | 53.2% | 22 070 |
| Total | | 12 618 | 10 872 | 8 384 | 13 353 | 15 708 | 2 757 | 2 275 | 2 723 | | 50 779 |

From the table we find a total of nearly 51 000 registered lorries and trucks, of which a fifth (i.e. 9 300 vehicles) fall in the segment 'light lorries', while the remaining four fifths are trucks with a maximum total weight of above 7.5 tonnes (i.e. 41 400 vehicles).

Within the light lorry segment, we find that the vast majority of vehicles have smaller engines of up to 300 HP, and further that the share of newer vehicles is relatively small. An important explanation for the latter is a trend where vehicles from this segment are now often no longer replaced with new vehicles of the same type, but rather by (particularly) vans with chapel, for which purchase and ownership are more attractive.

Within the truck segment, we find that the majority of vehicles have higher engine powers, but that there is a clear break around 500-600 HP, and there is a higher share of the vehicles with an engine power above 500 HP for the newer vehicles. Also for trucks, the majority of the registered fleet is older than 5 years, counted in number of vehicles.

For both segments, however, it is important to note that statistics from the Autosys registry include all vehicles, hereunder many old vehicles that are still registered, but not or hardly used. An important reason for this is that vehicles over 25 years old are exempt from annual fees, so that, combined with the lack of a scrapping deposit for trucks, owners have little incentive to wreck and deregister them. As a result, there are many older vehicles parked unused or only used a few times a year on farms around the country.

Another important point to note is that the Autosys registry does not provide information about the actual use of vehicles. Such information is therefore based on Statistics Norway's survey of trucks. Table 7.2 describes the sample from this survey in terms of age, engine power, and the use of trailers at least one time during the reporting period of one week.

*Table 7.2: Shares of trucks within different segments of the vehicle fleet. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

| | ≤ 5 years | | > 5 years | | |
|---|---|---|---|---|---|
| | Using trailer | Not using trailer | Using trailer | Not using trailer | Total |
| < 500 HP | 7.5% | 16.6% | 3.5% | 14.1% | 41.7% |
| ≥ 500 HP | 44.9% | 5.5% | 5.5% | 2.4% | 58.3% |
| Total | 52.3% | 22.1% | 9.1% | 16.5% | 100.0% |

From the table, it can be seen that the majority of the commercial vehicle fleet consists of trucks of up to five years old. The reason for this is that about half of all Norwegian trucks are exported when the leasing period (of typically 3-6 years) expires. Most of these newer trucks have powerful engines (≥500 HP). Given current limitations in terms of power and the availability of alternatives to (bio)diesel propulsion, it is therefore unlikely that many trucks within this segment will be electrified in the short term. This view is strengthened by the observation that the lion's share of (newer) trucks with powerful engines is used with trailer attached.

Focusing on newer trucks with engine power <500 HP, we see that these make up about a quarter of the total commercial vehicle fleet. Within this segment, particularly the trucks that do not use trailers (in the reporting week) are considered most suitable for electrification, and make up 16.6 % of the total fleet. The remainder of this segment, that does use trailers, makes up about 7.5 % of the total vehicle fleet, and largely consists of city trailers, i.e. lighter tractors with semitrailer which could also have potential for electrification.

Where the table above illustrated the shares of (the number of) trucks within different segments of the vehicle fleet, table 7.3 illustrates the share that each segment makes up in total annual mileage.

*Table 7.3: Share that different segments of the vehicle fleet make up of total annual mileage. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

| | ≤ 5 years | | > 5 years | | |
|---|---|---|---|---|---|
| | **Using trailer** | **Not using trailer** | **Using trailer** | **Not using trailer** | **Total** |
| < 500 HP | 9.3% | 10.9% | 2.7% | 5.7% | 28.6% |
| ≥ 500 HP | 62.2% | 3.1% | 5.6% | 0.5% | 71.4% |
| Total | 71.5% | 14.0% | 8.3% | 6.2% | 100.0% |

Here, it can be seen that while trucks up to five years old make up around 75 % of the vehicle fleet (cfr. table 7.2), they stand for over 85 % of the annual mileage. This is a noteworthy observation, given that user requirements are primarily set within this segment. Older trucks, in turn, made up around a quarter of the vehicle fleet, but stand for less than 15 % of total mileage.

A second observation is that most of the driving (71.4 %) is done by powerful trucks with ≥500 HP, of which the lion's share are used with a trailer attached. Based on current technological limitations, this implies that for a large share of driving, E-truck alternatives are unlikely to become viable options in the short term.

When focusing on newer trucks with engine power <500 HP, we see that these make up just over 20 % of total annual driving. Within this segment, the trucks considered most suitable for electrification (not using trailer) make up almost 11 % of total annual mileage, while tractors with lighter city trailers make up another 9 %. As seen from the ongoing pilots, there are at the moment three E-tractors, illustrating that this segment might have potential for electrification, in particular for shorter trips.

Although the above discussion illustrates the shares of different vehicle segments in the total fleet and in total driving, and as such provides several indications about the extent of the electrification potential, it does not take into account variations in day-to-day use and other requirements of trucks owners. As a next step, we therefore look at user patterns and use intensity. Figure 7.1 illustrates, for trucks up to 5 years old in different vehicle segments, the distribution of maximum daily mileages and their share in total mileage.

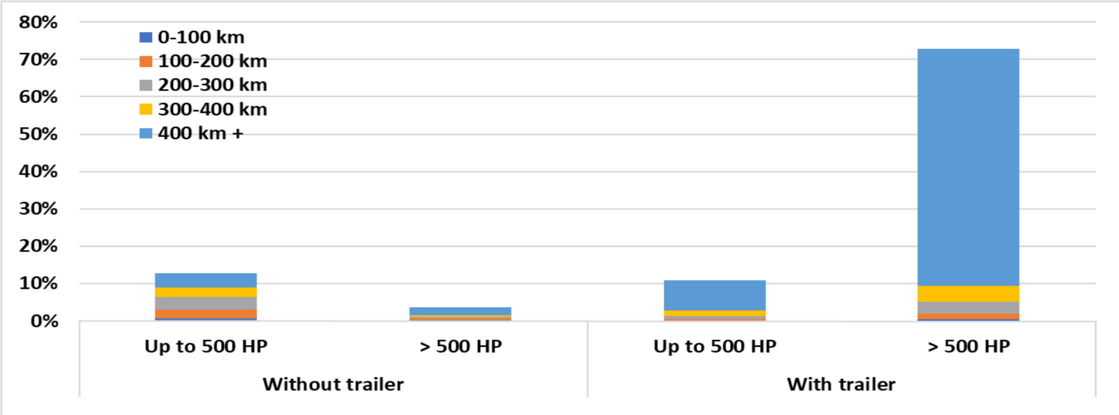



*Figure 7.1: Distribution of daily mileages for trucks of up to 5 years old, for engine power below and over 500 HP, and for driving with and without trailer attached. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

The figure illustrates that most driving is carried out by trucks with engines ≥500 HP and using trailers, confirming the findings above. In addition, however, we find that particularly driving with longer daily mileages (where electrification is less feasible), stands for much of the use, in particular for driving with trailer attached.

Vehicles with engine power below 500 HP, in turn, make up a modest share in total mileage, and the driving of these trucks with daily mileages up to 200 km and without trailer attached (i.e. where the potential for electrification in a short term is considered largest), makes up only around 3 percent of total mileage, while with trailer attached, this is less than 1 percent. These findings illustrate that with current technological limitations, the electrification potential in terms of vehicle-kilometers that can be driven electrically is currently small, although this potential might increase when access to charging infrastructure improves and would support longer daily mileages, or when the trucks can be equipped with larger batteries.

Further, we find that the distribution of daily maximum mileages is very similar for newer trucks with engine power between 200 and 499 HP and not using trailer (figure 7.2): the majority of driving is done for daily mileages beyond the practical range of current E-trucks, when taking into account today's technology and few charging opportunities other than at own facilities.

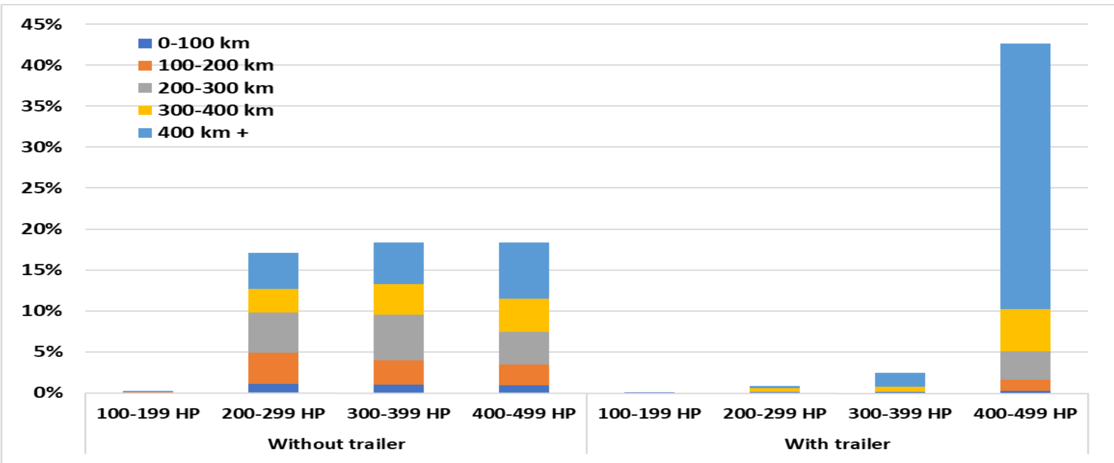



*Figure 7.2: Distribution of daily mileages for trucks of up to 5 years old, for different engine power categories, and for driving with and without trailer attached. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

After looking at engine power and trailer use in general, we zoom in on differences between different types of trucks. Figure 7.3 shows the shares in total mileage for different truck categories and daily mileage intervals, for trucks up to 5 years old and with engine power up to 500 HP.

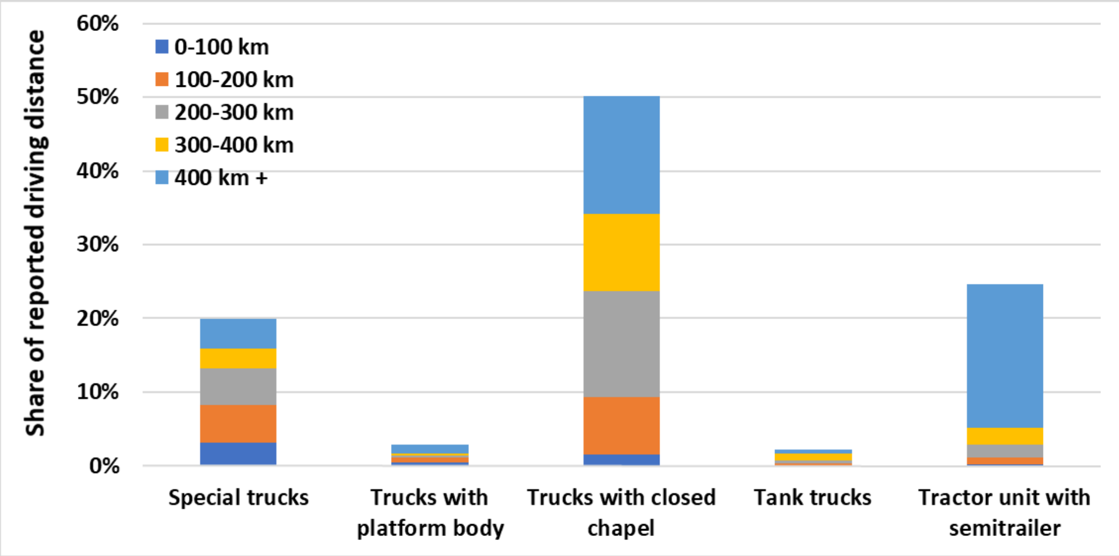



*Figure 7.3: Distribution of daily mileages for trucks of up to 5 years old and with engine power up to 500 HP, for different vehicle categories. Only driving with tractor unit includes trailer. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

From this figure, it can be seen that trucks with closed chapel stand for the highest share of mileage in this segment, particularly for the driving of shorter daily distances. Tractor units with semitrailer stand for around a quarter of total mileage, but are mostly used on longer distances that are currently less suitable for electrification. Special trucks, in turn, make up around 20 % of total mileage, in part over shorter daily distances. Trucks with platform body and tank trucks make up relatively small shares of total driving within this segment.

Next, we look at the maximum daily mileage for each truck, as reported in the reporting week for trucks up to five years of age, with engine up to 500 HP, and driving without trailer attached, except for tractors with semitrailer. This is illustrated in figure 7.4. In cases where the maximum daily mileage of a vehicle is below the maximum driving range of an alternative electric vehicle on a full charge (currently assumed to be limited to 150 km), the vehicles are considered to have potential for electrification (light-green shaded area). For vehicles with maximum daily mileages between 150-250 km, we assume a certain potential for electrification, provided that sufficient possibilities for daytime charging are available and/or improvements in driving ranges (blue-shaded area).

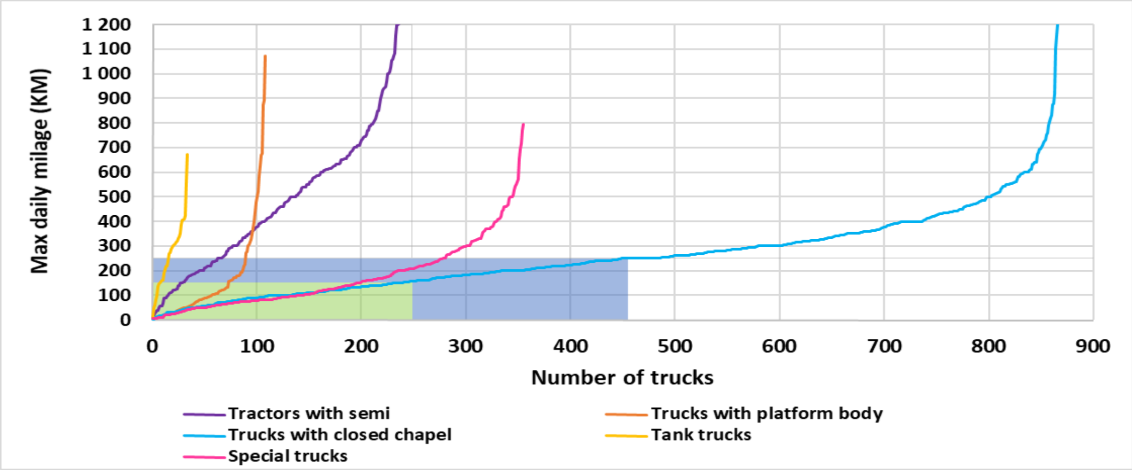



*Figure 7.4: Maximum daily mileages (km) for individual trucks in different truck categories in the sample. For trucks up to five years old, with engines up to 500 HP, and without trailer attached, except for tractors with semitrailer. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

From the figure, it can be seen that special trucks and trucks with closed chapel have most vehicles in the segment with potential for electrification, and thereby constitute the main market for electrification in a short term. This is also confirmed by the case study, where the first pilots with E-trucks were held with distribution trucks and refuse collection trucks. For tank trucks and tractors with semitrailer, maximum daily mileages for most vehicles exceed what can be expected from an electric propulsion alternative.

In the next section, we zoom in further on the different categories of trucks, as well as on possible opportunities for daytime charging to increase the effective daily range of truck alternatives with electric propulsion systems.

### 7.2.1 Trucks with closed chapel

When it comes to trucks with closed chapel (distribution trucks), the cumulative share of trucks for different maximum daily mileages is shown in figure 7.5. The reason for giving a cumulative presentation, is that this allows for an easy assessment of the implications of increased driving ranges with technological maturity, as well as uncertainty about driving ranges or variation between battery performance in summer- and wintertime.

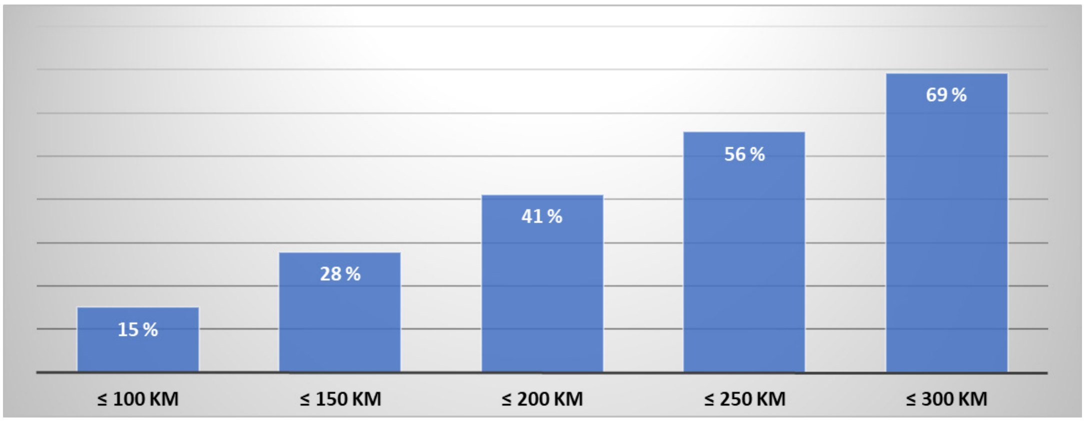



*Figure 7.5: Cumulative share of trucks with closed chapel with maximum daily mileages up to 100km, 150km, 200km, 250km and 300km. Only driving without trailer is included. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

The figure shows that the share of vehicles with maximum daily mileages up to 150 km, and as such potentially suitable for electrification given current technology, is modest, with 28 % of the vehicles in this segment. At the same time, another nearly 30 percent of the fleet has maximum daily mileages between 150-250 km, which might allow electrification if sufficient charging possibilities are present and/or battery capacities improve.

In Figure 7.6, we zoom in on possible charging opportunities. While the blue line shows the maximum reported daily mileage for individual trucks with closed chapel in ascending order, the orange markers indicate vehicles with a possible charging opportunity during the day (e.g. where they return to the same origin at least two times a day to load for a new trip). In these cases, maximum daily mileages are adjusted accordingly.

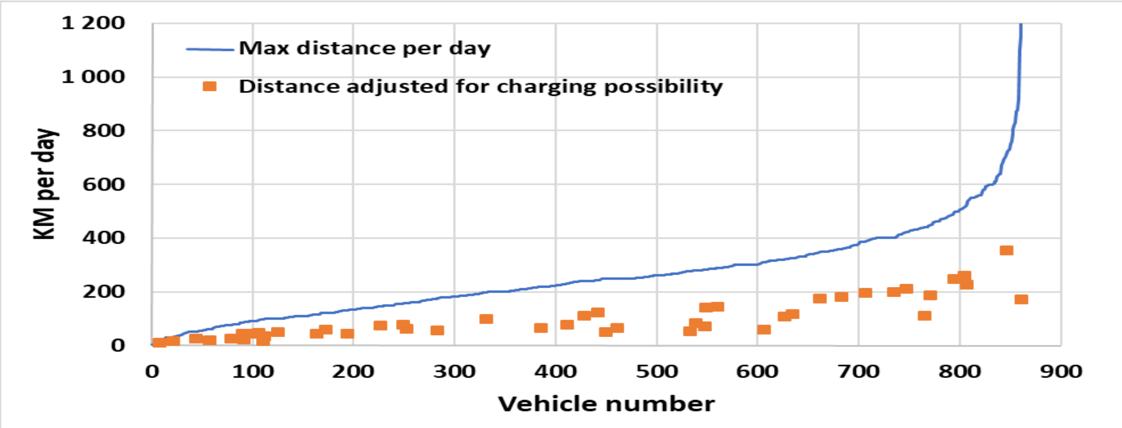



*Figure 7.6: Maximum daily mileages (km) for individual trucks with closed chapel, supplemented with adjusted distances in case of charging possibilities. Only driving without trailer is included. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

From this figure, we can see that a relatively large number of trucks with closed chapel have daily use patterns falling within the range of electric alternatives, although the relative share is modest, as we saw above. Further, of the trucks with daily mileages between 150-250 km, only around 4 % have two or more trips starting from the same post code on the same day, as a proxy for charging possibilities at a base.

### 7.2.2 Special trucks

Figure 7.7 gives a similar illustration as above, but now for special trucks, such as refuse collection, concrete-mixer, and rescue trucks.

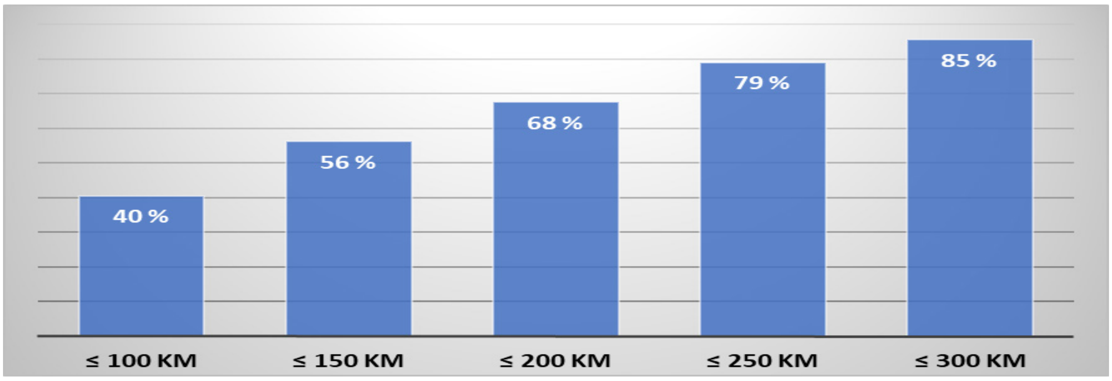



*Figure 7.7: Cumulative share of special trucks with maximum daily mileages up to 100km, 150km, 200km, 250km and 300km. Only driving without trailer is included. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

This figure confirms that well over half of special trucks have maximum daily mileages of up to 150 km, which suggests that there might be a substantial potential for electrification, although the number of vehicles within this segment is lower than for the distribution trucks above. For close to a quarter of special trucks, maximum daily mileages further lie between 150-250 km, which might allow some degree of electrification if sufficient charging possibilities are or become available.

Figure 7.8 zooms in on daytime charging possibilities, and adjusts daily mileages accordingly.

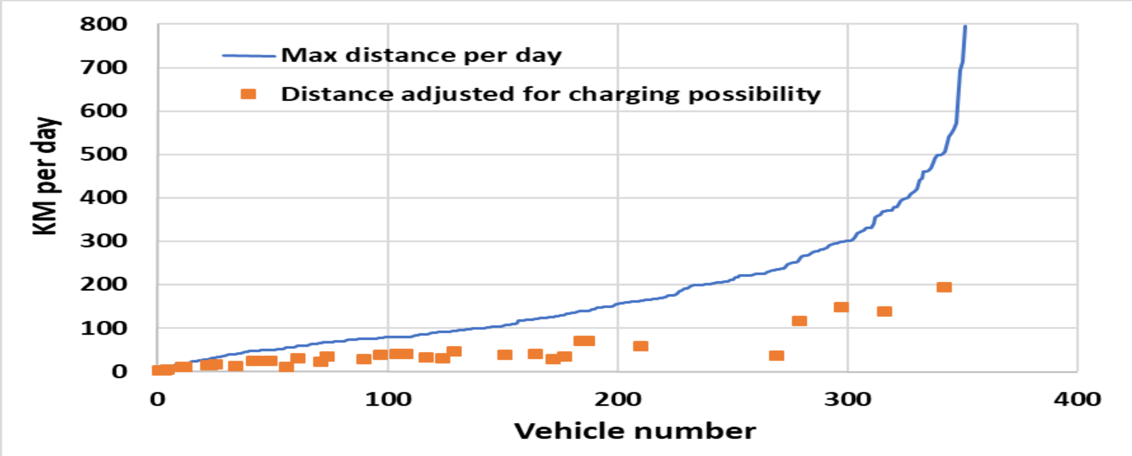



*Figure 7.8: Maximum daily mileages (km) for individual special trucks, supplemented with adjusted distances in case of charging possibilities. Only driving without trailer is included. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

This figure confirms that a substantial share of special trucks have maximum daily mileages for which electric propulsion might be an alternative. However, of trucks with daily mileages above 150 km, only a handful of the sample have two or more trips starting from the same post code on the same day, as a proxy for charging possibilities at a base.

### 7.2.3 Trucks with platform body

Figure 7.9 shows the cumulative share of vehicles for different maximum daily mileages, for trucks with platform body.

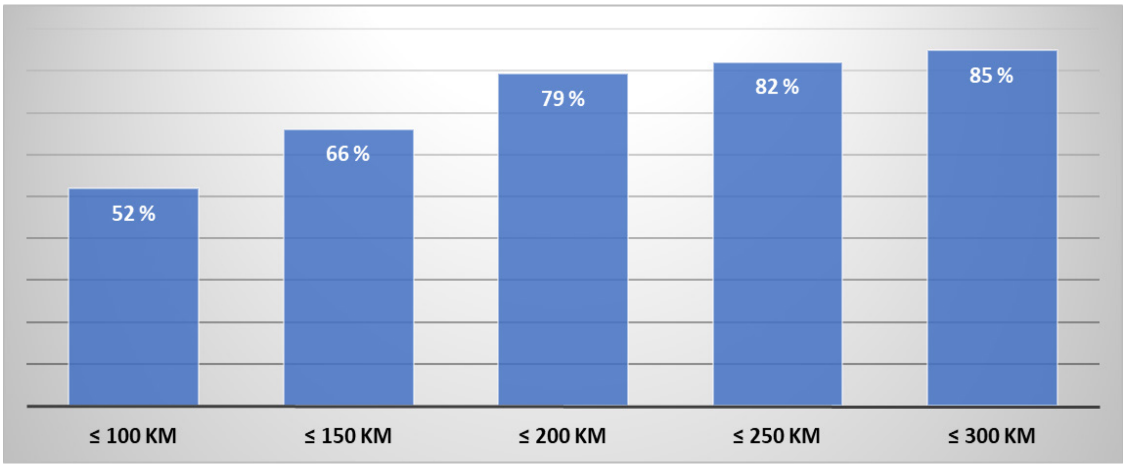



*Figure 7.9: Cumulative share of trucks with platform body with maximum daily mileages up to 100km, 150km, 200km, 250km and 300km. Only driving without trailer is included. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

This figure shows that the share of trucks with platform body with a maximum daily mileage of up to 150 km, is 66 %, while a significant share of the fleet might become suitable for electrification if substantial daytime charging is possible. However, it should be noted that the total number of trucks with platform body is much lower than the number of trucks with closed chapel and special trucks, and that the share of trucks with platform body in total annual mileages is small, as we saw in figure 7.3. This is because most of such trucks have an engine exceeding 500 HP. Trucks with platform body for example include trucks that are used for mass transport in the building and construction industry.

In figure 7.10, we zoom in on possible charging opportunities, by adjusting maximum daily mileages in cases where vehicles are assumed to have a possibility for charging during the day.

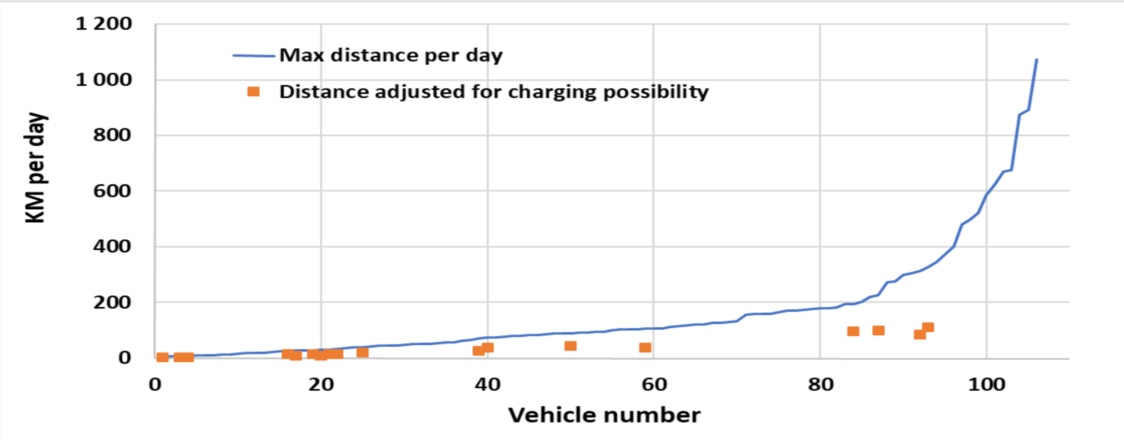



*Figure 7.10: Maximum daily mileages (km) for individual trucks with platform body, supplemented with adjusted distances in case of charging possibilities. Only driving without trailer is included. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

This figure confirms that a large share of trucks with platform body fall within the driving range of an electric vehicle alternative, but at the same time, that this vehicle segment in itself is relatively small. The figure further shows that it is particularly trucks with shorter daily mileages that might have opportunities for daytime charging, with multiple trips per day starting from the same post code. Of the trucks with maximum daily mileages between 150-250 km, and for which a certain degree of electrification might be expected provided sufficient charging possibilities, around 12 percent of the vehicles have multiple daily trips starting from the same post code.

### 7.2.4 Tank trucks

Figure 7.11 shows the cumulative share of vehicles for different maximum daily mileages, for tank trucks.

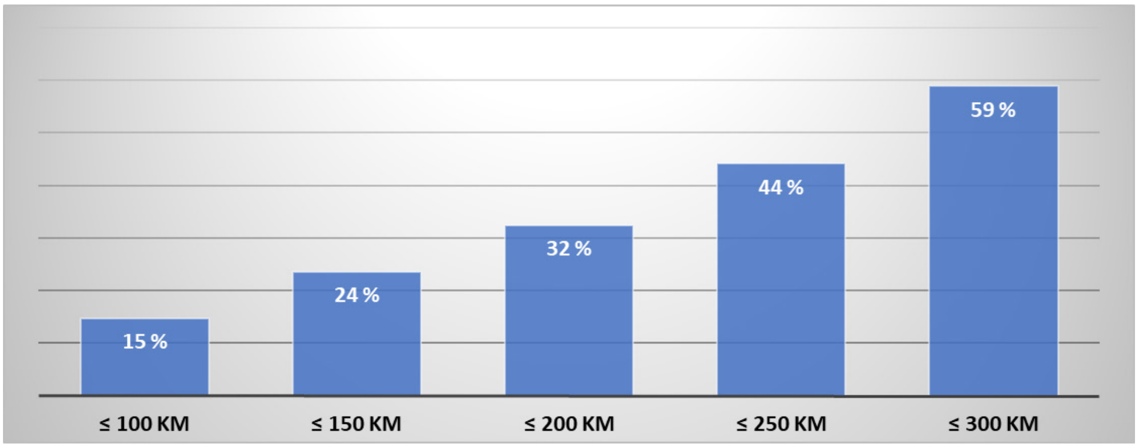



*Figure 7.11: Cumulative share of tank trucks with maximum daily mileages up to 100km, 150km, 200km, 250km and 300km. Only driving without trailer is included. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

Although it should be noted that the sample of tank trucks with engines up to 500 HP and not using trailer in SSBs survey of trucks, is smaller[39] than for other truck categories, the figure above shows that around a quarter of tank trucks has maximum daily mileages of up to 150 km, and as such could potentially be electrified. Around a fifth of the fleet furthermore has maximum daily mileages between 150-250 km and could allow some degree of electrification with substantial daytime charging, while over half of the tank trucks have daily mileages well exceeding what today's vehicle batteries currently support. Compared to the truck categories discussed above, the electrification potential for the tank truck segment therefore seems significantly more limited, and the share of tank trucks in total mileage (and as such the potential effect of electrifying the fleet) is also small, as we saw in figure 7.3.

In figure 7.12, we zoom in on cases in which tank trucks are assumed to have a possibility for charging during the day.

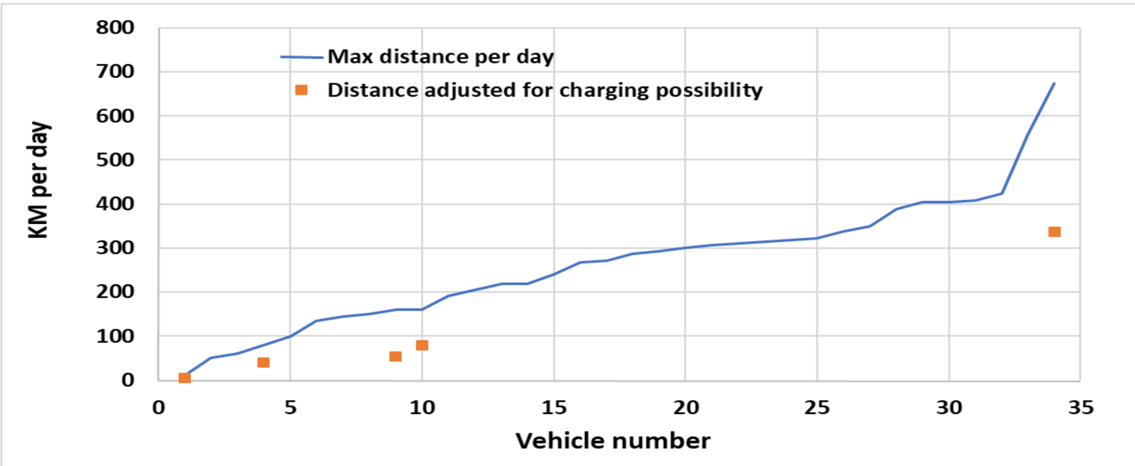



*Figure 7.12. Maximum daily mileages (km) for individual tank trucks, supplemented with adjusted distances in case of charging possibilities. Only driving without trailer is included. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

[39] The far majority of tank trucks included in SSBs survey of trucks has higher engine power and is driven with trailer.

The figure confirms the previous findings that in the tank truck segment, most vehicles have user patterns that exceed the driving range that E-truck alternatives currently can support. Although of the vehicles with maximum daily mileages between 150-250 km, 29 % might have a charging possibility, this is based on a small sample and only covers a handful of vehicles.

### 7.2.5 Tractors with semitrailer

Finally, figure 7.13 shows the cumulative share of tractors with semitrailer for different maximum daily mileages.

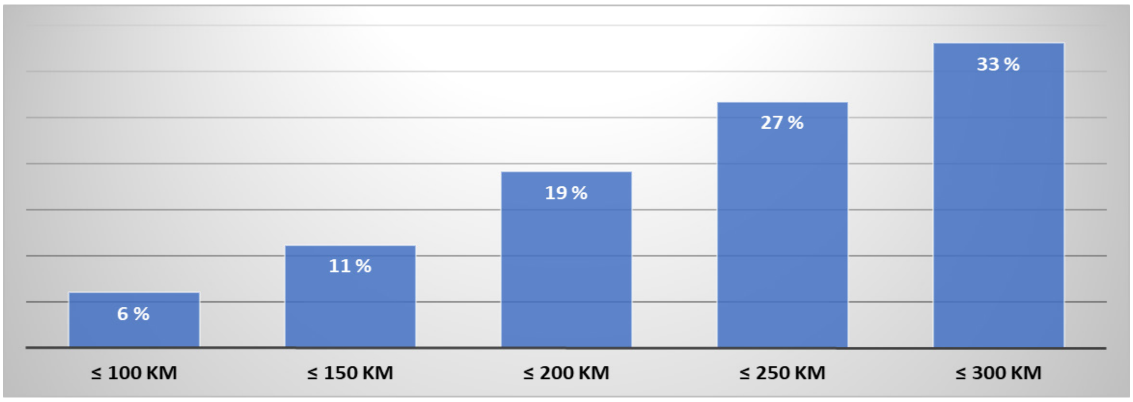



*Figure 7.13: Cumulative share of tractors with semitrailer with maximum daily mileages up to 100km, 150km, 200km, 250km and 300km. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

As can be seen from the figure, only 11 percent of tractors with semitrailers have a maximum daily mileage of up to 150 km, and as such, are considered to have potential for electric propulsion based on overnight depot charging, and at current technology levels.

At the same time, around two thirds of tractors with semitrailers have maximum daily mileages beyond 300 km, which currently makes electrification unlikely, even with significant daytime charging, unless the transport is organized between destinations with access to fast chargers (as is the case for one of the pilots described in chapter 6). This is not generally the case, as most vehicles are used within transport patterns where destinations vary from trip to trip and from day to day.

Figure 7.14 zooms in on possible charging opportunities during the day.

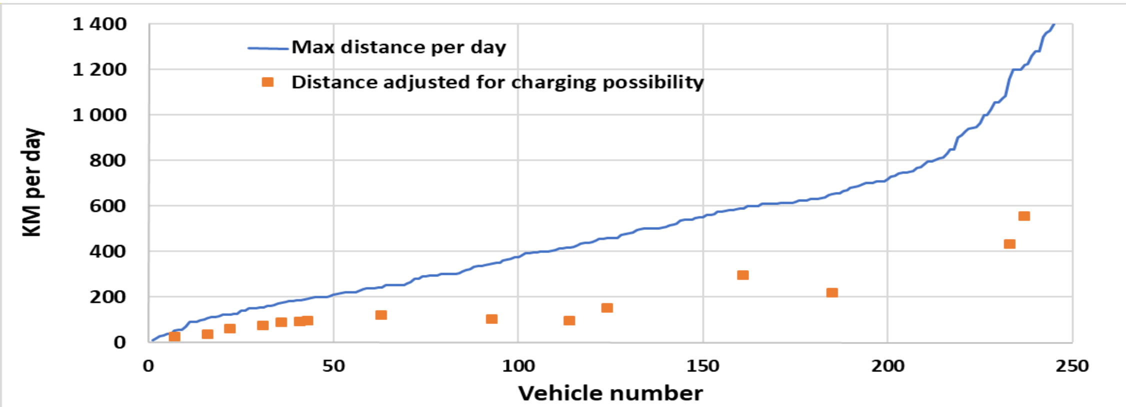
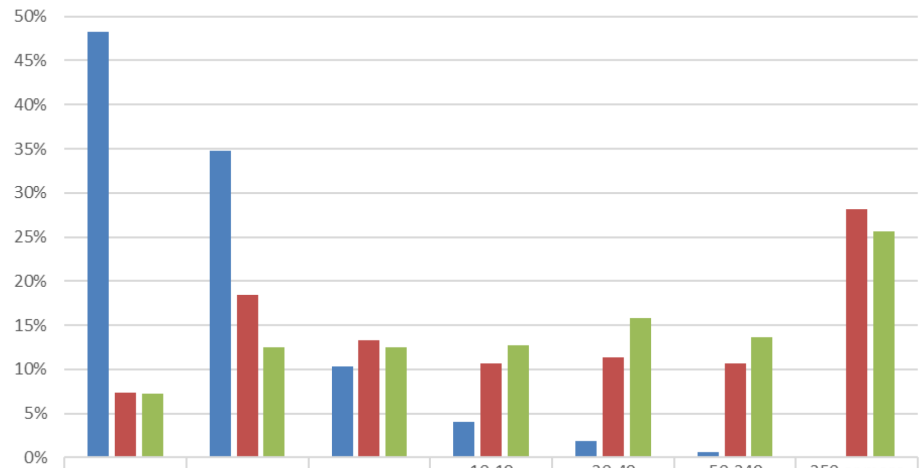



*Figure 7.14. Maximum daily mileages (km) for individual tractors with semitrailers, supplemented with adjusted distances in case of charging possibilities. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

The figure confirms that only a relatively small share of tractors with semitrailers have user patterns falling within the current driving range of electric alternatives. Most tractors have maximum daily mileages in excess of 150 km, implying that substantial daytime charging is required, or, at distances >250 km, that electrification is unlikely with current battery ranges. For illustration, only 13 % of vehicles with maximum daily mileages between 150-250 km have at least two daily trips starting from the same origin, with likely access to charging facilities during the day. These are relevant implications in light of the finding in figure 7.3, that tractors with semitrailer stand for nearly 25 % of the total annual mileage of newer trucks with engine power up to 500 HP and not using trailer (other than for tractor units).

## 7.3 Potential for electrification in a long term

In a longer time perspective, it can be argued that firms owning several trucks can redistribute transport routes between vehicles (for example by having the E-trucks carry out more of volume goods transports on shorter distances), and thereby increase the potential for electrification. This flexibility is difficult to quantify, but it is important to note that the transport industry is a very fragmented one, with a large proportion of transport firms consisting of sole proprietors. This is illustrated in figure 7.15.




| | 0-1 employees | 2-4 employees | 5-9 employees | 10-19 employees | 20-49 employees | 50-249 employees | 250 or more employees |
|---|---|---|---|---|---|---|---|
| Number of enterprises | 48% | 35% | 10% | 4% | 2% | 1% | 0% |
| Employees | 7% | 18% | 13% | 11% | 11% | 11% | 28% |
| Turnover | 7% | 13% | 13% | 13% | 16% | 14% | 26% |

*Figure 7.15: Share of number of firms, employees and turnover for the road transport industry. Source: Statistics Norway's Structural Statistics for Transport and Storage. Key figures, by statistic variable and employment group for the year 2017.*

As can be seen, nearly half of the firms in the road transport industry have only one, or none full-time employees, and 83 % of the firms consists of four or fewer employees. However, in share of turnover, which can be used as a proxy for the volume of transport carried out by each firm, 40 % can be attributed to firms with 50 or more employees, and these same firms also stand for about 40 % of employment.

Transport firms with larger vehicle fleets are likely to have more flexibility to redistribute transport tasks between vehicles, and thereby to increase the potential for electrification within their fleet, but the extent of this flexibility is difficult to quantify.

An additional factor complicating the quantification of such flexibility in a long term, is that the transport industry not only consists of hire-transport, but also of own-transporters, i.e. firms carrying out their transport tasks in-house. We do not have data on the number or share of firms that are own-transporters, but as an illustration, table 7.4 shows the distribution of both older and newer vehicles with engine below 500 HP and 500 HP and above, by whether transport tasks are carried out as own-transport or as hire-transport.

*Table 7.4: Distribution of vehicles over and under 5 years old and with engine up to 500 HP, by whether transport tasks are carried out as own-transport or as hire-transport. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

| **Vehicle age** | | **Own-transport in share of trucks** | **Own-transport in share of kms** |
|---|---|---|---|
| ≤5 years | < 500 HP | 34.9% | 29.4% |
| | ≥ 500 HP | 16.7% | 12.9% |
| >5 years | < 500 HP | 44.6% | 32.6% |
| | ≥ 500 HP | 28.1% | 11.7% |
| **Total** | | 26.9% | 17.8% |

Own-transport makes up 27 % of the trucks in the sample, but only stands for about 18 % of the mileage driven. This suggests that trucks used for own-transport drive less than trucks used for hire-transport. The share of own-transport – both in share of the number of trucks as in the share of kilometres driven – is also larger for the smaller engine sizes, and in particular for trucks older than 5 years.

The observation that own-transport to a larger degree is carried out using smaller vehicles and vehicles driving shorter mileages, compared to hire-transport, indicates that the former category could be more suitable for electrification than the latter. On the other hand, the fact that trucks used for own-transport make up a larger share of older vehicles, probably because they are used less intensively than vehicles in hire transport, works in the opposite direction, and might imply that a phase-in of electric vehicles will take more time. Of the firms currently piloting E-trucks in Norway and not operating in the recycling or waste disposal industry, all are operating as own-transporters.

Even with a certain degree of route redistribution and increases in public charging opportunities in the long term, however, a number of challenges for electrification in heavier vehicle segments remain. The main obstacles are related to technical limitations, and can be summarized as follows:

1) Engine power
2) Range limitations
3) Weight of batteries and loss of payload
4) Limitations on the use of trailer

In the following sections, we provide a short analysis of how the use of trucks in Norway varies with respect to engine power, transport distance, use of trailer, filling rate, and total weight, which are all related to the obstacles mentioned above. The data sources used for this analysis are the same as presented in section 7.2. As before, we focus on trucks of up to five years old, since the user requirements for new vehicles is most comparable to this vehicle segment.

### 7.3.1 Engine power

Table 7.5 illustrates the shares that vehicles with different engine powers make up in respectively the number of trips, in vehicle-kms, and in tonne-kms (so-called 'transport performance'). The sample and vehicle categories are the same as those used in the short term analysis in section 7.2.

*Table 7.5: Shares of vehicles with different engine powers in number of trips, total mileage, and tonne-kms. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

| Engine power (HP) | Trips | Vehicle kms | Tonnes kms |
|---|---|---|---|
| 100-199 | 0.2% | 0.2% | 0.0% |
| 200-299 | 7.3% | 6.8% | 0.8% |
| 300-399 | 8.3% | 7.7% | 1.4% |
| 400-499 | 15.7% | 15.7% | 9.7% |
| 500-599 | 53.3% | 54.2% | 66.1% |
| 600-699 | 8.0% | 8.2% | 11.2% |
| 700+ | 7.2% | 7.3% | 10.7% |
| **Total** | 100.0% | 100.0% | 100.0% |

From the table, we find that trucks with engine powers up to 400 HP stand for around 15 % of trips and vehicle-kms, but less than 3 % of tonne-kms (indicating that such trucks carry less goods than the average truck). Although trucks with engines between 400-500 HP make up somewhat larger shares, their share in tonne-kms is also considerably lower than their share in the number of trips and vehicle-kms.

Most driving, both in terms of the number of trips and in vehicle-kms, is clearly carried out by trucks with engines in the category 500-600 HP. With around two thirds of tonne-kms, their share in transport performance is also larger than proportional.

Finally, the table indicates that trucks with the highest engine powers stand for around 15 % of trips and vehicle-kms, and around 22 % of tonne-kms.

This illustrates primarily that if the power of E-truck alternatives would increase to 600 HP, the majority of the needs in the transport market would be met. However, such engine powers are well beyond the E-truck examples in today's pilots.

### 7.3.2 Range limitations

Table 7.6 illustrates how vehicles with different engine powers are used in practice.

This is done by looking, for different engine power intervals, at how much driving certain daily mileage makes up in total mileage. In other words: how important is driving up to e.g. 200 km a day?

*Table 7.6: Distribution of daily mileages for trucks of up to 5 years old, with different engine powers, as share of total vehicle mileage. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

| Engine power (HP) | Up to 100 km | 100-200 km | 200-300 km | 300-400 km | 400-500 km | 500 km and over | Total |
|---|---|---|---|---|---|---|---|
| 100-199 | 0.1% | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.2% |
| 200-299 | 2.5% | 2.2% | 1.1% | 0.6% | 0.2% | 0.2% | 6.8% |
| 300-399 | 2.8% | 2.8% | 1.1% | 0.7% | 0.2% | 0.2% | 7.7% |
| 400-499 | 4.7% | 4.4% | 2.9% | 1.0% | 0.6% | 2.2% | 15.7% |
| 500-599 | 12.4% | 8.3% | 6.6% | 4.1% | 5.3% | 17.6% | 54.2% |
| 600-699 | 2.1% | 1.1% | 0.9% | 0.6% | 0.8% | 2.7% | 8.2% |
| 700+ | 2.0% | 0.9% | 0.7% | 0.5% | 0.7% | 2.4% | 7.3% |
| **Total** | 26.6% | 19.8% | 13.2% | 7.5% | 7.6% | 25.3% | 100.0% |

This table replicates the findings of the section above, which showed that most driving is done with vehicles with engines between 500-600 HP, and to a lesser extent by vehicles with smaller engine. The current table, however, also shows that over a quarter of total driving is done by vehicles with daily mileages up to 100 km, another fifth by vehicles with daily mileages up to 200 km, and around 13 % by vehicles with daily mileages between 200-300 km. In light of the range limitations of current E-trucks, the table as such provides insights into the share that short-/medium distance driving (for which battery-electric propulsion may become viable in a long term) makes up in total driving.

At the same time, we find that a considerable share of all driving can be attributed to vehicles with daily mileages of (well) above 300 km, for which electrification might remain more challenging, also in a longer term.

### 7.3.3 Weight of batteries and loss of payload

In April 2019, European Parliament adopted a proposal that opens up for up to 2 tonnes of additional total vehicle weight for zero-emission trucks (European Parliament 2019, Transport & Environment 2019). This could negate the added weight of about 200-300 kWh of batteries, and thus make battery-electric distribution trucks more viable for logistics operations.

In table 7.7, we illustrate the distribution of total mileage with and without trailer attached, and whether it is the weight or the volume that fills up the loading capacity of the trucks, and as such is the dimensioning factor.

*Table 7.7: Distribution of total mileage with and without trailer attached, and whether it is the weight or volume that fills up the loading capacity of the trucks. For trucks up to 5 years old. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017.*

| | Weight goods | Volume goods | Total |
|---|---|---|---|
| Not using trailer | 5.1% | 22.9% | 28.0% |
| Using trailer | 15.9% | 56.1% | 72.0% |
| **Total** | **21.1%** | **78.9%** | **100.0%** |

It can be seen that, for close to 80 percent of the total mileage driven with cargo, it is the cargo's volume, and not its weight, that fills up the loading capacity. This indicates that the extra weight of batteries might not be as critical as is sometimes expected.

We have therefore checked how much of a vehicle's loading capacity is used on average, for trips with cargo. This is illustrated in table 7.8. Since it is the vehicle, and not the trailer that is most crucial, the table only includes mileage driven without trailer attached. This information provides insights into the extent to which vehicles might have room for the extra weight of a battery.

*Table 7.8: Distribution of total mileage without trailer attached, by the capacity utilization of vehicles and the vehicle's maximum allowed total weight. For trucks up to 5 years old. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017.*

| | Maximum allowed total weight | | | |
|---|---|---|---|---|
| **Weight of cargo in per cent of payload** | **<5 tonnes** | **5-15 tonnes** | **>15 tonnes** | **Total** |
| 10% | 0.3% | 9.8% | 1.7% | 11.7% |
| 20% | 0.2% | 9.7% | 1.9% | 11.8% |
| 30% | 0.9% | 14.5% | 2.6% | 18.1% |
| 40% | 0.5% | 12.9% | 3.2% | 16.6% |
| 50% | 0.6% | 10.9% | 2.4% | 13.9% |
| 60% | 0.1% | 5.6% | 2.5% | 8.2% |
| 70% | 0.1% | 4.1% | 1.9% | 6.1% |
| 80% | 0.2% | 2.5% | 3.1% | 5.8% |
| 90% | 0.2% | 3.5% | 1.9% | 5.6% |
| 100% | 0.1% | 1.8% | 0.4% | 2.3% |
| **Total** | 3.3% | 75.1% | 21.6% | 100.0% |

From this table, it can be seen that three quarters of total mileage of trucks up to 5 years old, and without trailer attached, is driven by vehicles with a maximum allowed total weight between 5-15 tonnes. Just over a fifth of total mileage is driven by trucks with a maximum allowed total weight over 15 tonnes, while only 3.3 % of mileage is driven by vehicles with small payload.

More importantly, the table makes clear that trips driven with cargo most of the time do not utilize the vehicle's full capacity: over 80 % of total mileage is driven with at least 20 % of the vehicle's capacity in terms of weight unutilized. Although it should be noted that in some cases, estimates on unutilized capacity may be caused by random variation in the survey of trucks' reporting week, this suggests that for a large share of these transports, vehicles could have considerable room for the extra weight of a battery, without violating vehicle weight restrictions.

Table 7.9 illustrates how much extra room, in terms of weight, vehicles with different payload would have for a battery, depending on capacity utilization.

*Table 7.9: Estimates of spare 'weight capacity' capacity that could potentially be used for a battery. By vehicle payload and capacity utilization, derived from the figures in table 7.8. In tonnes.*

| | Maximum allowed total weight | | |
|---|---|---|---|
| **Weight of cargo in per cent of payload** | **<5 tonnes** | **5-15 tonnes** | **>15 tonnes** |
| 10% | 4.1 | 9.5 | 14.9 |
| 20% | 3.7 | 8.4 | 13.5 |
| 30% | 2.9 | 7.4 | 11.4 |
| 40% | 2.6 | 6.3 | 10.1 |
| 50% | 2.0 | 5.2 | 8.4 |
| 60% | 1.7 | 4.3 | 6.7 |
| 70% | 1.3 | 3.1 | 5.0 |
| 80% | 0.8 | 2.3 | 3.3 |
| 90% | 0.4 | 1.2 | 1.6 |
| 100% | 0.0 | 0.0 | 0.0 |

In combination with the previous table, it can be seen that for the lion's share of mileage driven with cargo, vehicles would have considerable room for a battery: especially for vehicles with a payload above 5 tonnes, which stand for most of the mileage with cargo, there would often be enough spare 'weight capacity' to carry several tonnes of battery weight.

### 7.3.4 Limitations on the use of trailer

Table 7.10 illustrates the use of trailers for trucks and tractors with different engine powers, as share in the number of trips.

*Table 7.10: Share of trucks and tractors driving with and without trailer attached, in the number of trips with these vehicles. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

| | Trucks | | Tractors | |
|---|---|---|---|---|
| **Engine power (HP)** | **Not using trailer** | **Using trailer** | **Using trailer** | **Total** |
| 100-199 | 0.2% | 0.0% | 0.0% | 0.2% |
| 200-299 | 7.1% | 0.3% | 0.0% | 7.3% |
| 300-399 | 7.6% | 0.3% | 0.4% | 8.3% |
| 400-499 | 9.3% | 4.4% | 2.0% | 15.7% |
| 500-599 | 16.7% | 17.3% | 19.3% | 53.3% |
| 600-699 | 2.7% | 2.8% | 2.6% | 8.0% |
| 700+ | 1.6% | 3.8% | 1.8% | 7.2% |
| **Total** | **45.2%** | **28.7%** | **26.1%** | **100.0%** |

It can be seen that in terms of the total number of trips, over 45 % are driven without trailer attached. Trips without trailer are particularly driven by vehicles with engine powers ranging from 200 to 600 HP, and particularly with the larger engines within this interval.

When looking at the share of driving with/without trailer in vehicle-kms, rather than in the number of trips, the picture becomes somewhat different, as is shown in Table 7.11.

*Table 7.11: Share of the mileage of trucks and tractors driving with and without trailer attached,. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.*

| | Trucks | | Tractors | |
|---|---|---|---|---|
| **Engine power (HP)** | **Not using trailer** | **Using trailer** | **Using trailer** | **Total** |
| 100-199 | 0.2% | 0.0% | 0.0% | 0.2% |
| 200-299 | 6.4% | 0.3% | 0.0% | 6.8% |
| 300-399 | 7.1% | 0.4% | 0.1% | 7.7% |
| 400-499 | 6.9% | 5.5% | 3.3% | 15.7% |
| 500-599 | 5.7% | 17.7% | 30.7% | 54.2% |
| 600-699 | 0.6% | 3.1% | 4.5% | 8.2% |
| 700+ | 0.5% | 3.4% | 3.4% | 7.3% |
| **Total** | **27.5%** | **30.5%** | **42.1%** | **100.0%** |

Here, it can be seen that in terms of mileage, only around 28 % of vehicle-kms is driven without trailer attached, compared to over 45 % in terms of the number of trips. This difference is particularly apparent for vehicles with somewhat larger engines. These observations show that on average, trips using trailers are considerably longer than trips where trailers are not used.

## 7.4 Conclusions

In a short term, main challenges for the electrification of HDVs in light of Norwegian use patterns are related to limited driving ranges of battery-electric (pilot) vehicles, limited engine power, and consequently, the limited ability to drive with trailers attached.

Today, over 70 % of total mileage for trucks up to 5 years old is driven using trucks with engines over 500 HP. In this segment, there are, according to one of the major vehicle suppliers in Norway, currently very few alternatives to diesel.

Further, although it is these segments where electrification in a short term is most likely, trucks with engine <500 HP and daily mileages up to 200 km make up only 3 % (for trucks not using trailer) and 1 % (for trucks using trailer) of total mileage conducted with trucks of up to 5 years old. Within this segment, trucks with closed chapel constitute the largest group of vehicles, followed by special trucks such as refuse collection vehicles.

For battery-electric vehicles to be able to reach significant market shares for HDVs, there is therefore a need both for more powerful battery-electric engines than in today's pilots, and for driving ranges beyond 200 km. These needs are amplified by the observation that a large share of driving is performed with trailer attached, and that such trips are also longer on average than when not using trailer.

In a longer time perspective, it can be argued that firms owning several trucks can redistribute transport routes between vehicles, and thereby increase the potential for electrification. The potential of such flexibility, however, is hard to quantify, as the transport industry is very fragmented and consists of both hire-transport (with a high share of firms with a limited number of employees driving on contracts with multiple clients), and own-transport. Findings in our analysis suggest that own-transport to a larger degree is carried out using smaller vehicles and vehicles driving shorter mileages, compared to hire-transport. This would imply that the former category could be more suitable for electrification than the latter. On the other hand, the fact that trucks used for own-transport make up a larger share of older vehicles works in the opposite direction, and might imply that a phase-in of electric vehicles will take more time.

When focusing on engine power, we find that most driving, both in terms of the number of trips, vehicle-kms, and tonne-kms, is clearly carried out by trucks with engines between 500-600 HP. This illustrates that if the engine power of E-trucks would increase to 600 HP, this could go a long way towards meeting requirements in the transport market.

With regard to driving ranges, we found that over a quarter of total driving is done by vehicles with daily mileages up to 100 km, another fifth by vehicles with daily mileages up to 200 km, and around 13 % by vehicles with daily mileages between 200-300 km. Although a considerable share of all driving is carried out by vehicles with (much) higher daily mileages, these findings suggest that increasing battery capacity to support driving ranges of 300 kms would also allow for the electrification of a large share of transport.

When looking at whether trucks might have 'spare capacity', we find that trips driven with cargo most of the time do not utilize the vehicle's full capacity: over 80 % of total mileage is driven with at least 20 % of the vehicle's capacity in terms of weight unutilized. This suggests that for a large share of these transports, vehicles could have considerable room (often several tonnes) for the extra weight of a battery, without violating vehicle weight restrictions.

# 8 Truck cost analysis: Methodology and assumptions

## 8.1 Introduction

The previous chapter discussed the potential for the electrification of freight vehicles from a use pattern and driving range perspective. In the current chapter, we set the stage for an analysis of the cost competitiveness of different propulsion technologies vis-à-vis each other. This is done by developing a model which compares the costs of ownership for different vehicle types using different propulsion technologies. A related study for similar vehicle types and for Norway is carried out by the Norwegian Environment Agency (2018a)[40].

In line with the rest of the report, the predominant focus will be comparisons between battery-electric operation (and to a lesser extent hydrogen operation) vs. conventional diesel operation. To reflect future stages of production and expected price decreases for battery-electric and hydrogen vehicles, our analysis further considers four scenarios with different production/maturity stages of alternative propulsion technologies. The framework for the cost reduction for different maturity stages is a simplification and a first approximation. Within MoZEES, we are working on developing more detailed techno-economic analyses with bottom-up cost calculations than presented in this report.

Table 8.1 provides an overview of the different cost comparisons carried out in our model. Discussed vehicle types are based on categories from the National Freight Model (see Madslien (2015) and Grønland (2018) for more details).

*Table 8.1: Overview of cost comparisons in our model. All comparisons using our model are excluding VAT, given that enterprises can subtract VAT on incoming goods and services.*

| Vehicle types | Propulsion technologies | Production phase scenarios |
|---|---|---|
| Light distribution truck | Diesel | Base scenario/early stage |
| Heavy distribution truck | Biodiesel (pure) | Small-scale series production |
| Tractor for semi-trailer | Biogas | Small-scale series production & reduced hydrogen prices |
| Small van | Battery-electric | Mass production |
| Medium van | Hydrogen/fuel cell (only HDVs) | |

[40] An important characteristic in the approach of the Norwegian Environment Agency (and different from ours) is that they 'construct' battery-electric vehicles that do not exist today, by specifying requirements in terms of battery capacity for an electric vehicle to become fully interchangeable with today's diesel vehicles. They then make an assumption about the year in which such a vehicle could become available (varying years depending on the vehicle category). For that year, they then estimate the cost of the required battery pack based on cost development forecasts (decreasing costs) as well as an 'inconvenience cost' from producing at smaller-scale (a cost that also decreases over time). When this is done, costs and savings are discounted to a present value in 2018. For e.g. tractors with semitrailer, this means discounting a 'constructed' investment cost occurring in 2024, back to 2018, as well as other cost components from operation during the vehicle's ownership period of 4 years, i.e. 2024-2027.

The remainder of this chapter discusses the methodology used to develop this model and the cost components that are taken into account (including their sources).

## 8.2 Methodology

To be able to compare the costs of vehicles with different propulsion technologies, it is crucial to take into account the most important cost components of different technologies and vehicle types.

Although existing studies take different approaches with regard to their level of detail (e.g. which cost components are included), their core generally consists of a cost function which covers, as a minimum, technology-dependent differences in capital costs and energy-/fuel costs (Ahani 2016, Zhou 2016). Further, as a main rule, all cost elements are discounted to their present value (Sen et al. 2017).

In our model, we follow existing studies by developing a (relatively detailed) cost function. We distinguish between technology-dependent costs (i.e. cost elements that may vary between different propulsion technologies), and technology-independent costs (which are equal or assumed to be equal for all propulsion technologies).

Particularly when it comes to conventional diesel vehicles, the model is to a large extent based on validated and updated base parameters from the National Freight Model for Norway (Grønland 2018). At the same time, many of our model parameters and assumptions are in constant development. This is particularly the case for the cost premiums of alternative propulsion technologies, developments in energy/fuel prices, and any levies charged by public authorities. Furthermore, increases in the use of and experience with alternative propulsion technologies will contribute to better estimates, e.g. on the costs of maintenance and repair. The fact that our model setup is flexible makes it relatively easy to periodically incorporate new developments and updated information/estimates.

## 8.3 Technology-dependent cost components

Technology-dependent cost components can be broken down further into time-dependent cost components, distance-dependent cost components, and maintenance costs. In addition, technology-dependent costs are influenced by a number of indirect factors.

### 8.3.1 Time-dependent costs

#### Investment and capital costs

As mentioned in chapter 6.6, vehicles with battery-electric propulsion currently come at an additional cost, or a cost premium compared to conventional diesel vehicles (see also (Ahani 2016, Barrett 2017, Lee et al. 2018).

For biodiesel vehicles, both vehicle users and manufacturers previously reported that such cost premiums were modest: FAME-based biodiesel was considered suitable for conventional ICE vehicles with only small modifications. In the case of vehicles that had been operated using fossil diesel previously, these modifications included relatively cheap actions such as tank cleansing and the changing of seals, gaskets and filters (Hovi and Pinchasik 2016). In the case of new vehicle purchases, synthetic biodiesel, i.e. from cellulose, feedstock, and HVO-based biodiesel, can now be used in regular diesel vehicles without modifications, and thus without an extra cost premium on investment compared to vehicles designed for fossil diesel.

Vehicles using biogas technology, in turn, do come at a significant cost premium compared to conventional vehicles, something that primarily can be attributed to their smaller scale of production and the higher cost of gas tanks compared to diesel tanks.

However, cost premiums compared to conventional diesel vehicles are clearly highest for battery- and hydrogen-electric vehicles. This is due to both relatively high costs of batteries, fuel cell systems, and other key components, and the fact that these technologies are still in an early market phase with low volumes (buses) and one-off conversions or retrofits, from vehicles with conventional combustion engines (trucks).

Figure 8.1 illustrates how investment costs of battery-electric vehicles (and one hydrogen truck) in different vehicle segments currently relate to comparable ICE vehicles, based on a Norwegian sample for which data was collected by the authors (blue bars). It should be noted that these estimates are based on a first, rough approach, and that data availability is limited, particularly for hydrogen vehicles[41].

For illustration, we also show investment cost premiums for several categories of battery-electric vehicles as implied in a study by the Norwegian Environment Agency (2018a) with orange bars. It should be noted that the delimitation of these vehicle categories might be slightly different from the definitions used in our study.

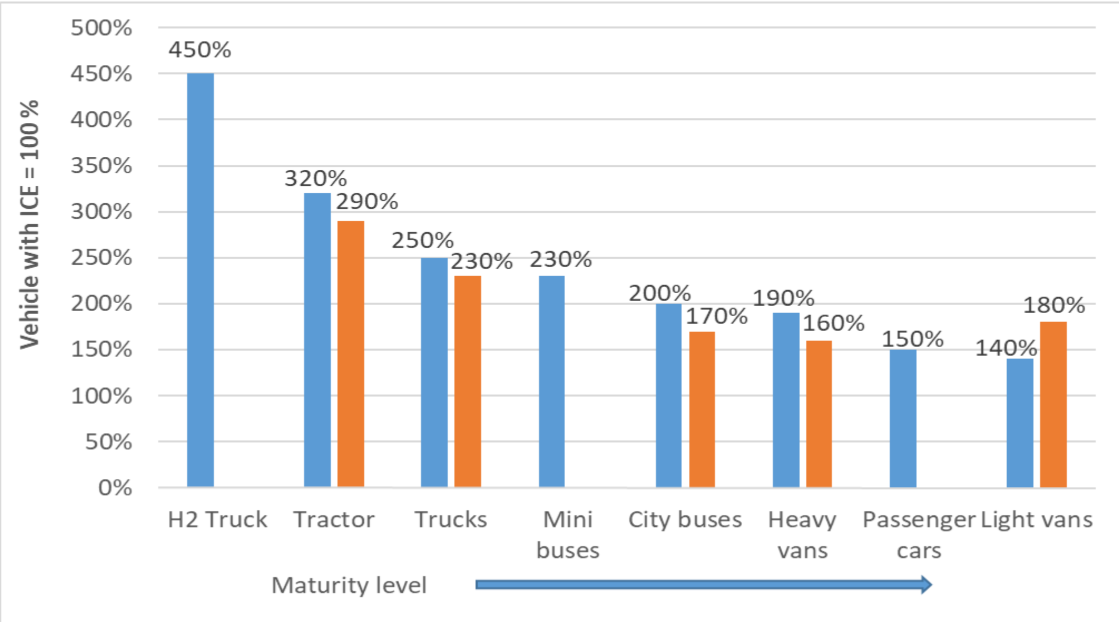



*Figure 8.1: Average investment cost premium for vehicles with battery-electric propulsion (and one hydrogen truck) relative to comparable vehicles with ICE. Based on a Norwegian sample, with data collected by the authors (blue bars), and on cost premiums implied in Norwegian Environment Agency (2018a) (orange bars).*

From the figure, it can be seen that cost premiums decrease with the maturity of electric propulsion technologies within a segment. The figure further confirms that for relevant vehicle categories, our estimates are in a similar order of magnitude as those implied in Norwegian Environment Agency (2018a).

[41] The observation for a hydrogen truck in the figure is based on the one truck currently in use in Norway. This limited number is one of the reasons for the larger focus on battery-electric vehicles in our analyses.

In the future, battery- and hydrogen-electric buses and trucks are expected to reach market stages with (cheaper) small-scale series production, and later the mass production of vehicles. It is therefore expected that over time, cost premiums compared to conventional vehicles will decrease materially (IEA 2018), as they have for e.g. passenger vehicles. In our analysis, this is reflected by looking at four production phase scenarios (described in more detail in chapter 9.2).

In the context of this study, it is desirable to distinguish between the reference investment costs of a vehicle (the conventional diesel alternative) and the cost premium of similar-type vehicles with alternative propulsion technologies.

With regard to (reference) capital costs for conventional diesel vehicles, our starting point for distribution trucks and tractors for semitrailers consisted of 2018 cost parameters as used in the National Freight Model. For vans, (reference) capital costs for diesel vehicles stem from a decomposition of listed prices for specified version of the Nissan NV200 (small vans) and the Volkswagen Crafter (medium vans). Listed prices are those used by the Norwegian Tax Administration (2019) and a fee/levy calculator for 2018 by Yrkesbil (2017)[42]. The reason for looking at these specific vehicle models is one of comparability: these are the only models within the small and medium van segments for which a comparable and official listed price is currently available also for their battery-electric version. On top of the base price of diesel, biodiesel, and biogas vans, the model includes a vehicle-specific registration fee and wrecking fee. Battery-electric (and hydrogen fuel cell) vans are exempt from these fees.

With regard to current cost premiums of vehicles with alternative propulsion technologies, estimates come from several sources. For biogas vehicles, estimates are based on data collected for the TØI report on a possible $CO_2$-fund for the Norwegian transport industry (Hovi and Pinchasik 2016) and respective updates/verifications using feedback from relevant actors in the Norwegian transport sector[43], including one of the main vehicle suppliers in Norway.

For battery- and hydrogen-electric vehicles, information on cost premiums for distribution trucks and tractors for semitrailers is largely based on the (very few) observations and experience from manufacturers and relevant Norwegian users/purchasers and suppliers in chapter 6, as well as sanity checks based on existing literature. The fact that such estimates are only available to a very limited extent has so far been a challenge in most related studies (Sen, Ercan et al. 2017). However, it is expected that data availability will improve in the future, given the increases in production scale and practical adoption expected for the coming decades.

For small and medium vans, information on current cost premiums for battery-electric vehicles is based on a comparison of (decomposed base) prices of the comparable conventional and battery-electric versions of the models mentioned above.

Cost premiums for hydrogen-electric vehicles, in turn, stem from information from respectively a purchaser and a supplier of heavy distribution trucks. Based on a decomposition, we derived 'early phase' cost premium estimates also for light distribution trucks and for tractors for semitrailers. For vans, we have chosen not to include cost comparisons of hydrogen alternatives due to a lack of and large uncertainty in cost data.

[42]Both these sources are based on the 'Vehicle database' of OFV, the Norwegian 'Information Council for Road Traffic' For the decomposition, we split up listed prices in VAT, vehicle-specific registration fee, wrecking fee, and the vehicle's base price excluding other components.

[43]As for biodiesel, new vehicles no longer come at a cost premium, this premium is set to zero in this report.

With regard to how cost premiums of alternative technologies develop with production phase maturity, we make a number of assumptions that are discussed in the scenario description in chapter 9.2.

An overview of assumptions on reference investment costs and cost premiums used in this study can be found in Appendix 2.

### Subsidies

Chapter 2.3 discussed that in certain cases, subsidies are available, partially covering the cost premium of zero-emission or biogas vehicles, and thereby reducing net investment costs for purchasers of such vehicles (but not costs of operation). However, as discussed, subsidies are only granted in a limited number of cases (or are limited in the case of the newly introduced scheme for vans)[44], and because one of the aims in this project is to illustrate when alternative propulsion vehicles can be competitive on their own, subsidies are not included in our model's cost functions. This is also in line with ENOVA's objective to trigger permanent market changes which in time become and remain a preferred alternative, even when subsidies are no longer available.

### Depreciation, residual values, and discount rate

In addition to varying investment costs, an important characteristic of alternative propulsion technologies is that technology-induced expenses and savings occur at different times throughout the vehicles' lifetime. As such, depreciation, residual values, and the typical lifetime/use period of vehicles are important aspects to consider when comparing costs across technologies (Sengupta 2017).

With regard to deprecation periods/periods of analysis, the literature takes different approaches. One approach is to analyze both lifecycle costs and 5-year vehicle costs of ownership (Zhou 2016), while others (Sengupta 2017) look at a 7-year horizon, based on the average replacement rate for the vehicle fleet they analyze. IEA (2018) looks at 10-year costs of ownership, based on the length of 'typical global ownership periods'.

In our model, the period of analysis is set to 5 years. This assumption is based on average vehicle leasing periods given in the cost functions in the National Freight Model[45]. Leasing periods are further considered equal across all technologies. Using periods of analysis of 5 years should be regarded as a conservative assumption for alternative propulsion technologies, as this entails that investment cost premiums (minus expected residual values) are spread out over relatively few years, and therefore are relatively high per driven kilometer. In addition, total savings on energy/fuel costs (see distance-dependent costs) versus conventional vehicles are smaller the shorter the time horizon that is used, again constituting a conservative assumption.

With regard to residual values, assumptions can be topic of discussion (Zhou 2016, Sengupta 2017, Norwegian Environment Agency 2018a), amongst others in light of the (current) lack of a second-hand market and thus of observed resale prices. Examples from the Norwegian market for passenger cars suggest that leasing companies initially assumed

[44] For the battery-electric van models discussed in this report, this new subsidy scheme would reduce the purchase price of a battery-electric version by about 8-9%, but leaves sizable cost premiums compared to regular diesel versions of the same vans.

[45] For semi-trailers, the leasing period in the National Freight Model is 4 years. This seemed somewhat short given the periods of analysis discussed above and in light of experience from other analyses. The Norwegian Environment Agency (2018) in their study also describes that industry partners report ownership periods of 3-5 years.

very low residual values for battery-electric vehicles due to the lack of information and data on battery lifetimes. When the market became more mature, residual values normalized but were still somewhat lower in 2015 for battery-electric vehicles than for gasoline vehicles (Kolbenstvedt et al. 2015). The rapid technical development also leads to lower residual values.

Assumptions on residual values in our analysis build on data from the National Freight Model for diesel vehicles, while for the other technologies, we assume the same residual value *share* of the vehicles' original values. Depending on the production phase scenario (see chapter 9.2), the residual value for battery-electric and hydrogen vehicles is further discounted (multiplied by a factor of 50 % in the scenario with early stages of production, 75 % under small-scale series production, and 100 % under mass production) to represent uncertainty associated with the second-hand market for vehicles with early-phase technology.

Finally, it is important to consider the discount rate, as future costs (and savings) have to be translated into present values. This is for example the case for future residual values or for energy-/fuel expenses that occur throughout the vehicles' lifetime. In the literature, the discount rate is often chosen based on public guidelines or similar vehicle cost analyses, sometimes supplemented with a sensitivity analysis (Ahani 2016, Zhou 2016, Sengupta 2017).

In our analysis, we have used a discount rate of 3.5 %, based on an upward adjustment from the rate used in the National Freight Model[46]. This discount rate stems from the commercial finance cost. In Norway, and for vehicles, this means leasing, for which interest rates are relatively low.

### 8.3.2 Distance-dependent costs

According to the International Energy Agency (IEA 2018), cost differentials between electric and conventional vehicles are significantly reduced the more intensively vehicles are used. At the same time, the current driving range of battery-electric vehicles effectively sets a limit to the distance that can be driven over the course of a year. As long as battery-electric vehicles exhibit limitations compared to conventional vehicles, cost comparisons will, at least partially, compare apples with pears, or have to be limited to use cases where the vehicles are interchangeable.

Table 8.2 gives an overview of the annual mileages assumed in our analyses, for the different vehicle types and for all technologies. The parameters in this table are based on mileages for different vehicle types used in the National Freight Model, and adjusted to reflect annual mileages that are feasible for battery-electric operation.

The implication of this adjustment is that particularly for the heavier vehicles (where driving ranges currently are most restrictive), we effectively look at whether alternative propulsion vehicles can compete with conventional vehicles in use cases with urban and regional distribution patterns. Not adjusting mileages and assuming mileages that are more typical for long-haul transport operations, would result in a lower per-km costs for alternative technologies, as fixed cost elements can be spread out over higher mileages. However, while possibly more feasible in the long term, it is currently not long-haul transport cases where conventional vehicles are most replaceable.

[46] The National Freight Model uses a discount rate of 2.5%, but this parameter stems from 2016, after which interest rates have increased slightly. In addition, 2.5% seemed somewhat low in the context of literature generally using rates >3%.

*Table 8.2: Overview of annual mileages assumed for different vehicle types.*

| Vehicle types | Annual mileage in km |
|---|---|
| Light distribution truck | 45 000 |
| Heavy distribution truck (closed unit) | 45 000 |
| Tractor for semi-trailer | 45 000 |
| Small van | 20 000 |
| Medium van | 25 000 |

## Energy costs and energy efficiency

When it comes to distance-dependent costs, energy costs are the most important cost component and differential. Energy costs depend on fuel type, energy efficiency (the vehicle's energy-/fuel consumption), energy prices, and distance driven.

To model energy costs for regular diesel vehicles, we use the same fuel consumption and price parameters that are used for the corresponding vehicle type in the National Freight Model. These parameters are regularly updated and available for different vehicle types/sizes. For biodiesel vehicles, fuel consumption is based on the same source, and takes into account the fact that fuel consumption is slightly higher for biodiesel than is the case for fossil diesel[47]. For biogas, battery-electric, and hydrogen vehicles, parameters for energy consumption are based on information supplied by relevant users and suppliers[48]. An overview of energy consumption parameters used in our analysis can be found in Appendix 2.

Price parameters, in turn, come from Statistics Norway and/or distributor's online price lists, and are summarized in Table 8.3 As for all cost elements in our analysis, fuel/energy prices are modeled excluding VAT, but include currently applicable levies such as the $CO_2$ and road use levies on regular diesel. Because it can be expected that such levies will in the future be used as policy instruments for incentivizing of discouraging the use of certain propulsion technologies, our model further allows for distinguishing between the base prices of energy/fuels, and any applicable taxes or levies that come on top.

*Table 8.3: Overview of fuel/energy prices used in our analysis (in NOK). Modeling is done excluding VAT but including any levies. Prices are assumed to remain constant throughout the period of analysis.*

| Fuel/energy type | Unit | Price excl. levies and VAT | $CO_2$-levy | Road use levy | Total price incl. VAT |
|---|---|---|---|---|---|
| Diesel | Liter | 6.24 | 1.33 | 3.75 | 14.15 |
| Biodiesel[49] | Liter | 11.42 | | | 14.28 |
| Biogas | Liter | 11.00 | | | 13.75 |
| Hydrogen | Kg | 72.00 | | | 90.00 |
| Hydrogen (low price scenario) | Kg | 36.00 | | | 45.00 |
| Electricity[50] | kWh | 0.67 | | | 0.83 |
| Electricity – fast charging premium | kWh | 1.00 | | | 1.25 |

[47] Biodiesel has a slightly lower energy content per liter, compared to fossil diesel.

[48] For vehicle types where specific information was not available for all propulsion types, consumption was calculated based on the energy content of different energy sources and the ratio of the energy source in question to diesel, for vehicle types where information for both was available.

[49] Biodiesel of type B100. At the time of writing, biodiesel of type HVO100 is 25% more expensive.

[50] Based on Statistics Norway's electricity price for business consumers for Q1 2019, including grid costs.

For electricity, in addition to a price for regular charging, we have added a cost component to reflect higher prices for fast charging, e.g. due to the larger power output required for fast charging. At public fast chargers, per kWh-prices tend to be considerably higher than for regular charging at e.g. a depot. At private chargers, fast charging will also be more expensive than regular charging, but exact amounts will depend on a number of situation-specific factors. In our analyses, we have assumed that fast charging costs 150 % the per-kWh price of regular charging.

It should further be noted that the price of hydrogen at most Norwegian filling stations has been 72 NOK/kg (90 NOK/kg incl. VAT) for a number of years. This price is set by the operators of the fuel stations to yield a similar per-km cost as would be the case using petrol, and doesn't reflect the actual supply/production costs of hydrogen at the current small scale (Dagbladet 2017, Hydrogen.no 2019).

At larger scales of demand and production, however, hydrogen prices can become considerably lower than the current pump price due to economies of scale. Based on estimates from a study by Greensight (2017), illustrated in Figure 8.2, and input from a firm producing their own hydrogen to be used for their own vehicles, we therefore also consider a scenario where hydrogen prices are 50 % lower. Factors contributing to such price decreases may be larger production volumes externally and/or increased demand for hydrogen, as well as cheaper self-production in the future.

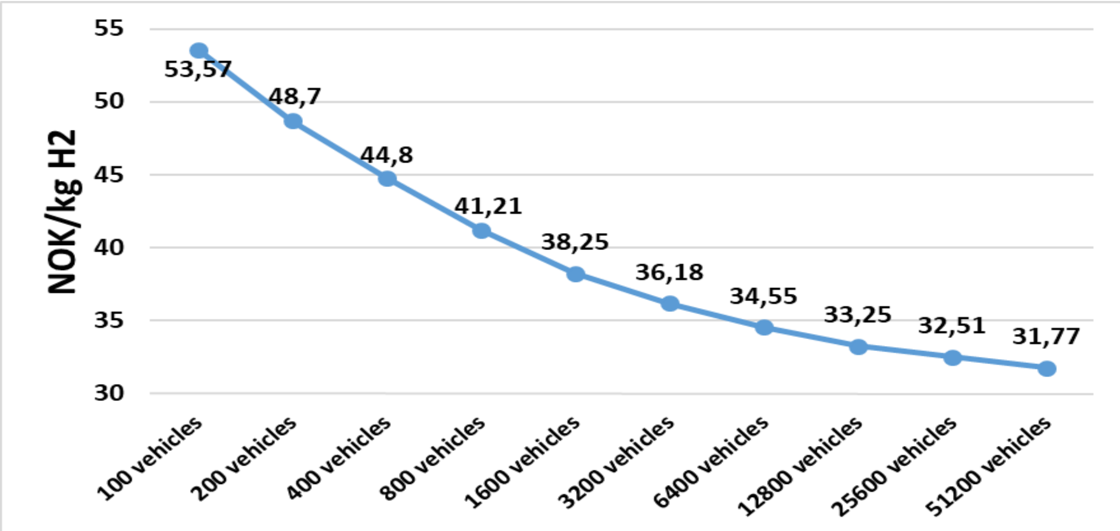



*Figure 8.2: Economies of scale in hydrogen production, Norwegian national perspective. Adapted from: Greensight (2017).*

Finally, it should be noted that our model assumes that the price of diesel remains constant (similar to e.g. Ruter (2018)). Some studies (Zhou 2016, Sen, Ercan et al. 2017) operate with diesel prices that increase over time[51]. This would increase the difference in energy costs between diesel and alternative propulsion vehicles in favor of the latter.

## Toll and ferry charges

Other distance-dependent costs are toll and ferry charges. Norwegian toll schemes have become the subject of heavy public debate following the introduction of new tolling

[51] Based on expectations of increasing prices on the global oil market and/or increased taxation of fossil fuels.

stations and increasing toll rates. In 2018, Norwegian Parliament adopted a proposal stating that toll charges for zero-emission vehicles can be set locally, and can vary between 0 and 50 % of the rates for conventional vehicles, after deduction of discounts (Norwegian Parliament 2018, Vegnett 2018). Although this decision entails that zero-emission vehicles in 'tariff group 1', i.e. passenger cars and vans, might lose their toll exemptions, commercial zero-emission vehicles over 3 501 kg ('tariff group 2') will keep their exemption status for the time being. Specifically for the Oslo toll ring, vehicles using pure biogas will in the future likely also receive reduced toll rates, but the practical implementation and implementation date is still to be decided upon (Aftenposten 2019, Avfallsbransjen 2019). Any such toll discounts are therefore not taken into account in our model.

As toll expenses depend on when, which and how often toll stations are passed, they may vary, meaning that cost savings from using zero-emission vehicles may also vary. To take into account toll expenses/savings, our model builds on estimates provided by the interviewed firms in chapter 6. In these estimates, incurred toll expenses are related to annual driving distances, suggesting an average cost of around 1 NOK/km. After the opening of new toll stations in Oslo from June 2019, it has become more complicated to estimate the maximum rate of savings in toll costs for a truck operating in Oslo.

However, these estimates stem from driving both in urban areas (with urban toll rings) and non-urban areas with fewer tolls, and also include vehicles with longer mileages (and as such lower per-km costs) than the mileages assumed in our analyses. Particularly battery-electric vehicles will, for the time being, predominantly be used on shorter distances and in urban areas. We have therefore chosen to focus on toll expenses in urban areas, with particular focus on Oslo.

In Oslo, toll expenses for the vehicles in this study are limited to just over 60 000 NOK per year. This is due to monthly ceilings amounting to ca. 2 toll passages per day. Because most vehicles that predominantly drive locally, have annual mileages below 60 000 km, but would generally hit or approach such monthly ceilings, their toll expenses per km will be higher than 1 NOK/km. In our model, we have therefore used an estimate of 1.5 NOK/km, but with a ceiling of 60 000 NOK annually.

### 8.3.3 Maintenance and repair costs

With regard to maintenance and repair costs for conventional vehicles, our cost functions build on regularly updated estimates from the National Freight Model (Grønland (2018), in which these costs are subdivided into general maintenance, tyre degradation, and wash, consumables, etc., and distinguish between different vehicle types[52].

While for the latter few components, little variation is expected between the different propulsion technologies, general maintenance costs are often assumed to be significantly lower for battery-electric and hydrogen/fuel cell vehicles. The main reasons for this assumption are that conventional vehicles consist of many more moving parts, require fluid changes, and experience stronger vibrations (Barrett 2017, ICCT 2017, Sen, Ercan et al. 2017), see chapter 6.6.

How large differences in maintenance costs are, or will become, however, is uncertain. Some (Zhou 2016) assume that maintenance costs for electric trucks make up around 30-50 % of the costs for a similar diesel vehicle, whilst others (Jadun 2017) expect the cost

[52] For distribution trucks and tractors for semitrailers, estimates stem from the corresponding vehicle categories in the National Freight Model, while for small and medium vans, estimates stem from the vehicle category 'Light Goods Vehicles'.

difference to increase following increasing use of battery-electric/fuel cell vehicles and increased maintenance experience.

The few observations based on Norwegian user experiences in Chapter 6.6 do not provide clear-cut answers either, but suggest that particularly in the current early phase, with very small-scale and inexperienced use, savings potentials have not yet fully been achieved. This might be amplified by early-phase uncertainty about the lifetime of electric batteries in practice: although physically replacing batteries is not necessarily very expensive, the replacement batteries themselves come at a significant cost. If firms recognize a need to factor in this risk (e.g. by reserving funds or entering into service level agreements), this effectively adds to the costs of operation of battery-electric vehicles vis-à-vis other technologies.

In our analyses, we have chosen to base general maintenance costs for diesel, biodiesel and biogas vehicles on the cost estimates from the National Freight Model, while for battery-electric and hydrogen/fuel cell vehicles, we have assumed that maintenance costs are 50 % of the level of conventional vehicles.

An overview of model assumptions on general maintenance costs for different vehicle categories and propulsion technologies is found in Appendix 2.

## 8.4 Technology-independent cost components

Technology-independent costs are costs that are equal across all propulsion technologies. A number of cost components presented here as technology-independent, might strictly speaking vary somewhat between technologies. However, these variations are considered to be small enough that they are unlikely to have a significant impact on the competitiveness of different technologies.

### 8.4.1 Insurance and administration

With regard to insurance premiums and administration costs, it can be argued that costs currently are somewhat higher for vehicles with alternative propulsion systems than for conventional vehicles. Insurance policies for these vehicles would for example cover higher values, and spare parts could be more costly, which could lead to on average higher insurance premiums. Also administration costs could in practice be somewhat higher due to new and unfamiliar aspects and the small scale introduction of alternative technologies in vehicle fleets, and due to a more active follow-up during the day to optimize the use and range of an electric truck.

However, there are currently still very few credible observations on cost differences between technologies in this respect, and because these cost elements make up only a small share of annual costs, any differences between technologies will either way only play a marginal role. We therefore assume that these costs are equal for all propulsion technologies, i.e. that they are technology-independent. In order to be able to present not only differentials, but also the total costs of ownership and relative shares of different cost components, insurance and administration costs are included in our model. Parameters are based on values from the National Freight Model[53].

[53] For small and medium vans, parameters used are those for the vehicle category 'Light Goods Vehicles' in the National Freight Model.

### 8.4.2 Annual weight fee

Until 2017, vehicles below 7 500 kg were subject to an annual weight fee, a yearly cost of several thousand NOK. This scheme has now been replaced by a 'traffic insurance fee' which is paid in through insurance companies.

For heavier trucks (7 500+ kg), an annual weight fee is set based on weight, number of axles, and suspension system. In addition, diesel vehicles are subject to an environmentally differentiated fee, which increases their costs compared to zero-emission vehicles. However, the environmentally differentiated component of the annual weight fee is small (under 1 400 NOK annually for the heaviest diesel vehicles with Euro V-engine, down to several hundred NOK for lighter vehicles or vehicles with Euro VI-engine). This yields such small differences, that the annual weight fee in practice can be regarded as technology-independent (Norwegian Tax Administration 2018a, Norwegian Tax Administration 2018b).

Because there are ongoing policy discussions about environmentally motivated changes to the current system, both the 'traffic insurance fee' and annual weight fee are included in our model, but will be seen to hardly differ between technologies.

### 8.4.3 Wage costs

Although wage costs for HDVs are assumed to be equal for all technologies[54], they are included in our model to illustrate their share in the total costs of operation and their importance compared to other cost drivers. Wage costs are based on parameters from the National Freight Model (for an overview, see Appendix 2): in addition to wage, they include social and holiday costs, with an underlying assumption of a 80 % activity rate (i.e. that 80 % of the wage costs are attributed to operational costs of a vehicle).

For vans, we have chosen not to include wage costs in our analyses. Main reasons for this are that drivers often are not dedicated to driving, but primarily have other assignments (e.g. craftsmen), and that many fewer hours are spent in the vehicle given the much shorter average annual mileage of vans than of HDVs.

### 8.4.4 Costs of tyre degradation, wash, consumables, etc.

As discussed in section 8.3.3, the National Freight Model subdivides maintenance and repair costs into general maintenance, and costs of tyre degradation and expenditures on washing, consumables, etc. Unlike for general maintenance, the latter few cost components are expected to exhibit little variation between the different propulsion technologies. In our model, these costs are therefore assumed to be equal across technologies, with parameters based on regularly updated estimates for the different vehicle types, from the National Freight Model.

[54] In practice, particularly in earlier phases of introduction, wage expenses might be somewhat higher for vehicles with alternative technologies. We saw previously that this can be the case if limitations of the new technologies reduce operational stability/necessitate back-up capacity and requires compensating measures, such as purchasing more vehicles or having more employees at work in order to operate at the same capacity Ruter (2018). Utslippsfri kollektivtransport i Oslo og Akershus', Versjon 10.

## 8.5 Costs of filling and charging infrastructure

Regular diesel is readily available at Norwegian filling stations, and although access to pure biodiesel is more limited today, its supply can be increased relatively easily through pumps at regular filling stations, without the need for material upgrades or construction. Access to suitable filling and charging infrastructure is currently still considerably more challenging for hydrogen vehicles, (larger) battery-electric vehicles, and vehicles using biogas. Such vehicles therefore still require (partially private) investments in filling/charging infrastructure, which often also requires additional space. Although user experiences in chapters 5 and 6 provided some insights in the costs of such infrastructure, it is not straightforward to attribute such costs to individual vehicles. The Norwegian Environment Agency (2018a) for example finds that the same charging infrastructure can often be used by multiple vehicles (affecting the costs attributed to one vehicle), and that the number, timing, and cost distribution can vary. For the time being, we have assumed that small scale charging based on 44 kW industry plugs with use of charger in the vehicle, is available.

# 9 Truck cost analysis: Results

## 9.1 Introduction

The current chapter presents results from the cost comparison model, for which methodology, assumptions, and parameters were described in the previous chapter. Cost comparisons are presented for five different vehicle types, and four scenarios of production phase maturity for battery-electric (all vehicle categories) and hydrogen vehicles (only HDVs).

With regard to the analyzed scenarios it should be noted that cost estimates for the current early production phase are based on the interviews, feedbacks, and information discussed in Chapter 6, while for future stages of production maturity, cost estimates (and thus results) are based on a first, rough approach as described in chapter 8.1. Particularly for hydrogen-electric vehicles, cost development paths are necessarily uncertain, since very limited information is available, and information that is available is based on a very early development stage, characterized by small production volumes of all components. Both for battery-electric and hydrogen-electric vehicles, we are therefore working on a more elaborate and detailed techno-economical approach for expected developments in costs of alternative technologies, in order to improve our estimates.

## 9.2 Scenarios

In the first, or base scenario, we consider today's status, with reference investment costs (for conventional diesel vehicles) and cost premiums (for alternative technologies) and assumptions as set out in Chapter 8.3 and illustrated in Appendix 2. In this scenario, battery- and hydrogen-electric HDVs are still in an early market stage, and are generally rebuilt versions or 'retrofits' of conventional vehicles. As such, investment cost premiums compared to conventional vehicles are relatively high.

Battery-electric small and medium vans, however, can be said to have surpassed the early pilot stage and are not included in the comparisons for the early stage scenario. Indeed, the cost premium of e.g. a Nissan e-NV200 compared to a similar diesel-based version is first introduced in the second scenario: small-scale series production.

In the second scenario, we assume small-scale series production of battery-electric and hydrogen vehicles, so that the cost premium for these technologies is lower than in the base scenario. We assume that battery-electric vehicles are twice as expensive as comparable conventional diesel vehicles, while hydrogen vehicles (HDVs only) are assumed to be three times as expensive as conventional vehicles.

The third scenario assumes the same small-scale series production and costs of battery- and hydrogen-electric vehicles, but with lower fuel price of hydrogen. These potential price decreases were discussed in chapter 8.3.2, based on the study by Greensight (2017) and cost-estimates for self-production by a Norwegian transport firm.

In the fourth scenario, we assume mass production of battery-electric vehicles, implying considerable reductions in cost premium reductions for both HDVs and for vans. In the model, mass production is operationalized as battery-electric vehicles being 1.5 times as expensive as conventional diesel vehicles, while the investment costs of hydrogen vehicles (HDVs only) is assumed to have decreased to double the level of conventional vehicles. Given that mass production is expected only in the medium- to long term, and (in the case of hydrogen vehicles) would imply considerable increases in demand for hydrogen as a fuel, it is reasonable to assume the same lower hydrogen prices as in the third scenario.

## 9.3 Base scenario/early phase

### 9.3.1 Light distribution trucks

Table 9.1 shows decomposed ownership costs per km for light distribution trucks, based on the inputs discussed in the previous chapter. In line with the assumption discussed in chapter 8, per-km costs are based on an annual mileage of 45 000 km for this vehicle category. Wage costs are included as separate category, to illustrate their order of magnitude compared to other cost drivers.

*Table 9.1: Decomposed ownership costs for light distribution trucks. Base scenario/early stage. Figures in NOK/km. Based on an annual mileage of 45 000 km for this vehicle segment.*

| | Diesel | Biodiesel | Biogas | Hydrogen | Battery-electric |
|---|---|---|---|---|---|
| Base investment | 3.39 | 3.39 | 3.39 | 3.39 | 3.39 |
| Investment premium | - | 0.00 | 0.93 | 14.31 | 8.78 |
| Wage costs (incl. social/holiday) | 9.15 | 9.15 | 9.15 | 9.15 | 9.15 |
| General levies | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 |
| Insurance + admin | 0.52 | 0.52 | 0.52 | 0.52 | 0.52 |
| Fuel/energy, excl. levies | 1.39 | 2.79 | 2.42 | 2.49 | 0.45 |
| $CO_2$-levy | 0.30 | - | - | - | - |
| Road use levy | 0.84 | - | - | - | - |
| Premium in case of fast charging | - | - | - | - | 0.22 |
| Tyres, wash, consumables, etc. | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 |
| General maintenance | 0.68 | 0.68 | 0.68 | 0.34 | 0.34 |
| Road toll | 1.33 | 1.33 | 1.33 | - | - |
| | | | | | |
| **Total incl. wage costs** | **18.42** | **18.67** | **19.24** | **31.01** | **23.66** |
| **Total excl. wage costs** | **9.27** | **9.52** | **10.08** | **21.86** | **14.50** |
| | | | | | |
| **Index incl. wage costs (diesel=100%)** | **100%** | **101%** | **104%** | **168%** | **128%** |
| **Index excl. wage costs (diesel=100%)** | **100%** | **103%** | **109%** | **236%** | **157%** |

From the table it can be seen that in the base scenario, hydrogen- and battery-electric operation are considerably more expensive than the other propulsion technologies. For light distribution trucks, vehicle-related ownership costs vary between ca. 9.3 NOK/km (diesel) and 21.9 NOK/km (hydrogen). On top of this come wage costs of around 9.1 NOK/km. This implies that for diesel-based light distribution trucks with average annual mileages, vehicle- and driver-related ownership costs make up about half of the total costs of operation each. All in all, at the mileages assumed here, vehicle-related ownership costs for battery-electric light distribution trucks are 57 % higher than for diesel operation, while hydrogen operation is 136 % more expensive. If also wage costs are taken into consideration, ownership costs for a battery-electric truck are nearly 30 % higher than for a diesel truck.

A second observation is that in the bigger picture, general levies (such as the annual weight fee), administration and insurance costs, wash, consumables, and tyre degradation costs are relatively small. Also general maintenance expenses (and potential cost savings for battery-electric and hydrogen-electric vehicles) seem to be relatively modest cost drivers.

Of particular interest are therefore the remaining cost components. Comparing diesel, biodiesel, and biogas operation, it should be noted that while costs for regular diesel in itself are lower, diesel operation is subject to the $CO_2$- and road use levies. In total, this makes distance-dependent costs for diesel slightly lower than for biodiesel operation, but slightly higher than for biogas vehicles. For biogas, however, this slight cost advantage is not enough to cover the cost premium of investment at the annual mileages assumed here.

Focusing on battery-electric operation, energy costs per-km are clearly the lowest of all technologies, even when including the cost premium assumed for fast charging. In addition come savings from road toll exemptions, although with around 1.33 NOK/km, this forms a relatively modest cost saving in the total costs, and neither savings on energy or road toll expenses are enough to compensate for the significant investment cost premium in this early phase of production.

Also for hydrogen, the toll exemption plays only a modest role. Currently, hydrogen's disadvantage is particularly the high cost premium of investment.

Figure 9.1 illustrates how per-km ownership costs for light distribution vehicles decrease with higher annual mileages, as fixed cost elements such as the investment cost premium are spread out over more kilometers. The lines in the figure include wage costs, but these only affect the level of the curves, not the relative position or cutting points between different propulsion technologies.

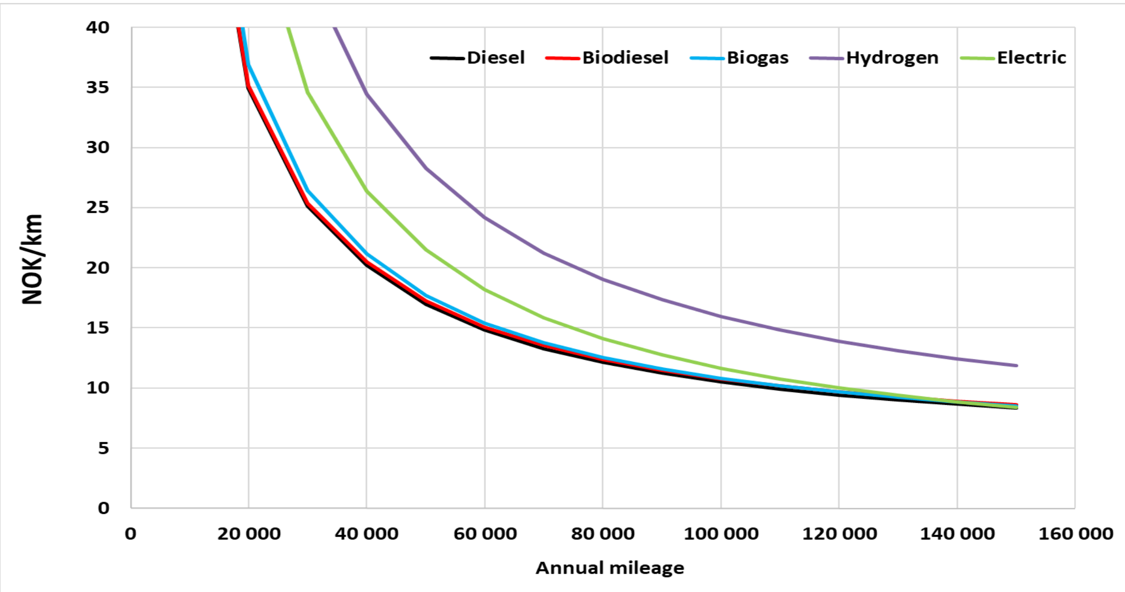



*Figure 9.1: Ownership costs and competitiveness of light distribution trucks with different propulsion technologies, for different annual mileages, in Base scenario/early stage.*

It can be seen that lower annual mileages will increase the per km cost, while higher annual mileages will decrease the per km cost, and since the slope is among others also dependent on the energy costs, there will be cost parity for the E-truck and the truck with diesel engine if the annual mileage is high enough. For the light distribution trucks, it currently takes unrealistically high annual mileages for battery-electric vehicles to be cost competitive with (bio)diesel or biogas operation (especially with current driving range limitations and charging requirements). Further, hydrogen operation of light distribution vehicles is currently more expensive regardless of mileage.

Although similar figures can be shown for all vehicle types and all scenarios, for reasons of space, we have chosen to summarize the mileages at which battery-electric and hydrogen operation become competitive versus diesel operation, in one table in section 9.6. This is done per vehicle type and for the different scenarios.

### 9.3.2 Heavy distribution trucks

For heavy distribution trucks, decomposed ownership costs per km are shown in Table 9.2 Per-km costs are again based on the annual mileages discussed in chapter 8, i.e. 45 000 km for heavy distribution trucks.

*Table 9.2: Decomposed ownership costs for heavy distribution trucks. Base scenario/early stage. Figures in NOK/km. Based on an annual mileage of 45 000 km for this vehicle segment.*

| | Diesel | Biodiesel | Biogas | Hydrogen | Battery-electric |
|---|---|---|---|---|---|
| Base investment | 4.49 | 4.49 | 4.49 | 4.49 | 4.49 |
| Investment premium | - | - | 1.26 | 16.61 | 10.58 |
| Wage costs (incl. social/holiday) | 9.15 | 9.15 | 9.15 | 9.15 | 9.15 |
| General levies | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 |
| Insurance + admin | 0.63 | 0.63 | 0.63 | 0.63 | 0.63 |
| Fuel/energy, excl. levies | 1.88 | 3.76 | 3.26 | 3.36 | 0.60 |
| $CO_2$-levy | 0.40 | - | - | - | - |
| Road use levy | 1.13 | - | - | - | - |
| Premium in case of fast charging | - | - | - | - | 0.30 |
| Tyres, wash, consumables, etc. | 0.94 | 0.94 | 0.94 | 0.94 | 0.94 |
| General maintenance | 0.76 | 0.76 | 0.76 | 0.38 | 0.38 |
| Road toll | 1.33 | 1.33 | 1.33 | - | - |
| **Total incl. wage costs** | **20.74** | **21.08** | **21.84** | **35.58** | **27.09** |
| **Total excl. wage costs** | **11.59** | **11.92** | **12.69** | **26.42** | **17.93** |
| **Index incl. wage costs (diesel=100%)** | **100%** | **102%** | **105%** | **172%** | **131%** |
| **Index excl. wage costs (diesel=100%)** | **100%** | **103%** | **109%** | **228%** | **155%** |

Here, it can be seen that per-km costs for heavy distribution trucks are somewhat higher than for lighter trucks, and vary from 11.6 NOK/km (diesel) to 26.4 NOK/km (hydrogen). The difference is mainly caused by the higher base investment and higher fuel consumption of heavy distribution trucks compared to light distribution trucks, and – particularly for hydrogen and battery-electric operation – the higher investment cost premium compared to conventional operation. On top of this again come wage costs of around 9.1 NOK/km.

All in all, at the mileages assumed here, vehicle-related ownership costs for battery-electric heavy distribution trucks are 55 % higher than for diesel operation, while hydrogen operation is 128 % more expensive. Relatively speaking, the cost difference between technologies thus is slightly smaller than for light distribution trucks.

Also for heavy distribution trucks, we find that general levies (such as the annual weight fee), administration and insurance costs, wash, consumables, and tyre degradation are relatively small cost drivers in the bigger picture, and also potential savings on general maintenance seem to be relatively modest.

Due to the higher energy consumption of heavy distribution trucks, however, cost savings of using electricity rather than other fuels are higher per km, but despite additional savings from the toll exemption (around 1.33 NOK/km), not enough to compensate for the high investment cost premium.

For heavy hydrogen trucks, the toll exemption also only plays a modest role in light of the high cost premium of investment.

An overview of what mileages are required for alternative technologies to become competitive is given in a summary table for all scenarios, in section 9.6.

### 9.3.3 Tractors for semitrailer

For tractors for semitrailers, decomposed per-km ownership costs (assuming annual mileages of 45 000 km) are shown in Table 9.3.

*Table 9.3: Decomposed ownership costs for tractors for semitrailers. Base scenario/early stage. Figures in NOK/km. Based on an annual mileage of 45 000 km for this vehicle segment.*

| | Diesel | Biodiesel | Biogas | Hydrogen | Battery-electric |
|---|---|---|---|---|---|
| Base investment | 4.67 | 4.67 | 4.67 | 4.67 | 4.67 |
| Investment premium | - | - | 1.19 | 24.28 | 18.38 |
| Wage costs (incl. social/holiday) | 9.15 | 9.15 | 9.15 | 9.15 | 9.15 |
| General levies | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 |
| Insurance + admin | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 |
| Fuel/energy, excl. levies | 2.81 | 5.62 | 4.88 | 5.03 | 0.90 |
| $CO_2$-levy | 0.60 | - | - | - | - |
| Road use levy | 1.69 | - | - | - | - |
| Premium in case of fast charging | - | - | - | - | 0.45 |
| Tyres, wash, consumables, etc. | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 |
| General maintenance | 0.93 | 0.93 | 0.93 | 0.46 | 0.46 |
| Road toll | 1.33 | 1.33 | 1.33 | - | - |
| **Total incl. wage costs** | **23.09** | **23.60** | **24.06** | **45.49** | **35.92** |
| **Total excl. wage costs** | **13.94** | **14.45** | **14.90** | **36.34** | **26.76** |
| **Index incl. wage costs (diesel=100%)** | **100%** | **102%** | **104%** | **197%** | **156%** |
| **Index excl. wage costs (diesel=100%)** | **100%** | **104%** | **107%** | **261%** | **192%** |

It can be seen that for semitrailer tractors, vehicle-related ownership costs vary from 13.9 NOK/km for diesel vehicles, to 36.3 NOK/km for hydrogen tractors. On top of this come wage costs of around 9.1 NOK/km. Reasons for vehicle-related costs being higher than for distribution trucks are primarily the higher fuel consumption of tractors, and a higher investment premium when opting for battery-electric or hydrogen propulsion. At the mileages assumed here, this implies that vehicle-related costs of ownership for battery-electric and hydrogen vehicles respectively are around 92 % and 161 % higher per km, than is the case for comparable diesel vehicles.

Again, we find that a number of cost elements are only small cost drivers in the bigger picture. Most relevant are per-km costs savings relating to fuel, and to a modest extent toll savings from battery- and hydrogen-electric operation. Potential savings on general maintenance are relatively small in the bigger picture, and together, these savings are not enough to compensate for the current high investment premium compared to a conventional diesel tractor.

An overview of what mileages are required for alternative technologies to become competitive is given in a summary table for all scenarios, in section 9.6.

### 9.3.4 Vans

As noted previously, battery-electric small and medium vans can be said to have surpassed the early pilot stage and are not included in the comparisons for the early stage scenario. Cost decompositions and comparisons for vans are available for the small-scale series production and mass production phase scenarios, while hydrogen operation is not considered for vans.

## 9.4 Small-scale series production (current and reduced hydrogen prices)

After looking at a scenario with early stages of production for larger battery- and hydrogen-electric vehicles (generally one-off conversions from ICE vehicles), the current section looks at scenarios with expected cost reductions based on small-scale series production, and as such at lower cost premiums of investment.

Because the only difference between the second and third scenario are reduced hydrogen prices (from the current 72 NOK/kg to 36 NOK/kg, both excl. VAT), these scenarios are considered together. Further, because ownership costs for the conventional technologies are unchanged between the scenarios, we chose not to replicate the same results for biodiesel and biogas operation.

### 9.4.1 Light distribution trucks

Table 9.4 shows decomposed ownership costs per km for light distribution trucks, given small-scale series production. As before, per-km costs are based on the same annual mileage of 45 000 km that is assumed for this vehicle segment.

*Table 9.4: Decomposed ownership costs for light distribution trucks. Small-scale series production with current and reduced hydrogen (fuel) prices respectively. Figures in NOK/km. Based on an annual mileage of 45 000 km for this vehicle segment.*

| | Diesel | Hydrogen | Hydrogen (reduced fuel price) | Battery-electric |
|---|---|---|---|---|
| Base investment | 3.39 | 3.39 | 3.39 | 3.39 |
| Investment premium | - | 7.51 | 7.51 | 3.88 |
| Wage costs (incl. social/holiday) | 9.15 | 9.15 | 9.15 | 9.15 |
| General levies | 0.02 | 0.01 | 0.01 | 0.01 |
| Insurance + admin | 0.52 | 0.52 | 0.52 | 0.52 |
| Fuel/energy, excl. Levies | 1.39 | 2.49 | 1.25 | 0.45 |
| $CO_2$-levy | 0.30 | - | - | - |
| Road use levy | 0.84 | - | - | - |
| Premium in case of fast charging | - | - | - | 0.22 |
| Tyres, wash, consumables, etc. | 0.80 | 0.80 | 0.80 | 0.80 |
| General maintenance | 0.68 | 0.34 | 0.34 | 0.34 |
| Road toll | 1.33 | - | - | - |
| | | | | |
| **Total incl. wage costs** | **18.42** | **24.22** | **22.97** | **18.76** |
| **Total excl. wage costs** | **9.27** | **15.06** | **13.82** | **9.60** |
| | | | | |
| **Index incl. wage costs (diesel=100%)** | **100%** | **131%** | **125%** | **102%** |
| **Index excl. wage costs (diesel=100%)** | **100%** | **163%** | **149%** | **104%** |

Compared to the early stage scenario, small-scale series production considerably reduces per-km costs for battery-electric light distribution vehicles. With vehicle-related costs of 9.60 NOK/km, battery-electric operation at these mileages is only 4 % more expensive than diesel operation, compared to 57 % in the base scenario with one-off conversions (for all technologies, wage costs of around 9.1 NOK/km come in addition). Although still coming at an investment cost premium, considerable savings due to lower fuel/energy costs, the toll exemption, and – to a modest degree – lower maintenance costs, almost compensate for the higher cost of purchase, which is lower than for the early stage scenario. The residual value is higher than for the early stage scenario.

When it comes to hydrogen trucks, we see that at current hydrogen (fuel) prices, hydrogen operation is 63 % more expensive compared to diesel operation (compared to 136 % in the base stage with one-off vehicle conversions or hydrogen retrofits). If in addition, hydrogen prices decrease to half their current level (as might be the case with larger production scales/self-production), this figure is reduced to 49 %.

At current hydrogen prices, fuel costs (incl. levies) for diesel and hydrogen are about the same, so that cost savings with hydrogen operation come from the toll exemption and somewhat lower general maintenance costs. Lower hydrogen (fuel) prices, however, would contribute to the cost premium of investment being recouped more quickly with savings on energy costs.

For an overview of the mileages that are required for battery-electric and hydrogen operation in different scenarios to become competitive, see the summary table in section 9.6.

### 9.4.2 Heavy distribution trucks

For heavy distribution trucks, decomposed ownership costs per km are shown in Table 9.5.

*Table 9.5: Decomposed ownership costs for heavy distribution trucks. Small-scale series production with current and reduced hydrogen (fuel) prices respectively. Figures in NOK/km. Based on an annual mileage of 45 000 km for this vehicle segment.*

| | Diesel | Hydrogen | Hydrogen (reduced fuel price) | Battery-electric |
|---|---|---|---|---|
| Base investment | 4.49 | 4.49 | 4.49 | 4.49 |
| Investment premium | - | 9.79 | 9.79 | 5.03 |
| Wage costs (incl. social/holiday) | 9.15 | 9.15 | 9.15 | 9.15 |
| General levies | 0.03 | 0.02 | 0.02 | 0.02 |
| Insurance + admin | 0.63 | 0.63 | 0.63 | 0.63 |
| Fuel/energy, excl. levies | 1.88 | 3.36 | 1.68 | 0.60 |
| $CO_2$-levy | 0.40 | - | - | - |
| Road use levy | 1.13 | - | - | - |
| Premium in case of fast charging | - | - | - | 0.30 |
| Tyres, wash, consumables, etc. | 0.94 | 0.94 | 0.94 | 0.94 |
| General maintenance | 0.76 | 0.38 | 0.38 | 0.38 |
| Road toll | 1.33 | - | - | - |
| **Total incl. wage costs** | **20.74** | **28.76** | **27.08** | **21.54** |
| **Total excl. wage costs** | **11.59** | **19.60** | **17.92** | **12.38** |
| **Index incl. wage costs (diesel=100%)** | **100%** | **139%** | **131%** | **104%** |
| **Index excl. wage costs (diesel=100%)** | **100%** | **169%** | **155%** | **107%** |

Conclusions that can be drawn from this table are similar to those for light distribution trucks, as small-scale series production would considerably reduce per-km costs for battery-electric heavy distribution trucks. Vehicle-related costs at the assumed annual mileages are 12.38 NOK/km, or 7 % higher than for comparable diesel vehicles (down from 55 % in the early production phase scenario with largely one-off conversions). On top of this come wage costs of ca. 9.1 NOK/km, which are equal for all propulsion technologies. Savings per-km for battery-electric operation again mainly come from lower energy costs per km, the toll exemption, and to a modest degree lower general maintenance costs.

When it comes to hydrogen trucks, vehicle-related costs of ownership are 69 % higher than for diesel (compared to 128 % given early phases of production), when assuming current hydrogen prices. If hydrogen prices were to decrease by half, this figure falls to 55 %.

Although the costs of ownership for hydrogen trucks are thus still considerably higher than for comparable diesel vehicles, after the purchase investment is made, each kilometer driven yields savings. For higher annual mileages, the difference between diesel and hydrogen operation therefore becomes smaller. This is also illustrated in the competitiveness summary for all scenarios, in section 9.6.

### 9.4.3 Tractors for semitrailer

For tractors for semitrailers, decomposed per-km ownership costs (assuming annual mileages of 45 000 km) are shown in Table 9.6.

*Table 9.6: Decomposed ownership costs for tractors for semitrailers. Small-scale series production with current and reduced hydrogen (fuel) prices respectively. Figures in NOK/km. Based on an annual mileage of 45 000 km for this vehicle segment.*

| | Diesel | Hydrogen | Hydrogen (reduced fuel price) | Battery-electric |
|---|---|---|---|---|
| Base investment | 4.67 | 4.67 | 4.67 | 4.67 |
| Investment premium | - | 10.40 | 10.40 | 5.38 |
| Wage costs (incl. social/holiday) | 9.15 | 9.15 | 9.15 | 9.15 |
| General levies | 0.03 | 0.02 | 0.02 | 0.02 |
| Insurance + admin | 0.97 | 0.97 | 0.97 | 0.97 |
| Fuel/energy, excl. levies | 2.81 | 5.03 | 2.52 | 0.90 |
| $CO_2$-levy | 0.60 | - | - | - |
| Road use levy | 1.69 | - | - | - |
| Premium in case of fast charging | - | - | - | 0.45 |
| Tyres, wash, consumables, etc. | 0.90 | 0.90 | 0.90 | 0.90 |
| General maintenance | 0.93 | 0.46 | 0.46 | 0.46 |
| Road toll | 1.33 | - | - | - |
| | | | | |
| **Total incl. wage costs** | **23.09** | **31.62** | **29.10** | **22.91** |
| **Total excl. wage costs** | **13.94** | **22.46** | **19.95** | **13.75** |
| | | | | |
| **Index incl. wage costs (diesel=100%)** | **100%** | **137%** | **126%** | **99%** |
| **Index excl. wage costs (diesel=100%)** | **100%** | **161%** | **143%** | **99%** |

For tractors too, conclusions are similar as for distribution trucks. Small-scale series production, and associated lower cost premiums of investment, give a considerable reduction in ownership costs for battery-electric and hydrogen-electric vehicles.

For battery-electric tractors, vehicle-dependent costs per km are 13.8 NOK/km (while wage costs of ca. 9.1 NOK/km that come in addition, are equal across technologies). This means that costs become about the same level as for diesel operation, at the mileages of 45 000 km per year assumed here (for early stages of production, we found that these costs were 92 % higher than for diesel).

The most important reason for battery-electric tractors coming at about par with diesel tractors, is the relatively high energy consumption of such tractors (and thus relatively high savings per km by using electricity rather than diesel), the toll exemption, and to a modest degree, lower costs of general maintenance. Together, these savings compensate for the cost premium of investment, and if vehicles are used more intensively (higher mileage), battery-electric operation will yield additional savings.

For hydrogen-electric trucks, at current hydrogen prices, vehicle-related ownership costs under small-scale series production are 61 % higher than diesel operation (down from 161 % in the scenario with early stages of production). A halving of hydrogen (fuel) prices can bring this difference down to 43 % by – in addition to hydrogen operation's savings on toll expenses and general maintenance – also yielding considerable savings through energy costs, for every kilometer driven. At higher annual mileages, the gap between hydrogen and diesel operation thus decreases, as is illustrated in the competitiveness summary table in section 9.6.

### 9.4.4 Small vans

For small vans, a decomposition of ownership costs for diesel and battery-electric operation is given in table 9.7 (assuming an annual mileage of 20 000 km). As discussed previously, for vans, we do not make comparisons with hydrogen operation due to a lack of and large uncertainty in cost data. We further focus on vehicle-dependent cost components and do not include wage costs. The reason for this is that drivers of vans often are not dedicated to driving. As wage costs are assumed to be equal across technologies, excluding this cost component does not affect conclusions.

*Table 9.7. Decomposed ownership costs for small vans. Small-scale series production (for small vans, i.e. current prices). Figures in NOK/km. Based on an annual mileage of 20 000 km for this vehicle segment.*

| | Diesel | Battery-electric |
|---|---|---|
| Base investment | 1.12 | 1.12 |
| Investment premium | - | 1.29 |
| Registration fee and wrecking fee | 0.30 | - |
| General levies | 0.15 | - |
| Insurance + admin | 0.88 | 0.88 |
| Fuel/energy, excl. levies | 0.46 | 0.15 |
| $CO_2$-levy | 0.10 | - |
| Road use levy | 0.27 | - |
| Premium in case of fast charging | - | 0.07 |
| Tyres, wash, consumables, etc. | 0.61 | 0.61 |
| General maintenance | 0.56 | 0.28 |
| Road toll | 1.50 | - |
| **Total (excl. wage costs)** | **5.94** | **4.40** |
| **Index excl. wage costs (diesel=100%)** | **100%** | **74%** |

From the table, it can be seen that small diesel vans, at the mileages assumed, have an ownership cost of around 5.9 NOK/km. This is considerably lower than for HDVs. Small battery-electric vans, produced in a stage of small-scale series production, in turn, are found to have ownership costs of 4.4 NOK/km.

When looking at the different cost components, we find that even though battery-electric vans come at an investment cost premium, their exemption from the registration fee and savings on general levies stemming from the annual 'traffic insurance fee' compensate for part of this. In addition, energy costs per kilometer are much lower than for diesel, even when assuming a premium for fast charging. Further, particularly the toll exemption and (more modest) cost difference for general maintenance result in further savings. Together, these factors, at mileages of 20 000 km/year, more than compensate for the higher costs of investment. Without the toll road exemption the costs would be equal.

### 9.4.5 Medium vans

For medium vans, a similar cost decomposition is shown in table 9.8, for annual mileages of 25 000 km.

*Table 9.8: Decomposed ownership costs for medium vans. Small-scale series production. Figures in NOK/km. Based on an annual mileage of 25 000 km for this vehicle segment.*

| | Diesel | Battery-electric |
|---|---|---|
| Base investment | 1.62 | 1.62 |
| Investment premium | - | 1.86 |
| Registration fee and wrecking fee | 0.86 | - |
| Wage costs (incl. social/holiday) | - | - |
| General levies | 0.12 | - |
| Insurance + admin | 0.70 | 0.70 |
| Fuel/energy, excl. levies | 0.58 | 0.19 |
| $CO_2$-levy | 0.12 | - |
| Road use levy | 0.35 | - |
| Premium in case of fast charging | - | 0.09 |
| Tyres, wash, consumables, etc. | 0.61 | 0.61 |
| General maintenance | 0.56 | 0.28 |
| Road toll | 1.50 | - |
| **Total (excl. wage costs)** | **7.02** | **5.36** |
| **Index excl. wage costs (diesel=100%)** | **100%** | **76%** |

Findings from this table are similar to those for small vans: despite an investment cost premium for battery-electric vans, savings due to the exemption from the registration fee and through general levies compensate for part of this premium. With distance-dependent costs (particularly in terms of energy costs and toll savings, but also savings on general maintenance costs) further being considerably lower than under diesel operation, every kilometer driven yields additional savings. In total, with 5.36 NOK/km, battery-electric costs of ownership are about 24 % lower than for a comparable medium-sized diesel van. Without the toll road exemption the difference would be within 3 %.

## 9.5 Mass production

We now turn to the scenario that assumes mass production and reduced hydrogen prices due to production scale increases.

### 9.5.1 Light distribution trucks

For light distribution trucks, with annual mileages of 45 000 km, decomposed ownership costs are shown in table 9.9.

*Table 9.9: Decomposed ownership costs for light distribution trucks. Mass production. Figures in NOK/km. Based on an annual mileage of 45 000 km for this vehicle segment.*

| | Diesel | Hydrogen (reduced fuel price) | Battery-electric |
|---|---|---|---|
| Base investment | 3.39 | 3.39 | 3.39 |
| Investment premium | - | 3.39 | 1.70 |
| Wage costs (incl. social/holiday) | 9.15 | 9.15 | 9.15 |
| General levies | 0.02 | 0.01 | 0.01 |
| Insurance + admin | 0.52 | 0.52 | 0.52 |
| Fuel/energy, excl. levies | 1.39 | 1.25 | 0.45 |
| $CO_2$-levy | 0.30 | - | - |
| Road use levy | 0.84 | - | - |
| Premium in case of fast charging | - | - | 0.22 |
| Tyres, wash, consumables, etc. | 0.80 | 0.80 | 0.80 |
| General maintenance | 0.68 | 0.34 | 0.34 |
| Road toll | 1.33 | - | - |
| | | | |
| **Total incl. wage costs** | **18.42** | **18.85** | **16.57** |
| **Total excl. wage costs** | **9.27** | **9.69** | **7.42** |
| | | | |
| **Index incl. wage costs (diesel=100%)** | **100%** | **102%** | **90%** |
| **Index excl. wage costs (diesel=100%)** | **100%** | **105%** | **80%** |

It can be seen that under our assumptions with regard to mass production cost premiums, both battery-electric and hydrogen-electric operation of light distribution trucks become considerably cheaper.

At the mileages assumed here, the ownership of battery-electric light distribution trucks is even found to have become about 20 % cheaper than for comparable diesel vehicles. The reason for this is that savings on particularly energy and road toll costs per km are significant compared to diesel operation, and more than compensate for the high investment premium.

For light distribution trucks running on hydrogen, we find that ownership costs under our assumptions regarding mass production become similar to those for comparable diesel trucks. Also here, savings on particularly energy costs (assuming that hydrogen (fuel) prices in this stage have fallen due to larger scale production as well), and road toll costs are important drivers. With more intensive use (higher annual mileages), costs of ownership for hydrogen vehicles will also fall below those of diesel trucks, as is illustrated in the competitiveness summary table in section 9.6.

### 9.5.2 Heavy distribution trucks

For heavy distribution trucks, decomposed ownership costs per km are shown in Table 9.10.

*Table 9.10: Decomposed ownership costs for heavy distribution trucks. Mass production. Figures in NOK/km. Based on an annual mileage of 45 000 km for this vehicle segment.*

| | Diesel | Hydrogen (reduced fuel price) | Battery-electric |
|---|---|---|---|
| Base investment | 4.49 | 4.49 | 4.49 |
| Investment premium | - | 4.49 | 2.25 |
| Wage costs (incl. social/holiday) | 9.15 | 9.15 | 9.15 |
| General levies | 0.03 | 0.02 | 0.02 |
| Insurance + admin | 0.63 | 0.63 | 0.63 |
| Fuel/energy, excl. levies | 1.88 | 1.68 | 0.60 |
| $CO_2$-levy | 0.40 | - | - |
| Road use levy | 1.13 | - | - |
| Premium in case of fast charging | - | - | 0.30 |
| Tyres, wash, consumables, etc. | 0.94 | 0.94 | 0.94 |
| General maintenance | 0.76 | 0.38 | 0.38 |
| Road toll | 1.33 | - | - |
| | | | |
| **Total incl. wage costs** | **20.74** | **21.78** | **18.76** |
| **Total excl. wage costs** | **11.59** | **12.63** | **9.60** |
| | | | |
| **Index incl. wage costs (diesel=100%)** | **100%** | **105%** | **90%** |
| **Index excl. wage costs (diesel=100%)** | **100%** | **109%** | **83%** |

For heavy distribution trucks, we also find that battery-electric trucks under mass production might become cheaper to own than comparable diesel trucks: with 9.6 NOK/km, vehicle-dependent costs are about 17 % lower than for diesel vehicles. This is due to significant savings on distance-dependent costs (particularly the much lower energy costs and road toll exemption).
Hydrogen trucks, in turn, are still a bit more expensive than diesel vehicles due to their high investment cost premium, at mileages assumed here. Distant-dependent cost components, however, all imply savings, the more intensively a vehicle is used (i.e. more competitive at higher annual mileages).

### 9.5.3 Tractors for semitrailer

For tractors for semitrailers, decomposed per-km ownership costs (assuming annual mileages of 45 000 km) are given in Table 9.11.

*Table 9.11: Decomposed ownership costs for tractors for semitrailers. Mass production. Figures in NOK/km. Based on an annual mileage of 45 000 km for this vehicle segment.*

| | Diesel | Hydrogen (reduced fuel price) | Battery-electric |
|---|---|---|---|
| Base investment | 4.67 | 4.67 | 4.67 |
| Investment premium | - | 4.67 | 2.34 |
| Wage costs (incl. social/holiday) | 9.15 | 9.15 | 9.15 |
| General levies | 0.03 | 0.02 | 0.02 |
| Insurance + admin | 0.97 | 0.97 | 0.97 |
| Fuel/energy, excl. levies | 2.81 | 2.52 | 0.90 |
| $CO_2$-levy | 0.60 | - | - |
| Road use levy | 1.69 | - | - |
| Premium in case of fast charging | - | - | 0.45 |
| Tyres, wash, consumables, etc. | 0.90 | 0.90 | 0.90 |
| General maintenance | 0.93 | 0.46 | 0.46 |
| Road toll | 1.33 | - | - |
| **Total incl. wage costs** | **23.09** | **23.37** | **19.87** |
| **Total excl. wage costs** | **13.94** | **14.22** | **10.71** |
| **Index incl. wage costs (diesel=100%)** | **100%** | **101%** | **86%** |
| **Index excl. wage costs (diesel=100%)** | **100%** | **102%** | **77%** |

Also for tractors for semitrailers, findings from the table are similar: at mileages of 45 000 km/year and given our assumptions for the mass production stage, battery-electric tractors, with vehicle-dependent costs of 10.7 NOK/km, are about 23 % cheaper to own than comparable diesel vehicles, while hydrogen tractors have close to the same ownership costs.

Every kilometer driven with a diesel truck is more expensive in terms of fuel costs, road toll, and general maintenance, and cost savings from electric propulsion therefore become higher the more the vehicle is driven.

### 9.5.4 Small vans

For small vans, a cost decomposition for diesel and battery-electric operation in a scenario of mass production is given in table 9.12 (assuming an annual mileage of 20 000 km).

*Table 9.12: Decomposed ownership costs for small vans. Mass production. Figures in NOK/km. Based on an annual mileage of 20 000 km for this vehicle segment.*

| | Diesel | Battery-electric |
|---|---|---|
| Base investment | 1.12 | 1.12 |
| Investment premium | - | 0.56 |
| Registration fee and wrecking fee | 0.30 | - |
| General levies | 0.15 | - |
| Insurance + admin | 0.88 | 0.88 |
| Fuel/energy, excl. levies | 0.46 | 0.15 |
| $CO_2$-levy | 0.10 | - |
| Road use levy | 0.27 | - |
| Premium in case of fast charging | - | 0.07 |
| Tyres, wash, consumables, etc. | 0.61 | 0.61 |
| General maintenance | 0.56 | 0.28 |
| Road toll | 1.50 | - |
| **Total (excl. wage costs)** | **5.94** | **3.67** |
| **Index excl. wage costs (diesel=100%)** | **100%** | **62%** |

From this table, it can be seen that at the mileages assumed for small vans, battery-electric operation, at about 3.7 NOK/km, is close to 40 % cheaper than a comparable diesel van. Despite the higher cost of investment in a battery-electric vehicle, also given mass production, savings on registration fee, but particularly on energy costs and road toll expenses, are large. Even if some of these advantages would be reduced through changes in policy (e.g. removal of exemptions), the ownership of a battery-electric small van will likely remain cheaper or competitive versus a comparable diesel vehicle.

### 9.5.5 Medium vans

For medium vans, a similar cost decomposition is shown in table 9.13, for annual mileages of 25 000 km.

*Table 9.13: Decomposed ownership costs for medium vans. Mass production. Figures in NOK/km. Based on an annual mileage of 25 000 km for this vehicle segment.*

| | Diesel | Battery-electric |
|---|---|---|
| Base investment | 1.62 | 1.62 |
| Investment premium | - | 0.81 |
| Registration fee and wrecking fee | 0.86 | - |
| Wage costs (incl. social/holiday) | - | - |
| General levies | 0.12 | - |
| Insurance + admin | 0.70 | 0.70 |
| Fuel/energy, excl. levies | 0.58 | 0.19 |
| $CO_2$-levy | 0.12 | - |
| Road use levy | 0.35 | - |
| Premium in case of fast charging | - | 0.09 |
| Tyres, wash, consumables, etc. | 0.61 | 0.61 |
| General maintenance | 0.56 | 0.28 |
| Road toll | 1.50 | - |
| **Total (excl. wage costs)** | **7.02** | **4.31** |
| **Index excl. wage costs (diesel=100%)** | **100%** | **61%** |

For medium vans too, we find that under mass production, battery-electric operation might become considerably cheaper than diesel operation. At mileages of 25 000 km/year, we find vehicle-dependent costs of about 4.3 NOK/km, which is almost 40 % lower than for a comparable diesel vehicle.

The explanations for this are the same as for small vans. Despite a higher one-off purchase cost, exemptions from registration fee, but particularly savings on energy costs and road toll expenses compared to diesel operation, are large, even if some of these advantages would be reduced through e.g. policy changes. Because it is particularly distance-dependent costs elements that yield savings, the more kilometers are driven with a vehicle, the larger the cost savings compared to a conventional diesel van.

Also for vans, a summary of mileages required for electric operation to become cheaper than using diesel, biodiesel, or biogas vehicles, is shown in a table in section 9.6.

## 9.6 Cost and competitiveness benchmarking

In the previous segments, we analysed how the cost competitiveness of battery-electric and hydrogen-electric vehicles improves with production phase maturity. It should again be emphasized that some of the cost parameters used in our analysis are more uncertain than others. This is particularly the case for estimates on cost premiums of vehicles with zero-emission propulsion systems. These estimates are based on information from interviews with operators and our own estimates for future production phases. Manufacturers are currently unwilling to provide estimates on envisioned prices for zero-emission trucks given series production. At the mileages assumed, battery-electric operation in a number of cases and for a number of vehicles even becomes cheaper than the ownership of comparable diesel vehicles.

However, mileages/use intensity may vary, and with distance-dependent costs for battery-electric and hydrogen vehicles being lower than for diesel, biodiesel, and biogas vehicles, the more kilometres are driven, the higher the savings from these technologies. In chapter 9.3.2, for example, we showed with a figure how different annual mileages affect the cost competitiveness of different propulsion technologies vis-à-vis each other.

Rather than replicating similar figures for the five vehicles and four scenarios, table 9.14 summarizes whether, and if so at what level of annual mileages/use intensities, battery-electric operation becomes cheaper than conventional operation.

*Table 9.14. Minimum annual mileages (km) required for battery-electric vehicles, to achieve lower per-km costs of ownership vis-à-vis other propulsion technologies. For different vehicle types and scenarios. Rounded to nearest thousand.*

<table>
<tr><th></th><th></th><th>Base scenario</th><th>Small-scale series prod.</th><th>Small-scale series prod., low $H_2$-cost</th><th>Mass production</th></tr>
<tr><td rowspan="4">Light Distribution Trucks</td><td>Diesel</td><td rowspan="3">Unrealistically high mileages</td><td colspan="2">52 000 km</td><td>21 000 km</td></tr>
<tr><td>Biodiesel</td><td colspan="2">47 000 km</td><td>19 000 km</td></tr>
<tr><td>Biogas</td><td colspan="2">37 000 km</td><td>11 000 km</td></tr>
<tr><td>Hydrogen</td><td colspan="4">Battery-electric always cheaper</td></tr>
<tr><td rowspan="4">Heavy Distribution Trucks</td><td>Diesel</td><td>144 000 km</td><td colspan="2">58 000 km</td><td>23 000 km</td></tr>
<tr><td>Biodiesel</td><td>129 000 km</td><td colspan="2">52 000 km</td><td>22 000 km</td></tr>
<tr><td>Biogas</td><td>131 000 km</td><td colspan="2">40 000 km</td><td>11 000 km</td></tr>
<tr><td>Hydrogen</td><td colspan="4">Battery-electric always cheaper</td></tr>
<tr><td rowspan="4">Tractors for Semitrailers</td><td>Diesel</td><td rowspan="3">Unrealistically high mileages</td><td colspan="2">43 000 km</td><td>19 000 km</td></tr>
<tr><td>Biodiesel</td><td colspan="2">39 000 km</td><td>17 000 km</td></tr>
<tr><td>Biogas</td><td colspan="2">35 000 km</td><td>10 000 km</td></tr>
<tr><td>Hydrogen</td><td colspan="4">Battery-electric always cheaper</td></tr>
<tr><td rowspan="3">Small Vans</td><td>Diesel</td><td rowspan="3">Not considered*</td><td colspan="2">8 000 km</td><td rowspan="3">ca. 1 000 km</td></tr>
<tr><td>Biodiesel</td><td colspan="2">7 000 km</td></tr>
<tr><td>Biogas</td><td colspan="2">5 000 km</td></tr>
<tr><td rowspan="3">Medium Vans</td><td>Diesel</td><td rowspan="3">Not considered*</td><td colspan="2">9 000 km</td><td rowspan="3"><1 000 km</td></tr>
<tr><td>Biodiesel</td><td colspan="2">8 000 km</td></tr>
<tr><td>Biogas</td><td colspan="2">3 000 km</td></tr>
</table>

** For small and medium vans, the base scenario for battery-electric vehicle production is not considered, as the segments can be regarded as having reached small-scale series production.*

The table makes clear that in the base scenario, larger battery-electric vehicles cannot compete on costs with conventional technologies.

In the scenario with small-scale series production of larger battery-electric vehicles, we see that these become competitive vis-à-vis diesel at annual mileages of between ca. 43 000 km (tractors) and 58 000 km (heavy distribution trucks). From data on vehicle usage, we find that such mileages are far from unusual for current diesel vehicles between 0-5 years old. Provided that the battery-electric alternatives provide comparable driving ranges, loading capacity, etc. (see chapter 7), they could thus be a realistic alternative.

Small- and medium-sized vans, in turn, are cheaper in operation than (bio)diesel or biogas vehicles above relatively short annual mileages, especially considering typical annual mileages of newer vehicles in these segments.

Finally, in the scenario with mass production of battery-electric vehicles, we see that HDVs become cost competitive versus diesel vehicles already from relatively low annual mileages of between 19 000 – 23 000 km, depending on the vehicle segment. Compared to biodiesel and biogas vehicles, the break-even point is even lower.

Battery-electric vans, in turn, are cost competitive already from mileages of around 1 000 km. Even when such vehicles would lose advantages such as toll exemptions/discounts, it therefore seems likely that they will remain a competitive alternative. Results from a recent market mapping (to be published) indicates that while future battery-electric vans are likely to be equipped with larger batteries and longer range, they will likely remain highly competitive with regard to cost.

Table 9.15 provides a similar illustration, but for mileages required for hydrogen-electric vehicles to achieve lower per-km costs of ownership compared to other propulsion technologies.

*Table 9.15: Minimum annual mileages (km) required for hydrogen vehicles, to achieve lower per-km costs of ownership vis-à-vis other propulsion technologies. For different vehicle types and scenarios. Rounded to nearest thousand.*

| | | Base scenario | Small-scale series prod. | Small-scale series prod., low $H_2$-cost | Mass production |
|---|---|---|---|---|---|
| Light Distribution Trucks | Diesel | Other technologies always cheaper | Unrealistically high mileages | | 57 000 km |
| | Biodiesel | | | | 49 000 km |
| | Biogas | | | | 37 000 km |
| | Electric | | Battery-electric always cheaper | | |
| Heavy Distribution Trucks | Diesel | Other technologies always cheaper | Unrealistically high mileages | | 65 000 km |
| | Biodiesel | | | | 58 000 km |
| | Biogas | | | | 44 000 km |
| | Electric | | Battery-electric always cheaper | | |
| Tractors for Semitrailers | Diesel | Other technologies always cheaper | Unrealistically high mileages | 134 000 km | 50 000 km |
| | Biodiesel | | | 115 000 km | 42 000 km |
| | Biogas | | | 125 000 km | 37 000 km |
| | Electric | | Battery-electric always cheaper | | |

Here, it can be seen that hydrogen-electric vehicles cannot compete in terms of ownership costs in either the base scenario or given small-scale series production of larger hydrogen vehicles. Even when hydrogen prices decrease to half today's level, it takes unrealistically high annual mileages for hydrogen trucks or tractors to compete with diesel equivalents.

In the scenario with mass production of larger hydrogen vehicles, and with reduced hydrogen prices, we find that vehicle use has to be (well) above the 45 000 km that we assumed in our analyses, and also that battery-electric operation has lower costs of ownership, regardless the annual mileage.

However, although the mileages found in the table are less likely for short-haul transport, they are relevant within segments of long-haul transport. As hydrogen, much more than battery-electric propulsion, can be suitable for longer-haul transport, this means that for some use cases, hydrogen operation might nevertheless be the alternative of choice (being cheaper than diesel, and, despite higher costs, more suitable/flexible than battery-electric HDVs). The decreased cost of battery-electric trucks in the mass production scenario will make it possible to install larger batteries for longer ranges, thus increasing the use potential, while keeping the cost-competitiveness versus ICE trucks. The toll road exemption significantly influenced the competitiveness of battery-electric and hydrogen vehicles in the small-scale production and mass production scenarios.

# 10 Buses: Potential for electrification in Norway and cost analysis

Chapters 7 to 9 reviewed the potential for electrification of trucks in Norway and gave a cost analysis of various scenarios of technological and production phase maturity. When it comes to buses, the situation is quite different; buses involve a closed system (set routes), whilst trucks can generally be considered an open system (no set routes or large variations)[55]. Although a detailed analysis of bus user patterns is beyond the scope of this report, here a short overview for E-buses is provided, as well as a short cost analysis.

## 10.1 Status and potential

This section reviews the E-bus models available on the European market (10.1.1) and other city trials that were ongoing (10.1.2) at the start of year 2017. Since this is the year the Oslo trials began, this shows the state of the art across Europe at the time. In addition, future targets for E-buses across Norway (and the 'potential' for E-bus electrification) are subsequently discussed (10.1.3), and a brief summary given of the status of E-buses in Norway (10.1.4.)

### 10.1.1 E-bus market

An increasing number of bus models have become available on the European market, with a maximum battery capacity of around ~400 kWh and with most utilising lithium-iron phosphate battery technology as of the year 2017 (Figure 10.1). Most offer some form of electric heating (with very few models having diesel heating as a sole option), though it may be possible to retrofit that for Nordic climates.

The charging solution depends on the route, the daily distance, the climate and topography a bus operates in, and the battery size. Many of the E-buses with larger batteries (>250 kWh) use plug-in charging as they are likely equipped with a large battery pack to allow full day operation, whilst those with smaller batteries can be fast charged to compensate for the smaller battery. Many manufacturers offer the possibility to choose different battery sizes and charging options to tailor the solution to local conditions (ZeEUS 2017). Major manufacturers up to 2017 included BYD, Ursuss and Optare.

[55] Exceptions to this may include e.g. waste collection and distribution routes.

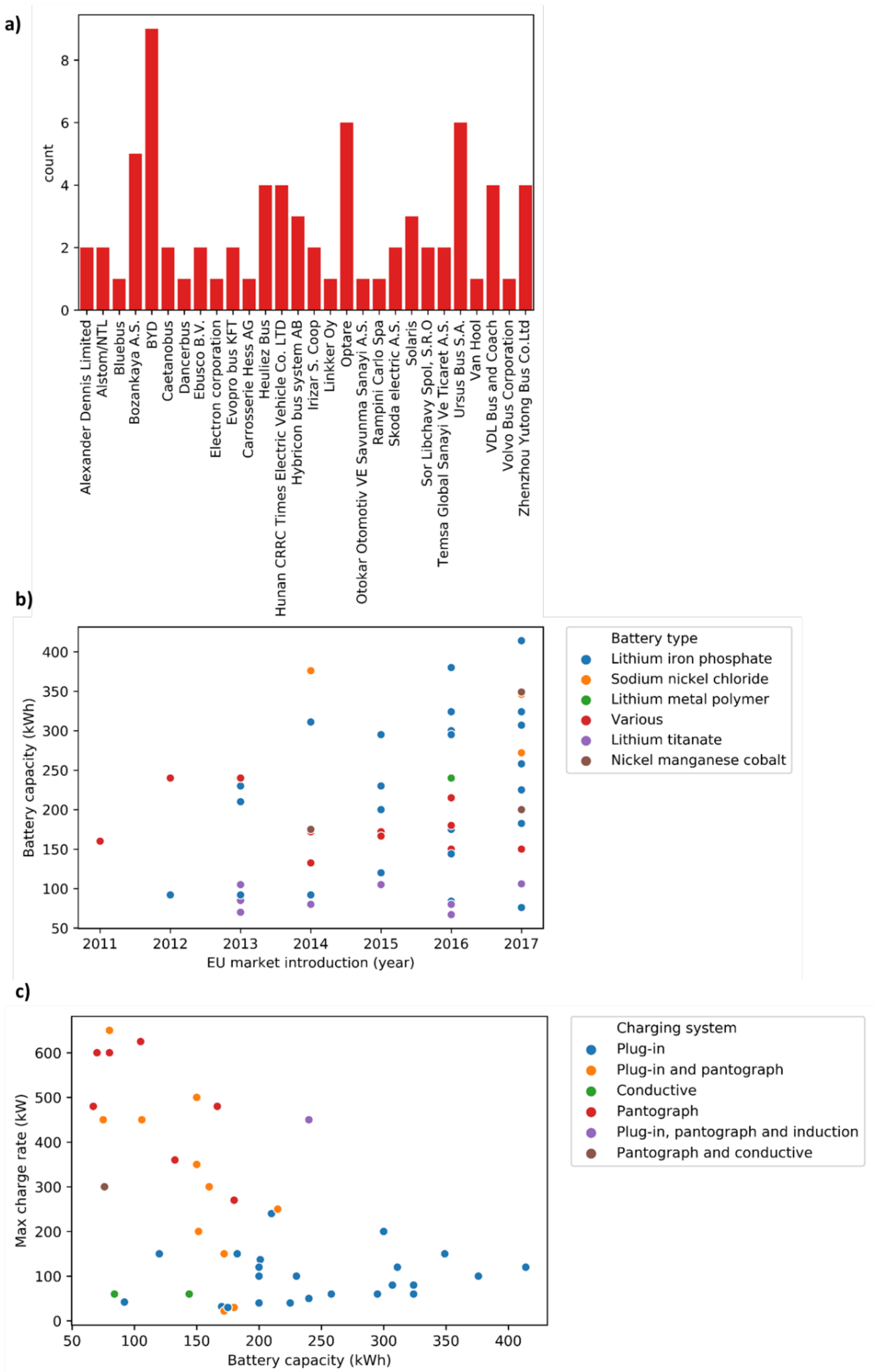



*Figure 10.1: a) Overview of the number of different bus models from different manufacturers available on the European market in 2017, b) Development of the types of E-buses available on the European market between 2011-2017, and c) Range, battery capacity and charging options of selected E-buses available on the European market in 2017. Data is derived from ZeEUS (2017).*

### 10.1.2 E-bus use in Europe

E-buses are being increasingly used for testing, pilot studies and in regular operation throughout the European region (Figure 10.2). Figure 10.3 shows cities where E-bus trials were based at the start of 2017. Looking ahead, a ZeEUS market forecast exercise (2017) predicts that the share of European E-buses will reach 50 % by 2030.

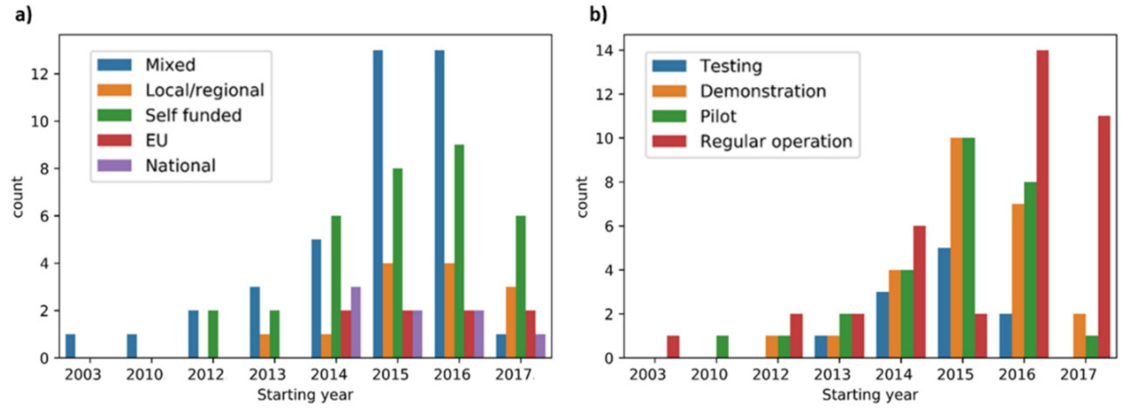



*Figure 10.2: Development of E-bus city trials in European region with time, a) their funding type, and b) their nature. Data is derived from ZeEUS (2017).*

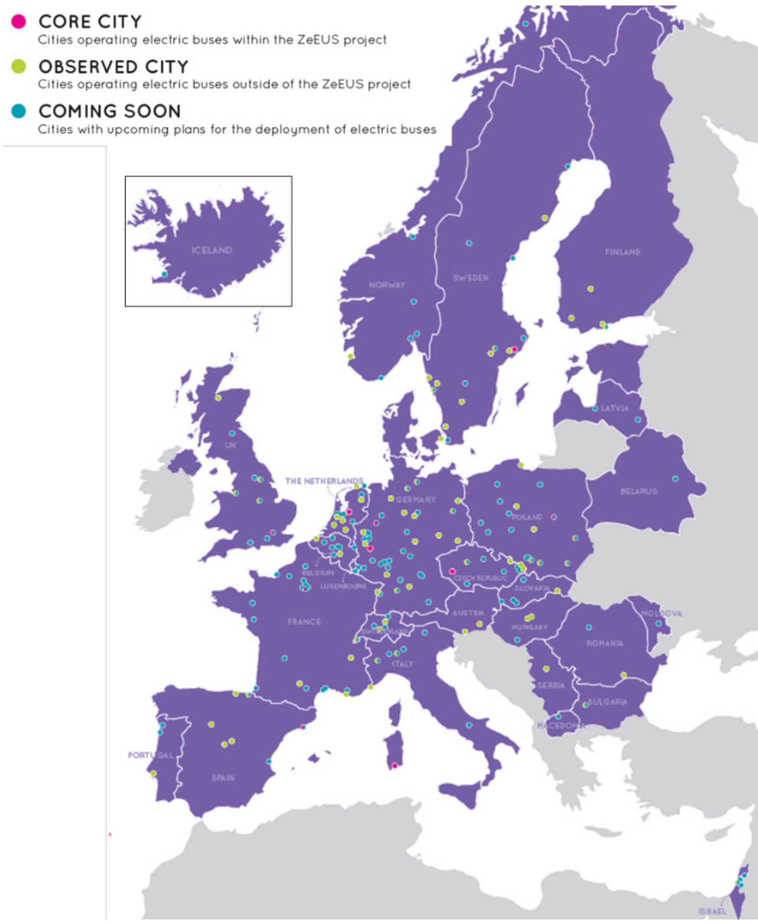



*Figure 10.3: E-bus operation in the European region as of the start of year 2017. Figure adapted from ZeEUS (2017). The Zero Emission Urban Bus System (ZeEUS) project ran from 2013 to 2018, and aimed to test electrification solutions at the heart of the urban bus system network through live urban demonstrations.*

As of 2017, most city trials utilized depot charging, rather than opportunity charging along the route alone (Figure 10.4). Some correlation exists between the length of the route and a higher battery capacity, showing a degree of bus design for specific use plans. In addition, it appears that use of opportunity charging was restricted to routes of around ~15 km or less. However, contrary to what might be expected, charging solutions (depot or opportunity) and battery size are not highly correlated to the topography of the route the E-buses were used on. This may be due to the early nature of the trials coupled with the fact that there may have not been so many choices for early-stage battery tailoring.

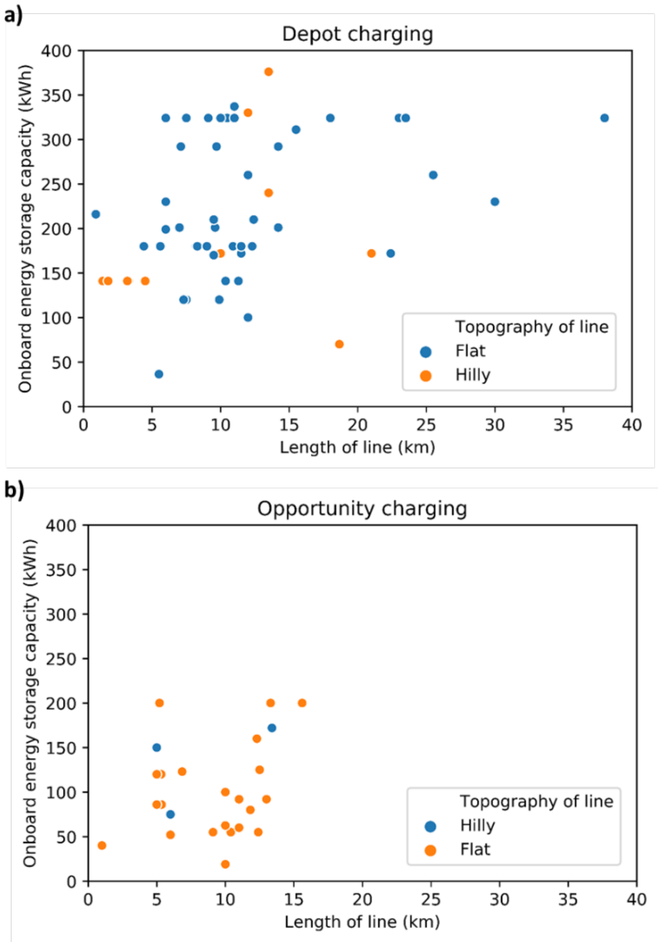



*Figure 10.4: Length of line and battery capacity of E-buses for city trials with flat and hilly routes, and divided into a) depot charging and b) opportunity charging categories.*

### 10.1.3 E-bus targets in Norway

Where buses drive locally in a closed system, the potential for E-bus use is high. In Norway specifically, there is a target at a National level for 100 % of all new city buses to be either zero-emission (battery or hydrogen) or using biogas, by 2025 (Norwegian Department for Transport 2017). When it concerns zero-emission bus solutions alone, there are multiple plans at a regional level set by local transport authorities. For example in the following three Norwegian cities:

- **Oslo**: Ruter has plans for a zero-emission bus fleet by 2028 (i.e. a fleet of 100 % E-buses and/or fuel cell buses) (Ruter 2018).
- **Drammen**: zero-emission bus solutions will be demanded by Brakar in new tenders by 2024 (Sundfjord 2019).
- **Hamar**: zero-emission fleet objectives have been set by Hedmark trafikk by 2030 (Fredheim 2019).

Regional driving of buses (i.e. outside of cities) is more complicated to address, and faces many of the same challenges as for heavy-duty trucks (e.g. range requirements). The NTP sets a target that by 2030, 75 % of new long distance buses should be zero-emission vehicles (Norwegian Government 2017).

### 10.1.4 E-bus status in Norway

By 2020 it is planned to have 416 E-buses in Oslo, Bergen, Trondheim, Drammen, Hamar, Haugesund, Bodø and Ålesund (NRK 2019). There will also be 55 Class II (regional) buses in operation from 2020 in Oslo, Hamar and Haugesund (Yrkesbil.no 2019). Many of these buses utilize pantograph charging, mostly at depot. Table 10.1 shows the quantity, bus manufacturer and type (solo/city bus versus articulated bus), charging concepts (pantograph or plug in), charging power, battery capacity (in kW) and battery type used in Oslo. Section 5.2 may be consulted for more information, and details the E-buses that are currently in use.

*Table 10.1: Summary of E-buses used in the Oslo region (Ruter 2019)*

| Project/ tender | Qty | Mfg | Bus type | Charging concept | Chg power (kW) | Battery capacity (kWh) | Battery type | Contains cobalt |
|---|---|---|---|---|---|---|---|---|
| Test 2017 | 2 | Solaris | solo | Pantograph | 300 | 75 | LTO | No |
| Test 2017 | 2 | Solaris | solo | Pantograph | 400 | 125 | LTO | No |
| Test 2017 | 2 | BYD | articulated | Plugin | 80 | 307 | LFP | No |
| Oslo 2019 | 30 | VDL | articulated | Pantograph | 300 | 170 | LTO | No |
| Oslo 2019 | 10 | VDL | solo | Pantograph | 300 | 127 | LTO | No |
| Oslo 2019 | 20 | BYD | articulated | Pantograph | 300 | 348 | LFP | No |
| Oslo 2019 | 4 | Solaris | solo | Pantograph | 400 | 146 | LTO | No |
| Oslo 2019 | 6 | Mercedes | solo | Pantograph | 250 | 243 | NMC | Yes |
| Romerike 2019 | 17 | Volvo | solo (w/seat belts) | Plugin | 150 | 200 | NMC | Yes |
| Romerike 2019 | 22 | BYD | articulated (belts) | Pantograph | 300 | 348 | LFP | No |

## 10.2 Cost analysis: method and assumptions

A favorable comparison of TCO with both ICE-buses and other low/zero-emission technologies is of key importance to E-bus uptake, although authorities at the regional level may decide to accept higher costs to get to a zero-emission bus fleet. Information obtained from interviews was thus used to calculate E-bus TCO for the current year[56] and 2025[57], which was compared to other technologies ($H_2$-, biodiesel- and ICE-buses). Resulting costs are given in $NOK_{2019}$ in constant prices.

[56] Some data obtained from operators derives from the year 2017 when the trials began.
[57] Assumed to represent a more optimized case.

A full list of assumptions are given in Table 10.2. The E-bus is assumed to have <300 kWh batteries and charging infrastructure (electricity at 1.0 NOK/kWh (Amundsen, Bruvoll et al. 2018)). TCO calculations do not account for operator risks posed, premature battery/spare part changes, any expansion required to the grid, or any residual value after the assumed lifetime (taken as the length of a typical tender period; in this case 8 years). The bulk of these assumptions are as for previous studies (Hagman, Amundsen et al. 2017, Amundsen, Bruvoll et al. 2018), but information collected in the interviews allowed for updated E-bus parameters. E-bus operating energy was consequently increased to include heating energy (from 0.9 kWh/km to 2.3 kWh/km), maintenance costs were adapted to be lower than ICE by 2025 (1.5 NOK/km for E-bus vs. 1.8 NOK/km for ICE), and E-bus fleet size was adapted to include the extra 10 % fleet vehicles required to manage the routes because of downtime during charging during the day[58]. It is assumed that the cost includes a battery guarantee, i.e. that the battery lasts the entire life of the tender, meaning that costs relating to uncertainty in battery lifetime are not accounted for. By 2025 it is assumed that the technology has matured so that the battery lifetime is equal to the lifetime of the bus.

The charging strategy for Oslo was assumed to be based on depot charging, due to the difficulties experienced by operators (at present) in installing opportunity charging in city centers. Charging costs using a depot based strategy were calculated assuming that a fleet of 30 E-buses share the use of 12 x 300 kW chargers and 18 x 50 kW chargers. Charger costs were taken to be 1.40 and 0.54 MNOK each, respectively, including mounting and cables. These values are based on the current operation of one E-bus operator in Oslo. Costs were divided over the lifetime of the infrastructure, taken to be a typical tender period[59]. Resulting (calculated) costs per km driven were consequently adapted from those in Hagman, Amundsen et al. (2017) and Amundsen, Bruvoll et al. (2018) from 2.2 NOK/km to 1.6 NOK/km. Looking to the future, charger costs were assumed to fall by 10 % by the year 2025.

For the comparative buses modelled; the ICE-bus represents a Euro VI diesel, with mandatory biofuel blend (10 % in 2018 whereby 3.5 % is HVO, at 11.3 NOK/l (Circle K 2019)), the $H_2$-bus has a commercial fuel cell ($H_2$ at 72 NOK/kg (Uno X 2019), assumed to reduce to 36 NOK/kg with moderate production increases (Greensight 2017) and the biodiesel-bus represents a Euro VI diesel with 100 % advanced renewable biofuel (at 11.4 NOK/l (Circle K 2019). These prices exclude VAT[60]. Refueling infrastructure for biodiesel- and ICE-buses was not included (i.e. it was assumed that existing infrastructure can be used), whilst for $H_2$-buses the infrastructure was included as part of the fuel cost.

[58] The analysis assumes that the number of drivers did not increase; i.e. the extra buses are only needed to ensure that there are always fully charged buses for drivers to use.

[59] Infrastructure lifetime was assumed as the typical length of a full tender period.

[60] Prices for diesel/biodiesel vary from day to day. Input values used in this assessment stem from supplier price lists and were checked against historical price developments to ensure that they were representative.

*Table 10.2: Assumptions used in the total cost of ownership (TCO) calculations. Note: parameters are adapted from previous analysis (Hagman, Amundsen et al. 2017, Amundsen, Bruvoll et al. 2018) based on interviews. *unit of NOK/kWh for E-bus, NOK/kg for $H_2$-bus and NOK/l for ICE buses using diesel and biodiesel. The base price of diesel excluding VAT and levies was 6.24 NOK/liter, with additional $CO_2$- and road use levy (excluding VAT) of respectively 1.33 NOK/l and 3.75 NOK/liter. Electricity price can be assumed as 0.67 NOK/kWh with an additional 50 % cost for fast charging. **Calculations assume 30 E-buses share use of 18 x 50 kW and 12 x 300 kW depot chargers ***unit of kWh/km for E-bus, kg/km for $H_2$-bus and l/km for ICE buses using diesel and biodiesel. **** As based on the national freight model, assuming discount rates are low in Norway.*

| | E-bus | | $H_2$-bus | | ICE-bus | | Biodiesel-bus | |
|---|---|---|---|---|---|---|---|---|
| | 2017 | 2025 | 2017 | 2025 | 2017 | 2025 | 2017 | 2025 |
| Vehicles required to serve a route due to charging downtime requirements (normalised to 1) | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Individual bus driving distance (km/y) | 80 000 | | 80 000 | | 80 000 | | 80 000 | |
| Vehicle lifetime (y) | 8 | | 8 | | 8 | | 8 | |
| Infrastructure lifetime (y) | 8 | | | | | | | |
| Interest on invested capital (%) | 3.5**** | | 3.5**** | | 3.5**** | | 3.5**** | |
| Fuel costs excl. VAT (NOK/unit*) | 1 | | 72 | 36 | 11.3 | 11.3 | 11.4 | 11.4 |
| Vehicle capital cost (MNOK) | 4.5 | 3.0 | 8.0 | 4.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| Infrastructure capital cost (MNOK/50 kW charger at depot)** | 0.54 | 0.49 | | | | | | |
| Infrastructure capital cost (MNOK/300 kW charger at depot)** | 1.40 | 1.26 | | | | | | |
| Fuel/energy use (unit/km***) | 2.30 | 2.00 | 0.10 | 0.10 | 0.42 | 0.41 | 0.42 | 0.41 |
| Maintenance (NOK/km) | 2.0 | 1.5 | 3.0 | 2.0 | 1.8 | 1.8 | 1.8 | 1.8 |

## 10.3 Cost analysis: results

Figure 10.5 presents the resulting change in TCO per km driven. For the current day, the ICE-bus TCO was calculated as 10.2 NOK/km. This compares favorably with studies where calculated TCO was 0.92 USD/km (8.4 NOK/km) for a driving distance of 80 000 km (Bloomberg New Energy Finance 2018) and 1.1 USD/km (9.7 NOK/km) where driving distance was 90 000 km (Gohlich, Fay et al. 2018).

The results indicate that although currently E- and $H_2$-buses have higher TCO than ICE buses using biodiesel and regular diesel (mostly due to the high vehicle capital costs for these technologies), by 2025 E-bus TCO is more comparable with ICE buses using diesel and biodiesel. These figures also account for an additional 10 % E-buses that are needed in the fleet to deliver the same transport as an ICE fleet. If it is assumed that by 2025 the fleet use is optimized so these extra vehicles are not required, then E-bus TCO is only 3 % higher than an ICE bus (compared to around 8 % higher with the extra vehicles included)[61]. The $H_2$-bus is also expected to reach more competitive levels by 2025.

Other studies find that E-bus TCO becomes favorable to ICE-buses by 2025 (Gohlich, Fay et al. 2018), or is even already favorable at the current time (Bloomberg New Energy Finance 2018); differences between studies are due to variation in assumptions and large uncertainty. An example is lower investment costs used in the calculations coupled with a long vehicle lifetime. In Oslo specifically, Ruter expects that by 2025, city E-bus operation will be economically competitive with ICE-bus operation due to increased demand and larger production volumes of both batteries and vehicles (Ruter 2018). For articulated buses, they believe that economic profitability comes 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 cause scarcity of raw materials and increases in purchase prices. Comparison of TCO between technology types is even less clear to operators, and from the supplier side, battery availability (and quality) is a concern.

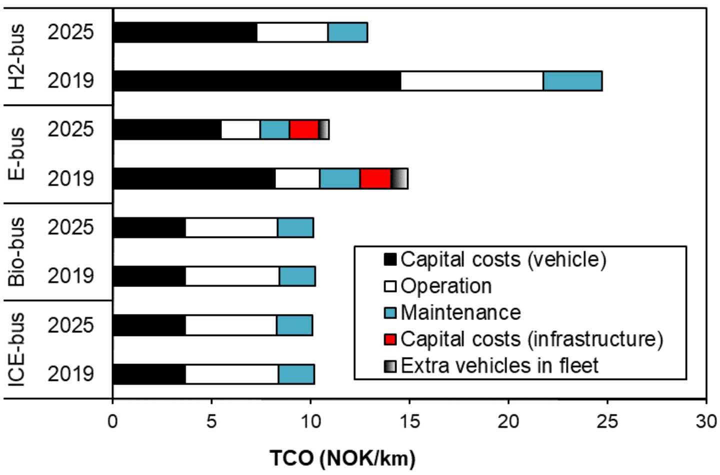



*Figure 10.5: A summary of the total cost of ownership (NOK/km) for E-buses, $H_2$-buses, biodiesel buses and ICE-buses in 2017and 2025. The cost of extra vehicles in the fleet required for the E-buses is presented in graduated fill, since there is large uncertainty here.*

[61] These results do not include the costs (~15 million NOK) of the expansion required to the grid, since the lifetime of these cables/transformers is high (>50 years).

## 10.4 Sensitivity analysis

Uncertainties in this study are large, making a sensitivity analysis (where key parameters are varied) of key importance. Aside from investment costs for buses and chargers, research shows there are also TCO differences with battery size (Bloomberg New Energy Finance 2018) and charging option (Gohlich, Fay et al. 2018). Previous studies also show that E-bus TCO improves further in relation to ICE-buses with longer bus routes (Bloomberg New Energy Finance 2018), but others note that this is uncertain due to battery and charging limitations (Hagman, Amundsen et al. 2017, Amundsen, Bruvoll et al. 2018).

Key parameters varied in this sensitivity analysis relate to vehicle investment costs and charging solution chosen. Aside from the parameter in question that was varied, all other parameters were kept the same as from the main analysis unless specified.

### 10.4.1 Variation of vehicle costs

The reduction in E-bus TCO shown in Figure 10.5 between 2019 and 2025 is predominantly due to a reduction in assumed vehicle capital costs, assuming battery market maturity and large-scale E-bus production. Vehicle investment costs are thus a key parameter to vary in a sensitivity analysis.

If an optimistic value is considered for the E-bus vehicle investment cost in 2025 (2.5 MNOK vs. 3 MNOK), TCO in 2025 is directly comparable with an ICE-bus at around 10 NOK/km for both options. In contrast, if a less optimistic E-bus investment cost is considered (3.5 MNOK vs. 3 NOK), E-bus TCO in 2025 is 19 % higher than for an ICE-bus. Changing the interest parameter from 3.5 % to 6 % did not greatly change the result.

Operator feedback was also accounted for that an additional 10 % vehicles are a baseline requirement in all fleets for the same service level, to cover downtime and maintenance[62]. It was assumed that the increase in fleet size to cover vehicle downtime did not increase the other cost components. This increased the E-bus TCO (for 2025) from 11.0 NOK/km to 11.5 NOK/km, but relative to an ICE-bus that also requires 10 % additional buses in reserve, the TCO only increased by 2 %-points (i.e. from 8 % higher to 10 % higher).

### 10.4.2 Variation of charging solution

The main analysis in this report assumes that 30 chargers (18 x 50 kW and 12 x 300 kW) may be shared between 30 buses, but this assumption would vary in practice depending on the charging solution chosen by an operator. Optimizations to the routes and E-bus usage will also be made looking to the future, enabling the bus-to-charger ratio to be decreased. Thus, a variety of analyses were made to compare the TCO resulting from various charging solutions, both with and without route optimization. These analyses were based on the input from one E-bus operator in Oslo, and the charging solutions they currently use.

A summary of the different scenarios for charging solutions used in the analysis, and the costs of these, is given in Table 10.3 and 10.4.

[62] This is in addition to the 10 % extra E-buses that are accounted for in the main analysis to give the same service level as a fleet of ICE buses, to account for downtime during charging time.

*Table 10.3: Various charging scenarios which may be taken (depot based, opportunity based, and a mixture of both), and the subsequent bus: charger ratios that may consequently be required. Un-optimized (current time) and optimized scenarios are given (optimized values are projected only). Values are based on the experience of one E-bus operator in Oslo. *Opportunity based solution is theoretical, not based on current operation practices in Oslo.*

| Charger type | Number of chargers required | | | | | |
|---|---|---|---|---|---|---|
| | Depot based solution | | Depot and opportunity based solution combined | | Opportunity based solution* | |
| | Current | Optimized | Current | Optimized | Current | Optimized |
| 50 kW (depot) | 18 | 18 | 10 | 10 | | |
| 80 kW (depot) | | | 1 | 1 | | |
| 300 kW (depot) | 12 | 12 | | | | |
| 300 kW (endstops) | | | 2 | 2 | | 1 |
| **Buses in fleet (number)** | **30** | **60** | **12** | **15** | | **8** |

*Table 10.4: Various investment costs for chargers and buses (costs for 2025 are projected only). Values are based on the experience of one E-bus operator in Oslo.*

| Charger type | Costs (million NOK) | | | |
|---|---|---|---|---|
| | Hardware alone | | Total (hardware, mounting, cables etc.) | |
| | Current | 2025 | Current | 2025 |
| 50 kW (depot)* | 0.26 | | 0.54 | It may be expected that total costs are reduced by 10 % |
| 80 kW (depot)* | 0.45 | | 0.74 | |
| 300 kW (depot)* | 1.00 | | 1.40 | |
| 300 kW (endstops)** | 0.90 | | 2.95 | |
| **Buses in fleet (costs)** | | | **4.5** | **3.0** |

Results of the analysis are shown in Figure 10.6. As can be seen, depot charging and opportunity charging represent the charging solutions with the lowest TCO, with projected optimizations by the year 2025. Both of these solutions give comparable TCO to that of an ICE-bus. Depot charging alone allows the use of chargers with relatively low cost, whilst for an optimized opportunity charging solution, the high cost of opportunity chargers at endstops is offset by the high number of buses that may use them. Where a mix of depot charging and opportunity charging is used, the high cost of the opportunity charging points is not offset over a high number of buses. According to TCO analysis performed by Ruter, the cost of depot charging solutions will also vary with different routes, meaning the most favorable solution must be chosen on a case by case basis.

However, these solutions also come with varying practicalities. For example, where an opportunity charging solution alone is chosen, the buses may not be preheated before use. Thus, heating energy will be consequently higher. This is not accounted for in the analysis.

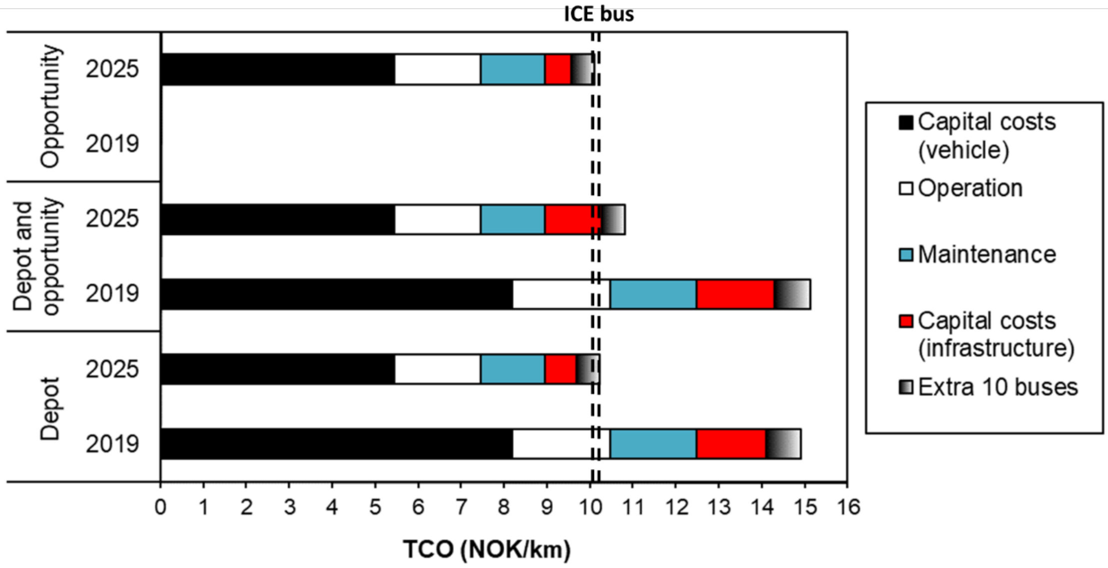



*Figure 10.6: A summary of the total cost of ownership (NOK/ km) for E-buses with depot based, opportunity based and a mix of depot and opportunity based charging solutions, both for the year 2019 and as projected for an optimized case in the year 2025. The TCO for a corresponding ICE-bus, in 2019 and as projected for 2025, is shown by the dotted line for comparison. The cost of extra vehicles in the fleet required for the E-buses is presented in graduated fill, since there is large uncertainty here.*

### 10.4.3 Summary of findings

Due to the variation of TCO with input parameters, results presented here are only indicative and have high associated uncertainty. Nevertheless, it is clear that although currently, a great challenge relating to E-buses is their high upfront cost compared to diesel buses with mass vehicle production, the potential is high for competitive E-bus TCO compared to other technologies in future. This is with upcoming larger scale production of E-buses and a projected decrease in investment costs. The charging solution chosen must be carefully dimensioned and planned, and will be route dependent.

# 11 Discussions and conclusions

## 11.1 Adaption of zero-emission vehicles

Heavy-duty vehicles, such as buses and trucks, cause substantial emissions of $CO_2$, both in Norway and in other countries. Ambitious climate commitments and policy objectives such as in Norway's National Transport Plan, however, require large emission reductions and a strong transformation to achieve a large-scale adoption of zero-emission vehicles.

In this report, we described the status and prospects for alternative, zero-emission propulsion technologies, both globally and from a Norwegian perspective. Although rapid developments are taking place in the market for battery-electric passenger cars, and to a lesser extent also for vans, further technological and market maturity is required before zero-emission propulsion technologies can become a full-fledged alternative for HDVs. This applies particularly for trucks.

For buses, the phase-in of battery-electric solutions is accelerating. At the start of 2019 for example, there were fewer than 20 battery-electric city buses in operation in Norwegian cities, while during 2020, 416 electric buses are planned to be phased-in in eight Norwegian cities. The adoption of E-trucks is lagging behind this development. The reason for this is that the demand and production of E-buses is moving from a phase of testing towards small to medium-scale series production. This development is driven by terms and conditions on environmental performance set in public transport procurement, and use cases being more suitable than for trucks due to fixed routes and a greater number of opportunities to charge during the day. Meanwhile, E-trucks are currently only available as vehicles rebuilt from diesel engines, although the first manufactures will have a limited number of small-series produced vehicles for sale with delivery in the first half of 2020, and several manufacturers claim to be preparing series production of battery-electric and hydrogen trucks over the next couple of years. Detailed plans, however, remain scarce.

## 11.2 User experiences

For this report, we analyzed experiences from small-scale pilots with E-buses and E-trucks in Norway, focusing on purchasing processes, the current technology status, vehicle choices, use and user requirements, and other performance aspects. Despite the fact that these pilot projects have so far been ongoing for only a relatively short time period, the first experiences with E-buses and E-trucks (particularly with vehicles in the waste and recycling sectors) have predominantly been positive, as stated by the users themselves. Although there have been some major problems - as well as minor 'teething' problems – leading to downtime of individual vehicles, most operators are well pleased and hopeful regarding the future adoption of more battery-electric vehicles. However, the interviews also indicated a number of challenges that have to be addressed to decrease and remove barriers to investing in battery-electric solutions for the day-to-day operation of trucking and bus companies. If a transition to electric HDV use is to be made, charging infrastructure must be further developed, possibly with support from authorities where streetside charging points for e.g. E-buses are required. Interviews also highlighted the importance of keeping incentives to encourage the uptake of zero-emission technology, and keeping an emphasis on the environment in public tenders to give electric HDVs a competitive edge.

The greatest challenge relating to electric HDVs is their high upfront cost compared to similar ICE vehicles. This means that, although operation-related and maintenance costs are comparable (or lower), total ownership costs are currently higher for these vehicles.

## 11.3 Barriers

In addition to high investment costs, a number of important barriers for the adoption of battery-electric vehicles are limitations to range, weight and volume cargo capacity restrictions, and the current limited access to charging/filling infrastructure. In a shorter term, uncertainty about operational stability and a lack of knowledge of how these vehicles can be operated under Norwegian conditions also form barriers.

With regard to weight and capacity restrictions, current technology yields a trade-off between driving range and freight capacity, particularly for E-trucks. For one of the pilot E-trucks for example, the battery weight and limitations on vehicle weight reduced the effective payload with 2.5 tonnes compared to a similar ICE truck, and battery placement can also lead to (smaller) reductions in volume capacity. For E-buses, batteries have yielded small reductions in the maximum number of standing places, but as the total standing place capacity is never fully utilized according to an operator, the real passenger capacity is not expected to differ from ICE buses.

For E-trucks, where the trade-off between driving range and vehicle capacity is considered most relevant, it can be expected that battery development and larger-scale production will somewhat negate this challenge, or that losses in capacity can be compensated for by using E-trucks on assignments where capacity utilization is lower than the average for ICE trucks. Weight and capacity restrictions may also become less restrictive following legislation adopted by European Parliament in April 2019, opening up for a two-tonne additional total vehicle weight allowance for larger zero-emission trucks (European Parliament 2019, Transport & Environment 2019). Given current battery technology, two tonnes of batteries are equivalent to a driving range of ca. 150-200 km for trucks.

With regard to operational stability, experiences from E-truck and E-bus operation have shown that this cannot yet be taken for granted. During startup periods, when trucks or buses were taken into use for the first time, a number of issues led to more downtime than usual due to e.g. a lack of service and repair experience, or long lead times for spare parts. These barriers need to be reduced. For both E-buses and E-trucks this necessitated in several places keeping back-up capacity in place (using ICE vehicles), which adds significantly to the capital cost of operation. Extra vehicles are always needed in a vehicle fleet to account for downtime, but the interviewed bus operators expressed that the need for back-up capacity is greater for operation with electric vehicles For example, feedback was received that an extra 5-10 % of buses was required in the fleet to account specifically for e.g. downtime during charging. However, it is expected that increasing experience (leading to vehicle use optimization) and technological progress will largely negate these challenges.

In addition, vehicles using alternative propulsion technologies currently face barriers related to charging and refueling. In cases where driving ranges are such that daytime charging is required, vehicles are effectively unavailable part of the time. If charging is required outside of regular break times – such as during the night or during imposed resting or lunch breaks when the vehicle stands still anyway – this may impact the effective use time of the vehicle.

This also means that producing the same level of services may require a larger number of vehicles. On top of additional capital costs, this could also require more person-hours, leading to higher wage costs. Further, if charging stations or hydrogen filling stations are not readily available (as they are for diesel), this can increase costs by means of relatively high prices (following limited competition among suppliers), by necessitating detours (for filling), or by setting route limitations (range) which would lead to a need to adapt driving patterns and distribution routes.

## 11.4 Potential for electrification

In light of the current limitations in driving ranges, we analyzed the potential for electrification of trucks from a use pattern perspective. In the short term, we found that main challenges (given Norwegian user patterns and requirements) are related to limited battery capacity (and thus driving ranges), limited engine power of current offerings, and consequently, the limited ability to drive with trailers attached. Today, the large majority of long-haul driving with newer trucks is done with engines over 500 HP, for which there are currently few alternatives to diesel. Trucks with lower engine power and daily mileages suitable for electrification currently make up only a fraction of total mileages. For E-trucks to reach significant market shares, there is therefore a need both for more powerful engines than in today's pilots, and for driving ranges beyond 200 km. These needs are amplified by the observation that a large share of the total driving is performed with a trailer attached, and that such trips are also longer on average than when not using trailer.

In a longer time perspective, it can be argued that firms owning several trucks can redistribute transport routes between vehicles, and thereby increase the potential for electrification. This potential is hard to quantify, but our findings suggest that if the engine power of E-trucks would increase to 600 HP and battery capacity would support driving ranges of at least 300 kms all year, this would allow for the electrification of a large share of transport. Today, about 84 % of trips and vehicle-kms and about 78 % of tonne-kms is namely carried out with engines up to 600 HP, while driving with daily distances up to 300 km makes up nearly 60 % of total annual mileages driven with newer trucks. The faster filling time of hydrogen means that the range limitations discussed above are not relevant for hydrogen trucks if there is sufficient hydrogen infrastructure in place.

With regard to vehicle weight and capacity restriction and the trade-off between driving range and freight capacity, we looked at the extent to which trucks might have 'spare capacity'. Here, we find that most trips driven with cargo do not utilize the vehicle's full capacity; over 80 % of total mileage is driven with at least 20 % of the vehicle's capacity in terms of weight unutilized, suggesting up to several tonnes 'spare' room for the extra weight of a battery. Whether this is actually the case in practice is dependent on whether some trucks are always driven with less weight, whether there are parts of distribution routes that have less weight, or whether the data fully identifies variations in transport volumes during the year.

With regard to charging challenges, feedback from the pilot projects analyzed in this report indicates that if a transition to electric heavy-duty transport is to be made, charging infrastructure must be further developed. Although currently depot charging is used by most operators, an emphasis is increasingly being placed on fast charging.

For buses, in closed systems such as in cities the potential for E-bus use is high. This is reflected in Norwegian targets for all new city buses to be either zero-emission (battery or hydrogen) or using biogas by 2025, and in the multiple plans at a regional level set by local transport authorities. Regional driving of buses (i.e. outside of cities) is more complicated to address, since it faces many of the same challenges as for heavy-duty trucks (e.g. range requirements).

## 11.5 Ownership costs

With regard to the costs of ownership of vehicles using alternative propulsion technologies (E-buses and E-trucks) versus ICE vehicles, we carried out cost comparisons for several scenarios of production maturity.

For ICE-trucks, cost functions were predominantly based on validated and regularly updated base parameters from a National Freight Model for Norway, and are representative of the average cost of ICE vehicles. For battery-electric propulsion and hydrogen-electric propulsion, parameters were based on several sources and assumptions on reductions in vehicle production costs in more mature phases of production. Given the early development of this market, the lack of transparency on the costs of battery-electric and hydrogen solutions, and uncertainty regarding operational characteristics, these estimates are currently less reliable than those established for diesel vehicles.

From our cost analysis, we found that in current, early stages of production, larger battery-electric trucks cannot compete on costs with vehicles using diesel, biodiesel, or biogas, without incentives. The main reason for this is the large cost premium of investment when purchasing a battery-electric truck. When this cost premium decreases, as we assume through a scenario with small-scale series production, we find that these vehicles in the future may become competitive vis-à-vis diesel vehicles at annual mileages of between ca. 43 000 km (tractors) and 58 000 km (heavy distribution trucks). From data on vehicle usage, we find that such mileages are far from unusual for current ICE vehicles that are 0-5 years old. Provided that the battery-electric alternatives provide comparable driving ranges, cargo capacity, etc., they could thus become a cost competitive alternative. However, there are other barriers to overcome, such as development of infrastructure for fast-charging, establishing knowledge about the operational characteristics, and the development of second hand market for these vehicles.

In turn, small- and medium-sized vans in the current phase with small-scale series production are cheaper in operation than (bio)diesel or biogas vehicles for relatively short annual mileages, especially considering typical annual mileages of newer vehicles in these segments.

Finally, in the scenario with mass production of battery-electric vehicles, we see that HDVs become cost competitive versus diesel vehicles already from relatively low annual mileages of between 19 000 – 23 000 km, depending on the vehicle segment. The main reason for this is the low energy cost when operating on electricity. Compared to biodiesel and biogas vehicles, the break-even point is even lower.

Battery-electric vans, in turn, are cost competitive already from annual mileages of around 1 000 km in the mass production scenario. Even if such vehicles would lose advantages such as toll exemptions/discounts, it therefore seems likely that they will remain a competitive alternative from an economic point of view. Range and charging time, and less flexible vehicle use, are however barriers that may still reduce the diffusion of these vehicles into the fleet.

For E-buses, results indicate that although currently E-buses have higher TCO than ICE-buses running on diesel or biodiesel (mostly due to the high vehicle capital costs for these technologies), by 2025, TCO is more comparable with such ICE-buses. These figures also account for an additional 10 % E-buses that are needed in the fleet to deliver the same level of transport services as an ICE fleet, in light of e.g. charging downtime. The charging strategy for the modelled E-buses was assumed to be based on depot charging, due to the difficulties experienced by operators (at present) in installing opportunity charging in city centers, and was based on the number and type of chargers/buses used by one operator interviewed. Although results have high associated uncertainty, it is nevertheless clear that the potential is high for competitive E-bus TCO compared to other technologies in future. This is with upcoming larger scale production of E-buses and a projected decrease in investment costs. The charging solution chosen must be carefully dimensioned and planned, and will be route dependent.

Hydrogen-electric vehicles were found to have higher total annual costs than battery-electric vehicles for all the analyzed vehicle segments. This situation is in part due to battery solutions for trucks and buses entering into more mature stages of production, while hydrogen solutions are less developed and lag behind.

## 11.6 Measures

Overall, the adoption of zero-emission propulsion technologies on HDVs does not necessarily happen automatically even when ownership cost parity is reached. This is due to a number of barriers, one of them being the high investment costs resulting from limited demand and production scale. In order to speed up the manufacturers' start-up of series productions, demand must be created through requirements in public and private tenders. Especially for buses and waste collection trucks, zero-emission technology can be phased in through new tenders. In order to speed up the phase-in, public transport companies and municipalities can introduce change orders to existing contracts, such as has been done for bus contracts in Oslo.

Further, predictability in the framework for ownership and operation is important. Because incentives through policy instruments such as purchase tax or VAT exemptions, are much weaker for vans, buses and trucks than for passenger cars, other incentives are needed. For HDVs and enterprises, main policy instruments for encouraging the uptake and further diffusion of zero-emission technology are support through the ENOVA scheme and 'zero-emission fund'. Further support schemes include the Pilot-E and Klimasats programs.

Local incentives such as free (or reduced costs for) toll-road passing and access to bus lanes will also foster increased adoption of E-trucks and E-buses. Finally, in light of the particularly high cost of investment and lack of incentives in the form of purchase fee exemptions (as is the case for passenger cars in Norway), other economic measures need to be used. Examples are changes in tax deduction regulation for battery- and hydrogen-electric vehicles (e.g. by allowing the tax deduction of the full purchase costs already in the first year, or by expanding the current (slight incentive) for electric vans in the so called zero-emission fund, to also apply for electric trucks) may also improve incentives for adoption.

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# Appendix 1: Example of a questionnaire used in the interviews

## Elektrisk renovasjonsbil

*Prosessen bak innkjøpet av bilen(e).*

- Ligger det en strategi bak innkjøpsprosessen?
- Hvordan var beslutningsprosessen?
- Ble brukerne involvert (sjåførene)?
- Var det utfordrende å finne leverandør?
- Har sjåførene fått noen form for opplæring?
- Har dere fått økonomisk støtte til innkjøpet?

*Hvordan brukes sammenliknbare dieselbiler generelt?*

- Dieselforbruk per km, per dag, per år, distanse per dag og år (eventuelt hvordan det er fordelt i bilparken – er det biler som kjører kort, langt etc.), brukstimer per dag og år.
- Antall skift, antall sjåfører

*Generelle spørsmål om el-lastebil*

- Når ble el-lastebilen(e) satt i operasjonell drift?
- Hva slags bruk er kjøretøyet innkjøpt til?
- Hvilke(t) merke(r) har kjøretøyet og hvem har levert påbygget
- Er kjøretøy(ene) originalt produsert med elektrisk fremdrift eller er de(n) ombygget?
- Hvilket firma har evt. stått for ombyggingen?
- Hvor stor batteripakke (i kWh)
- Hva er motorens effekt (i kW)
- Hva er tilbakemeldingene fra bilansvarlig og sjåfører på kjøretøyet?
- Har det så langt vært utfordringer med annen mekanikk på bilen, som f.eks. bakløfter eller komprimator og som kan skyldes at bilen har elmotor?

*Informasjon om drift med elversjon*

- Operative timer pr dag
- (Forventet antall) Operative dager pr år
- Har det vært perioder med driftsbrudd som skyldes tekniske utfordringer?
- Rekkevidde og forskjeller i teoretisk versus virkelig drift (sommer og vintertid, kjøring med og uten last, kurvatur og topografi)
- Lastekapasitet vs diesellastebil

- Lades bilen i løpet av dagen, og eventuelt hvor?
- Ladetid og ladeeffekt
- Ladeinfrastruktur (hvor lades bilen og er det et problem med manglende ladeinfrastruktur), type ladekontakt, kostnader for å etablere lading, når lades bilen)
- Batteriforringelse og forventet levetid
- Har dere måttet endre på driftsrutiner for å få bilene til å fungere i daglig drift?
- Har dere oppdaget problemer eller fordeler som dere ikke forutså før innkjøpet?
- Har dere fått tilbakemelding fra «publikum» der bilene opererer?

*Service og vedlikehold*

- Hva slags serviceavtale har dere med leverandør?
- Hva forventer dere i forhold til vedlikeholdskostnader og -behov?

*Er det mulig å dekomponere merkostnad knyttet til investering:*

- (Chassis)
- Elmotor
- Batteri
- Montering/ombygging

*Distanseavhengige kostnader*

- Energikostnad (kr/kWh)
- Energiforbruk
- Vedlikeholdskostnader
- Bompenger (gj.sn. bompengekostnad pr utkjørt km for tunge biler (mer enn 3.5 tonns totalvekt) for bil med forbrenningsmotor (er renovasjonsbiler fritatt?)

## Offentlige rammebetingelser

*Offentlige rammebetingelser, insentiver, dispensasjoner, etc. som kan bidra til forsert innfasing av elektriske kjøretøy?*

- Krav til, eller belønning av, miljøvennlige kjøretøy i anbudsprosesser?

# Appendix 2: Assumptions used in the cost models

1. Overview of reference investment costs and cost premiums
2. Overview of leasing period, depreciation, residual values, discount rate?
3. Energy consumption parameters
4. Maintenance and repair costs

Interest rate (finance cost): 3.50 %

Annual wage of drivers: 408 000 NOK

Social costs, rate: 14.2 %

Holiday costs, rate: 12.0 %

Activity rate: 80 %

**Reference investment costs (rounded), in NOK:**

| | |
|---|---|
| Light distribution truck | 982 000 |
| Heavy distribution truck (closed unit) | 1 251 000 |
| Semi-trailer (truck unit) | 1 369 000 |
| Small van | 144 000 |
| Medium van | 261 000 |

**Cost premiums compared to comparable diesel vehicle:**

| | Base scenario/early stage | Small-scale series production | Mass production |
|---|---|---|---|
| Light distribution truck | Biogas: ca. 30 % more expensive. Battery-electric: ca. 215 % more expensive. Hydrogen: ca. 350 % more expensive. | Battery-electric vehicles assumed to be twice as expensive as comparable conventional diesel vehicles. Hydrogen vehicles assumed to be three times as expensive as comparable conventional diesel vehicles | Battery-electric vehicles assumed to be 1.5x as expensive as comparable conventional diesel vehicles. Hydrogen vehicles assumed to twice as expensive as comparable conventional diesel vehicles |
| Heavy distribution truck (closed unit) | Biogas: ca. 30 % more expensive. Battery-electric: ca. 200 % more expensive. Hydrogen: ca. 320 % more expensive. | | |
| Semi-trailer (truck unit) | Biogas: ca. 30 % more expensive. Battery-electric: ca. 330 % more expensive. Hydrogen: ca. 450 % more expensive. | | |
| Small van | Biogas: ca. 30 % more expensive. Battery-electric: ca. 170 % more expensive. | | |
| Medium van | Biogas: ca. 40 % more expensive. Battery-electric: ca. 210 % more expensive. | | |

### Leasing periods:

| | |
|---|---|
| Light distribution truck | 5 years |
| Heavy distribution truck (closed unit) | 5 years |
| Semi-trailer (truck unit) | 5 years |
| Small van | 5 years |
| Medium van | 5 years |

### Residual values:

| | National Freight Model, conventional diesel vehicle, after 5 years | Alternative propulsion technologies |
|---|---|---|
| Light distribution truck | 26 % of original value | Same residual value share as for diesel vehicle.<br><br>For battery-electric and hydrogen vehicles, discounted by 50 % in early stage scenario, and by 25 % in small-scale series production scenario |
| Heavy distribution truck (closed unit) | 23 % of original value | |
| Semi-trailer (truck unit) | 28 % of original value | |
| Small van | 26 % of original value | |
| Medium van | 26 % of original value | |

### Energy consumption parameters:

| | Unit | Light distribution truck | Heavy distribution truck (closed unit) | Semi-trailer (truck unit) | Small van | Medium van |
|---|---|---|---|---|---|---|
| Diesel | Liter/km | 0.223 | 0.301 | 0.450 | 0.073 | 0.093 |
| Biodiesel | Liter/km | 0.244 | 0.329 | 0.493 | 0.080 | 0.102 |
| Biogas | Liter/km | 0.220 | 0.297 | 0.444 | 0.072 | 0.092 |
| Hydrogen | KG/km | 0.035 | 0.047 | 0.070 | 0.011 | 0.014 |
| Electricity | kWh/km | 0.669 | 0.902 | 1.350 | 0.219 | 0.279 |

### General maintenance: costs in NOK/km:

| | Diesel / biodiesel / biogas propulsion | Battery-electric / hydrogen propulsion |
|---|---|---|
| Light distribution truck | 0.68 | 50 % of general maintenance costs for diesel vehicles of same vehicle category |
| Heavy distribution truck (closed unit) | 0.76 | |
| Semi-trailer (truck unit) | 0.93 | |
| Small van | 0.56 | |
| Medium van | 0.56 | |

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