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Potentials of electric vehicles in innovative city-logistics: A case study from Karlsruhe, Germany

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Summary

Urban traffic is increasing, resulting in congestions, air pollution and greenhouse gas emissions. One option to reduce urban traffic and its impacts are innovative city logistics concepts (CLC) in combination with battery electric vehicles (BEV). However, logistics service providers (LSP) are reluctant to implement CLCs or BEVs due to little knowledge on the potential economic and ecological benefits. Thus, our aim is to explore the acceptance of CLCs and BEVs among LSPs and to analyze the economic and ecological benefits of such concepts and how BEVs contribute to potential benefits. Using expert interviews as well as techno-economic and ecological analysis, we find that BEVs show the highest acceptance among LSPs, followed by city-hubs, micro-hubs with electric freight bikes on the last mile and night-time delivery. We also find that micro-hubs improve the economic and ecological performance of logistics operations, while night-time delivery shows no benefits. BEVs turn out to be more expensive for both CLCs but clearly improve the ecological performance.

Keywords: freight transport, city traffic, mobility concepts, BEV (battery electric vehicle), pollution

1 Introduction

Urbanization, economic growth and structural economic changes such as globalization, increasing world trade or e-commerce lead to increasing road transportation, especially in urban areas [1]. This results in heavy congestions, air pollution and greenhouse gas emissions in urban areas [2, 3], which cause high economic costs, health problems up to death and accelerated climate change [4, 5].

One way to reduce urban road traffic and its negative impacts are innovative city logistics concepts (CLC). These mostly refer to the prevention and consolidation of transport or a reduction of transportation impacts by shifting to more ecological modes of transport [6, 7]. To an increasing extent, the use of battery electric vehicles (BEV) in transportation logistics in order to replace conventional light commercial vehicles or medium- to heavy-duty trucks is discussed [8–10], especially in combination with innovative CLCs [11, 12]. In addition to the advantages of CLCs, such as reducing the number of trips and trip distance, BEVs come with many advantages, such as emitting less noise, less air pollutants and less carbon dioxide, which is very valuable, especially in urban areas. Furthermore, BEVs in logistics have the potential to reduce transportations costs [11]. However, logistics service providers (LSP) are still reluctant to implement CLCs and to integrate BEVs into their fleets. This is due to the high investment costs and high organizational efforts required. Furthermore, the economic and ecological benefits of CLCs and BEVs are not always obvious and rarely discussed in the existing literature.

Against this background, the aim of this paper is to explore the acceptance of CLCs and BEVs among LSPs and to analyze, whether innovative CLCs are economically and ecologically beneficial from the LSP's perspective and how the integration of BEVs contributes to that.

Hence, in this paper, we answer three research questions:

1. How high is the acceptance of LSPs towards innovative CLCs and BEVs?
2. How do innovative CLCs compare to conventional logistics from an economic and ecological perspective?
3. How do BEVs contribute to the profitability and ecological impact of innovative CLCs?

The paper is structured as follows. First, we outline our methods and data in section two, before we describe and analyze our results in section 3. In section 4, we provide a discussion of our results and conclusions.

2 Methods and data

2.1 Methods

First, we selected CLCs to be analyzed within this paper based on a literature review. Second, we explored the acceptance of CLCs among LSPs and collected logistical and financial data on the logistics operations of various LSPs with semi-structured expert interviews. Third, we used the data, supplemented by data from literature, to carry out a techno-economic and ecological analysis for two selected CLCs and LSPs with in-depth case studies.

In the literature, various innovative CLCs are discussed, such as the use of alternative fuel vehicles, company-specific city-hubs, consolidation in company-independent urban consolidation centers, distribution over micro-hubs, parcel shops or stations, underground transportation networks, high-speed freight trains, utilization of alternative existing infrastructures (e.g. tram), night-time delivery or automated delivery with drones or robots [7, 13–15]. We selected those CLCs for a further examination that can be realized within the city and region of Karlsruhe, Germany, that can be implemented in the short-term as well as by a single LSP and that are considered most relevant in the literature. Consequently, we focused on city- and micro-hubs (with bundling opportunities), urban consolidation centers, night-time logistics, use of parcel stations and BEVs.

In order to assess the acceptance of CLCs among LSPs, we conducted 13 semi-structured expert interviews with experts from different logistics industries. The purpose of the interviews was 1.) to reveal the acceptance of LSPs to use BEVs and to implement the selected CLCs, and 2.) to derive logistical and financial data regarding the current transportation operations of LSPs. For the acquisition of experts for our interviews, we contacted about 100 random LSPs in the city and region of Karlsruhe, where our research project was based. The interviews were based on an interview guide. Its first part consisted of a set of mostly open questions on logistical framework conditions and the awareness as well as acceptance of CLCs. Its second part consisted of mostly quantitative questions on typical parameters of logistical operations, such as vehicle types used, trip duration and distances, duration of breaks, number of trips in urban areas etc. as well as of questions on a potential implementation of e-mobility and CLCs. We took interview minutes in bullet point form. For the evaluation of the interviews, the given answers were analyzed question by question over all companies as well as logistics industry-specific. The 13 experts interviewed are from LSPs of the following sectors: two general cargo carriers, three wholesalers, a bakery chain, a clothes retailing company, three transport companies for special transports, two courier-express-parcel (CEP) service providers and a newspaper sales department. The size of the companies ranges from less than 10 employees (8 %), 10 to 50 employees (15 %), 50 to 250 employees (23 %) to over 250 employees (54 %).

The CLCs and LSPs for the in-depth case studies with techno-economic and ecological analyses were chosen based on three criteria: 1.) the willingness of the interviewed experts/LSP to implement the innovative CLC, 2.) the general operational feasibility of the innovative CLC and 3.) the sufficiency of data derived from the interviews for conducting a deeper techno-economic and ecological analysis of the given concept in the respective LSP. The chosen LSPs and concepts were a CEP service provider with a micro-hub-concept and a bakery wholesaler/delivery service with night-time delivery. Furthermore, BEVs were considered relevant for both case studies.

Subsequently, we conducted techno-economic and ecological analyses. The analyses are based on data collected in the expert interviews. Missing data for the analyses was collected through further literature and desk research. For analyzing the costs, we used total cost of ownership (TCO) calculations. They aim at a comprehensive consideration of all costs linked to implementing and utilizing a process, technology or concept, instead of focusing on the purchase price only [16]. Furthermore, TCO calculations can be used to compare the status quo with potential new solutions from an economic point of view. Consequently, as suggested by Piscopo et al. [16], we first analyzed the status quo, therefore the existing logistics structures of the LSPs, allowing us to examine the technical compatibility of the selected innovative CLC and BEVs with existing structures. More specifically, we set up an average use case for each selected LSP and analyzed vehicle types, trip lengths, break and operation times. Thus, we were able to determine suitable BEVs with corresponding ranges and charging times as well as the suitability of the selected CLC. In addition to the TCO calculation, processing times and CO_2-emissions were determined and compared between the status quo, the utilization of BEVs and the innovative CLC.

Hereafter, we outline the methodological details of the techno-economic and ecological analyses. The TCO are calculated for the (transportation) logistics operations of the selected LSPs, first, for their status quo, second, for their chosen CLC: micro-hubs for CEP service provider, night-time delivery for bakery delivery service and BEVs for both. In this case, the TCO primarily consist of costs for vehicles of type x ($V_{x,TU}$) and personnel ($P_{x,TU}$) and they are calculated per parcel, pallet or, more general, transportation unit (TU) and are therefore divided by the number of TUs per vehicle (cap_x). The vehicle costs are split in fixed ($V_{x,fix}$) and variable ($V_{x,var}$) costs and can be calculated as follows:

$$V_{x,TU} = \left[V_{x,fix} + V_{x,var}\right] / cap_x \tag{1}$$

Fixed vehicle costs are costs that occur irrespective of the number of kilometers travelled by a vehicle. In terms of CLCs, these are the purchase price of a vehicle (PV_x), as well as taxes (TX_x) and insurance costs (IS_x). In the context of this paper, the fixed costs are calculated per year. For this purpose, the purchase price must be divided by the depreciation period (DV_x) to retrieve the value of the annual depreciation. Adapted from Auffermann and Siedlarek [17], the following equation is used:

$$V_{x,fix} = \left(\frac{PV_x}{DV_x}\right) + TX_x + IS_x \tag{2}$$

Variable costs are costs that depend on the number of vehicle kilometers driven and consist mainly of fuel costs. In the context of this paper, they are calculated from the average energy consumption (diesel or electricity) per kilometer (EC_x) multiplied by the energy price (EP_y), therefore the diesel price for vehicles with combustion engine (with y =0) or the electricity price for BEVs (with y= 1). Additionally, costs for tires, repair and maintenance are added (RM_x). The following equation is used (based on [17]):

$$V_{x,variabel} = EC_x * EP_y + RM_x \tag{3}$$

Depending on the CLC selected, costs of charging infrastructure (I_x) for BEVs and location costs for extra hubs need to be added. The costs for the charging infrastructure are to be assigned to the fixed vehicle costs but are treated as a separate category in the calculations for reasons of clarity. The purchase price for the corresponding charging infrastructure (PI_x) is divided by the fixed depreciation period (DI_x) to obtain the annual depreciation value. Depending on the vehicle type the charging infrastructure can be a small wall-box or a fast charging point.

$$I_x = \frac{PI_x}{DI_x} \tag{4}$$

The personnel costs are calculated, as shown below, from the total trip durations (working time) per day (T_x) multiplied by the corresponding hourly wage (W) in relation to the number of TUs delivered. We assume that the number of TUs delivered per trip corresponds to the vehicle's capacity, eventually multiplied by the number of trips per vehicle and day. Furthermore, the volume of the TU and the volumetric capacity of the vehicle used determine the maximum number of TUs per vehicle (p_x) (in consideration of the given utilization). Consequently, the personnel costs can be calculated as follows:

$$P_{x,TU} = [T_x * \mathrm{W}] / p_x \tag{5}$$

Location costs, in case of the micro-hub-case, can be calculated from the rental costs of the floor space with the average rental price per square meter multiplied by the number of operating days.

To compare the processing times, the trip durations per vehicle type must be determined. They consist of loading time ($t_{L,x}$), travel time ($t_{T,x}$) and unloading time ($t_{U,x}$). The individual loading time per TU depends on the type of load (a single parcel has a shorter loading time than a whole pallet).The unloading time per stop depends on the number of TUs which are delivered together. In this paper, we assumed a fixed number of TUs for each stop ($p_{stop,x}$). Therefore, we must calculate the time which it takes to unload each TU from the vehicle ($t_{unloading,x}$) and multiply it with the corresponding fixed number of TUs per stop. Additionally, with regards to the CEP service provider's operations, time is required to take the TUs from the vehicle to their final destination ($t_{walking,x}$), which must be added to the unloading/delivery process. Beyond that, for each stop, time must be added until a parking spot is found ($t_{searching,x}$). In this case, the total unloading time per stop consists of the three mentioned components: finding a parking spot, unloading the TUs and walking time to the final destination. For other use cases with different types of recipients, there is no time required for finding a parking spot or walking to the final destination. Instead, e.g. for use cases with companies as recipient, some waiting time ($t_{waiting,x}$) at each stop for organizational tasks is assumed. For both cases the equation (6) can be adjusted:

$$t_{U,x} = t_{searching,x} + (t_{unloading,x} * p_{stop,x}) + t_{walking,x} + t_{waiting,x} \tag{6}$$

The total unloading time per trip is the unloading time per stop multiplied by the number of stops per trip (*n*). Regarding travel time (the time each vehicle x is driving on the calculated trip), it should be noted that different average speeds ($\bar{V}$) of vehicles apply inside the city (ic, km driven inside the city) and outside the city (oc, km driven outside the city). The travel time is therefore calculated with the driven kilometers divided by the corresponding average speed. Furthermore, depending on the type and duration of the trip, there can be several trips per vehicle and day, so that the total duration of all trips per day is a multiple of the individual trips (*m*).

$$T_x^1 = \left(t_{L,x} * p_x + t_{T,x} + t_{U,x} * n\right) * m \qquad with: \; t_T = \frac{ic}{\bar{V}_{ic}} + \frac{oc}{\bar{V}_{oc}} \tag{7}$$

While the equation (7) can be applied to all concepts which are operated during daytime only, the concept of night-time deliveries needs a further specification, since there are different average speeds during day- and night-time ($\bar{V}_T$) [1, 12]. To define day- and night-time speeds ($\bar{V}_T$) we choose T= 0 for day trips and T= 1 for night trips. Additionally, there is only one trip per vehicle and day, so one trip duration equals the entire day trip:

$$T_x^2 = t_{L,x} * p_x + t_{T,x} + t_{U,x,n} * n \qquad with: \; t_T = \frac{ic}{\bar{V}_{T,ic}} + \frac{oc}{\bar{V}_{T,oc}} \tag{8}$$

Furthermore, the average processing or lead-time of a TU ($\bar{X}\,LT_x$) must be considered. In contrast to the trip durations, comprising the total time of a trip starting and ending at the hub, the processing time defines the average time that a TU requires until it reaches its recipient - starting from the hub. For each vehicle type x it consists of the loading time, the travel time to get to the final destination of each TU to be delivered ($t_{F,x}$) and the unloading time required for the stop. In order to obtain reasonable processing travel times, it is necessary to add up travel times for each TU to be delivered, always starting to count at the hub (from the hub to the destination of the first TUs (first stop), from the hub to the TUs which are delivered second (second stop), and so on up to the TUs which are delivered last (last stop)). The sum of these travel times is divided by the total number of stops (as there is more than one TU delivered per stop)). A similar calculation is needed to gain a reasonable average processing unloading time. While for the first delivered TUs just the unloading time of the first stop must be included, for the TUs delivered last the unloading times of all previous stops are summed up as processing time. Therefore, the average is used in the equation (9). Since there might be several trips per day, the time required for driving back to the hub (return time, $t_{Rx,m}$), after having delivered the last TUs, is also included in the calculation in order to reflect the dwell time of the TUs in the hub. The processing time per TU and vehicle type is calculated as follows:

$$\bar{X}\,LT_x = \left[\left(t_{L,x} * \ p_x + \frac{\sum_1^n (t_{F,x,n})}{n} + \frac{\sum_1^n (t_{U,x,n})}{n}\right) * m + \sum_1^{m-1} (t_{R,x,m}) \ \right] / m \tag{9}$$

Finally, we calculated the CO_2-emissions resulting from the logistics operations of the different concepts. Here we calculate the emissions which emerge during the use of the vehicle and not the emissions linked to the production of a vehicle and its parts. The average energy consumption per kilometer is multiplied by the corresponding emission factor. In order to determine the emissions for the daily mileage, the resulting value must be multiplied by the corresponding number of kilometers.

2.2 Data

The first case study, the CEP service provider with micro-hubs as innovative CLC, focuses on replacing the currently used 3.5t gross vehicle weight (GVW) delivery vans by heavy-duty trucks (HDT) distributing mobile micro-hubs (on trailers) in the city centers, from where flexible electric heavy-load freight bicycles distribute parcels to the customer on the last mile. Now, the CEP companies deliver the parcels to the customer by using the 3.5t vans for the entire trip, starting at a regional distribution center. The vans all operate one round trip per day and we assume that each van has to drive approximately the same distance from the regional distribution hub to the city area. The improvements of the logistics operations consist of a reduction of the trip sections traveled outside the city area. This is made possible by using a smaller number of HDTs (26 t GVW HDT with trailer) with two swap bodies each, which contain a multiple number of parcels compared to vans. Each of these vehicles drives to two defined locations and places one of the swap bodies as micro-hub there. The electric freight bicycles are stationed in the city and do not have to be transported to the hubs. Potentially required exchangeable batteries can be transported to the hub in the swap bodies. Another option for charging the electric freight bikes are charging spots next to the micro-hub.

The starting point for the parameters of the techno-economic assessment is the information provided by the CEP service providers in the interviews, e.g. the number of parcels transported and delivered per stop and per trip with a van. A delivery volume of 175 parcels per van and two parcels per stop were assumed as average value, after evaluating the interview data. Thus, each van stops on average 87.5 times per tour. According to the literature, the usable transportation volume of a van is 12 m^3 [18]. At a utilization of approx. 90 % (interview information), the 175 transported parcels thus fill 10.8 m^3 of the vehicle. This results in a volume per parcel of approx. 0.0617 m^3. This is roughly the size of two shoeboxes. For the swap bodies, at a given capacity utilization of 90%, 16 pallets are transported per swap body [19]. Taking into account the internal size of a swap body and the previously calculated average size of a parcel of 0.0617 m^3, 35 parcels can be transported per pallet. It is therefore assumed that 560 parcels can be stored per swap body and 1120 parcels per HDT with trailer. Furthermore, it is assumed that the swap bodies at the regional distribution center have been packed in such a way that the parcels or pallets are available in the correct order, according to the freight bicycle trips. Thus, we assume that no space is required inside the swap bodies for handling the parcels. For an electric freight bicycle, a usable volume of 2 m^3 is assumed [20], with an optimal utilization rate of 100%. Therefore, 32 parcels can be transported per electric freight bicycle. For the scenario where conventional vans are replaced with the corresponding BEV, charging stations for overnight charging must be installed at the regional distribution center, where the vans start their trips.

For the bakery delivery trips, according to interview data, an 18t HDT is used as an average vehicle. Differences between regular and cooling trucks are not included in the calculation. As 18t HDTs can load between 12 to 20 pallets, depending on their equipment, 17 pallets were chosen as average value according to expert statements.

At a given capacity utilization of 80% (interview information), 13 pallets are transported per vehicle and trip. According to the interview, the average tour length for the bakery supplier is 90 km with 10 stops per trip. Considering this information, 1.3 pallets are unloaded per stop on average. So far, diesel HDTs have been used for the bakery delivery trips. An important aspect for night-time deliveries however, is a low noise level. For that reason, BEV HDTs are required. Since in the expert interview payload was not mentioned as relevant criterion, we chose the number of pallets per HDT and thus, transportation volume not weight as criterion of comparison and limiting factor. Based on expert information, we assumed that an 18t electric HDT has the same transportation volume as a conventional diesel HDT.

In the following tables, some exemplary data is shown. Table 1 shows the vehicle prices for both CLCs. Table 2 shows the driver wages and Table 3 the logistics parameters for the 3.5t vans in CEP delivery, while Table 4 shows the techno-economic parameters for 3.5 t vans. All parameters are assumed and calculated for Germany in 2019.

Table 1: Vehicle prices in 2019

Vehicle type	Diesel [EUR]	Battery [EUR]	Source
Van (max. GVW 3,5t)	40,000	73,779	[21, 22]; Following [12, 21, 22]
Truck (max. GVW 18t)	78,000	167,611	[21]; Following [12, 23, 24]
Train vehicle with swap body with swap body (max. GVW 26t)	155,000	280,886	[21] and expert knowledge; Following [12, 21] and expert knowledge
Heavy load Bicycle	-	15,000	[25]

Table 2: Working days and driver wages in 2019

Parameter	Abbreviation	Unit	Value	Source
Driver wage daytime	S^{day}	EUR/h	25	[26]
Driver wage nighttime	S^{night}	EUR/h	28.8	[12]
Working days per year	diu	d/y	300	[17]

Table 3: Logistics parameters for status quo of CEP service provider and vans

Parameter	Unit	Value	Source
Total number of stops/trip	#	87.5	Own calculation based on interviews
Total numbers of parcels/van*	#	175	Own calculation based on interviews
Number of parcels per stop	#	2	Interview data
Average parcel size	m^3	0.0617	Own calculation based on interviews
Available vehicle volume	m^3	12	[18]
Capacity utilization	%	90	Interview data
Used vehicle volume	m^3	10.8	Own calculation based on interviews
Loading time per parcel	min	0.5	Own assumption
Loading time per trip	min	87.5	Own calculation based on interviews
Unloading time per stop (with two parcels)	min	3	[27]
Time loss per stop (parking)	min	1	Own assumption
Unloading time per tour	min	350	Own calculation based on [17]
Duration of delivery stop	min	4	Own calculation based on Interviews
usable for charging	h	0	-
Duration of warehouse stop	h	14	Interview data (overnight) / Own assumption
usable for charging**	h	12	Own assumption

Length of trip	km	80	Own assumption based on interviews
length of trip in town	km	66	Own assumption
length of trip out of town	km	14	Own assumption
Number of trips per vehicle and day	#	1	Interview data
Distance between two stops (in town)	km	0,74	Own assumption
Distance to first stop	km	8	Own assumption
in town	km	1	Own assumption
out of town	km	7	Own assumption
Average speed daytime in town	km/h	30	Expert knowledge
Average speed daytime out of town	km/h	50	Expert knowledge
Average speed night-time in town	km/h	40	[12]
Average speed night-time out of town	km/h	60	[12]

* According to utilization

** Overnight/sufficient for recharging

Table 4: Techno-economic parameters for the 3.5t vans in 2019

Parameter	Abbreviation	Unit	Diesel	BEV	Source
Number of trips	m	#/d	1	1	Interview data
Operating life	Z_x	y	8		[28]
Vehicle price	A_x	EUR	40,000	73,779	[21, 22]; Following [12, 21, 22]
Fuel consumption	M_x	l/100km kWh/100km	11	42	[21]; Following [21, 28]
Fuel price	P_y	EUR/l EUR/kWh	1.066	0.184	[29, 30]; [31, 32]
Maintenance, repair and tire costs	W_x	EUR/km	0.11864	0.15	[21]; Following [28, 33]
Tax	S_x	EUR/y	211		[21]
Insurance costs	L_x	EUR/y	4400		[21]
List price charging point	I_x	EUR	-	2000	[34]; [35]
Operating life infrastructure	i	y	-	15	[36]

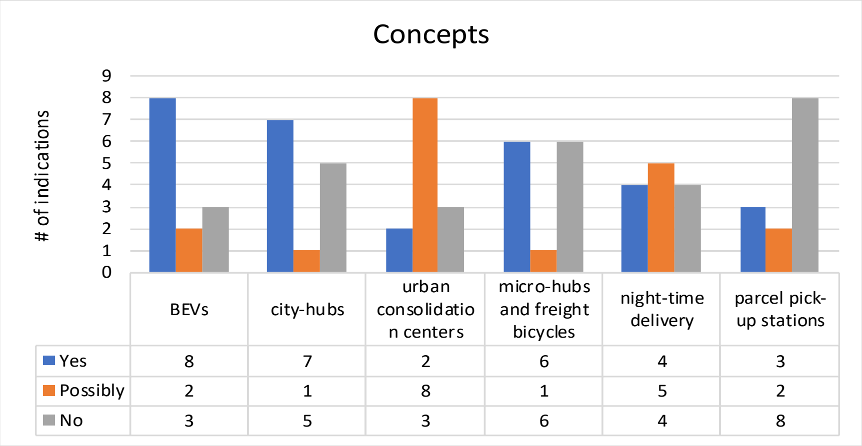
3 Results

3.1 Willingness of LSPs to use BEVs and innovative CLCs

Our literature review revealed several innovative CLCs that are discussed in theory and practice: (1) company-specific city-hubs close to urban areas, (2) company-independent urban consolidation centers, (3) inner-city micro-hubs with electric freight bicycles on the last mile, (4) night-time or off-hour delivery and (5) parcel pick-up stations. All of them can be implemented with BEVs in general. Thus, they were all subject to the expert interviews with the LSPs.

As a result of the expert interviews, we revealed that BEVs, independently from a specific city logistics concept, showed the highest acceptance among LSPs (see Figure 1). Short ranges compared to diesel vehicles, however, are one of the main obstacles for implementing BEVs, as well as excessively high prices for BEVs. Uncertainties regarding the long-term sustainability of BEVs are also a reason for a tendency to reject this technology. Additionally, limited charging infrastructure for BEVs are an obstacle. Currently the objective, even of the companies approving BEVs, is to achieve a partial use of BEVs and not to replace the entire vehicle fleet.

City-hubs and micro-hubs with electric freight bicycles were identified as further popular CLCs, but also night-time delivery, parcel-pick-up stations or urban consolidation centers received some acceptance. With regard to night-time delivery, three companies stated that their sites are already supplied at night by long-distance transports and that overnight delivery to the end customer does not seem feasible without a change of the entire supply chain or a too long (more than a day) waiting period of goods in the distribution center. Company-specific city hubs were not actually considered an innovative CLC, since many LSPs already operate respective city-hubs. Furthermore, it has to be noted, that responses were very industry-specific. Especially CEP service providers, for example, were open to micro-hubs and parcel-pick-up stations, whereas carriers preferred city-hubs.



	BEVs	city-hubs	urban consolidation centers	micro-hubs and freight bicycles	night-time delivery	parcel pick-up stations
■ Yes	8	7	2	6	4	3
■ Possibly	2	1	8	1	5	2
■ No	3	5	3	6	4	8

Figure 1: Willingness of LSPs to implement BEVs and innovative city logistics concepts

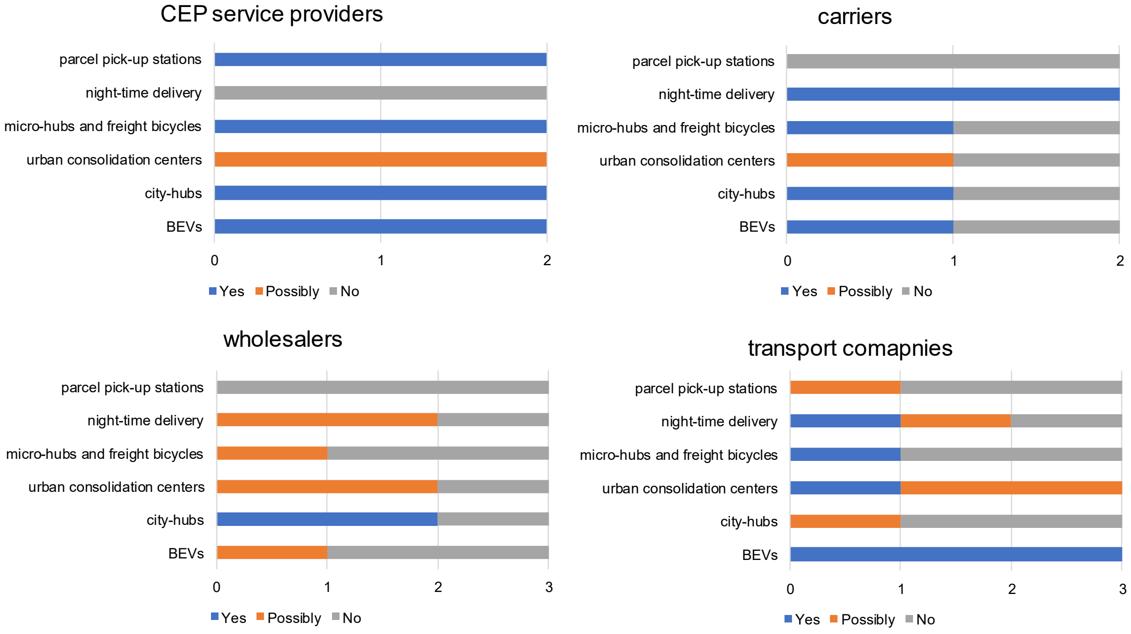


Figure 2: Approval or rejection of the concepts depending on the industry sector among the companies surveyed with more than one company per sector.

While the two surveyed general cargo carriers have different views on the individual CLCs in four out of six cases, the two CEP service providers agree in their assessment of all concepts (see Figure 2). There is also little agreement for the companies classified as transport companies and the wholesale companies. The overview by concept and sector is shown in Figure 2.

It should be noted that some of the companies evaluate the concepts positively but see problems in their implementation. For example, a bakery wholesaler assesses the night-time delivery positively, but mentions problems with regards to the economic efficiency and therefore evaluates it only as partially suitable. These differences are not visible in the figures above, as they only show tendencies within the industry sectors surveyed. The differences can be explained by the different goods' characteristics. While CEP service providers transport the same type of goods (parcels), the type and size of the goods transported by the other companies varies significantly, even within the individual sectors. Two of the wholesale companies transport food, among other things, and must therefore comply with different standards. The same applies to the three transport companies surveyed, which in contrast to the CEP service providers, have focused on other goods or a different type of transport. One transport company focusses on fast deliveries, which, for example, excludes every CLC which extends the processing time, while another company delivers medical goods and needs to fulfil specific standards with their vehicles which cannot be guaranteed with certain CLCs. This indicates that their requirements for CLCs vary strongly.

3.2 Economic and ecological analysis

As described above micro-hubs and night-time delivery turned out to be the most popular innovative CLCs. Therefore, we selected those for further analyses. Micro-hubs were particularly popular among CEPs and night-time delivery seemed to be very appropriate for bakery deliveries (wholesaler), therefore we calculated the TCO and CO_2-emissions for these two case studies.

When switching the CEP service provider's logistic concept to micro-hubs with freight bikes, costs per parcel would decrease by about 26 %, while reducing the CO_2-emissions by about 72 % (see Figure 3). In case of a shift from regular diesel 3.5t vans to BEV vans, logistics costs per parcel would increase by approximately 5 %. However, CO_2-emission savings of about 39 % could be realized. Since there would be no speed differences between diesel vans and BEV vans for the distribution, there is no effect on processing times.

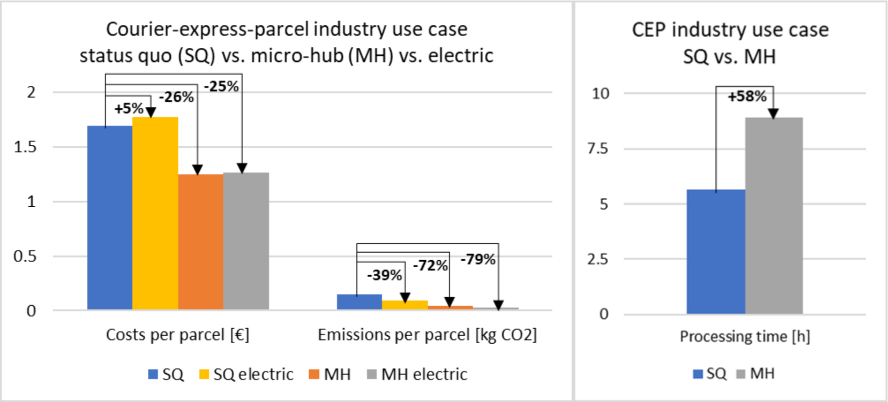


Figure 3: Costs and emissions of micro-hubs and usage of BEVs regarding use cases of the courier-express-parcel industry

When combining the micro-hub concept with BEVs, cost savings of 25 % can be achieved and total savings of CO_2-emissions of about 79 %. As already explained, the micro-hub concept combines a HDT trailer with electric freight bicycles. While the HDT trailer can drive up to four trips a day and therefore distribute eight micro-hubs during a day (this includes distributing the (fully loaded) micro-hub in the morning at a specific place as well as collecting it in the evening), every freight bicycle can run seven smaller trips a day. In order to be able to operate seven trips a day, an additional swap battery and a local charging point (e.g. a wall-box) is required for the electric freight bicycle, since its range is not sufficient for all trips. The additional costs are included in the calculation.

As micro-hubs imply an additional step for loading the freight bicycle, extra processing time is needed. Therefore, the use of micro-hubs increases the processing time by about 58 %.

For the bakery delivery case study, our calculations for 18t trucks indicate that BEVs, as well as night-time delivery with BEVs would be a more expensive solution, leading to cost increases of 15 and 17 % (see Figure 4). On the other hand, emission reductions of 28 % could be realized. Night-time delivery was calculated as a substitute for deliveries during the day and not as an addition. The higher expected average speed at night leads to shorter processing time at night (about 8%).

Our results showed that BEVs tend to increase costs of logistics operations. The combination of BEVs with innovative logistics concepts, however, can improve the profitability of BEVs, but it strongly depends on the specific logistics industry use case. A big advantage of BEVs and innovative city logistics concepts are lower CO_2-emissions. Differences in processing times, must be considered as well.

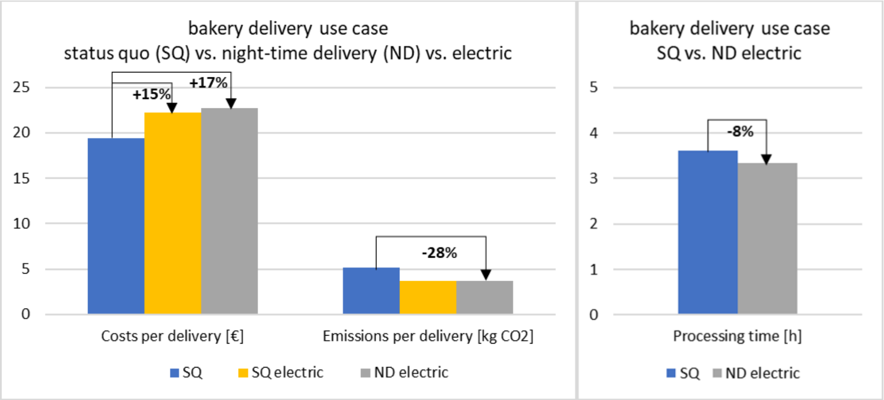


Figure 4: Costs, emissions and processing time of night-time delivery and usage of BEVs regarding use cases of the bakery delivery industry

4 Discussion and conclusions

Some of the parameters used in the calculations are subject to uncertainty and need to be discussed. First, most parameters are based on interview statements and are mostly average values. Thus, they do not represent an exact but rather tentative image of reality. Nevertheless, calculations with average values can give a good first indication of the impact of CLCs and BEVs. Beyond that, the statements of both interviewed CEP LSPs were compared in order to validate the parameters and to derive a meaningful use case. Uncertainties also exist regarding the trip length, amongst other parameters, since the CEP LSPs have not provided clear information on this. For this reason, information from other industries, e.g. the express transport company interviewed, was used to determine an average trip length. Furthermore, we derived parameters from the literature or compared interview data to literature data from various sources. For bakery deliveries, the utilization of the number of pallets as limit of a HDT load must be reviewed critically. This was applied, since information on the number of pallets has been given during the interviews, while information on payload was not available. At the same time, the weight of the transported goods was mentioned as a limiting factor of the vehicle during the interview, which emphasizes the importance of payloads. In order to validate the use of BEV HDTs, the payloads of electric trucks were compared to payloads of diesel trucks. Our analysis showed that the payloads were not identical but after validation with experts, they were considered sufficient to replace diesel trucks with the respective BEVs. One drawback of our analysis is that adequate BEVs are not available for all concepts that have been reviewed here. While some battery-electric vans are already available on the market, HDTs are still not produced in large scales by the big truck manufacturers. Beyond that, even if economic benefits are achievable for some CLCs under specific conditions, it can be doubted that LSPs would immediately adapt their logistics structure. This is caused by the very rigid delivery structures of the logistics industry and the connected high risks of the implementation of innovative CLCs.

In this present paper, we identified innovative CLCs, explored the acceptance of CLCs among LSPs in the Karlsruhe area and evaluated the technical, economic and ecological efficiency of selected CLCs in comparison with the status quo. Thus, we assessed potential CLCs for the Karlsruhe area. A major feature of this work is the connection of the qualitative exploration of the acceptance of CLCs among LSPs from Karlsruhe and the development of suitable use cases for the quantitative analysis.

The literature review shows that a large number of innovative CLCs exist. Our expert interviews reveal that there is no general solution to the challenges of city logistics, but that individual and flexible approaches are required depending on the LSPs' and goods' characteristics. E-mobility turns out to be the best known innovative concept but is currently rejected by most of the interviewees - at least on a larger scale - due to high prices and short ranges, although most of the trips could be sufficiently covered by existing BEVs. Thus, the calculation of company-specific business cases considering the entire fleet and all trips, showing that the range of existing BEVs is sufficient, is recommended. Concerning CO_2-emissions, the results show that a large proportion of emissions can be saved by switching to innovative CLCs. The use of BEVs plays an important role in this context, although the overall CO_2 savings may be lower than calculated in this paper, because of the high CO_2-emissions from battery manufacturing processes, which were not considered in this work. We also showed that innovative CLCs, such as micro-hubs with electric freight bicycles, can be beneficial from an economic point of view. Although companies in the Karlsruhe area are currently rather reluctant to switching to BEVs and other innovative CLCs, a general awareness of the problem and the desire for better solutions is emerging. Also due to decreasing battery prices and the further development of the technology in the future, a better recognition of BEVs and other innovative concepts can be expected. Currently, BEVs are not always cost-covering but with the perspective of the reduction of battery prices it can be recommended that LSPs should prepare to switch to BEVs and other innovative CLCs in the next years.

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