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Vehicle requirements for electric cargo bikes in commercial transport

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Abstract

Facing problems such as population growth cities have to cope with lack of space and increasing emissions from the transport sector. The need for commercial transport is rising and new sustainable mobility solutions have to be considered. One example is the deployment of electric cargo bikes. To develop a new vehicle concept the heterogeneous user characteristics need to be analysed to identify requirements. By looking at driving profiles and transported goods use cases were developed and included freight transport i.e. the CEP segment, last mile delivery and service transport such as municipal, craftsmen or care services. The results showed that based on the user characteristics all focused segments are suitable for e-cargo bikes. The characteristics differ in particular in operating times, downtime and number of trips, which places higher demands on the charging system and management in the case of service transport due to longer and more frequent travel times.

Keywords: Electric cargo bike; commercial transport; driving profiles; last mile delivery; vehicle requirements.

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1. Introduction

Cities today are facing the problem of a constant increase in population leading to a lack of space. Traffic accounts for a large proportion of land consumption. In commercial traffic, e-commerce and the demand for same-day-deliveries are increasing rapidly. According to the Pitney Bowes parcel shipping index the global parcel volume accounts for 87 billion with a yearly growth of 17 % since 2014 (data includes 13 markets [1]). In Germany the volume of parcels sent rose by 114 percent from 1.4 billion in 1996 to 3.03 billion in 2017 [2]. High annual mileages and the main use of trucks and light duty vehicles with combustion engines in freight transport lead to a high proportion of CO_2 emissions as well as strong nitrogen (NO_2) and particulate matter (PM10) emissions, which lower air quality. EU limit values and in particular values set by the World Health Organization for PM10 and NO_x emissions are often exceeded, forcing cities to take measures such as low-emission zones or diesel bans [3]. However, in order to comply with the limit values and at the same time meet the demand for transport, new solutions in commercial transport must be considered to ensure efficient and low-emission transport even in densely built areas. In addition to local and global emissions, the increase in traffic also leads to congested cities and traffic jams, which in turn increases travel times and could influence the speed or timeliness of a delivery.

In recent years especially e-commerce led to a growing market share for business-to-consumer (B2C) deliveries compared to business-to-business (B2B) [4]. As the number of home deliveries grows problems arise as the deliveries become more time critical and complex. Home delivery is convenient for many recipients but comprises inefficient factors for city logistics such as failed deliveries and spatial dispersion of residents. A distribution of shipments via smaller distribution centres would have advantages in this respect. There are several solutions to meet the demand and offer more sustainable solutions than the conventional dispersion via van deliveries. Automated systems can play an important role in last mile delivery for example through automatic delivery stations, i.e. lockers where consumers pick up their parcels themselves. Other concepts involve autonomous unmanned aerial vehicles (UAV or drones) that became a large research area within the past years [5]–[9]. Potential is seen in particular in reduced delivery costs through the elimination of labour costs [8]. Overall more sustainable solutions for home delivery lies in the choice of fleet that the shipment is distributed in. By including micro hubs in well located distribution networks smaller and lighter electric vehicles could be an environmentally friendly alternative to conventional or alternative powered light or heavy duty vehicles. In this context, three- and four-wheeled L-class vehicles offer potential for replacing larger commercial vehicles [10], [11]. Furthermore, even smaller vehicles such as cargo bikes offer potential for the distribution of goods in dense traffic in urban areas by being more flexible and causing less externalities [4]. These vehicles appear more and more in urban transport. Concepts are being developed for commercial traffic and in particular for the CEP sector (e.g. ONO, KYBURZ ePedelec, Rytle, Schaeffler Bio-Hybrid). In some applications, they offer a good alternative to larger vehicles including the CEP sector, food, construction, service and retail logistics [12]. The advantages of the use of electric cargo bikes for cities are particularly evident in reduced emissions (CO_2, air pollution and noise) and depending on the vehicle size less land consumption. According to a study by the German Aerospace Center (DLR) [13] the technical substitution potential of mileage carried out by ICE vehicles with electric cargo bikes lies between 19 % and 48 %. The numbers are based on volumes of transported goods and shipment distances and show that the deployment of more cargo bikes could have a large impact in regard to their substitution potential. The companies also have potential advantages, such as increased efficiency and productivity of their logistic processes and thus reduced costs.

For the development of a suitable concept for multiple applications, certain vehicle requirements are relevant. At the same time, the various commercial segments are characterised by heterogeneity in terms of usage profiles and vehicle requirements, such as transport volume. In order to develop a comprehensively applicable concept with short charging times and necessary transport capacities as well as further characteristics, travel profiles and user characteristics must be known in order to be able to respond to specific vehicle requirements. In this paper, possible fields of application and vehicle requirements for the use of such vehicles are first comparatively analysed. Then concrete use cases and their travel profiles, personal user requirements and transport goods are presented. Based on this, first potential vehicle specifications can be derived, which would be necessary for an advantageous use of an electric cargo bike.

The research was conducted within the project "Zero-Emission Cargo Bike for Smart Cities" funded by the Ministry of Economics Baden-Württemberg with the aim of developing a new all-electric two-wheeled battery-powered cargo bike. Contrary to the pedelecs mainly used (< 250 W and < 25 km/h) a more powerful motor and a battery capable of fast charging and recuperation are intended to meet the requirements of commercial traffic.

2. Methodology

In order to identify user requirements in commercial transport, various application areas must be analysed with regard to transport tasks. Different methods were combined to form use cases (see Figure 1). For a comprehensive approach, a competitive analysis of two- and three-wheeled cargo bikes and electric scooters as well as a stakeholder analysis was carried out by desk-based research. In order to verify results from the previous literature research and to identify use cases, ten telephone calls with potential interest groups such as municipalities, delivery services and the CEP sector were made before the written survey. A standardised questionnaire has been created from this information and through internal discussions. This survey collected data on user and tour profiles in order to understand when and how the vehicles operate. In addition to the type of movement, the transported goods are of great importance for the dimensions of the transport box. The topics of the 27 questions were related to:

- User/ tour profiles
- Transported goods
- Transport box
- Procurement criteria

The pre-selection of the use cases depended on contacts and networks from the DLR as well as those of the project partners. Together with further desk-based research, a meta-analysis of existing and potential fields of application was carried out. On this basis six use cases were created.

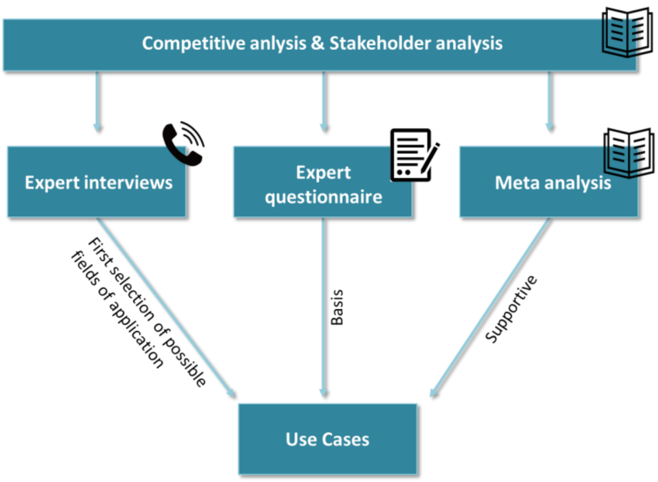

Fig. 1 Methodology for the use case analysis

With regard to the **user profile**, the characteristics of the tours were queried over the day and over a week. Information such as trip lengths, daily mileage, number of trips, operating times and information on downtimes and idle times are relevant. Derivable from this are in particular potential charging possibilities between shifts as well as during the tour, therefore the variance of the driving profile by plannable or unplannable routes is of importance. The type approval of the vehicles is also important and depends e.g. on the permitted maximum design speed. Therefore, both the average speed and the maximum speed desired for an e-cargo bike are significant for the vehicle requirement. Furthermore, the requirement for the driving licence class depends on the vehicle class as well as the power and speed. If the cargo bikes are classified in the L category (UNECE EU Regulation No. 168/2013), drivers often require a driving licence (e.g. A, A1, A2). If the holding of a specific driving license is regularly not the case in a company, it could be an obstacle for the deployment of those e-cargo bikes. Based on these tour characteristics, a morphological box with various parameters of interest for the conception of a vehicle was created. Figure 2 shows the morphological box with the method groups formed (left column) as well as the corresponding classifications (characteristics of the method groups). The method originates from the creativity technique and goes back to Fritz Zwicky with the development of the General Morphological Analysis (GMA). The aim is "investigating the totality of relationships contained in multi-dimensional, non-quantifiable problem complexes" [14] with application in many disciplines and research purposes [15]. The answers on the tours within the use cases are entered in the box, making the overlays identifiable. In this way, similarities, such as main operating times and idle times in-between trips, can become visible.

Route planning	Continuous																Discontinuous							
Route pattern	Direct																Dispersed							
Daily mileage	<50 km								51-100 km								>100 km							
Ø Tour length [km]	0-10		11-20		21-40		41-60		61-80		81-100		101-120		121-140		141-160		161-180		181-200		>200	
Number of tours	1		2		3		4		5		6		7		8		9		10		11		12	
Trip times (WKDY)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Trip times (WKND)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Idle time (min)	0-5		5-10		10-15		15-20		20-25		25-30		30-35		35-40		45-50		50-55		55-60		>60	
Downtime (h)	0		1		2		3		4		5		6		7		8		9		10		>10	
Parking space	Public space								Rental/sharing station								Depot							
Ø Velocity	0-15 km/h				16-25 km/h				26-35km/h				36-45km/h				46-55km/h				>56km/h			

Applicable for 1 use case | Applicable for 2 use cases | Applicable for 3 use cases | Applicable for 4-6 use cases

Fig. 2 Morphological box to assess tour profiles of commercial transport applications

Vehicle concepts developed for commercial transport, particularly need to be adapted to the **transport needs** of users. Design and layout of the transport box are therefore central factors, especially the maximum payload and the transport volume. In addition to the required properties, e.g. the decoupling of the box, the characteristics of the goods, e.g. cold/hot goods or the need to carry electrical equipment for use at the destination can vary depending on the industry and results in different demands on the transport box.

Further requirements are also important, e.g. with regard to safety features such as two-wheel ABS, brake assistants or the haptics of the handlebar in form of a warning sign. Although these are not only related to the commercial sector, they generally play an important role in the development of future vehicle concepts. However, not only the design of the vehicle is important but also the costs for the user. These contain on the one hand operating costs for the fleet but also maintenance.

3. Potential application fields and vehicle requirements

To answer the question on how an electric cargo bike should be developed, it is important to examine the current application fields and market structure of existing vehicle concepts. Furthermore, various potentially obstructive framework conditions for the use are identified. In addition to the special user requirements, this should also make it possible to identify fields of action that influence the vehicle design and possible success.

3.1. Potential fields of application in urban transport

For the potential fields of application, a distinction is made between freight and commercial passenger transport. Ruesch et al. (2013) and Schmid and Bohne (2016) provide a good overview with regard to classification in commercial transport [16]. Their findings is adapted in Figure 3 and reduced to potential fields of application for electric cargo bikes. Several research papers and studies discuss the possible application fields and impacts of changing the existing fleet to electric cargo bikes in city logistics [12], [17]–[22].

In freight transport, particularly the CEP sector is one potential application field that has been researched extensively, for example in [4], [13], [23], [24]. In some cities of Europe the large CEP companies already deliver packages with e-cargo bikes such as DHL, UPS, DPD or HERMES (most of the vehicles are not in the L category). CEP services have a high impact on congestion especially due to pick-up and delivery operations and environmental quality in urban traffic. Particularly in connection with micro depots, new alternatives to existing distribution systems can be developed. The second subcategory in freight transport is intralogistics and comprises in-house transport e.g. in factories, distribution centres, airports or hospitals [25]. In some of these commercial segments e-cargo bikes could potentially substitute trips made by cars or vans. Another category in commercial transport is service traffic i.e. passenger traffic. This refers to traffic that is induced by service-oriented activities which are related to economic services. They can be B2C such as craftsmen services for households, home care services or the cleaning of chimney systems. In B2B operations these include e.g. security services, services for gas, telephone or electric and water, cleaning of buildings or catering services [26]. The focus in this paper is on public authorities, e.g. park maintenance or street cleaning. Further interesting stakeholders are companies with delivery services (B2C) e.g. in retail, food or office deliveries or the pharma industry.

Even though, electric cargo bikes could also be deployed in individual transport this is not in the focus of the project. As a subcategory of commercial transport, business traffic is trips taken for work or business purpose. The use of cargo bikes could make sense in some aspects such as marketing and promotion trips but these are very specific operations, and therefore are not considered in the following analysis.

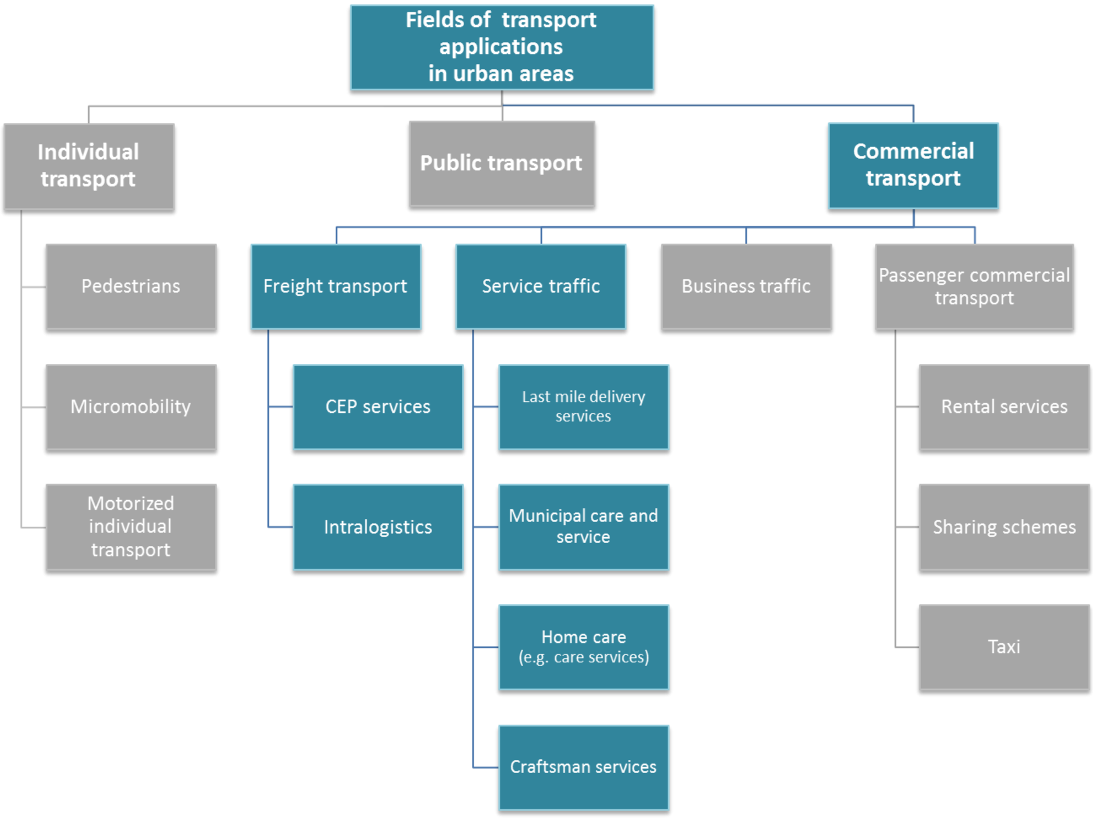

Fig. 3 Fields of application in transport for which a potential use of electric cargo bikes would be conceivable (Modified from Ruesch et al. 2013; Schmid and Bohne 2016)

3.2. Vehicle requirements and market analysis of cargo bikes

In the choice of vehicles for the fields of application, a distinction is initially made between two-, three- and four-wheeled cargo bikes with or without electric drive. While e-bikes up to 250 watts continuous power and a maximum design speed of up to 25 km/h are not subject to any type approval, those which exceed these specifications are in accordance with EU regulations in the L category (Regulation (EU) No. 168/2013 [27]). This means that different conditions of use apply to these vehicles. For example, in some countries they may not be used on cycle paths and require a driving license. However, many cities have an insufficient bicycle infrastructure that does not offer enough space for cargo bikes in the future, especially in the case of potential substitutions. In addition to flowing traffic, the parking space for cargo bikes is also a factor. Multi-track vehicles therefore require more space for parking [28]. In very densely constructed areas, problems could also arise because the turning circle is comparatively larger.

A market comparison shows that e-cargo bikes below the L category have to charge between four and ten hours, depending on the model, whereas L category cargo bikes have a comparative charging time of four to six hours. A critical characteristic in commercial transport is the charging time, which must coincide with the operating times of the vehicles. It is therefore often not possible to charge the vehicle during the time of loading. In addition, passive cooling of the batteries means that the vehicles have a shorter service life outside of moderate climate zones. The ZEC-Bike project aims to overcome these obstacles by developing a battery-electric cargo bike with a fast charging and recuperative battery. The vehicle should furthermore be designed in a way that enables full payload at standard speeds even in different topographies.

According to the ZIV (2019), in 2018 electric cargo bikes accounted for 4% of total cumulative sales of electrically powered bicycles in Germany, corresponding to 39,200 units. However, these only include pedelecs with a maximum design speed up to 25 km/h and a continuous rated power of 250 watts. S-pedelecs or e-bikes account for 1% of total sales, but no distinction is made between cargo bikes and bicycles [29]. A look at the market models shows that the majority consists of two-wheeled cargo bikes in the Long John design and thus the load position in the front area. The average range is 80 km with a charging time of between four and eight hours. The payload also varies between 100 - 255 kg (incl. 72 kg driver). The transport volume depends on the different containers.

4. Definition and results of the use cases

The use cases that have been defined cover municipal park maintenance, municipal street cleaning, two use cases from the CEP industry and one delivery service. For the results, the route profiles are important as well as the goods to be transported, which are considered separately in the following. For transported goods an additional desk-based research was conducted and further use cases were formed.

4.1. Tour profiles

Municipal services, i.e. park maintenance and street cleaning are only active in shorter time periods, which refer to approximately two hours in the morning and two hours in the afternoon during the week, in some cases also on weekends (WKND). In the case of municipal park maintenance the number of trips can vary depending on the number and location of destinations. As with freight transport, the break is used as stand time, and the short period of operation offers a long downtime, however not in the depot. With an average speed of 16-25 km/h in total, high speeds are not reached in urban traffic. While the use case for park maintenance showed direct routes to the destination and back to the depot, street cleaning has a dispersed route pattern. The vehicle is not constantly actively in use but is also temporarily pushed or parked during the activity.

CEP services show a different trip pattern compared to municipal services. Although the operating times are only limited to weekdays, their duration occupies most of the day from 9:00 or 10:00 to 19:00 or 20:00 o'clock (see Figure 4). The number of trips is very high (up to 10) due to many deliveries per day. There are only short idle times between the trips, which vary depending on the loading time or breaks. During idle times and downtimes, which exceed 10 hours, most of the vehicles are parked at the depot or, depending on the concept, on rented or stationary micro hubs. During these times, and especially during downtime, the vehicle is given enough time to recharge batteries.

Special cases are particularly characterized by delivery services due to their diversity. Depending on the service vehicles can either be only partially in use for small deliveries or constantly which makes it difficult to characterize one vehicle for all purposes. The existing use case is a delivery service with B2B operations and four hours of service time at the destination. Planning of the routes is variable and thus discontinuous. Furthermore, the routes are direct and vehicles return to the company directly after the service is completed. The time span of business hours is 18 hours both on weekdays (WKDY) and weekends. Operating hours are between 06:00 to 23:00 o'clock and allow stand times of six to eight hours per vehicle. Idle times in-between tours, which can be up to four trips a day, are 45-50 minutes long and located in public spaces. These circumstances pose greater challenges for charging management and require for fast charging options. In general, the type of delivery service, however, might differ substantially depending on the type of service offered.

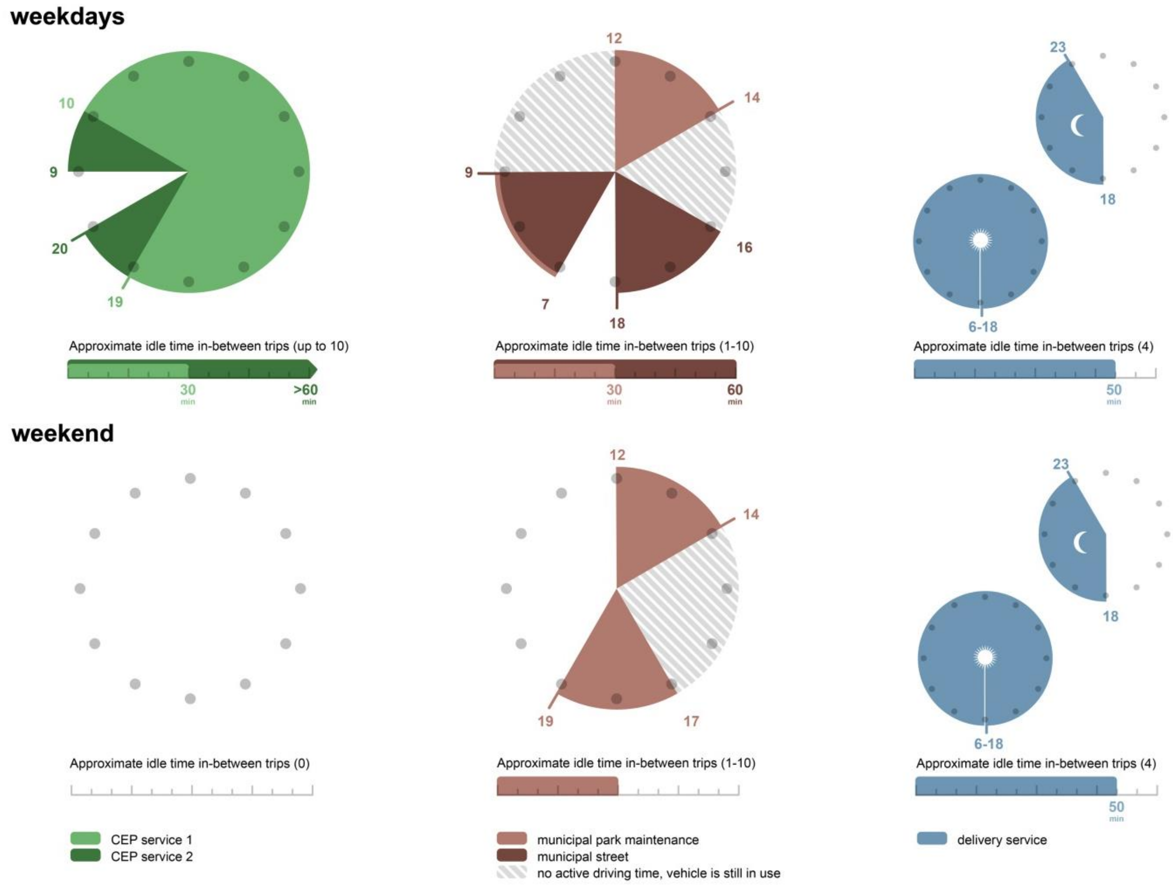

Fig. 4 Operating hours of municipal services and CEP services during weekdays and weekends (visualization by our colleague Robert Hahn)

Overall, the route planning as well as the route patterns differ greatly depending on the application. In Figure 5 the morphological box is applied to the five different use cases and shows overall tendencies regarding tour profiles. The usage profiles of urban freight traffic are concentrated in particular on working times during the day and with short trips of up to 20 km and daily ranges of less than 100 km. The number of tours varies between 1 and 10, with up to four trips on average for many applications. The operating times overlap in particular on weekdays between 07:00-18:00 o'clock. Idle times are mostly based on lunch breaks and last between 30 minutes and one hour. The limited operating time allows downtimes of more than 10 hours in permanent parking spaces in the depot and offers sufficient possibilities for charging. The route pattern is mostly continuous and always dispersed with short time frames for stops. Depending on the local traffic conditions and due to the use of insurance-free cargo bikes (max. design speed < 25 km/h), the average speed is always less than 25 km/h (see Figure 3).

Route planning	Continuous																Discontinuous							
Route pattern	Direct																Dispersed							
Daily mileage	<50 km								51-100 km								>100 km							
Ø Tour length [km]	0-10		11-20		21-40		41-60		61-80		81-100		101-120		121-140		141-160		161-180		181-200		>200	
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Downtime (h)	0		1		2		3		4		5		6		7		8		9		10		>10	
Parking space	Public space								Rental/sharing station								Depot							
Ø Velocity	0-15 km/h				16-25 km/h				26-35km/h				36-45km/h				46-55km/h				>56km/h			

Applicable for 1 use case | Applicable for 2 use cases | Applicable for 3 use cases | Applicable for 4-5 use cases

Fig. 5 Summary of the use cases for a profile of requirements for electric cargo bikes

4.2. Transported goods

The required payload varies greatly both in terms of mass and volume (see Figure 6). However, it appears that CEP services in general require a higher payload (up to 178 kg) while delivery services need very different load capacity depending on their services (between 25 kg and 200 kg). Municipal services, for example, require up to 100 kg. The volume is also widely differing. The length varies from 60 centimeters up to 2 meters. Also the width has a variance between 55 cm and 120 cm, and is determined in particular by the characteristic of either two-wheeled or multi-lane vehicles. With regard to the transport box height, CEP in particular supplies services of larger dimensions between 100 and 130 cm. In addition to the dimensioning of the transport box, the construction with regard to certain transported goods is important. For municipal services the transport of electric and bulky equipment is more important and presents an exclusion criterion for vehicle types. In the service sector especially in food delivery services, active cooling or heating could be necessary for food transport. The condition of a box on castors was classified as less important. However, intralogistic traffic was not covered by the responses but standardised dimensions, such as half a euro pallet and the ability to move on castors, could be important here. This is of lesser importance for the other traffic types under consideration. In addition, when CEP services are used, cargo wheels often require removable boxes which are easier to replace for swap bodies.

	Municipal services			Delivery services			CEP services		
	User 1	User 2	User 3	User 4	User 5	User 6	User 7	User 8	User 9
Load capacity [kg]	≤ 75 kg	≤ 50 kg	≤ 100 kg	≤ 200 kg		≤ 25 kg	≤ 125 kg	≤ 178 kg	
Volume [LxWxH]	200 x 100 x 100 cm	100 x 80 x 50 cm		83,5 x 61,5 x 76,1 cm	L: 60 cm (2-3 boxes stackable)	58 x 55 x 55 cm	80 x 120 x 100 cm	150 x 90 x 130 cm	15 grey boxes
Transported goods	Shovel, broom, leaf blower	Hedge trimmer, leaf blower, chain saw, brush cutter	Mower	Small set of cleaning equipment	Food	Fresh fish, ice cubes	Parcels		

* without driver

Fig. 6 Transported goods of nine use cases in Europe

5. Conclusion

The deployment of cargo bikes provides many advantages against the background of meeting climate targets but also local conditions such as air quality and congested cities. They can contribute to sustainable urban logistics over the last mile reducing land use, CO_2 emissions and improving air quality. The low weight in particular makes the vehicle more energy-efficient than larger delivery vehicles. The battery can therefore be smaller in size, which requires less critical raw materials in production.

An analysis of the current situation shows that some pilot projects and research have already been carried out and that there is great interest in promoting this type of mobility. However, the market overview shows that the supply of different vehicles, especially in the L-class segment, is still very low. In order to create an attractive vehicle for many applications in commercial transport various stakeholders and their needs must be satisfied. For an understanding of the different fields of application, the forming of use cases as well as the use of the morphological box was a suitable method. In this way, it was possible to analyse similar trip and transport characteristics and derive vehicle requirements from them. Results showed that all applications have a potential to be substituted by e-cargo bikes. However, the commercial segments have differing requirements especially regarding transported goods that can be met through a variety of transport boxes offered with the vehicle. To serve the CEP sector a large volume especially in height (up to 1,3 m) is needed in order to fit many parcels in one load while for the municipal services the boxes need to fit in electric machines such as lawn mowers or sweepers. More difficult is the design for service transports, as these can have very heterogeneous requirements depending on their trip purposes. The vehicle must therefore be designed in such a way that various sized transport boxes can be used for different applications. This also applies to the design for the concept of the drive system and especially the battery due to longer and more frequent travel times in a longer period of daily use (overlaps between 07:00 and 19:00 o'clock). With fast charging the electric cargo bike could be charged during the drivers' lunch breaks or in-between trips which usually take up to half an hour as well as during the longer downtime hours (up to 10 hours) in the depot.

In the planning of mobility concepts, the use of micro hubs is particularly important in relation to urban logistics. As a result, smaller areas can be supplied with shorter tour lengths. Although there are already some approaches in this direction, the transport infrastructure as well as sites for such hubs must be established.

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