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Requirements of German logistics companies for charging battery-electric trucks

Results of a combined survey and interview study

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Summary

The electrification of heavy-duty road transport and logistics operations presents a significant challenge in meeting CO_2 reduction goals. Despite increasing attention to battery-electric trucks (BETs) as a primary strategy among manufacturers, their market share remains limited in Europe and Germany. Logistics companies, as primary users of heavy-duty vehicles (HDVs), face various challenges such as tight budgets, time constraints, and diverse operational needs, which significantly influence the adoption of BETs. Previous studies have identified general key obstacles including purchase price, charging infrastructure availability, vehicle range, payload limitations, total ownership costs, technology perception, and operational adaptations. However, further investigation is needed to understand company-specific requirements and operations of different logistics segments, especially regarding charging infrastructure limitations.

This study employs a mixed methods approach to explore logistic companies' perspectives on charging infrastructure and BET adoption. A survey of German logistics companies, followed by semi-structured interviews, provides insights into current fleet operations, attitudes towards BETs, and motivations for electrification. The survey findings highlight the diverse vehicle types and driving profiles within logistics fleets, with a focus on identifying most readily electrifiable trucks (RETs) based on usage patterns. Analyses of survey data, conducted mainly through descriptive statistics, reveal the complexities of trip planning, on-site charging infrastructure, and public charging implications for BET adoption. Interviews with selected respondents further delve into company characteristics, daily operations, usage intentions, and barriers related to BET adoption and charging infrastructure.

The results indicate that the regularity and plannability of trips differs across tour types and distances, impacting the potential integration of BETs in operations. Tour regularity varies greatly for individual vehicles beyond urban applications, impacting the flexibility needed for charging. The longest coherent parking time is predominantly spent on private property, with home depots being more important than client locations. Challenges for establishing and using charging infrastructure include the lack of medium voltage grid connections for fast charging at home depots, heterogeneous conditions at client waiting and loading areas, and uncertainties regarding the availability and operational integration of public charging infrastructure.

Companies in the sample operating a large number of RETs also hold the most positive attitudes towards BETs, with some already deploying such vehicles. Factors influencing the engagement of logistics companies in fleet electrification include personal motivations, growing customer demands for decarbonised transport, and regulatory requirements. Methodological limitations of the study include a bias towards large fleets in the sample, limiting extrapolation of findings to the broader market. Key recommendations include addressing barriers to at-home and client location charging to support fleet electrification efforts effectively. The findings provide insights into the operational considerations and motivations driving charging infrastructure deployment and fleet electrification. Furthermore, they offer implications for policymakers and industry stakeholders aiming to accelerate the transition to electric HDVs.

Contents

1 The challenge of electrifying heavy-duty road transport and logistics operations

To meet the stringent CO_2 reduction goals for heavy-duty vehicle (HDV) fleets, manufacturers need to increase sales of alternative fuel vehicles (AFVs). Battery-electric trucks (BETs) currently occupy a central position in all manufacturer strategies but despite recent increases, their market share has been limited so far, at 0.9% in Europe in 2022 and 1.1% in Germany (Acea, 2023). This includes both medium (above 3.5t) and heavy-duty vehicles (above 12t), both of which we will subsume under HDVs and BETs in this study. Purchases and the inclusion of these vehicles in real-world operations need to be increased to reach the set goals.

Logistics companies represent the key user group for HDVs and consequently BETs but are part of a challenging and heterogeneous market (Göckeler et al., 2022; Muratori et al., 2023). Key challenges in the logistics sector are tight budgets, time restrictions, and the necessity to meet client needs. Additionally, the sector is heterogeneous and has demands for different vehicle configurations, which greatly surpass the number of application contexts in the passenger sector while at the same time operating much fewer vehicles (Berggren et al., 2015). From repeated shuttle routes to cross-country tramp transport, HDVs need to cover a variety of operations. This includes not only different distances but also different types of locations and consequently varying break schedules (Göckeler et al., 2022). From this user perspective, electrification would ideally be able to cover all previously carried out operations. However, adaptations can also be considered, with potential challenges but also chances for optimizing operations and routes.

Currently, we know too little about the conditions of real-world logistics companies for widely implementing BETs and their corresponding charging infrastructure. First studies have investigated the attitudes of logistics companies in Germany and Europe towards alternative fuel vehicles and corresponding drivers and barriers.

Anderhofstadt and Spinler (2019) conducted a Delphi study with 23 experts from manufacturers, logistics service providers and infrastructure providers to consultants and researchers. They identified purchase price, charging infrastructure, and vehicle range as key obstacles for BETs. A more detailed analysis of obstacles and minimum requirements for the usage of BETs was done by Ragon and colleagues (2022) who surveyed and interviewed over 30 leading European logistics companies. They found that particularly infrastructure and vehicle availability (delivery times), as well as vehicle range, payload limitations, total costs of ownership and uncertain depreciation, drivers' technology perception, efforts to adapt operational patterns, and truck reliability are among the main barriers preventing the widespread diffusion of BETs. Göckeler et al. (2022) surveyed 250 logistics service providers in Germany and also identified the availability of charging or refuelling infrastructure as one of the most important criteria for AFVs, supporting the findings above. Additionally, the authors showed that the average daily mileage of the respondents was less than 800 km for all applications and that vehicles were typically parked for 16 hours, spread over the course of the day. About one third of parking hours was due to jams, loading and unloading, or waiting. These first findings from Germany and Europe consequently show that infrastructure availability, paired with break times and parking locations have been generally identified as key levers for a further diffusion of BETs but warrant further research.

Latest international studies confirm and extend these findings from the German studies. For example, Konstantinou and Gkritza (2023) found that BETs tend to be evaluated positively by American truck fleet managers. They reported higher BET purchase intentions for companies owning for-hire fleets, generating high revenue (100 million dollars or more), and owning larger truck fleets. Particularly, the aspects relating to for-hire fleets point to the return-to-base nature of

the fleet and the lower mileage of the trucks as important drivers of BET purchase intention. Furthermore, the authors report that higher-than-average mileage, owning more heavy- than medium-duty trucks, and the importance of fuel economy tends to be associated with a lower purchase intention. In contrast, higher awareness of fast charging as well as perceived environmental importance is associated with higher purchase intention.

To sum up, one main group of factors influencing the willingness to adopt BETs are infrastructures and organisational requirements, e.g., tour planning, functional suitability of BETs, fuel infrastructure and price, vehicle availability, financial incentives and fleet regulations (see also Bae et al., 2022; Cantillo et al., 2022; Muratori et al., 2023; Parker et al., 1997; Zhang et al., 2019). The second group of factors relates to motivations and attitudes on the individual and organisational level, such as environmental consciousness or driver resistance (see also Cantillo et al., 2022; Seitz et al., 2015; Sugihara et al., 2023).

Meanwhile, technical analyses are optimistic and assume that trucks will be able to recharge within their mandatory break after 4.5 hours of driving (Nykvist & Olsson, 2021; Speth & Plötz, 2024). However, this assumption also requires a high level of public infrastructure deployment, as shown by Shoman et al. (2023), Speth et al. (2022), or Menter et al. (2023). Although the Alternative Fuels Infrastructure Regulation (EU, 2023) sets ambitious targets for truck charging infrastructure, the construction will take several years, mainly due to necessary electricity grid connections (Burges & Kippelt, 2021).

With this working paper, we therefore aim to dive deeper into the specific requirements and driving behaviours of different types of logistics companies, particularly in light of a limited availability of charging infrastructure. We therefore ask:

1) To which extent can current operations of logistics companies account for charging events and how does this differ between the different applications in the sector?
2) Which factors motivate the engagement of logistics companies in fleet electrification?

To this end, we look at the logistics companies' current fleets and operations and ask them about their considerations towards BETs, charging infrastructure, and their reasoning behind engaging or not engaging with the topic. In this way, we can describe potential chances and barriers for the introduction of this technology in the sector and provide recommendations for facilitating this change.

This paper is structured as follows. Section 2 presents the mixed methods approach of the study, outlining the survey and interviews we conducted. In section 3, we present the results of each part of the study and how they build on each other. Finally, section 4 discusses the findings and section 5 derives key take-aways and arrives at a conclusion.

2 Methods

An explanatory sequential mixed methods approach (Creswell, 2013) was used for this study. With this approach, we were able to first get an impression of conditions and perspectives of a larger number of logistics companies with a survey, followed by more in-depth questions about the reasoning and motivations in semi-structured interviews. Consequently, each data source addresses both research questions and the results are ultimatley integrated to form the base for the discussion.

Survey

For recruiting participants, we compiled a list of German logistics companies alongside contact information of a person responsible for the companies' vehicle pools. If no personal contact information could be found, we used the company's general e-mail address. We then sent out an e-mail explaining the content of the project and asking for participation in the online survey. We sent out a total of 1,178 invitations and reminders and obtained n = 50 valid responses to the questionnaire (i.e., 8.5% response rate). Invitations were sent on January 25th, 2023, and the reminders two weeks later. In total, the survey was conducted over three weeks. At the end of the survey, we asked the participants if they agreed to be contacted for the follow-up interviews, with n = 19 initial positive responses. Finally, six of those 19 companies confirmed their initial response and were interviewed.

Table 1 presents an overview of the companies which participated in the survey and both their general characteristics and the characteristics of the respondents themselves. The majority of respondents represent small and medium-sized firms in terms of their fleet with up to 40 vehicles (n=34). Most surveyed logistics companies conduct long-distance transport (n=35) and/or distribution traffic (n=17) and are active in the construction industry (n=19). The majority of respondents are the CEO of their company (n=36, 52%) and around 10% of respondents (also) take on the roles of fleet managers, buyers, and dispatchers. These key roles match that around a third of respondents report being able to make purchase decisions for BETs and building decisions for infrastructure by themselves (n=15, 30% respectively) and that around half of the respondents could make these decisions jointly with others in the company (n=26, 52% for BET purchases; n=25, 50% for infrastructure decisions).

Table 1: Company and respondent characteristics

	Number of responses	Share of total responses (%)
Fleet size		
1 - 20	22	44%
21 - 40	12	24%
41 - 60	5	10%
61 - 80	2	4%
81 - 100	2	4%
101 or more	7	14%
*Main logistics segment**		
Construction industry	19	38%
Long-distance transport	35	70%

	Number of responses	Share of total responses (%)
Agriculture & Forestry	10	20%
Chemicals & mineral oil	6	12%
Distribution traffic	17	34%
Transport (vehicles, containers, heavy-duty)	9	18%
Mining & Quarrying	2	4%
Municipal services (e.g., waste disposal)	5	10%
Other	14	28%
*Role of the survey respondent**		
Fleet manager	8	12%
Buyer	7	10%
Dispatcher	7	10%
CEO	36	52%
Driver	3	4%
Other	8	12%

Notes. *Multiple answers were possible.

The survey contained four main parts. In the first part, respondents were asked to provide general information on their company. This information included the number of vehicles in the company's pool, the duration of their usage, and what they are used for. In the second part, participants provided information on the kinds of trips they undertake with their vehicles. This included the regularity, regions, and stops of the trips. We also collected information on how and where the drivers typically spend the legally mandated driving break after 4.5 hours. The third part collected information on the respondents' attitudes towards battery-electric trucks, the trucks' perceived effects on the company's image with potential employees, customers, and other logistics companies, as well as the status of electrification of the company's fleet. In the last part of the survey, participants answered questions on the implications that battery-electric trucks would have for trip planning, on-site charging infrastructure, and public charging. These data were mainly analysed using descriptive statistics, since sample sizes were too small to apply inferential statistics. To facilitate interpretation, we divided the sample into subgroups according to their current driving profiles and the size of their fleets.

The results show that the companies use a multitude of vehicle types and driving profiles, each with different characteristics and suitability for already available BET models. For the analyses that differentiate results by vehicle types and driving profiles, we focus on highlighting and further characterising the share of currently used diesel vehicles that could currently be most readily electrified. We define these most readily electrifiable trucks (RETs) based on an archetypal usage: (1) We set 8 hours as lower threshold for the longest coherent daily parking time to provide an adequate slot for low-power recharging. (2) We set 500 kilometres as upper threshold for daily mileage, since currently available BET models with battery capacities of up to around 550-650 kWh (CALSTART, 2024; Link et al., 2021) may already handle this distance. Daily mileage was derived from the yearly mileage as indicated in the survey divided by 304 days (= 365 calendar days in 2023 - 52 sundays - 9 national holidays). Following this definition, our dataset contains 26 companies with such an archetypal RET-usage and 24 with other truck usage.

To simplify the visualisation of our results, we also divided the sample according to the size of the companies' vehicle fleets. The 25 percent quantile of the total number of vehicles marks the upper limit for small fleets (i.e., 10 vehicles; n = 13 companies). The 75 percent quantile marks the upper limit for medium fleets (i.e., more than 10, but less than 57 vehicles, n = 24). Large fleets thus consist of 57 to 250 vehicles (n = 13).

Interviews

The follow-up interviews with survey respondents that were willing to further expand on their survey answers were held in November 2023. In total, n = 6 interviews were conducted. Table 2 displays an overview of the interviewees' companies and roles. The interview questionnaire consisted of five parts: company characteristics; daily operations; evaluations, usage intentions, and chances and barriers for using battery-electric trucks; breaks and conditions for charging infrastructure at private locations; and finally breaks and (potential) charging infrastructure usage at public locations.

Table 2: Overview of the interviews

Interview ID	Company type	Role of the interviewee
I1	Intermodal logistics	Authorised signatory
I2	Medium-sized logistics company	Fleet manager
I3	Logistics service provider	Dispatcher
I4	Regional logistics company	CEO
I5	Full-service transport and logistics company	CEO
I6	Crane and heavy transport logistics	Field service staff

All interviews were automatically transcribed, and the transcripts then cleaned and improved by hand. Transcripts were then analysed with the qualitative content analysis software MaxQDA in the following way: First, since the interviews were held in a semi-structured way, answers needed to be clearly assigned to the matching questions. Per question, each respondent's answer was then summarised and analysed for similarities and differences with the other respondents' answers to the question. The results section reports the main trends and differences in these answers and relates them back to the survey.

3 Results

Data were analysed in two steps. First, the results of the survey were analysed as an input for the more detailed data collection in the interviews. Second, the interview data were analysed and put in context with the survey results in order to compare and deepen our initial findings.

3.1 Survey results

We first present an overview of the 50 surveyed logistics companies and their characteristics.

Vehicle fleets

The number of vehicles in the companies' fleets varies between one and 250 vehicles, with an average of 48 vehicles per company. Most companies in the sample (70%) buy all or most of their vehicles. Leasing is less common (28%), with seven companies leasing around half of their vehicles, and seven companies leasing most or all of their vehicles. Companies leasing all or most of their vehicles have on average larger fleets (76 trucks, SD = 81) than companies purchasing all or most of their vehicles (45 trucks, SD = 54). For those purchasing approximately half of their vehicles and leasing the remainder, the average fleet size stands at around 34 vehicles (SD = 51). Furthermore, the companies operate their vehicles for a mean of 5.8 years (SD = 1.9), with a minimum of three and a maximum of ten years. This number also varies depending on whether the companies buy or lease their vehicles. Companies leasing all or most of their vehicles have on average shorter times of ownership (4 years, SD = 1) than companies purchasing all or most of their vehicles (7 years, SD = 4). For companies with balanced purchasing/leasing fleets, the average time of ownership is 11.5 years (SD = 11). The surveyed companies' vehicles run an average of 110,571 km per year (SD = 40,400 km; Min = 12,000 km; Max = 250,000 km).

Driving characteristics

The most common types of haulage tours[1] were short hauls (n=35, 70% of the surveyed companies) and round-trip services (n=29, 58%). Line hauls (n=18, 36%), shuttle services (n=16, 32%), and tramp traffic[2] (n=15, 30%) follow as a tour type of around a third of the surveyed companies. Only few companies (n=7, 14%) indicated that they run encounter services with their heavy-duty vehicles.

RQ 1. To which extent can current operations of logistics companies account for charging events and how does this differ between the different applications in the sector?

To answer the first research question, we look at the companies' current driving profiles and tour characteristics, as well as the duration and location of driving breaks. This will enable us to identify driving profiles that already today support the integration of BETs or remain a challenge for truck electrification.

Tour characteristics

Figure 1 shows the regularity and plannability of haulage tours in different applications. It can be seen that long-distance international and European trips tend to be less plannable, while shorter distances are more regular and plannable. However, even regional trips can be different with regard to how plannable they are. High regularity and plannability is quite rare and applies to urban and

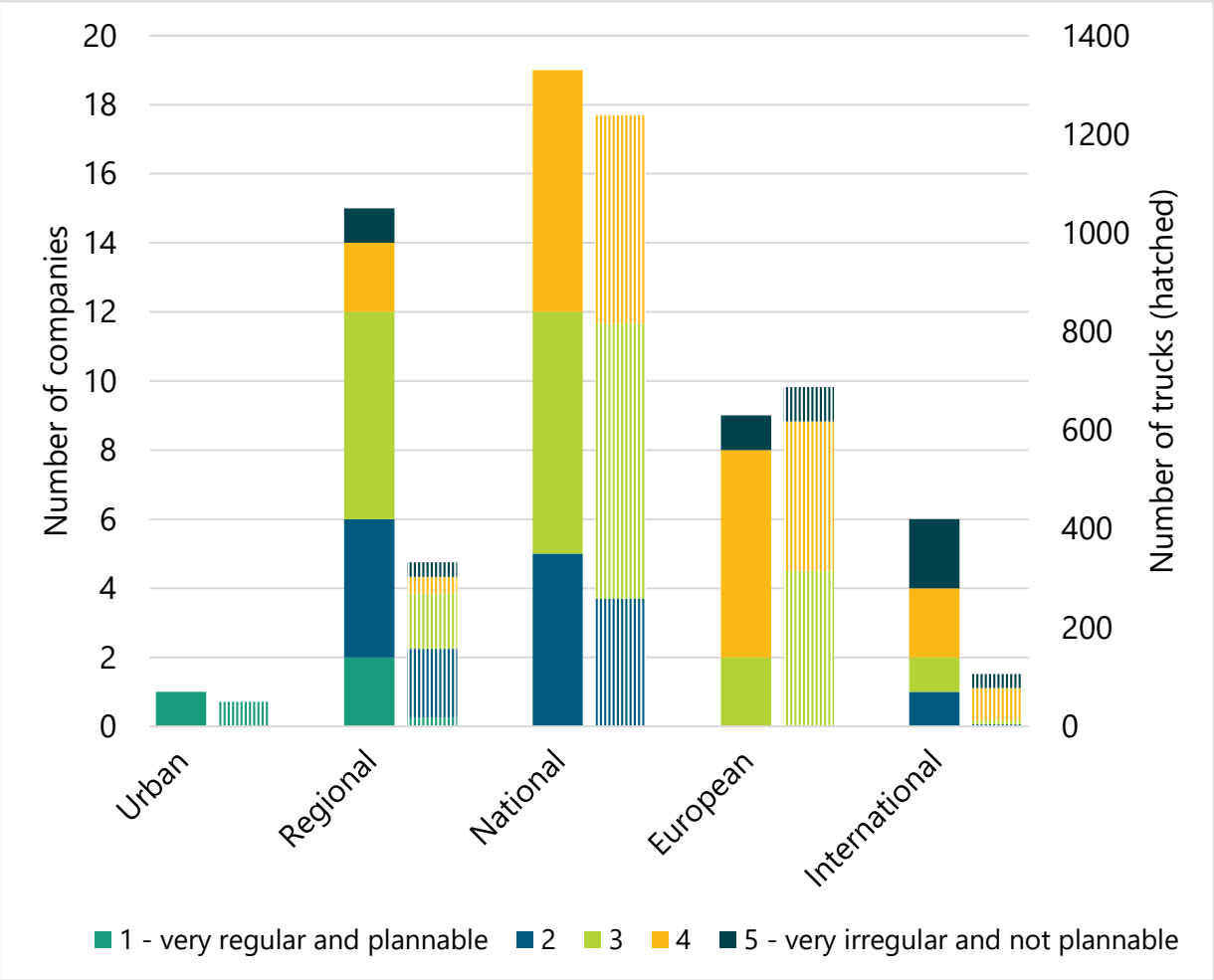
[1] Multiple answers could be chosen for this question.

[2] Transporting goods without a regular schedule or route. Equivalent to tramp shipping.

regional traffic only. It can also be seen that while many companies operate regional tours, they possess only relatively few vehicles, and similarly for international tours[3].

Figure 1: Regularity and plannability of different kinds of haulage tours

Survey question: How would you describe the regularity and plannability for the majority of your company's heavy-duty vehicles over the course of a month?



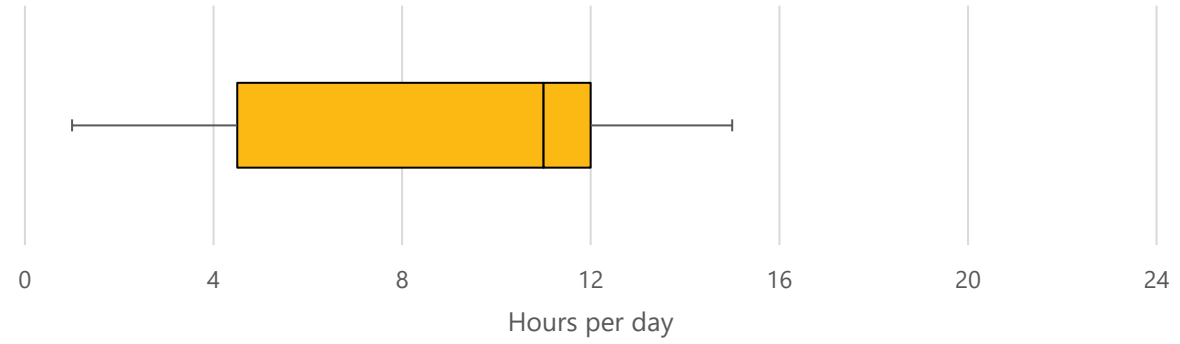
Total parking time

Figure 2 shows the average total parking time per day that the respondents estimated for their respective companies (N = 42). It can be seen that the average total parking time of the companies' trucks per day is eleven hours, with a minimum of one and a maximum of 15 hours. For most companies, the total parking time varies between 4.5 and twelve hours. Some of the shorter parking times originate from companies operating a double-shift system (N = 6).

[3] The kind of tours indicated in this figure is what the companies indicated they mainly operate. The corresponding number of trucks per company was not split between different kinds of tours. Therefore, this figure and all similar figures work under the assumption that if a company indicates to mainly operate a certain kind of tour, this applies to all their trucks. Consequently, the number of trucks displayed in these figures represents an upper limit.

Figure 2: Average total parking time of trucks per day

Survey question: How long do you estimate the average parking time of your heavy-duty vehicles per day?

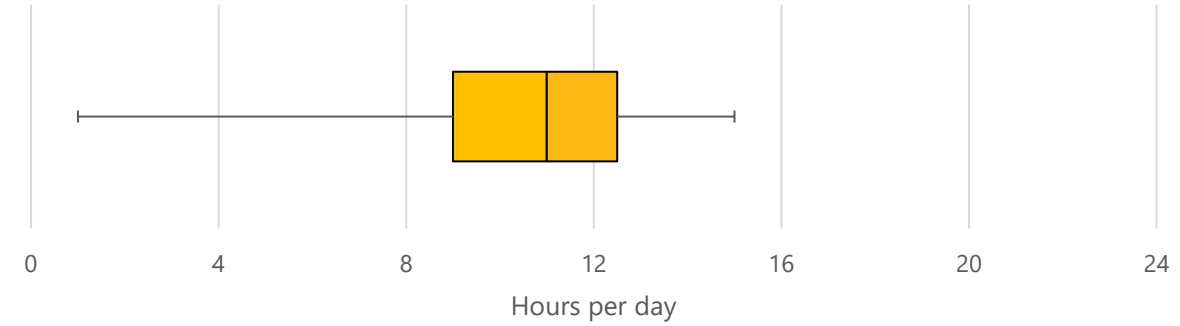


Longest coherent parking time

Figure 3 shows the longest coherent parking time per day for the surveyed logistics companies that provided valid answers (N = 36). The longest coherent parking time is eleven hours (median), with a minimum of one and a maximum of 15 hours. For most companies, the longest coherent parking time varies between nine and 12 hours. For a few companies operating with a double-shift system, the longest coherent parking time is considerably shorter.

Figure 3: Longest coherent parking time per day

Survey question: What is the longest coherent parking time per day?



Location of longest parking time

Figure 4 shows that trucks rather stop at private properties than public spots during their longest coherent parking time, irrespective whether the number of companies or trucks is rated. However, public spots remain highly frequented, contributing between 33-37 % (company-weighted) and 36-49 % (truck-weighted). This emphasises the demand for rather low-power charging facilities at both locations, private and public. If trucks use public parking spots, off-highway rest areas, road-side parking and unmanaged parking lots are most frequented, irrespective of the usage profile. In contrast, when trucks use private properties, we observe notable differences between RET-usage (rather own property: 82 % company-weighted; 97 % truck-weighted) and other truck usage (more evenly split between own and foreign properties).

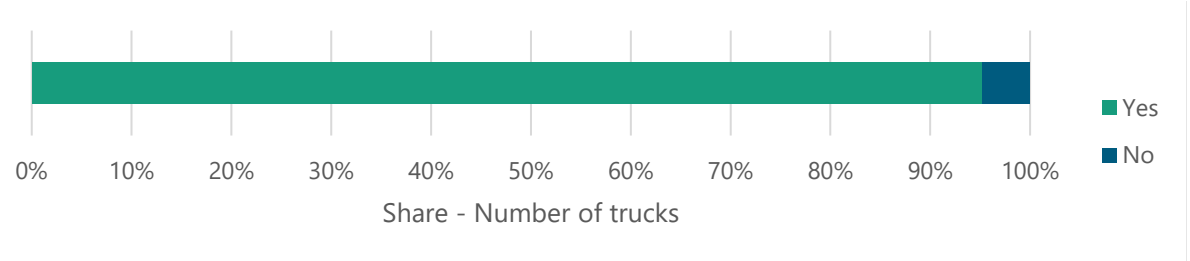
Figure 4: Location of the longest coherent parking time for companies with RETs and other companies

Survey question: Where is the longest coherent parking time usually spent?

Figure 5 shows that the vast majority of trucks stop in a public space for the mandatory breaks. Only five percent of trucks virtually never stop in public spaces during their mandatory driving breaks.

Figure 5: Public parking during mandatory breaks

Survey question: Do your drivers stop in public places during the mandatory breaks?



On long distance trips, the mandatory breaks are predominantly spent in public spaces such as rest areas off the highways or in industrial areas, as shown in Figure 6. Private property of a customer is used less often, but more often than unmanaged public parking lots. A few trucks seem to spend the mandatory breaks on their company's property.

Figure 6: Location of mandatory breaks on long-distance trips

Survey question: Where do you usually spend the mandatory break after 4.5 hours when you are driving long-distance? Multiple answers may be chosen

RQ2. Which factors motivate the engagement of logistics companies in fleet electrification?

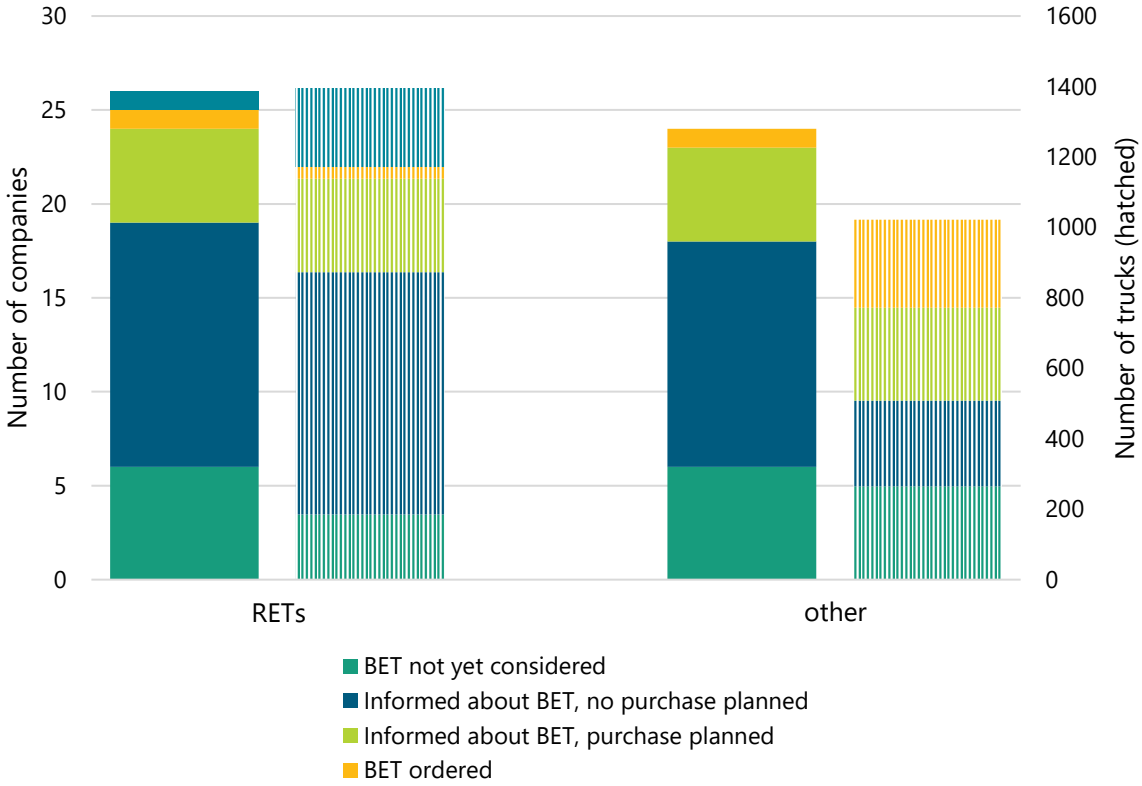
To answer the second research question, we look at the status quo of activities and plans towards BETs in the surveyed companies, the perceived pressure to act on BETs and the image consequences of BETs as well as the attitudes towards BETs among the surveyed decision-makers.

Status quo of activities and plans towards BETs

Figure 7 shows that companies operating RETs do not show different BET plans and activities. While the one company that already deploys BETs also operates RETs, the extent to which BETs already play a role is distributed similarly between companies with RETs and those without. The additional breakdown by number of trucks shows that the companies that have ordered BETs are those with larger vehicle fleets.

Figure 7: Role of BET in companies with and without RETs

Survey question: What role have battery electric trucks played in your company to date?



Perceived external pressure and image

Figure 8 shows that external pressure to purchase BET is perceived to be rather low. Companies with large fleets seem to perceive some BET activities by their competitors, but do not feel any pressure to act arising from these activities. Companies with medium and large fleets perceive customer expectations to purchase BET to some extent. Most companies agree that purchasing BETs currently does play a role in the sector.

Figure 8: External pressure surrounding BET

Survey question: Please indicate how strongly you agree with the following statements.

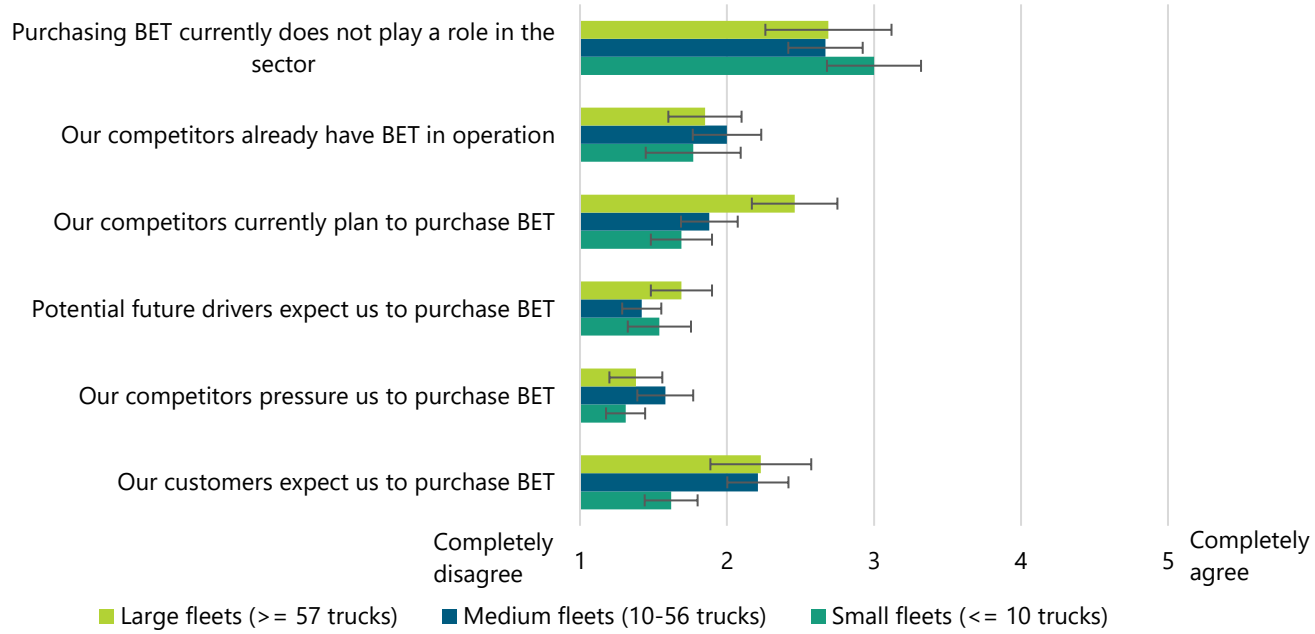
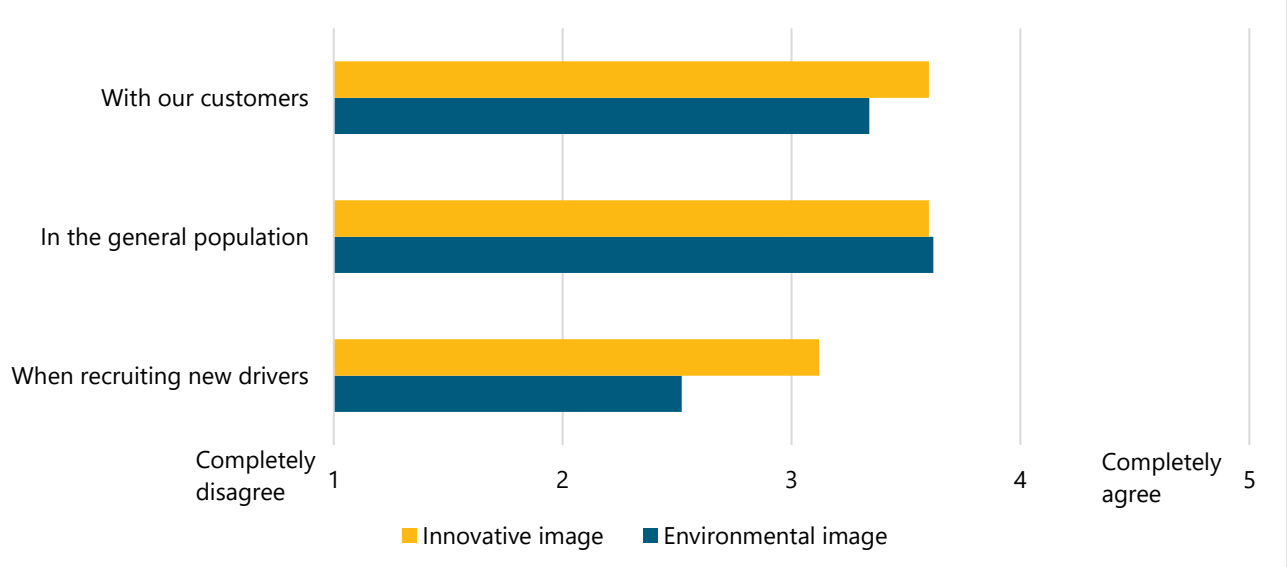


Figure 9 shows that purchasing BETs is generally thought to improve the innovative image of a company rather than the environmental image with the customers and when recruiting new drivers. With regard to the general population, survey respondents think that purchasing BETs would benefit both the company's environmental and innovative image to a similar extent.

Figure 9: Consequences of BET purchase on innovative and environmental company image among different target groups

Survey question: Please indicate how much you agree with the following statements: Adding BETs to our fleet would showcase us as an innovative / environmentally friendly logistics company.



Attitudes towards BETs

Figure 10 shows that all surveyed companies on average have a neutral standpoint towards BET. An exception are companies with small fleets, which on average perceive the deployment of BETs to be rather useless for their purposes, while they deem these vehicles to be advantageous at the same time. Companies with large and medium fleets perceive the deployment of BETs to be rather pleasant.

Figure 10: Attitudes towards BET in companies with small, medium and large fleets

Survey question: Adding BETs to our fleet would be...

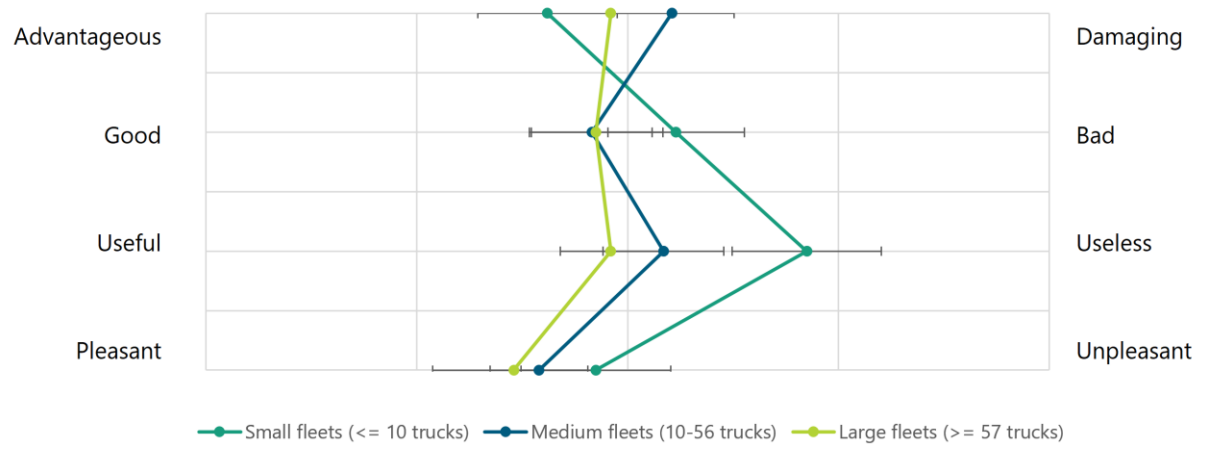
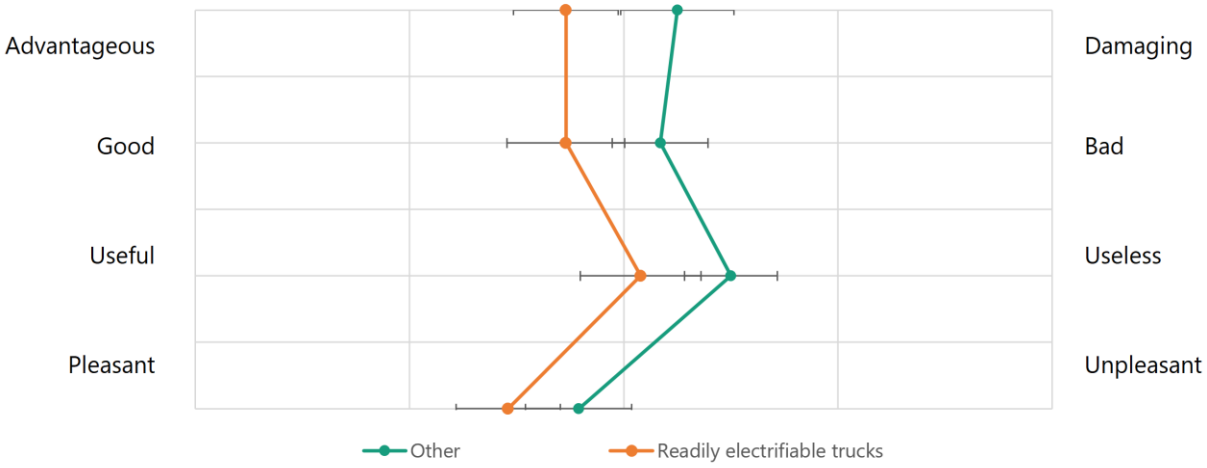


Figure 11 shows that companies with RETs perceive BET to be more advantageous, better, more useful and more pleasant than companies with other driving profiles.

Figure 11: Attitudes towards BET in companies with RETs and other companies

Survey question: Adding BETs to our fleet would be...



3.2 Interview results

The six logistics companies that were interviewed cover a wide variety of transport applications, vehicle types, and operations. They can therefore provide additional in-depth insights into the opportunities and challenges for charging electric heavy-duty vehicles. We consider these results as context-dependent cases that can provide insights into the unique circumstances of different logistics companies and offer first takeaways in planning for companies with similar profiles and customer requirements. In addition to the data provided by the survey, these results offer insights into the "how" and "why" of the companies' decisions, activities, and expectations.

RQ 1. To which extent can current operations of logistics companies account for charging events and how does this differ between the different applications in the sector?

To extend our answer to the first research question with interview results, we look at the types of tours that companies cover, the regularity of these tours and the characteristics of the corresponding stop and break times.

Opportunities and challenges for battery-electric trucks and charging infrastructure construction or usage by location

We divide the description of tours, stops and the associated opportunities and challenges for charging by the three locations *at home*, *at the clients*', and *at a public location*. For each location, the relation to tour types that the respondents made in the interviews is described and the opportunities and challenges are laid out and, where relevant, compared to those at other locations.

At home

Charging at the company's home location, i.e. the depot, was named as relevant for all tour types as all vehicles return to this destination at some point in their operation during the week. The home location is, however, most frequented by vehicles that are exclusively used during the day. It is therefore most relevant for charging the vehicles covering these types of tours slowly over night.

For tours involving double shifts where the change in drivers occurs at the home depot, interviewees considered fast charging to be a prerequisite as there are usually only 1-2 hours of stop time before the next driver starts their shift.

For longer tours, the depot marks the start and the end location. During these times, the vehicles are often there overnight. However, this varies between the companies and the days of the week. For one company, for example, during the week 10-12 vehicles are *at home* on average, whereas, on the weekend, there can be 30-40 vehicles, including those stopping between longer tours. Home charging for vehicles covering longer tours can hence build on slow charging, with fast charging mattering more while on the road during the tour.

Barriers for charging infrastructure at home were named by all interviewees but varied between those not pursuing concrete activities yet and those already planning infrastructure. One interviewee explained their current position as waiting for large, scalable solutions that would allow to charge a large number of vehicles right away through combining the necessary requirements of electricity grid connection to medium voltage, electricity generation, and storage. The first requirement was also a key point mentioned by the logistics companies already planning to build charging infrastructure. They named the lack of appropriate connection power provided by their energy supplier at the logistics site as a key bottleneck. As an alternative, some of the interviewed companies have looked into installing a combination of PV and energy storage to supply electricity to the charging stations:

> *"It will be decisive in the next years who generates energy. That means those people that have a PV system or warehouse with several 10,000 square meters and the respective kilowatt peak.*

> *I will even go so far that we will need the ability to save energy in 3, 4, 5 years. Everything rests on that, storage potential." (I4)*

One logistics company has found this to be a necessity to address the perceived risks of powering electric vehicles in the future but also to significantly increase the necessary investments:

> *"Our electricity provider would need to give us the opportunity by delivering more electricity. That is a huge topic at the moment because in the industrial area in which we have our warehouses, the capacity is almost at its limit and the provider has signalised that there will not be any more for now. [...] This forces us to think extremely about PV and buffer storage and results in a dramatic increase in the amount to be invested. [...] Their [the provider's] last wording was the best because it was more than five years. That led us to say: "Okay, we can really not wait that long because at the latest in 2035 we will have the topic of the end of registrations for combustion engine vehicles. So we will have to be fit and smart until then. Therefore, we not have to get our act together because relying on that happening is extremely risky. [...] No offence but that is suicidal. Then I could shut up my shop immediately, that is so risky." (I2)*

At the clients'

Charging at client locations was considered helpful for all tour types but most relevant for tours involving multiple stops and going beyond urban and regional distribution without repeated returns to the home depot in a day. At intermediate or final client destinations, two types of stops were reported as central to operations: waiting times and unloading or loading times. The respondents explained that charging while waiting for unloading or loading to commence would be ideal. Wait times can be counted as break times unlike the actual loading process, which counts as working time for the driver. Charging during this time would hence not disrupt the established break patterns but would rather be an efficient extension.

However, the respondents find that wait times vary greatly and cannot easily be predicted beforehand. Additionally, at some destinations, wait areas are centralised, whereas at other destinations waiting happens directly at the loading ramp. A variety of charging points and a flexible scheduling system would therefore have to be installed by the client to serve vehicles while they wait, depending on the current layout of the site. The operations of the interviewed company supplying cranes to building sites presents an additional special case. Here, the crane vehicles themselves remain at the client's location for the duration of the construction activity in which they are used. Electrifying them would hence require charging infrastructure at construction sites – a prospect that the interviewee considers unlikely for now.

As a key bottleneck for charging at the clients', interviewees pointed out the dependency on the client's willingness to build charging infrastructure. Next to this more obvious point, they also pointed to potential additional barriers even if the clients were willing to build charging infrastructure or have it built. For example, in one case, the logistics company itself offered to build charging infrastructure at a key client's site. However, the expensive electricity tariffs charged by the landlord of the client's site would negate the price advantages for fuel in comparison to diesel:

> *"I have a client with a warehouse to which we drive back and forth with a diesel truck three times a day. And for these tours, I wanted to use the electric truck. [...] Now I am talking to the operator there of which my client is a tenant, how we could make this work. I could build the charging station, that would work, but we currently disagree about the electricity prices. [...] I could buy the electricity wonderfully here and get around 25-26 Cent, that is quite affordable. That would be around 5-6 Cent below the diesel. But when I talk to the operator and they want 50 Cents, that would mean that I would have to adjust prices for the client by 20%. Nobody will pay that. They are all excited about the project but it must not cost more." (I3)*

The corresponding lack of a business case in both the logistics company's and the client's interests has led to ongoing negotiations between all parties and no results yet.

At a public location

Public charging was considered most relevant for long-haul tours and for those tours ending at client locations without an established charging infrastructure. Out of the three, considerations of this charging location were most hypothetical in nature as this type of charging is not available yet and it thus leaves most open questions for the interviewees. It was clear, however, that this type of location was the most variable in the companies' operations.

Interviewees consequently pointed to the importance of being able to strategically use public charging to cover their operations. On the one hand, this pertained the specific locations of the charging infrastructure. One interviewee pointed out that the location would have to be far enough from key destinations to cover remaining distances and offer most added benefits. On the other hand, the importance of availability and reliability of the infrastructure was mentioned - illustrated by the respondents' idea of requiring a reservation system.

For the public location, the driver was mentioned as a key variable. To serve their needs, the respondents pointed to the importance of having relevant break-time facilities, e.g. for food and hygiene, close by. Importantly, public charging would also require further clarifications for the drivers regarding charging versus break times. The interviewees pointed out that charging in breaks will not be accepted by the drivers if it adds private time to their tours. This would also pose a challenge to the company as a whole as extended working and break times would postpone nightly rest times and consequently the drivers' earliest possible start time the next day. Additionally, one interviewee pointed out that it was unclear whether the vehicle itself would be suitable for the driver to spend their break while charging, e.g. because of potential noise, heat development, and/or the consequential necessity to check on things during the charging process.

RQ2. Which factors motivate the engagement of logistics companies in fleet electrification?

All interviewees point to numerous barriers that still exist for integrating battery-electric trucks into logistics operations. Nevertheless, only one interviewee states to not have been involved with electrification at all so far. The other interviewees name three key motivators for being active in electrifying their fleet and building charging infrastructure despite the persisting challenges.

Motivators for heavy-duty vehicle fleet electrification

First, interviewees mention personal motivation for the topic. For example, an interviewee that has been using an electric vehicle in their private life, has looked into the electrifications of heavy-duty vehicles and has remained up to date on the topic.

Second, respondents name growing customer requirements and interest for decarbonised transport services as a motivator:

> *"We now have the first two clients that specifically demand that we can use two [electric] vehicles with them. We have actually waited for quite a long time to also have the willingness on the side of the customers to cover the additional costs for the electrification of our fleet since we didn't want to do it as a pure marketing gag. [...] We have been open but in our industrial segment this is only bearing fruit now because the first clients are concretely asking for it. The first calculations that we could have offered just deterred people upfront since we actually had factors 2-2.5 in the cargo rates. And that did not lure anybody into saying "we are ready to spend so much more money for a green 'image' of our products"." (I1)*

Nevertheless, some of them still perceived clients as reluctant and as not willing to pay more for electrified transport:

> *"I don't know if it will be electric. At the moment, I think, prices are around three times as high. Right, there are government subsidies but lots of other factors next to it and for example, clients would not pay something like that at the moment." (I2)*
>
> *"So, the clients want that, yes. They don't want to pay anything but they want it." (I3)*

Third, regulatory requirements were considered a key motivator. On the one hand, regulations at the EU level require manufacturers to sell more alternative fuel vehicles in the heavy-duty sector - a requirement that logistics companies observe as they will be the ones operating these vehicles. On the other hand, regulations at the local level were mentioned, with electric vehicles adhering to, for example, noise restrictions for deliveries in cities.

Challenges for heavy-duty vehicle fleet electrification

The challenges that interviewees named for heavy-duty vehicle fleet electrification were connected both to the operation of the vehicles themselves as well as to the establishment of charging infrastructure.

On the vehicle side, factors that challenged their motivation to integrate BETs were the necessity to inform and educate both vehicle drivers and garage personnel. For the former, both operating and charging the vehicle were mentioned as necessary points requiring further education. The latter was a matter for those companies that maintain and repair their own vehicles on site. Their maintenance and repair personnel is specialised in diesel trucks and would require a different skillset for providing the same services for battery-electric trucks.

On the infrastructure side, medium voltage grid connection was named as the key challenge for establishing appropriate charging infrastructure at the home depot (compare section on "At home" charging). Outside of depot charging, the availability and reliability of charging infrastructure at both the clients' and public locations was named as a perceived obstacle for fleet electrification.

4 Discussion

4.1 Current operations of logistics companies: can they account for charging events?

Regularity and plannability of routes and stops can differ a lot between and within different logistics applications. This means that different tour profiles require different degrees of flexibility in charging but also that seemingly regular tours like short-distance traffic can be irregular and involve different locations and clients on any given day. Direct conclusions based on simple knowledge about tour types can hence not be drawn and modelling exercises based on such limited data should be careful and transparent in this regard.

The longest coherent parking time is predominantly spent on private property, with the home depot of larger importance than the clients' locations. The interviews support this finding and show that during the week, the longest break being spent at the home depot is predominantly true for single-shift vehicles overnight. The number of vehicles can, however, vary greatly with the irregular addition of long stops for returning long-haul vehicles, for example on the weekends. Besides vehicles operated in two shifts, which were reported to have the least stop times and consequently least breaks on home property, the data hence shows considerable opportunities for overnight home charging and charging at client locations in the surveyed fleets.

The interviews identify factors that influence charging opportunities beyond break times . Specific barriers to slow overnight charging at the home depot were not discussed. However, available power at the nearest substation has been found to be a key bottleneck for the necessary medium-voltage grid connection for slow charging a large number of vehicles over night or fast charging of vehicles at the home depot. Enabling fast charging would be especially relevant for the vehicles that do not stop overnight and need to be recharged in 1-2 hours between shifts.

While the logistics companies themselves consider investments in PV and electricity storage as short-term alternative to resolve grid extension shortages, this alternative needs to be strategically balanced and discussed versus a system-wide cost-optimal energy system. Decentral PV installations and storage (potentially necessary for days with low solar radiation) can lead to further grid integration challenges or redundancies. Consequently, existing regulation should be modified to facilitate forward-looking network expansion rather than supporting this alternative path.

The second key location for longer truck stops are client facilities. The interviewees' explanations illustrate that there is potential in these locations for easing the pressure on public charging. However, clarity needs to be achieved regarding the differentiation or overlap between break and charging times. Additionally, infrastructure setups and organisational systems would have to be devised that allow for a seamless integration of charging processes into the waiting times and locations connected to loading and unloading. This requires the cooperation and willingness of customers to set up charging infrastructure for and with logistics companies. The development of additional systems, for example for bookings or reservations could further benefit these private-to-private charging relations in addition to their application for public charging. For specific logistics operations, such as the crane and construction business, charging connections at a new construction site could already be included in a building plan from the get-go, for example if they would be installed at the site in any case for usage at a later point in time.

The survey results show that public parking is more common for legally mandated breaks of vehicles covering longer distances. Here, the interviewees point to the necessity of break facilities for the

drivers, the clarification of overlap or distinction between break and charging times, as well as the reliability of having a charging spot upon arrival or in time for recharging for the next part of the tour.

Most frequented public charging locations

Our survey highlights the substantial need for off-highway and street-side parking options for trucks, particularly during the mandatory breaks on long-distance trips (see Figure 6) and to a smaller extent during the longest coherent parking time (see Figure 4). Herein, charging during the short mandatory breaks on longer trips between home or client locations will most likely require fast charging as provided by the Megawatt Charging System (MCS). Reasons for this substantial role may be diverse, such as proximity to the customer, compliance with delivery windows, parking spot shortage along the highway, or avoiding fee-based spots. However, current infrastructure buildout schedules like the German Initial Charging Network or the European-wide AFIR (Alternative Fuels Infrastructure Regulation) prioritize fast-charging locations close to the highway network (within around 3 km driving distance) and schedule potential off-highway charging hubs later. While this may cover large shares of all truck stops (Plötz & Speth, 2021), we recommend that this prioritisation be reconsidered to allow for more flexible deployment of charging infrastructure at any demand hotspot.

4.2 Which factors can motivate engagement in fleet electrification?

The data show that those companies in our sample that operate a large number of readily electrifiable trucks (RETs) are also more positive towards BETs and one of the companies already deploys such vehicles. However, the descriptive data also show that the two groups appear to be similar with regard to the envisioned future role of BET for the company.

Finally, the survey shows that purchasing BETs is perceived by the companies to potentially improve their innovative image. However, they do not consider it as a big factor influencing their environmental image and do not see it to play a big role for recruiting new drivers. The interviews show that a willingness or demand by clients for zero-emission transport positively contributes to the logistics company engaging in electrification. Additionally, a general openness to electrification in the private lives of decision-makers, e.g. with regard to electric cars, can have an impact on their commercial activities to electrify their firm's fleet. This matches the findings on decisionmakers for electrifying passenger car fleets whose intetion to campaign for BEV procurement has been found to be positively influenced by their personal interest in EVs (Globisch et al., 2018).

Methodological limitations

Our sample is biased towards large fleets and lacks representation from companies with small fleets. Specifically, 13 companies (26%) reported small fleets of less than 10 trucks while another 13 companies (26%) reported large fleets of more than 50 trucks. However, according to data from The Federal Logistics and Mobility Office (BAG, 2020), the majority of freight transport companies (83%) operate less than 10 trucks, while only 1% have large fleets of more than 50 trucks. Unfortunately, allocating the exact number of trucks to small or large fleets is not possible.

Any extrapolation of the BET market diffusion in the total market based on this study may be limited but is potentially more reserved. First, this follows from our imbalanced sample that might limit a more positive outlook on a fast BET diffusion, since small-fleet companies tend to have a more negative view. Second, the highly fragmented and heterogeneous nature of logistics market structures entails diverse potential usage profiles and specialisations. Even with our comprehensive two-step study utilising surveys and interviews, it is challenging to fully encompass this complexity. For further studies and modelling exercises, it is important to keep in mind this heterogeneity of the sector.

5 Conclusions

In conclusion, current heavy-duty logistics operations in Germany offer a wide variety of charging opportunities, but face persisting barriers to electrification. Removing the barriers to home depot charging, such as restricted medium voltage grid connections, and supporting the build-up of charging infrastructure at client locations can be first key steps to support fleet electrification. Additionally, logistics companies need a clearer legislative framework regarding the public charging of BETs, particularly with respect to the differentiation between break and charging times of drivers and the availability of charging slots upon arrival. The present study shows that each charging location and charging situation requires individual support measures, and charging at home and client locations holds as much weight in the system as public fast charging – each in their own terms.

6 List of figures

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8 References

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