Summary

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

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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

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[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-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.

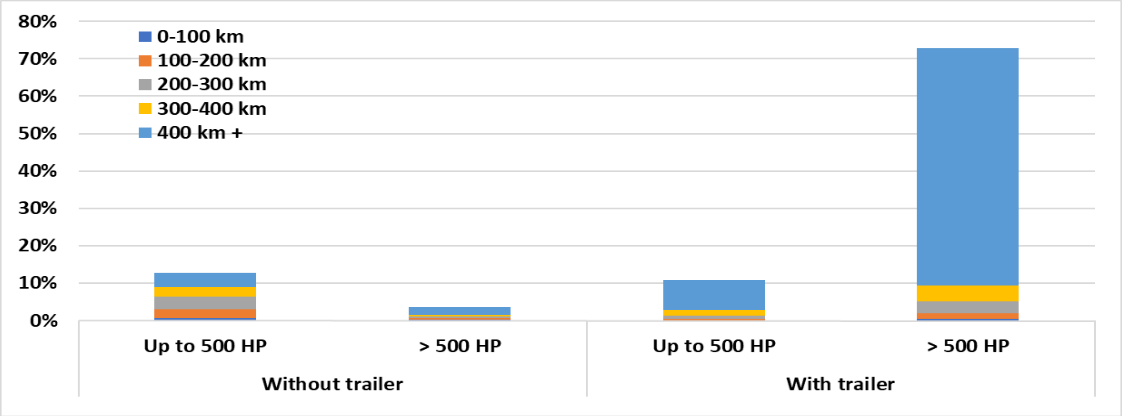

Figure S.1: Distribution of daily mileages for trucks of up to 5 years old, for engine power below and over 500 HP, and for driving with and without trailer attached. Source: Base data of Statistics Norway's 'survey of trucks' for 2016 and 2017 and Autosys registry.

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.