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Feasibility study of the electrification of the urban goods distribution transport system

Project within Transport Efficiency

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1 Executive summary

The recent EU white paper on transport[1] sets the target to achieve essentially CO2-free city logistics in major urban centres by 2030. Local, regional as well as federal authorities will likely push the use of zero emission vehicles in city centres by means of regulations and incentives.

With its energy efficiency, lower running costs, low emissions and reduced noise, the concept of electrification of urban transport might well be a win-win situation for all stakeholders involved.

The project has studied the feasibility of the electrification of urban goods transport by involving all relevant actors in the transport value chain. In addition, leading research actors has contributed with research and input on policy implications, information and communication technology and business perspectives.

The study indicates that we will start to see a transition from conventional vehicles to electrified commercial vehicles within the time period 2015 to 2025. During this period electrified trucks are predicted to become cost competitive from a TCO perspective in several urban good distribution applications. Since the vehicle utilization is seen to be critical for establishing the business case, the transition to electrified vehicles can be expected to go quicker for other urban vehicles with much higher yearly mileage and/or high energy use per kilometer, e.g. city buses and refuse trucks.

The EU target of 2030 is already now technically feasible and again the study show that by that time the electrified vehicles may well also be the most economically choice. However, reaching such a high market penetration as the target “essentially CO2-free city logistics” indicates will require significant support with appropriate policies in the timeframe 2015-2025.

To boost the transition from conventional to electric and hybrid trucks for city distribution in the city of Gothenburg, there are several options that would be beneficial for transporters. For example, charging stations easily accessible for charging during day time, one possibility is to have charging available at loading areas during distribution. Another is to exclude electric vehicles from the congestion charge.

ICT and business model innovations will have an important role to support the development in the transition period in minimizing financial risks and uncertainties experienced by the vehicle customers. Further, authorities on all levels (local cities to national) need, short term, to increase the understanding of the benefits as well as the limitations of electrified urban vehicles and develop policies supporting (i) the unique modes of operation zero tail-pipe emission can offer and also (ii) high vehicle utilization.

2 Background

The recent EU white paper on transport[2] sets the target to achieve essentially CO2-free city logistics in major urban centres by 2030. Local, regional as well as federal authorities will likely push the use of zero emission vehicles in city centres by means of regulations and incentives.

A more electrified urban transport system offers significantly higher transport system energy efficiency, no local emissions in urban areas, much reduced noise from commercial vehicles and the potential for a large scale zero emission transport system when renewable energy is used.

With recent progress in energy storage technology and automotive electric motors and drives, electrified commercial vehicles for city application (such as city buses, goods distribution and refuse) are now beginning to seem both technically and economically viable. Such products are also just emerging on most global markets. Examples are the Electric Maxity from Renault Trucks[3], New Energy buses in Shanghai from Sunwin[4], electric refuse trucks from PVI[5] and city distribution vehicles from Smith Electric Vehicles[6].

With its energy efficiency, lower running costs, low emissions and reduced noise, the concept of electrification of urban transport might well be a win-win situation for all stakeholders involved.

The project has studied the feasibility of the electrification of urban goods transport by involving all relevant actors in the transport value chain. In addition, leading research actors has contributed with research and input on policy implications, information and communication technology and business perspectives.

3 Objective

The aim of the project is to create valuable knowledge on the possible business opportunities for the project parties in electrified goods distribution. The improved understanding of the cost and benefits (economical as well as environmental) of urban vehicle electrification will be new and helpful input for authorities and organisations responsible for funding, regulations and incentives to their future programmes.

From the project we expect: (i) a well-defined urban transport reference case, (ii) a modelling approach and initial simulation model incorporating vehicle energy use, associated emissions as well as business aspects, (iii) a (limited) number of scenarios for the electrification of the reference transport application, (iv) specification of the information and communication systems required for realization of the scenarios, (v) details of the full value chain in the scenarios and possible business models for all actors, (vi) assessments of the scalability of the selected electrification concepts and requirements for their deployment including implications of different policies and (vii) an outline for a demonstration project if the electrification concepts analysed looks promising.

4 Results and deliverables

4.1 Introduction

This report presents the results from the FFI project Feasibility study of the electrification of the urban goods distribution transport system where the feasibility of electrifying medium to heavy urban goods distribution trucks have been investigated. As a case study, an existing transport system in the Swedish city of Göteborg is used. The project is a joint research effort between a vehicle Volvo, Victoria Institute, Gothenburg University, School och Business, Economics and Law, Schenker AB, Göteborg Energi, and the Swedish Transport Administration.

In order to assess the viability of electrification, the project deals with the technical and economic aspects linked to the implementation of different vehicle designs. In particular results from a novel approach of selecting vehicle powertrains from a total cost of ownership (TCO) point of view is presented. Optimization is used to identify the best candidate for vehicle electrification in this particular transport application. A number of actual urban goods distribution routes have logged and combined with previously available driving patterns. In addition forecasts of vehicle, powertrain and energy costs have been made for years 2015 and 2025 as input to the analyses.

Since the internal combustion engine enjoys a status as the dominant design, Midler & Beaume [1] argues that it is necessary to take into account such factors as customer practices, ecosystem borders and regulations in order to break this dominance. The introduction of electrified vehicles in city logistics thus calls not only for an evaluation of the costs and technical difficulties but also of other types of values created or lost in comparison with business as usual. In order to evaluate such factors, information and communication (ICT) needs were evaluated together with possible business model changes.

4.2 WP1 Use cases

Transport task description

To define use cases for goods distribution in Göteborg, major transporter Schenker and their contractors “TGM” and “Bäckebols åkeri” were studied. The applications in focus are goods distribution to shops and offices and the distribution of refrigerated and frozen goods to shops and restaurants. The use cases are limited to trucks >3.5 tons.

TGM and Bäckebols åkeri distribute goods in the area of larger Gothenburg including the city of Gothenburg and 12 surrounding municipalities. This area is divided into about 60 distribution areas, where one distribution truck covers a single area in one shift. Additionally, there are a number of extra trucks that distribute in different areas depending on the need. ~7 of the trucks distribute within the city center of Gothenburg, ~25 in the area surrounding the city center, ~25 cover of the areas further from Gothenburg, and the remaining trucks are extra trucks. Except goods distribution, also refrigerated and frozen foods are delivered by about 10 vehicles covering the all distribution areas.

Vehicle and route data collection

To study the goods distribution of TGM and Bäckebols åkeri, observations of drivers during shifts, interviews and data logging of trucks were done. The observations in-vehicle provided information on the typical delivery and collection schedules, type of goods and the use of trucks (e.g. auxiliary systems such as tail lift and cooling systems).

Data logging was also performed to collect vehicle route data on maps, speed and acceleration of the vehicles versus time, daily driving distance and the weight of goods. Location, speed and acceleration of the vehicles and the weight of the goods were recorded continuously during two weeks, see figure 1.

The distribution routes of TGM and Bäckebols åkeri were seen to be quite general and similar to the competitors in the region. According to Schenker, the very small distribution areas in the city are in Gothenburg more specific to Schenker due to the large amount of customers in the city and the very short distance between them. Based on the information collected, the different types of distribution routes could be categorized into zones. The city center distribution areas covered a daily distance of 40 km, the immediate surrounding area 80 km, and the outer area of larger Gothenburg 140 km.

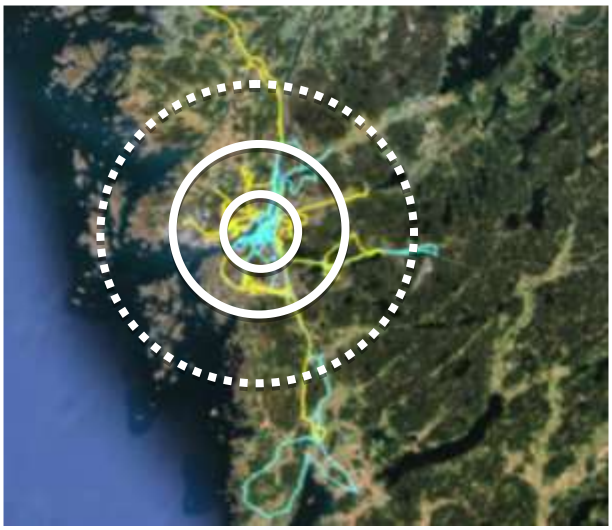


Figure 1. Example of logged routes. The circles are showing the three typical distribution areas; city center, the immediate surrounding area, and the outer area of larger Gothenburg.

4.3 WP2 Electrification scenarios

To create electrification scenarios, it was assumed that also the future vehicle solutions should meet the needs of the current use cases and no radical changes in how goods are distributed locally are expected within the 2025 time frame.

Taking the collected data into account, 16 different scenarios were developed for the study. These scenarios contain different combinations of daily driving distance (40, 80 or 140 km per shift), different transport task (standard or refrigerated) different charging possibilities (only night or night & lunch charging) and one- or two-shift use (a max 1 h charging opportunity in each shift is assumed). Table 1 summarizes the different scenarios.

Scenario	Truck type	Shift driving distance (km)	Charging and use schedule
1	Box	40	Night
2	Box	40	Night & lunch
3	Box	40	Night & lunch, dual shifts
4	Box	40	Night, dual shifts
5	Box	80	Night
6	Box	80	Night & lunch
7	Box	80	Night & lunch, dual shifts
8	Box	80	Night, dual shifts
9	Fridge	140	Night
10	Fridge	140	Night & lunch
11	Fridge	140	Night & lunch, dual shifts
12	Fridge	140	Night, dual shifts
13	Box	140	Night
14	Box	140	Night & lunch
15	Box	140	Night & lunch, dual shifts
16	Box	140	Night, dual shifts

Table 1. Definitions of the different scenarios used in the optimization and analysis.

The vehicles considered in the study are distribution trucks with an unloaded mass of about 8000 kg. Two variants of truck bodies are considered, one with a standard box body, and one with an actively refrigerated body for frozen and refrigerated goods. In addition, the projects partners together also made local price forecasts for diesel fuel price and electric energy price up to 2025.

Ownership cost evaluation

The presented scenarios, together with logged vehicle data, provide the input for future vehicles to study. This evaluation is made from the perspective of the end customer and the most cost effective powertrain for each scenario, with respect to total cost of ownership is identified through a novel optimization methodology developed by Hellgren & Jacobsen[7] and further by Hellgren[8]. In this approach, sub system sizes for every possible powertrain layout are optimized, and fuel and capital costs of the resulting vehicles are calculated in all transport scenarios, both for 2015 and for 2025. During the optimization, a number of constraints such as acceleration, speed requirements, maximum allowable battery mass are set. For example, an electric powertrain is not feasible if the driving distance is so demanding that the battery becomes unrealistically large. Some of the most important constraints are shown in Table 2.

i	Description
1	Acceleration time restriction, 0-50 km/h. Battery power is assumed to assist.
2	Continuous top speed demand. Battery power is assumed to not assist.
3	Gradeability requirement.
4	Engine portfolio restriction. There is a finite set of available engine sizes.

Table 2. Constraints for conventional vehicle. The constraint number is represented by i.

For every scenario, six different powertrain topologies are evaluated and designed to minimize TCO. Table 3 lists all powertrain variants evaluated for each scenario.

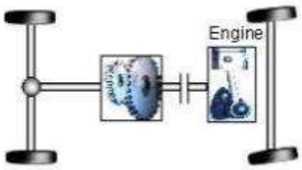
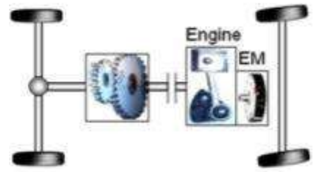
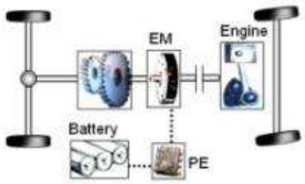
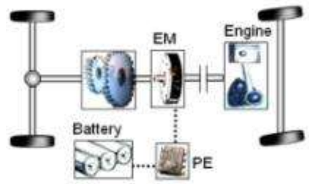
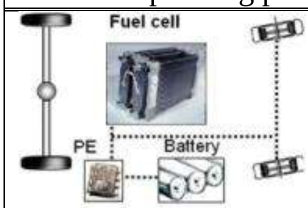
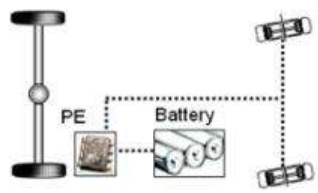
	
Conventional. No electric drive system present in powertrain.	***Micro hybrid.*** A specially designed electric motor and battery enables frequent engine cranking. Engine is shut off during longer idling periods.
	
Parallel hybrid. Has an electric drive system for engine cranking and brake energy regeneration. It also enables the diesel engine to operate in more efficient operating points.	***Parallel plug-in hybrid.*** A larger battery enables external charging and full-electric driving.
	
Series plug-in hybrid. A fuel cell is used for driving situations where the energy/power in the battery not is sufficient.	***Electric.*** All propulsion power is handled by the electric drive system and the battery. Relies on external charging.

Table 3. The different powertrain concepts evaluated in the optimization.

Conventional powertrain

The ownership cost for the conventional powertrain is defined by (1) and (2). The optimization problem (1) points out the engine size that minimizes the TCO and which also fulfills all the constraints defined; C_i.

$$\min c_{\text{conv}}(P_{\text{eng}}) \text{ with respect to } C_1..C_N \quad (1)$$

$$c_{\text{conv}} = c_{\text{chass}} + c_{\text{eng}} + c_{\text{trans}} + c_{\text{driveline}} + c_{\text{FC}} \quad (\text{€/km}) \ (2)$$

Micro hybrid powertrain

The micro powertrain has the ownership cost defined by (3) and (4). As for the conventional powertrain there is only one design variable; engine size. Also the constraints are equal. The only difference is the cost terms for the start-stop electric drive system which are added.

$$\min c_{\text{micro}}(P_{\text{eng}}) \text{ with respect to } C_1..C_N \quad (3)$$

$$c_{\mathrm{micro}} = c_{\mathrm{chass}} + c_{\mathrm{eng}} + c_{\mathrm{trans}} + c_{\mathrm{driveline}}$$

$$+ c_{\mathrm{microeldrive}} + c_{\mathrm{batt}} + c_{\mathrm{masspen}} + c_{\mathrm{FC}} \quad (€/\mathrm{km}) \quad (4)$$

Hybrid vehicle powertrain

Equation (5) and (6) defines the TCO for the parallel powertrain. As (5) shows there are now four design variables: engine size, battery size, electric drive power, and battery type.

$$\min c_{\mathrm{parallel}}(P_{\mathrm{eng}}, E_{\mathrm{batt}}, P_{\mathrm{eldrive}}, type_{\mathrm{batt}}) \text{ with respect to } C_1..C_N \quad (5)$$

$$c_{\mathrm{parallel}} = c_{\mathrm{chass}} + c_{\mathrm{eng}} + c_{\mathrm{trans}} + c_{\mathrm{driveline}}$$

$$+ c_{\mathrm{pareldrive}} + c_{\mathrm{batt}} + c_{\mathrm{masspen}} + c_{\mathrm{FC}} \quad (€/\mathrm{km}) \quad (6)$$

Constraints for payback time of the electric drive system, battery portfolio restriction and speed requirement at electric propulsion are added to the constraints previously defined.

Plug-in vehicle powertrain

A major modification of the plug-in vehicle modeling is the addition of electricity cost. Another addition is a constraint handling the restricted charging power related to grid and battery power.

Electric powertrain

The analysis of the electric powertrain resembles the plug-in vehicle. A major difference is that the cost and mass of engine, transmission and driveline is excluded.

Assumptions

In addition to the energy prices, a large number of assumptions and data settings are required for the optimization. Some of the main assumptions are listed in Table 4 below.

Aspect	Setting
Battery technology	Both power and energy optimized Li-ion batteries are evaluated (the power/energy ratio (W/Wh) for the power optimized batteries is 34 and for the energy optimized it is 6).
Battery pack cost	The 2015 battery pack cost is assumed as: 735 EUR/kWh (energy opt.) and 3330 EUR/kWh (power opt.). The expected yearly decrease is 5%, (- 40% in the years 2015-2025).
Electric drive system cost	Specific price of the electric drive system is 40 Euro/kW.
Fuel cell cost	The cost for a fuel cell power unit for the series hybrid is assumed to be 2000 EUR/kW in 2015 and 500 EUR/kW in 2025.
Charging infrastructure cost	The cost for access to the charging infrastructure is integrated in the electricity cost in the model. An extra cost for using higher charging power is used.
Charging	Charging is performed at lunch (mid-shift) and/or at night. The lunch charging time is limited to 1 hour and the peak charge power is 100 kW.
Cargo mass & auxiliary power	Assumed to be constant during a transport task.
Driver costs	Driver costs are excluded from the optimization, (assumed to be independent of powertrain technology).

Table 4. Some of the main assumptions for the optimization.

The costs listed in the table above are considered to be costs to the vehicle manufacturer. To calculate a final customer price of these sub-systems, a mark-up of +50% is used.

It is assumed that the requirement of payback time for a vehicle with an alternative (i.e. not conventional or micro-hybrid) powertrain, is 5 years. This is the maximum time allowed for the energy savings to compensate for the increased price due to the new hybrid or electric vehicle sub-systems. For plug-in and electric vehicles, the battery price is spread over the life time of the battery (which for example could be realized by leasing).

A critical aspect when evaluating electrified vehicles is the battery lifetime. An electrified vehicle will rarely be cost efficient if frequent battery replacements are needed. To handle this, a battery wear model of "cycle counting" type is used. In this, a battery has a limited number of charge-discharge cycles (typically, thousands of deep cycles and millions of shallow cycles). The consequence is a non-linear relation between battery size and battery lifetime. Doubling the battery size will normally more than double the battery lifetime. The general trend is that the previously described optimization proposes a battery sized in such a way that a costly battery replacement is just avoided during vehicle lifetime. An interesting insight is that vehicle powertrain electrification will imply a shift from fuel costs to battery investment costs.

Results year 2015

Figure 2 shows the range of calculated lifetime cost per kilometer for all scenarios and per powertrain topology. Figure 3 shows the calculated cost per scenario for the four most cost effective powertrain types. Powertrains violating constraints are excluded from the results. For example, in figure 4 no hybrids appear since they all violate the 5-year payback requirement.

Some observations can be made:

1. From a TCO perspective, there is a close race between the conventional and micro hybrid powertrain in all scenarios. The TCO difference is so small that they can both be considered as the most cost efficient candidate.
2. The hybrid powertrain is never feasible.
3. The series hybrid powertrain has the highest TCO for all driving scenarios. The main reason is the high anticipated cost of the fuel cell power unit.
4. The electric powertrain battery in the long distance driving scenarios, s9-s16, is significantly larger compared to the other scenarios.
5. The electric powertrain always has the lowest energy consumption but its purchase price is 2-3 times larger compared to the conventional powertrain.
6. The TCO decreases for all powertrains when dual shifts (s3, s4, s7, s8, s11, s12, s15 and s16) are utilized.
7. Parallel plug-in and electric powertrains becomes reasonable from a TCO perspective if dual shifts and lunch charging are utilized.
8. Utilizing a fridge truck (s9-s12) significantly increases TCO and the relative energy consumption (s13-s16 are the same transport tasks without fridge auxiliary energy consumption).

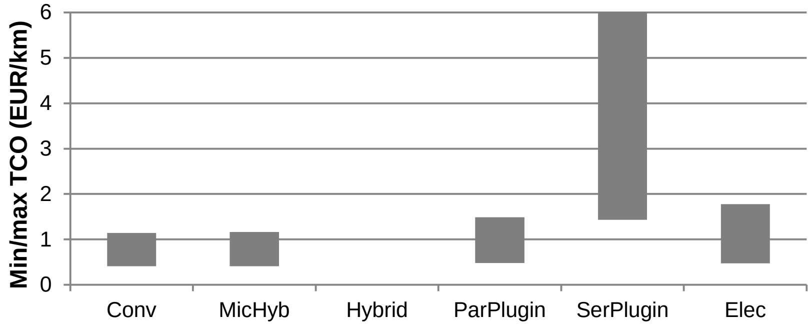


Figure 2. The ranges of calculated TCO for all 2015 scenarios and per powertrain

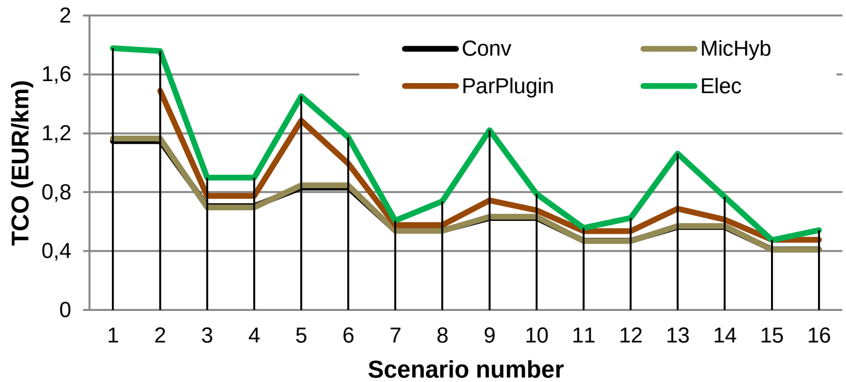


Figure 3. The calculated TCO for the optimized powertrains in each scenario in 2015.

Results year 2025

For the 2025 results the following reflections can be made:

1. The powertrain choice for 2025 is more complex compared to year 2015. There is no clear winner. The best choice depends on driving scenario.
2. Despite the higher diesel price, the TCO is in general only slightly affected compared to year 2015. By introducing lunch charging and/or dual shifts, the TCO can even be decreased compared to year 2015. One explanation is that the anticipated battery price reduction compensates the increased diesel price.
3. The TCO decreases for all powertrains if dual shifts are utilized.
4. The hybrid powertrain is feasible only in four scenarios.
5. The series plug-in is not a cost efficient choice, especially in the really common transport task rage of 80 km (s5-s8).
6. The electric powertrain is frequently a cost efficient choice. It has the lowest TCO, or very competitive TCO, if dual shifts and/or lunch charging are utilized.
7. The electric powertrain is always the most energy efficient choice.
8. The parallel plug-in powertrain, as the electric powertrain, is disfavored by a short transport task (40 km per day as in s1-s4) and the exclusion of lunch charging. The explanation is probably that a longer transport task favors the distribution of the added capital (primarily cost of the battery).

9. The conventional and micro hybrid powertrain is cost efficient when the operation range is short and the utilization is low. The reason is that a high investment in powertrain technology is not motivated if the vehicle usage is low.
10. The battery size of an electric powertrain running less than 80 km/day (s1-s8) shall be ~50 kWh. For more extensive daily operation (~140 km/day), 80-140 kWh battery is adequate.
11. A typical parallel plug-in battery size is ~25 kWh. Exceptions are dual shifts and extensive daily operation, where larger batteries can be used.

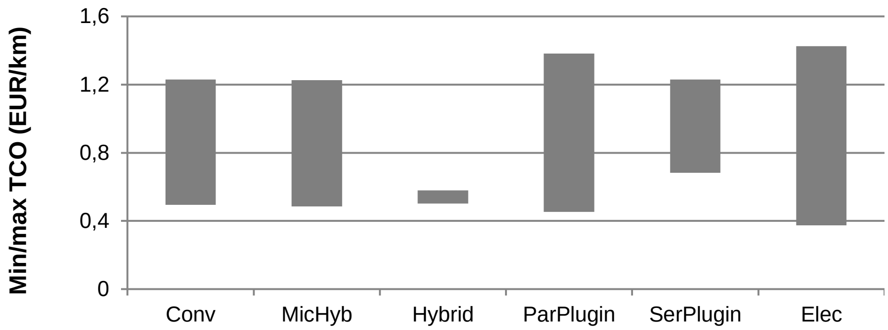


Figure 4. The TCO-range in the different 2025 scenarios per powertrain type.

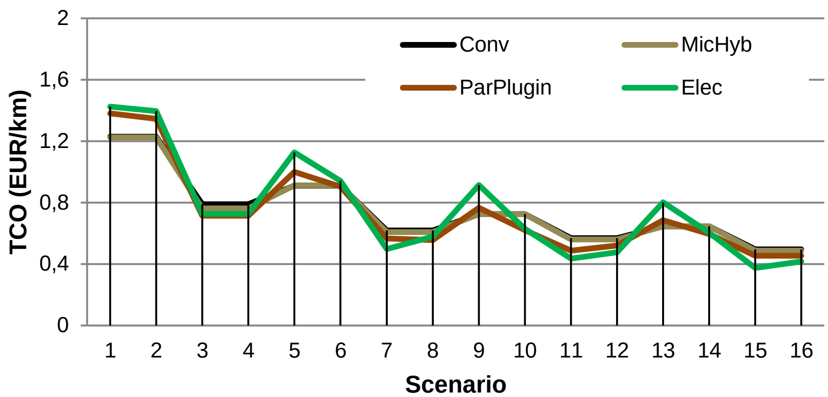


Figure 5. The calculated TCO for the optimized powertrains in each scenario in 2025.

Optimization results summary

A strong trend from the analysis of year 2025 is that fully electric and plug-in hybrid vehicles turns out to have a low TCO, i.e. are cost effective in relation to conventional powertrains (even without any incentives). A major explanation is the assumption of increasing fossil fuel prices. Fully electric vehicles are favored by shorter distances between the charging points. Another reflection is that two-shift operations lower the TCO for all technologies, especially investment demanding ones such as fully electric.

For the full report of WP2 Electrification scenarios, see appendix A2.

Life Cycle Assessment

To determine the environmental benefits of the electrification of distribution trucks, a life cycle assessment was done in a master thesis project by Inzunza Soriano and Laudon[9]. The authors performed a life cycle assessment (LCA) on the drivetrain of the Volvo FE Hybrid and a concept plug-in hybrid of the same vehicle size, to be able to determine if the hybrid and plug-in hybrid are preferable from an environmental point of view, considering the whole life cycle. The estimated life cycle distance of the distribution truck was set to 1 000 000 km (15 years), or 66 000 km/year. The yearly distance is higher than that of the Volvo FL models used for distribution by TGM. However, the results give an indication of the environmental impact difference between the base line diesel truck and the hybrid and plug-in hybrid trucks.

A dozen components in the hybrid drivetrain have been identified, including a lithium-ion battery and an electric motor. These components were studied throughout their life cycle: raw material extraction, material processing, manufacturing processes, transportation, use phase, maintenance and disposal. In order to quantitatively assess the environmental impact of all lifecycle stages, four different environmental indicators have been used: global warming potential, acidification potential, human toxicity potential and resource depletion potential. In addition, energy use and two weighting methods, EPS and Eco-indicator 99, have been used.

The result shows that for the distribution vehicle it is the step to hybridization that gives the largest environmental gain. Modification to a plug-in hybrid configuration of the same vehicle showed a small additional environmental benefit. The total energy use in terajoules (TJ) during the well-to-wheel phase for the different vehicle configurations are decreasing from ~17TJ for the conventional diesel truck by 2,5TJ to the hybrid truck and a further 0,5TJ for the plug-in hybrid. The plug-in hybrid energy use depends heavily on the charging possibilities. With increasing charging possibilities, the energy use can be expected to drop further.

4.4 WP3 Communication needs

As noted in the simulation results, the vehicle utilization has a major impact on the TCO. Due to the low running costs, vehicles with electric propulsion will become increasingly cost effective once you operate it at the electric range limit of the vehicle. Every supportive tool that can be used to increase the amount of kilometers the vehicle is propelled by electricity will hence become valuable. Care must also be taken to ensure that the vehicle is operated to maximize the effect of non-monetary incentives. Services based on ICT may provide such support from several aspects.

In goods distribution, planning the route assigned to each vehicle should take the vehicle electrical properties and the potential charging opportunities into account. The strategy used by Schenker for the city distribution today, is based on pooling of goods to a certain area within the terminal from which the drivers load into their trucks. The way goods are divided between trucks is dependent on both how Gothenburg has been divided into specific delivery areas and the drivers’ collective knowledge and experience. Route optimization based on electric range may for example result in a different division of the delivery areas or completely redefined routes for vehicles with electric propulsion. Electric only areas may also be defined by cities in the future, where only electric propulsion is allowed. By utilizing geo-fencing, hybrid vehicles in these zones could be controlled to only use electric propulsion. The electric only zones could then, at given times or dynamically be modified, should there be a need for this. Detailed collection of route choice and energy consumption of individual vehicles could be fed into the distribution planning system in order to better optimize the goods delivery planning.

Especially fully electrical vehicles will become sensitive to disturbances of the planned route. To support the driver information regarding unforeseeable events (e.g. accidents, traffic jams, and road works) should be provided along with suggestions on how to solve the situation.

Electric range could be further extended if energy could be supplied throughout the day. Integration of navigation services and charge spot supplier back-end could be used to support the driver with locating available charge spots and, if possible, reserve them. Further cost savings could be accomplished by utilizing the variance in electric energy/energy transfer price. Information exchange between energy suppliers and vehicle charging systems enable charge scheduling where the vehicle consumes energy at times where the cost is low.

In all the presented cases the ICT-services must be regarded as supportive to planning personnel and drivers. They should be able to adapt when the user chooses another solution than the one provided. Once implemented they will not only support the vehicle fleet propelled by electricity but conventional vehicles will also benefit from for example optimized routes, although with a smaller effect on the TCO.

4.5 WP4 Business models

Teece[10] describes the business model concept as an articulation of the logic behind how a business creates and delivers value to customers as well as of how revenues and costs are balanced in order produce a profit. Studies of possible business models for electric vehicles done by Kley et al.[11] and Gomez et al[12] , show that it is possible to do well educated guesses about general roles and possible rooms for new business models. However, they also confess that it is impossible to grasp or conceptualize all the possible business models associated with the emerging technology.

As business models are actor specific, we chose to assess benefits and drawbacks of possible business model features to the most important actor in the industrial value chain namely the transport provider. If the proposed technology cannot sustain a profitable business model for this actor, the adoption of commercial electric vehicles will never spread beyond enthusiasts or highly specialized users.

Challenges

Several of the challenges that face electrified commercial vehicles appear to have already been encountered and analyzed in research on personal vehicles. Kley et al[13] categorize research on attempts to popularize electric cars into four categories: better utilization of the vehicle capacity, extended utilization by for example adding applications such as off-peak charging and vehicle-to-grid, secondary usage of components to boost salvage value and finally, efforts to increase acceptance of particularities (e.g. range limitations).

For this paper, measures belonging to all of these categories were considered. In the TCO calculations, we test the value of increased utilization of the vehicle by implementing dual work shifts and we replicate the results of Neubauer et al[14] as well as Feng & Figliozzi[15] in the sense that the competitiveness of hybrid and electric solutions today is low if utilization is within that of the average drive pattern.

The implementation of vehicle-to-grid technology was considered and found technologically feasible. However, since this feature would decrease the accessibility of the vehicle and research conducted by Tomíc & Kempton[16] and Mullan et al[17] show that its monetary value is uncertain this feature was not evaluated further.

The residual value of the vehicle depends on several factors such as battery capacity and quality, technology progress and market development. Considering the low certainty with which these factors currently may be assessed and the potentially high impact of the residual value, such estimations were left out.

The ICT functions discussed earlier in this paper is an example of the fourth category of attempts to lower the hurdle.

Results

In order to explore how the transport providers' business models would be affected by the different powertrains, an exploratory study involving meetings, interviews, site visits, and a workshop was conducted. To reduce complexity, the powertrains were grouped as two general alternatives, hybrids and full-electrics, and were then compared to the known business-as-usual.

The business models features discussed for the two main alternatives shared several positive effects. Reduction of local pollution lowers the need for large ventilation systems in indoor environments and opens up for new ways to work in connection with the vehicles and possibly increasing the efficiency of refrigeration operations due to more effective climate control. Indoor operation also opens up the possibility for other types of innovation and design associated with loading, storage and delivery eliminating the need for reloading and gaining access to areas previously off limits.

The reduction of noise and pollution also improves flexibility when it comes to zoning requirements and working hours, opening up for such solutions as pure urban logistical centers or urban consolidation centers. However, these attractive values require support from new regulations. Without such regulation it is up to the transport provider to leverage these positive features together with other actors.

The most obvious loss of value to the transporter is that of limited range and flexibility. The hybrid vehicle does however not suffer as much from this drawback.

The impact of the battery on price and TCO means that a purchaser of a vehicle might be concerned with the high uncertainty about battery lifespan and residual value. Interpreting this through financial theory there exist information asymmetry between vehicle producers and their customers. In order to overcome this gap the producer may provide extensive guarantees or use different types of lease agreements. These solutions would transfer risk from the customers to the producers. In order to reduce the initial price hurdle, vehicle producers may use different business models such as razor-and-blades (a low initial price which is recovered through a cash-flow tied to the vehicle over its lifespan) or pay-per-use (where the transport provider only pay for the hours and distance driven). It is however also possible for the transport provider to break up their own business model by letting in other parties into their value chain. This can be done through different types of leasing agreements with the vehicle producer or a third party like a bank, for the whole vehicle or separately to the battery, turning the high initial cost into a steady stream of outlays.

The results also indicate that there is no single vehicle solution that fits all transport tasks of a transport operator. For an optimal customer solution there is an increasing need for vehicle producers to tailor the vehicle for the buyer's specific driving range and task. Potentially, the vehicle should also be modular in order to make it possible for reconfiguration during the vehicle's life time. For the vehicle producers however, it normally is a business model challenge to maintain a diversified product platform.

Policy support

In the short term it appears as if the only thing which will make the case of electrified goods distribution more competitive is the existence of considerable incentives. There are several strategies for doing this. As shown above, the value of non-monetary support such as restricting access to urban areas for noisy and polluting vehicles is high. Other alternatives may be allowing certain vehicles to use lanes normally designated for taxis or public transport. The value of such regulations would be considerable and possible to calculate for individual actors. Using non-monetary regulations as support is also a low cost alternative for governments and local decision makers. It is however important that such steps are implemented in a coordinated manner so that regulations and support do not vary between areas. Small markets, such as Sweden, need to be homogeneous and easy to access in order to provide any form of incentives for establishment.

Penalizing the use of fossil fuels or introducing direct subsidies are probably more effective for electrified commercial vehicles than for cars due to the fact that there is much less need for an extensive public charging infrastructure. Commercial vehicles have predictable routes and the subsidy would therefore only need to cover the vehicle, the battery and the immediate charging station. Annual fuel use of commercial vehicles is generally also much higher than for cars and thus also the emission saving potential through electrification.

4.6 WP5 Concept scalability and deployment

The most important parameters that will influence if and how electrified vehicle solutions can be used for urban goods distribution are the conditions for goods transport in a city, vehicle charging possibilities and energy price, possibilities for services to increase the efficient use of electric and hybrid vehicles, market setting, supplier relations and regulation support.

Concerning the conditions of a city, the size and density has an influence of locations of customers and how closely they are located, which in turn, affects the routes for distribution. The length of routes and number of stops at customers has a significant impact on the possible electrification scenarios. Another factor with a significant influence is the traffic situation. This includes the quality of roads and traffic systems and the level of congestion. Bad roads and uneven or slow traffic flows can lead to increased energy consumption as well as limited route options for distribution. Also the transport company location compared to the goods terminal and the customer locations, will limit the possible route options at distribution.

Charging possibilities and energy price will vary between cities. During the present project, charge infrastructure of the type required if the distribution vehicles should charge during the day has been assumed to be non-existent. The situation is quite different in several European cities with Brussels and Dublin serving as good examples. Both cities have well above ten charging spots that can deliver more than 40kW. From an energy supply point of view, grid tariffs aiming to reduce peak power consumption will by far have the greatest impact on infrastructure establishment. For energy price, the price of diesel is assumed to have a greater influence than the electricity price on the rate of electrification.

A business model should be well adapted for a specific business environment. Moving a business or scaling it in size will most likely affect several different aspects of a business model, and managers may have to make changes in unexpected places. The adaptations needed are mainly defined by changes in the market setting, supplier relations and regulations.

Discussing market conditions, both the size of customer segments and customer preferences may shift when changing markets. Since utilization was identified as one of the most important aspects, areas with few customers or short aggregated distances becomes problematic for pure EVs. It is therefore likely that this type of vehicle will not be profitable in such settings until the cost of the vehicle has dropped to a level close to that of a traditional vehicle, or other beneficial values identified in the report are visualized financially.

Since the initial success relies on collaborative efforts from several actors, small cities may have an advantage as they are often more tightly knit with many close, often personal relations of informal nature, which may be beneficial when setting up small scale EV/HEV operations. Municipalities with horizontally and vertically fragmented decision processes might experience problems getting operations up and running.

Implementing regulations that benefit vehicles, e.g. differentiated congestion charges, free parking or access to specific lanes, are less financially risky but potential alternatives for municipalities which want to push for the implementation of these vehicles. EV and HEV solutions have been tested and evaluated in several metropolitan projects and found to be largely unproblematic.

Since the success of the business models suggested in this report rely to a great extent on business and public creating and maintaining a united front against CO_2 intensive alternatives, while cooperating in the support of EV/HEV solutions, countries where these sectors cooperate poorly will face challenges succeeding with an electrification of the transport sector. This means that the business models discussed in this report might be difficult to implement in foreign markets without the support from existing institutions or the establishment of new ones.

4.7 WP6 Demonstration project outline

The project results in showed that to reach a competitive cost of ownership, vehicle utilization is an important factor. It is therefore paramount to maximize the use of hybrid and electrified trucks to reach an acceptable level of ownership cost. The higher initial cost of electric and hybrid drivelines have to be balanced with the lower running cost for electricity compared to diesel. To keep down the cost of the battery to a more affordable level it is also important to minimize the range between battery charging opportunities. These challenges need to be tackled for electrified trucks to be feasible.

To be able to plan and perform a successful demonstration project, it is therefore necessary to further study the goods distribution from a vehicle fleet perspective and optimize the vehicle utilization for the transport work. A future project would study city distribution from a fleet perspective and develop an optimized distribution fleet of electrified trucks. The solution should balance the following points to be feasible from a user transport company perspective:

- Route optimization based on transport assignments
- Charging strategy
- Driver shift planning
- Vehicle specifications to match transport assignment and maximize environmental benefits

5 Conclusions and future research

The study indicates that we will start to see a transition from conventional vehicles to electrified commercial vehicles within the time period 2015 to 2025. During this period electrified trucks are predicted to become cost competitive from a TCO perspective in several urban good distribution applications. Since the vehicle utilization is seen to be critical for establishing the business case, the transition to electrified vehicles can be expected to go quicker for other urban vehicles with much higher yearly mileage and/or high energy use per kilometer, e.g. city buses and refuse trucks.

The EU target of 2030 is already now technically feasible and again the study show that by that time the electrified vehicles may well also be the most economically choice. However, reaching such a high market penetration as the target "essentially CO2-free city logistics" indicates will require significant support with appropriate policies in the timeframe 2015-2025.

To boost the transition from conventional to electric and hybrid trucks for city distribution in the city of Gothenburg, there are several options that would be beneficial for transporters. For example, charging stations easily accessible for charging during day time, one possibility is to have charging available at loading areas during distribution. Another is to exclude electric vehicles from the congestion charge.

ICT and business model innovations will have an important role to support the development in the transition period in minimizing financial risks and uncertainties experienced by the vehicle customers. Further, authorities on all levels (local cities to national) need, short term, to increase the understanding of the benefits as well as the limitations of electrified urban vehicles and develop policies supporting (i) the unique modes of operation zero tail-pipe emission can offer and also (ii) high vehicle utilization.

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