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Potentials of electric freight vehicles in combination with urban consolidation centres for last-mile delivery

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Summary

The performance of urban road freight transport in Germany has risen sharply in recent years. This leads to an increase in the frequency with which goods are delivered to the city. A technical-economic analysis was carried out to show the potential of electric freight vehicles in combination with urban consolidation centres on the basis of the driving data of a CEP service provider. The analyses show that costs in various use-cases can be reduced. From an economic perspective, the use-case of an electric urban fleet operated in a consolidation centre showed a suitable solution for sustainable urban logistics.

Keywords: case-study; van; EV (electric vehicle); Fleet; mobility concepts

1 Introduction

The performance of urban road freight transport in Germany has risen sharply in recent years [1]. The increasing parcel deliveries and the demand for new delivery concepts, such as same-day delivery, lead furthermore to an increase in the frequency with which goods are delivered to the city and thus to an increase in the utilization of transport capacity [2]. Through rising e-commerce activities and urbanization, the number of parcels delivered by courier, express, and parcel (CEP) services in Germany has almost doubled between 2000 and 2017 and is projected to continue to rise by 5% per year [3]. Since urban freight vehicles are primarily powered by fossil fuels, with the increased transport performance also the emissions rise [4]. Although road freight vehicles account for less than 10% of the total mileage in urban areas, they emit 11.5% of all CO_2 and one-third of all NOx that is related to road traffic [5]. Especially pollutant emissions in the city have increased to a critical level today, which is why in particular first cities in Germany, are now pulling the strings and are forced to banish older diesel vehicles from their inner cities [6, 7]. Therefore, the conventional freight transport is not justifiable with a sustainable urban development, which is why alternative powertrain and logistics concepts are needed for urban freight transport.

That electric vehicle (EV) is a feasible measure has to been demonstrated in several case studies and field experiments [8–11]. The question of whether electric freight vehicles (EFV) are economic or not, however, has been answered differently. Besides the advantages of EFVs, which are mainly related to their economic and ecological potential, several weaknesses when compared to conventionally powered freight vehicles have been identified, namely: high procurement costs, limited driving range, and limited availability and model diversity [11]. That causes a small number of electric vehicles are currently used in commercial transport and only a few experiences are known about the requirements, costs and benefits in everyday logistics. Nevertheless, some of the first innovative solutions developed and demonstrated in the area of electric urban freight transportation and city logistics did not reach economic viability and therefore terminated after a trial phase. One of the reasons is, that the information and the experience on the efficiency and reliability of electric delivery vehicles could not yet be sufficiently described or tested. Therefore, it is more important to find and focus on the right niche applications in urban transport.

Inner-city delivery traffic is an interesting field of application for electric mobility in many respects. On the one hand, short distances and frequent stops offer favorable conditions for the economical operation of electric freight vehicles (compared to conventional vehicles). On the other hand, especially in densely populated inner-city areas, a reduction in noise and pollutant emissions from delivery traffic can lead to a considerable improvement in the quality of life. Therefore, it is necessary to rethink current business models and logistics concepts and to show the potential for electrical delivery in inner-city traffic.

A sustainable urban delivery concept is the combined use of battery-electric freight vehicles with urban consolidation hubs. Battery electric vehicles are emission-free in delivery, but lower in vehicle range compared to conventional powered vehicles. However, the suitable use of urban consolidation centres (UCC) could optimize urban and suburban transport routes, so that the electric ranges of the vehicles can be considered for urban transport. Also, timing in urban delivery is one of the most important criteria. The fragmenting of transport could give more flexibility for just-in-time and overnight delivery [12]. This raises the question of what economic potential would result from the use of electric vehicles in combination with an urban consolidation centre for last-mile delivery. Since the implementation is strongly dependent on the individual driving profile and the constellation of the vehicle fleet, a technical-economic analysis was carried out based on the driving data of the fleet of a CEP service provider in Berlin. The results show that UCC can enable a sustainable and cost-effective operation of electric urban fleets. Both, the electrification of the urban fleet and the operation of a UCC, should to be implemented as an overall concept.

The analysis was carried out within the framework of the EU project proEME "Promoting Electric Mobility in urban Europe" which was co-funded by the ERA-NET initiative “The Electric Mobility Europe”. This initiative aims to further advance electric mobility in Europe by taking transnational e-mobility research and policy exchange toward deployable solutions.

The objective of this paper is to show comprehensive use-case analyses for the critical last-mile delivery from an economic perspective. In the following section, the core methodology, the results and finally the conclusion is presented.

2 Methodology

In the cost-sensitive transport sector, the purchase of new commercial vehicles is primarily determined by the total operating costs of the vehicles. Thus, alternative powertrain concepts in vehicles are only cost-effective for fleet operators if all costs accumulated during operation are equal to or less than those of the previous vehicle after the intended holding period or depreciation period. However, the added value of emission-free operation of battery electric vehicles is still not a decisive purchase decision criterion for fleet operators. For this reason, the total cost of ownership analysis is essential to identify possible fields of application for electric commercial vehicles. Since operating costs depend on the respective transport task of the fleet, a specific application case must be considered. In different use cases, the influence of a simulated urban consolidation centre on the considered fleet is to be analysed. The analysis aims to carry out a cost-effectiveness analysis of battery-electric vehicles in operation in an urban consolidation centre and thus to derive a basis for decision-making for electric mobility in urban logistics. Figure 1 shows the systematic illustration for the use case analysis. In the following sections, detailed information on the individual calculation steps is given.

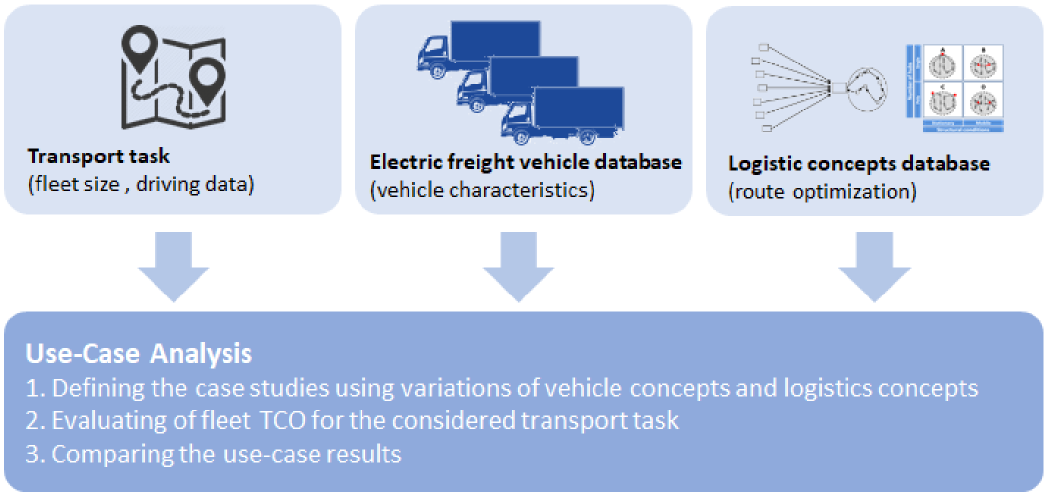

Figure 1: Systemic structure of the use case analysis for the technical-economic evaluation of battery-electric fleets in combination with urban consolidation centres

2.1 Input parameters for the use-case analysis

To evaluate the techno-economic potential of battery-electric delivery vehicles in an urban fleet, a total cost of ownership (TCO) calculation is carried out. The base for this is provided by the driving data of a selected fleet of a CEP service provider, which is responsible for delivery within a postcode area in Berlin. The dataset consisted of four diesel-fueled light-duty vehicles (N1) with diverse driving profiles for a whole week of operation in October 2018, which makes them suitable for representing CEP service operations in urban Germany in this particular research setting. The time-velocity profiles were recorded via a GPS tracking system and gave information about: the overall tour mileage, the share of the distance that was driven (from the depot to the service area and inside the service area), the number of stops per tour and the tour duration. The data was also aggregated to derive the annual mileage. To do this, the average daily mileage was multiplied by the assumed number of working days in Germany in the year 2020. These are 252 days. Finally, the number of kilometers driven during the holding period (5 years) was computed.

As another input for the calculation, the conventional vehicles that are currently used in the logistician's fleet and equivalent battery-electric vehicles that could be used to replace these vehicles were defined. As a reference for the conventional vehicle, the four vehicles are taken from the trip data recording. These are all from the Brand Mercedes-Bens, vehicle model Sprinter, with a gross vehicle weight of 3.5 tons in vehicle class N1. Then potential electric vehicles need to be identified and evaluated based on their operability for the specific transport task and tour profile. For this purpose, battery-electric series vehicle models for the German market in 2020 were first collected in a vehicle database and then a suitable reference vehicle was selected which could meet the predefined transport tasks.

To simulate an urban consolidation centre in the considered transport task, characteristics of urban consolidation centre from pilot projects will be projected to the use-case here. For this purpose, all best-practice projects that have tested or simulated the use of urban consolidation centres in specific applications need to be collected and their impact on the tour profile specified. Next, a meta-analysis of these cases concerned with the simulation and evaluation of freight consolidation schemes was undertaken. In the first step of the meta-analysis, from all cases that provided quantitative results on the impact on the aforementioned parameters were collected, the consolidation centres were categorized based on the structural conditions (stationary or mobile as defined in [13]) and the number of hubs (single or poly). This resulted in four hub types (see Figure 2). The

22 cases were classified as follows: in 14 cases a type A hub was applied, in six cases a type C, and two cases were concerned with a type D hub. A type B hub was found in no case.

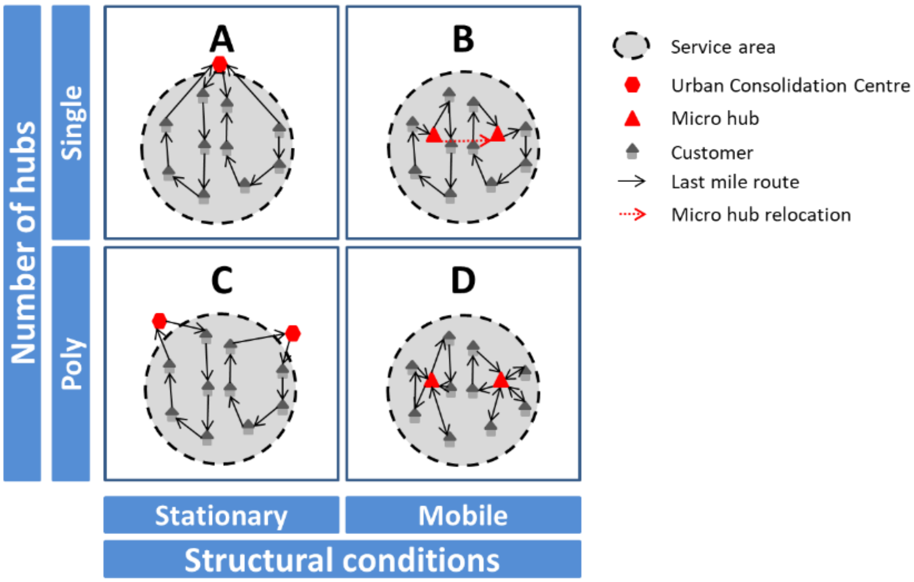

Figure 2: Different types of UCC by number of hubs and structural condition

From a total of 32 collected projects, 16 cases concerning a UCC scheme in an urban area making use of vehicles of the N1 segment were collected, only one case provided information that was adequate for further usage, see [14]. The documentation of the study design, the results and, most importantly, how they were achieved and used to calculate different scenarios, was detailed enough to derive quantitative impacts on four of the aforementioned logistic parameters from it. For each scenario, the change in the number of vehicle kilometers (mileage inside delivery area), the truck travel time (tour duration), the number of truck stops (stops per tour), and the number of trucks were presented.

	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Number truck-kilometres in city centre	475	451	323	421	382
Total truck travel time (in hours)	12.9	12.2	9.6	11.7	10.9
Number of truck routes in city centre	217	208	144	188	166
Number of truck stops in city centre	486	453	361	424	391
Number of trucks in city centre	186	182	77	150	125

Figure 3: Logistical results for store deliveries in different scenarios for the case in Nijmegen [11]

It were 632 recipients inside the delivery area [14]. They provided data of five scenarios: in each scenario the number of recipients inside the delivery area who received consolidated deliveries varied. In the base case (scenario 0) all recipients were supplied independently while in the best-case scenario, all 632 recipients were supplied from the UCC. The number of participating recipients in the remaining scenarios was 92, 200, and 300. The first three factors directly influence the vehicle's energy consumption and accordingly the operating costs as well. However, the mileage was the only parameter for which a change could be determined in the way that it could be entered in the TCO calculation.

Through a coefficient of determination analysis, the relationship between the number of recipients (independent variable) and the mileage (dependent variable) inside the delivery area was determined. Additionally, through a regression analysis, the impact of the consolidation centre as presented in the case described above on the mileage was calculated (see Figure 4). The regression coefficient is $R^2 = 0.9786$. Thus, a very strong relationship between the independent (number of recipients) and the dependent (mileage inside delivery area) variable was detected.

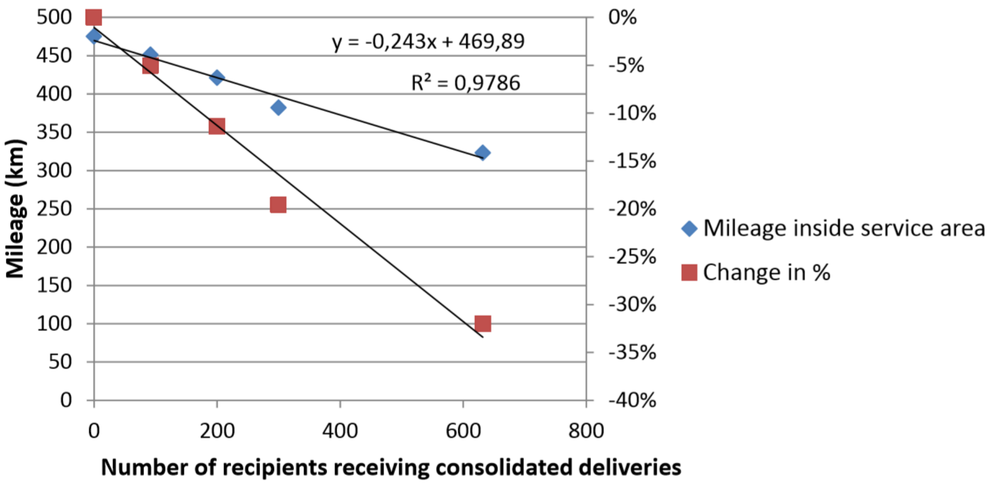

Figure 4: Impact of type a UCC depending on mileage and number of recipients

Through the regression analysis, the change in the parameter mileage for any number of recipients being supplied by the UCC could be computed. The average number of stops per tour per vehicle is 21. It was assumed that the number of stops per tour equals the number of recipients in the used references study of van Rooijen & Quack [14]. Therefore, the impact of a type A UCC on a tour with 21 stops would be -2.2%.

2.2 Use-case definition

Before applying the logistic model to different use cases, the base case was formulated. The base case illustrates the traditional transport concept of the CEP service provider which is shown in Figure 5. Four vans are starting at the suburban depot to the urban delivery area. From the data tracking, it was found that the average tour of the fleet vehicles had a length of 145.2 km, took 10.3 h and had 21 stops. The average payload of the fleet vehicle was 621 kg. The average period between the end of one and the beginning of another tour, the uninterrupted overnight rest time, was found to be 14.5 h. The average distance from the depot to the delivery area (first stop) and the way back from it accounted for half of the mileage (72.5 km). This was used as the hub-to-hub transport route in the alternative (simulated) use cases with UCC.

In Figure 5 the delivery concept with a UCC is shown. In the hub-to-hub transport, the payload of the previous four vans needs to be summed up which is 2,484 kg. Therefore, for the hub-to-hub transport route, a truck needs to be operated which has an average daily mileage of 72.5 km and an average payload of 2,484kg. The introduction of a type A UCC located at the edge of the delivery area leads that instead of four now three vans are operated for the urban delivery (see urban consolidation centre in Figure 5). As described in chapter 4.4 the implementation of UCC led to a decrease in mileage inside the delivery area of 2.2 %. Consequently, the mileage inside the delivery area decreases from 290.5 km to 283.8 km by 6.7 km per day. This added up to 1,688 km per year and 8,442 less travelled kilometers over the holding period. Therefore, the mileage of each of the three vans is now 94,6km. The mileage from the depot to the UCC remained the same. Furthermore, the tour profiles of fleet vehicles operated in UCC can be further optimized so that instead of three vans now two vans are operated. This requires that the two vans are capable to manage the total mileage and total payload of the urban delivery transport. For each of the two vans, that would be a mileage of 141.9 km and a payload of 1242 kg. Since suitable ICE (Internal Combustion Engine) and BEV (Battery Electric Vehicle) vans for that transport task were founded from the described vehicle database, the use case "urban consolidation centre with tour optimization" was created (see Figure 5). It was considered that the geographical distribution of the receivers (based on the tracked coordinates) in the urban area can be handled/delivered by the two vehicles.

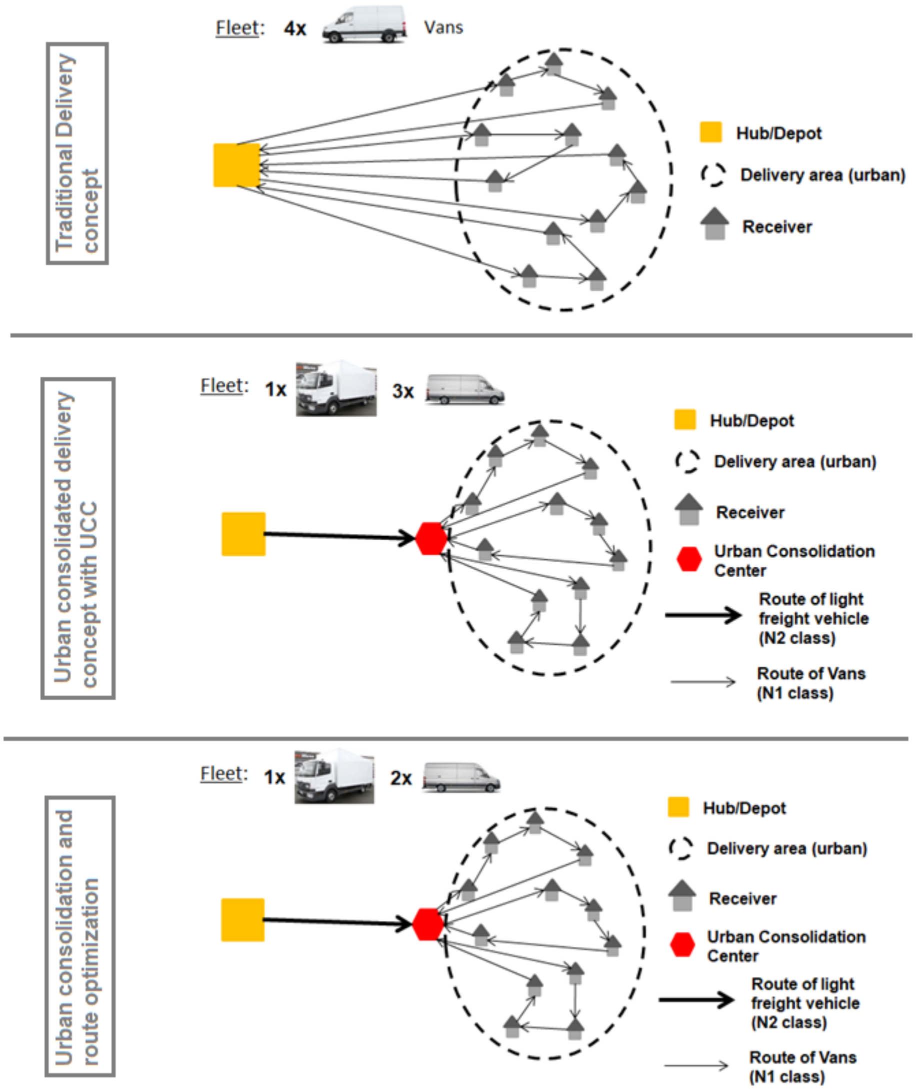

Figure 5: The delivery concept in the different use cases

Table 1 Summarizes the key facts (about the transport task) of the three delivery concepts and illustrated the further distinction per use case in terms of the powertrain of the fleet vehicles. Three powertrain-specific fleet compositions are possible: only ICE-Vehicle in the fleet (ICE-Fleet), only BEV in the fleet (BEV-fleet) or ICE-Vehicle for hub-to-hub transport and BEV for urban delivery as the mixed fleet. The defined use cases were further defined by potential vehicle models which are listed in Table 2 in the Appendix.

Table 1: Use cases of different transport concepts and powertrains in the fleet

	Transport task		**Powertrain of fleet vehicles**		
	Hub-to-hub route: average daily mileage/average daily payload	Last-mile route: average daily mileage/average daily payload	ICE-Fleet	BEV-Fleet	Mixed Fleet
Traditional Transport	145,2 km/ 621 kg		Case 1	Case 2	-
Urban Consolidation centre (simulated)	72,5 km/2484 kg	94,6 km/828 kg	Case 3.1	Case 4.1	Case 5.1
Urban consolidation centre + Tour optimization (simulated)	72,5 km/2484 kg	141,9 km/1242kg	Case 3.2	Case 4.2	Case 5.2

2.3 Calculation of fleet operating costs

The various use-cases will then be evaluated according to economic criteria. A total cost calculation (TCO) is carried out for each vehicle in the use case and this is added together as the fleet TCO. The total cost of ownership (TCO) of a vehicle is defined as the sum of the fixed (one-time) investment costs of the vehicle and the fixed as well as variable operating costs. The variable operating cost are distinguished by mileage- and time-related operating costs. In particular, the mileage-related operating costs are calculated from the energy costs, the maintenance and repair costs and the toll costs. For the calculation of the energy costs the approach according to [15] is used. The calculation structure from [16] is used for the M&R costs. And for the calculation of the resale value the approach according to [15] is assumed. To make the calculation adjustable to different environments, it is important to take market-specific factors (taxes, incentives, utility/fuel prices) into consideration.

3 Results

The described approach shows that through the data recording and analysis of real driving data and the use case analysis suitable delivery concepts for the last mile delivery can be derived. Figure 6 shows the results from the fleet TCO calculation for different case studies. Case 1 according to traditional transport with ICE-Fleet, Case 2 according to traditional transport with BEV-Fleet, Case 3 according to urban consolidated delivery concept with UCC and ICE-Fleet, Case 4 according to urban consolidated delivery concept with UCC and BEV-Fleet and finally Case 5 according to urban consolidated delivery concept with UCC and urban BEV Fleet.

In General, labor costs are the biggest cost driver in the base case and all other use cases with a share of 52 to 60% of the TCO. Although the labor costs differ between the use case groups, within one group they remain the same. This is due to the assumption that the tour length and thus the working hours are independent of the vehicle´s powertrain. Drivers of N2 vehicles, on the other hand, need a truck driver´s license which is why their wages are higher and they are more expensive than the drivers of N1 vehicles. However, since the N2 vehicle´s TCO are only partially assigned to each use case TCO, the use case with a UCC (and hence with an N2 vehicle in the fleet) are cheaper than the ones without. The vehicle purchase prices are the second most expensive cost factor. EFVs are substantially more expensive than diesel vehicles. In this particular simulation, EFV energy costs are about four-fifth of conventional vehicles ones, and their maintenance and repair (M&R) costs are almost only half as high.

In the use-case analysis Case 2 shows the lowest fleet TCO. This is due to the low energy consumption costs and maintenance costs as well as the vehicle tax exemption for BEVs. The sum of additional investment costs for the vehicle (especially the traction battery) and own electric charger in the depot is lower than the potential savings. Case 3 is slightly cheaper than Case 1 due to more efficient routing and thus energy consumption costs saved by switching to an urban consolidation centre with a 12-ton truck responsible for hub-to-hub delivery. Case 4 differs from Case 3 in that instead of diesel vehicles, battery-electric vehicles are now used. Since in the calculation the TCO of the battery-electric light-duty vehicles are lower than that of the diesel-powered light-duty vehicles, the fleet TCO is more cost-effective in Case 4 than in Case 3. In Case 5, an urban consolidation delivery concept with UCC is also pursued, with an urban fleet of battery-electric light-duty vehicles and a diesel vehicle for regional hub-to-hub delivery.

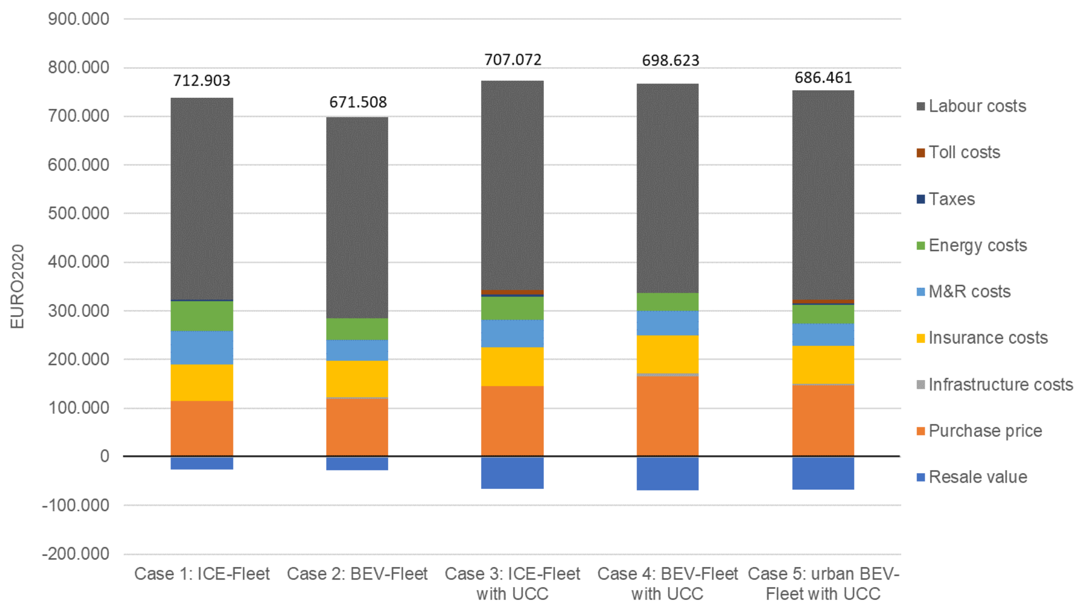

Figure 6: Fleet-TCO for different use-case (case 1 and 2 according to traditional transport, case 3, 4 and 5 according to the urban consolidated delivery concept with UCC)

Figure 7 shows the results of the Fleet-TCO calculation for different case studies. Like in figure 6, Case 1 represent traditional transport with ICE-Fleet and Case 2 traditional transport with BEV-Fleet. Case 3, 4 and 5 are compared to the evaluation in figure 6 additionally with the determined route optimization resulting in lower mileage. Consequently, the fleet TCO is lower in these three case studies due to the energy cost savings. Case 5 (urban consolidated delivery concept with UCC and urban BEV Fleet) now shows the lowest fleet TCO. This is because further costs can be saved by route optimization in the urban region.

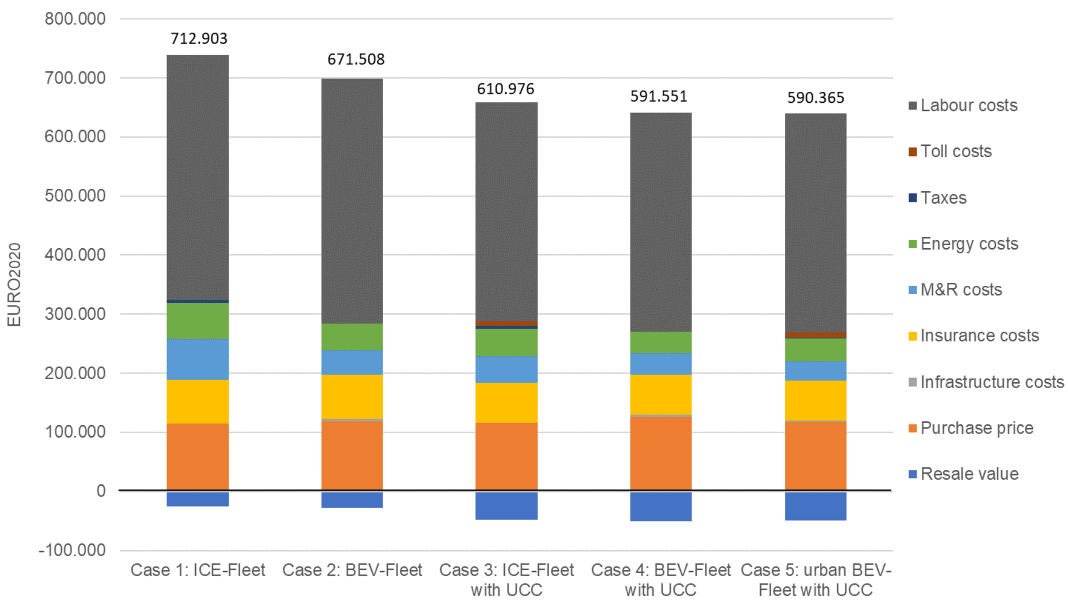

Figure 7: Fleet-TCO for different use-case (cases 1 and 2 after traditional transport, cases 3, 4 and 5 after urban consolidated and route optimization delivery concept)

4 Conclusion

The analysis shows that already today (the simulation year 2020) battery-electric light-duty vehicles have reached TCO parity compared to conventional diesel (Case 2). Therefore, the switch to an electrified urban vehicle fleet is economically favorable for the considered transport application in Berlin. The use of a consolidation centre for the considered use-case analyses results in smaller cost savings. However, for an all-electric fleet with an electric 12-ton truck for hub-stroke delivery, the cost savings are not as high as with a diesel 12-ton truck. All cases considered with an electric fleet finally resulted in a lower TCO than the traditional delivery. The presented approach for route optimization by changing the transport task of the vehicles shows further cost-saving potentials for all case studies.

The analysis focuses on a purely economic evaluation of the potential. Other aspects influencing the operation of the vehicles were not considered in the evaluation. Like higher range requirements for the vehicles for other transport tasks. However, the simulative approach shows a suitable way to identify concrete applications for zero-emission vehicles in urban road freight transport.

Appendix

Table 2: Fleet composition in the different use cases

ID.Nr.	Cases	Number of vehicles	vehicle Class & Powertrain	Logistic concept
1	Base case: ICE-Fleet	4	ICE-Vans	traditional
2	BEV-Fleet	4	BEV-Vans	traditional
3.1	ICE-Fleet with UCC	3	ICE-Vans	UCC
		1	ICE-heavy-duty vehicle	UCC
3.2	ICE-Fleet with UCC	2	ICE-Vans	UCC
		1	ICE- heavy-duty vehicle	UCC
4.1	Electric fleet with UCC	3	BEV-Vans	UCC
		1	BEV- heavy-duty vehicle	UCC
4.2	Electric fleet with UCC	2	BEV-Vans	UCC
		1	BEV-heavy-duty vehicle	UCC
5.1	Urban BEV-Fleet with UCC	3	BEV-Vans	UCC
		1	ICE-heavy-duty vehicle	UCC
5.2	Urban BEV-Fleet with UCC	2	BEV-Vans	UCC
		1	ICE-heavy-duty vehicle	UCC

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