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Alternative powertrains in road-bound heavy-duty transport: a quantitative determination of user requirements for heavy-duty vehicles and their infrastructure

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Summary

In view of climate change, measures to reduce CO_2 are urgently required and much discussed. The transport sector plays a pivotal role here, accounting for approximately 20 % of the total CO_2 emissions in Germany. Alongside passenger cars, the main emitters of CO_2 are long-haul heavy-duty vehicles (HDVs) due to their high mileages and fuel consumption. Switching powertrains to a CO_2-neutral technology in this sector can make a large contribution to reducing emissions and thus to reducing the burden on the environment and climate.

Such a switch can only be successful if it is in the interests of the daily users of these vehicles. This study determines and quantifies the user requirements for vehicles and infrastructure in long-haul heavy goods transport in order to be able to design alternative powertrain technologies accordingly.

A quantitative research method was applied based on a qualitative study, which identified economic, ecological and technical user requirements. A web-based questionnaire was designed in the first step and data collected. The data obtained were then used for descriptive and correlation analyses. In total, 70 participants or companies took part in the study.

The analyses show that economic requirements, especially total costs of ownership and reliability, are very important. The freight forwarding and logistics sector is characterized by strong competition and high cost pressure so that companies here have little financial leeway, in particular for implementing environmentally-friendly measures. There are marked differences of opinion among users concerning ecological requirements. The questions about infrastructure requirements revealed that many users are willing to accept longer refuelling or recharging times (between 10 and 30 minutes) and detours (up to 20 km).

Users are generally quite open-minded and can imagine switching to alternative powertrains. Regression analyses show that users are more willing to switch to alternative powertrains if they prioritise the total costs of ownership over the entire lifetime of the vehicle, because alternative drives often have advantages here due to lower energy costs. The willingness to switch declines, on the other hand, if users give more weight to investments – alternative powertrains are often characterized by a higher purchasing price. Correlation analyses also reveal that larger companies and users who know more about alternative powertrains are more likely to be willing to switch.

Contents

1 Introduction

Decisions to set CO_2 limits for HDVs and buses in almost all industrial nations are an indication of the increasing focus on how important heavy-duty commercial vehicles are for climate protection. According to the EU Commission, the average CO_2 emissions of heavy-duty vehicles must be cut by 30 % by 2030 (European Commission 2019). Long-haul heavy goods traffic, 99 % of which runs on diesel, is a major emitter of carbon dioxide (Shell Deutschland Oil GmbH 2016, p. 27). Switching to carbon-neutral alternatives is the only way to reduce emissions and comply with legal limits in the future in spite of increasing volumes of freight transport and economic growth.

However, at present, there is no consensus concerning the options for using alternative powertrains and fuels in general and especially in the heavy-duty commercial vehicle segment. As well as technical issues, user requirements for vehicles and infrastructure differ from those in the segment of light-weight commercial vehicles and passenger cars. In order to achieve a successful switch to alternative powertrains in heavy goods transport, it is essential to have a better grasp of these user requirements. To create transparency in this regard, user requirements must be examined in more detail. The research question of this study is therefore:

What are the current user requirements for road-bound heavy-duty transport in Germany concerning vehicles and infrastructure, and what do these requirements look like?

In a first step, the study quantifies and prioritises the requirements of HDV users in the freight-forwarding and logistics sector. This is based on the requirements identified in interviews with experts, which can be split into technical, economic and ecological issues. In particular, the aim is to arrive at a better grasp of vehicle and infrastructure requirements in order to identify suitable alternative powertrain technologies and to design and then model the associated system in a second step.

This paper is divided into six chapters. After the reviewing the existing literature, the method and data collection process are explained. The descriptive and correlation data analyses and their results are presented in chapter four and discussed in chapter five. In addition, the limitations of the study are also pointed out. Finally, chapter six presents the conclusions and an outlook to the need for future research.

2 Literature review

This chapter reviews the existing literature. There are many studies on the subject of user requirements for alternative powertrains, but most of them differ in one of three aspects: transport or vehicle segment, type of technology or methodological approach.

The majority of studies research the requirements and adoption behaviour in the segment of passenger cars. Only a few studies look at user requirements specifically for heavy-duty commercial vehicles. Hackbarth and Madlener (2013) examine customer preferences when choosing alternative drive systems for private cars in Germany. The most important selection criteria are high fuel efficiency, lower emissions and vehicle range. One study, which looked at the segment of commercial vehicles, was carried out by Golob et al. (1997). They analysed preferences for alternative powertrain technologies in large vehicle fleets, including light-weight commercial vehicles. They conclude that users in different markets have different preferences. Capital costs are more important for operators of public fleets, while private fleets give operative and practical aspects higher priority. Both user groups assign high priority to vehicle range and fuelling station availability.

With regard to the type of technology, there are only a few studies on the *general* requirements and preferences for alternative powertrains in the heavy-duty commercial vehicle segment. Most of the research examines individual alternative powertrains, often fuel cell or battery-electric vehicles. Walter et al. (2012) conducted one study that looked at customer preferences for fuel cell technology in commercial vehicles. This study identified the preferences of decision-makers concerning road sweepers and concluded that new kinds of requirements such as noiseless and zero-emission operation play an important role in this niche market for fuel cell commercial vehicles. Zhang et al. (2019) conducted a general examination of alternative powertrains. They analysed factors that influence the selection of commercial vehicles with alternative powertrains. The study identified positive correlations between the relevance of maintenance costs and improved image on the one hand and the willingness to make a selection on the other hand. There are negative correlations between possibilities for maintenance and the willingness to choose.

With regard to the methodological approach, it is possible to apply either a qualitative or a quantitative research method. These two methods are often combined, whereby a qualitative analysis is done first, on which the quantitative analysis is then based. The qualitative study, on which this working paper is based, examined user requirements for road-bound heavy-duty vehicles in a first step by interviewing the CEOs or fleet managers of freight-forwarding and logistics companies. The objective is to prioritise and quantify the identified user requirements in another step. The following user requirements were cited during the qualitative interviews:

1. Economic
   - Total cost of ownership (TCO)
   - Investment
   - Reliability
   - Consumption

2. Technical
   - Range
   - Infrastructure
   - Loading capacity
   - Cabin equipment
   - Performance / Engine Power
   - Time needed to refuel
   - Driver assistance systems

3. Ecological
   - Toll classification
   - Environmental protection
   - Avoidance of driving bans
   - Image/marketing
   - Pressure from clients

The quantitative methodology of this working paper focused in particular on technical aspects regarding infrastructure and vehicle properties in order to capture user requirements more precisely.

3 Method and data

3.1 Method

A quantitative online survey was conducted as part of this working paper, which was based on the qualitative expert interviews that identified economic, ecological and technical user requirements.

The questionnaire for the web-based survey is made up of five sections and was drawn up with a view to the subsequent analysis to examine the correlations between vehicle user requirements, infrastructure user requirements and the willingness to switch to alternative powertrains in more detail.

The first section asks questions about the characteristics of the company and the vehicle fleet and about how much the respondent knows about alternative powertrains. These are simple closed questions regarding the structure of the fleet and its operation. Specifically, there questions about the total number of vehicles and vehicles per weight category. There are also questions about the type of procurement and the minimum, average and maximum daily mileage. The latter is intended to provide information about the minimum range a vehicle with an alternative powertrain should cover, and at what distances refuelling stations for the corresponding powertrain system should be distributed. There is also a question about the type of transport task performed and the downtime of the vehicles to provide more information in this regard. Section two makes up the main part of the questionnaire and addresses the prioritisation of the different technical, ecological and economic user requirements using two matrix questions. In the first matrix question, respondents indicate how important this aspect is to them on a 5-point scale. The scale ranges from important, quite important, neutral, less important to unimportant. Selecting a scale with an odd number is done to give respondents the chance to express a neutral opinion. In the second matrix question, respondents should indicate the five aspects that are most important to them. This aims to force a clear statement about which aspects are considered really relevant, because the first matrix question offers the opportunity to simply rate all the issues as very important. Section three can be regarded as belonging to part two: respondents are asked again how important ecological, economic and technical requirements are for users with regard to alternative powertrains but, unlike part two, they should indicate whether or not they agree with seven statements on a 5-point scale. Some statements are taken from Seitz (2015) and Globisch (2017), others were formulated independently. Section four of the questionnaire examines infrastructure requirements using four open questions and the refuelling behaviour of users using a matrix question. This part is very important, especially with regard to subsequent system modelling, because it retrieves specific quantifiable aspects regarding infrastructure. The final section collects company-related data, some of which are sensitive. This is why they were asked at the end of the questionnaire (Schnell et al. 2011, p. 337). They include the number of employees in the company and individual job descriptions. Table 1 provides an overview of the questionnaire's different sections.

Table 1: Overview of the questionnaire's sections

Section	Aim	No. of questions	Scale
I: Preselection / company data	Identify target group and obtain basic info about company	12 (10 simple closed, 2 matrix)	Nominal and ordinal / metric
II: Prioritisation of user requirements	Determine preference structure of user requirements	2 (matrix)	Ordinal / metric
III: Attitude towards alternative powertrains	Find out about users' attitude	1 (matrix)	Ordinal / metric
IV: Specification of technical user requirements and infrastructure	Determine specifications of technical user requirements	2 (simple closed, matrix)	Ordinal / metric
V: (Sensitive) company information	Obtain organisational information	4 (simple closed)	Nominal and metric

3.2 Data

Having drawn up and implemented the questionnaire, it was tested empirically in a pre-test and then revised accordingly. The actual field phase of the revised questionnaire lasted about six weeks. Several different channels were used to recruit participants. On the one hand, the 16 freight-forwarding and logistics associations throughout Germany were contacted and asked to send the survey link to their members or publish it in their newsletters. Journals from the freight and logistics sector were also approached and asked to publish the link. In addition, several existing contacts were approached directly, among others, the test persons who had already taken part in the preceding expert interviews. Finally, an incomplete number of freight-forwarding and logistics enterprises in Germany were contacted by e-mail. After one to two weeks, all the contacts were sent a reminder.

With regard to the participants, it is unclear how many potential target group participants were ultimately informed about the survey. The overview provided by the online tool only contains information about how often the link was clicked, how many questionnaires were begun, and how many were actually completed: Of the 115 potential participants in Germany who followed the hyperlink to the questionnaire, 99 actually started it. Of these 99 participants, 70 finally completed the questionnaire in full. Seven participants who started the survey were not part of the target group (e.g. had no HDVs in their fleet). As a result, the analysis is based on a sample of 63 participants from Germany. The majority of these participants are managing directors. In addition, there were HDV drivers, dispatchers and fleet managers.

4 Results

This chapter presents the analysis and results of the study. The analysis is divided into a descriptive and a correlation part, both of which were performed in line with the questionnaire sections. The descriptive analysis was performed in a first step. Following an overview of the most important company and fleet characteristics (sections I and V), statistics are presented on the vehicle user requirements (sections II and III), the infrastructure user requirements and fuelling behaviour (section IV). The correlation analysis of the data is then described. Correlation and regression analyses are used to determine correlations. Again, the correlation results are divided into fleet and company characteristics, vehicle user requirements, infrastructure user requirements and fuelling behaviour.

4.1 Descriptive analysis

Company and fleet characteristics

The sample was analysed using different company characteristics such as size, type of goods transported, type of procurement and transport task performed. With regard to company size, the distributions confirm that the sector is characterized by medium-sized enterprises: One quarter of the participating companies have 11 to 50 employees, one quarter 51 to 100 and another 25 % 101 to 200 employees. Larger companies with 201 to 3000 employees make up about 17 %, while only a small proportion have fewer than 10 employees and an even smaller share has more than 3000. A slight preference for financing is revealed when looking at the type of procurement for heavy-duty commercial vehicles. Many organisations also pay cash and take advantage of leasing offers. Vehicles are very rarely rented. More than half of the companies primarily transport palletised goods. Other frequently cited types of goods include bulk goods. In the additional information given in the form of open answers, besides removal goods and containers, machines are often mentioned, which, strictly speaking, could also be counted as non-palletised goods. Companies perform mainly a mix of different transport tasks (Figure 1). This mix was able to be specified in more detail in the open information provided. According to this, the majority of companies work in local goods transport in combination with one or several other transport tasks. Tramp traffic is the most frequent sole transport task of a company, but is also often mentioned as part of a mix. The transport area covered is national for more than 75 % of the companies; the remaining 25 % are equally split between regional and international transport.

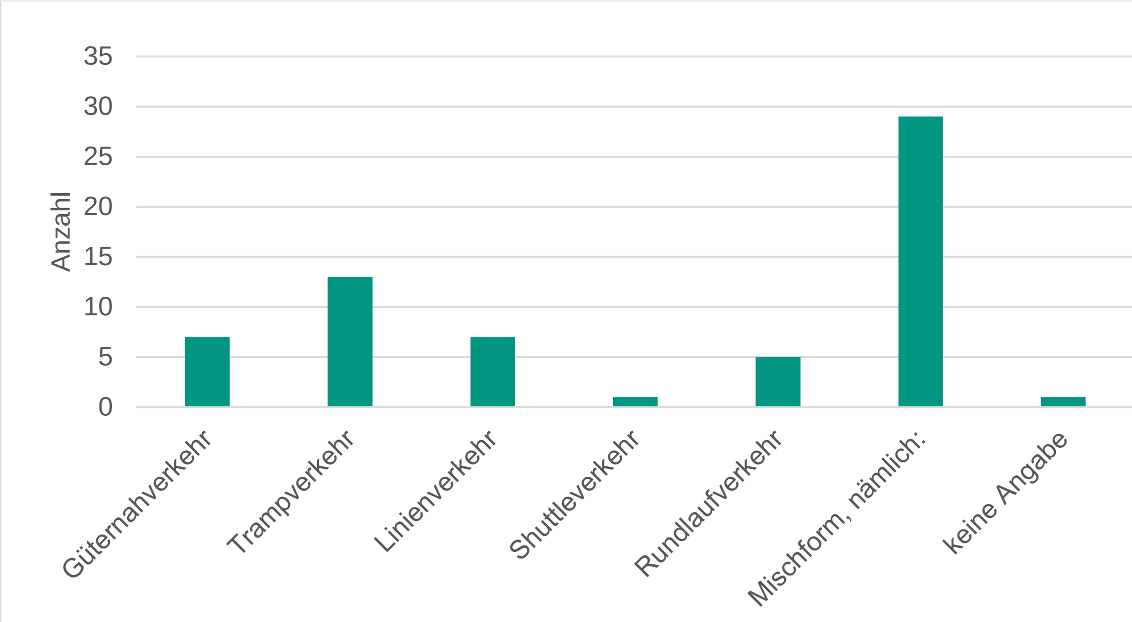

Figure 1: Main transport task

More than 50 % of the participating companies' fleets have fewer than 100 HDVs. The average service life of the heavy-duty commercial vehicles is between three and five years for 67 % of the participating companies; fewer use their vehicle for more than five years (33 %), and no company uses a vehicle for less than three years. The average daily mileage for most users is between 400 and 800 km (Figure 2). Approximately one third of users drive 100 to 400 km on average. A minority drive more than 800 km or less than 100 km. Work is done in two shifts in only 31 % of the companies; the majority do not work shifts. This also means that the majority of vehicles are parked for longer periods of time. More specifically, downtimes are between zero and four hours for 18 %, between four and eight hours for 20 % and between eight and twelve hours for 62 % of the participating companies.

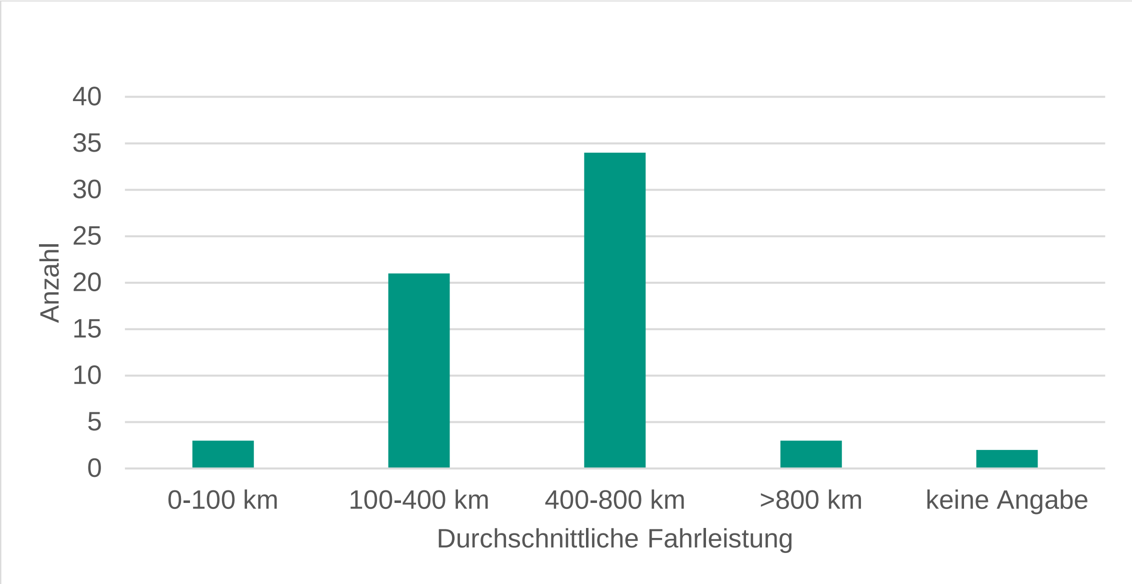

Figure 2: Average mileage

If users' knowledge is divided into different kinds of alternative powertrain, it becomes clear that gas-powered HDVs are the most familiar for most respondents. 68 % indicated they know something/a lot about this type of drive system. 47 % have some knowledge of catenary-hybrid trucks, and 46 % know something about battery-electric trucks. Little is known about fuel cell HDVs, and almost 40 % have never heard of power-to-gas trucks. Correspondingly, a similar picture emerges regarding the interest or intention to purchase an alternative powertrain. However, the use of a filter function here meant that only those respondents were asked who had indicated in the preceding question about the state of knowledge "yes, heard about it and know something/a lot about it" or "yes, already heard about it but know nothing/hardly anything about it". Only battery-electric and gas trucks are actually owned by several companies at present, so the interest in these two types of powertrain is correspondingly high. Many respondents are also interested in fuel cell trucks, while catenary trucks are only of interest to very few users (Figure 3).

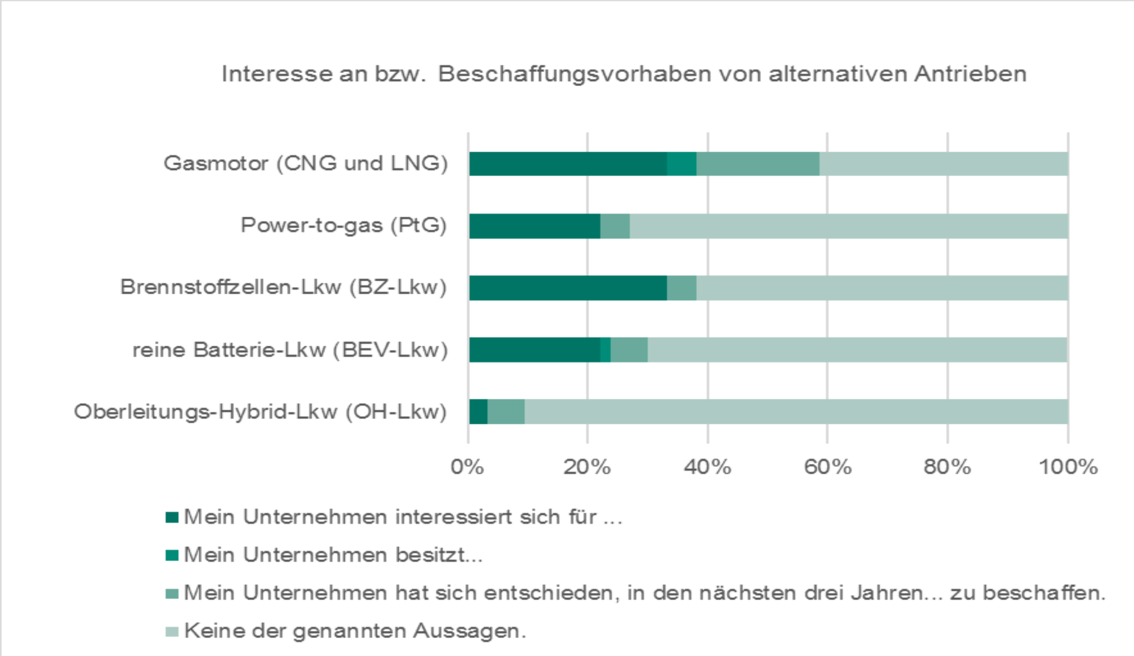

Figure 3: Interest in or plan to purchase vehicles with alternative powertrains

User requirements

The main part of the questionnaire identified and quantified the most important user requirements concerning alternative powertrain technologies and the corresponding system. The respondents indicated on a scale from (1) important to (5) unimportant, how important different requirements are for them. To obtain an overview of the results, Figures 4 and 5 show the arithmetic mean and the standard deviation for the variables of the 16 user requirements. A low mean value corresponds to a high relevance of the respective variable or requirement. The standard deviation is a measure of how much this deviates from the mean. A high standard deviation therefore indicates very different evaluations (Raab-Steiner and Benesch 2018, p. 108).

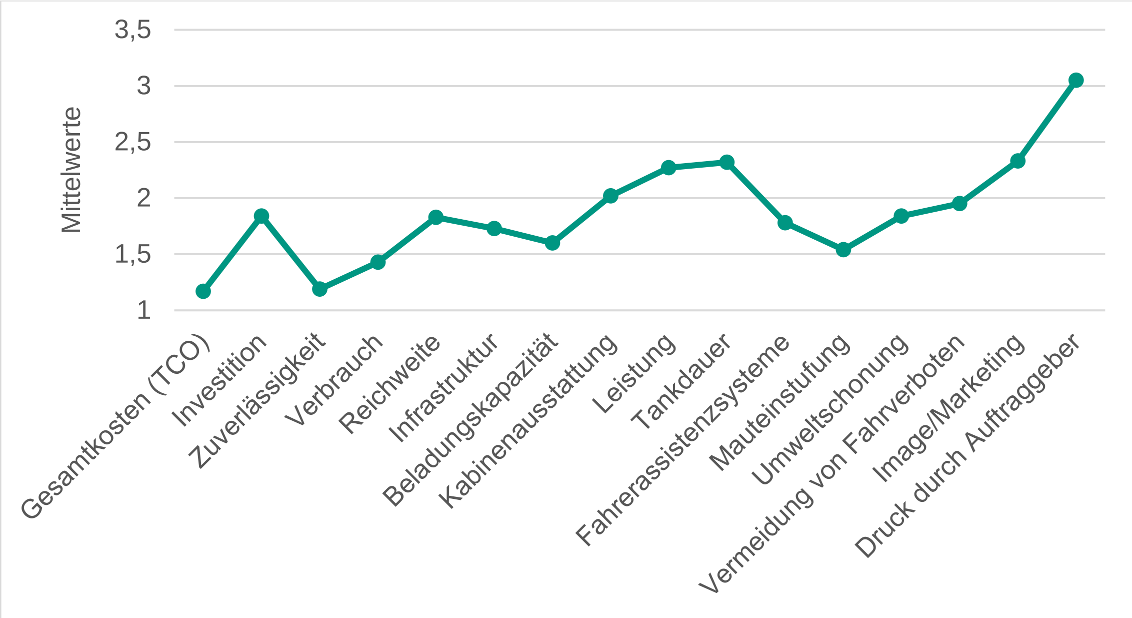

Figure 4: Mean values of the relevance of user requirements

The lowest mean value is found for the user requirement of TCO. The other three economic requirements of consumption, reliability and investment also have a mean of less than two. The standard deviations for the four economic requirements are very low when compared to the other two categories. This indicates that the respondents agree on the importance of the economic requirements. A more differentiated picture emerges when looking at the technical requirements. Range, infrastructure and loading capacity have the lowest mean values, while time to refuel and engine power have mean values above two. The higher standard deviations here also suggest different opinions with regard to the technical requirements. However, the highest standard deviations are found for the ecological aspects. There are very low mean values for toll classification, environmental protection and avoidance of driving bans. Image/marketing and pressure from clients show the highest mean values of all. Calculating the mean values per category results in 1.4 for the economic requirements, 1.9 for the technical requirements and 2.1 for the ecological requirements. When taking the standard deviations into account as well, it becomes apparent that there are also large differences of opinion in the final category.

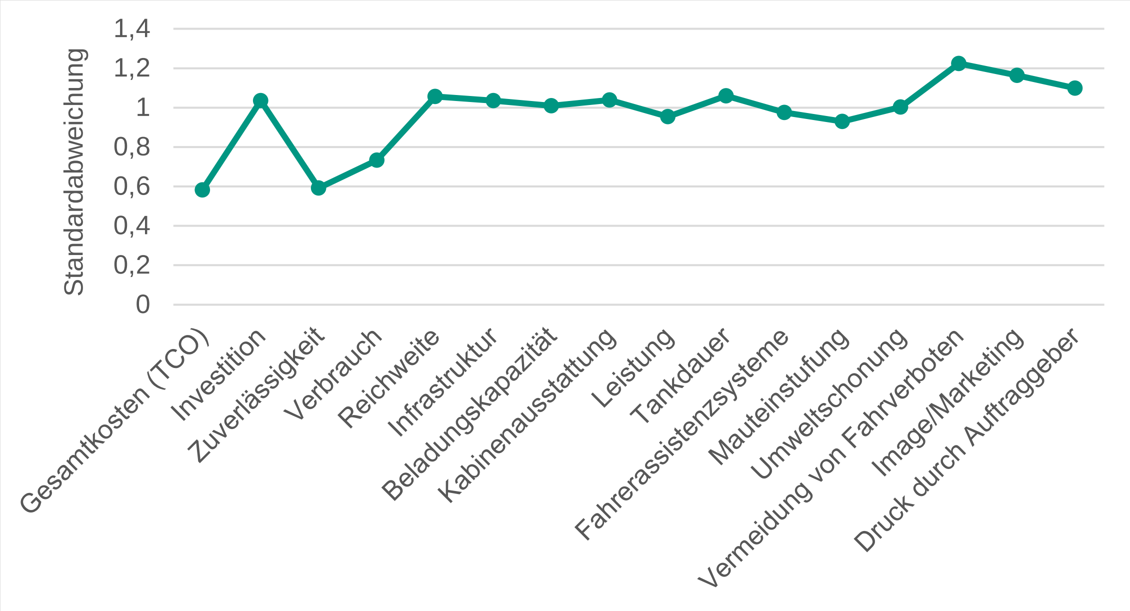

Figure 5: Standard deviation of the relevance of user requirements

A differentiated picture emerges when the attitudes of respondents towards alternative powertrains are examined based on statements. With a mean value of 2.52, companies seem quite willing to switch to alternative powertrains. 50 % of those questioned (rather) agree with this statement, while 27 % are still undecided. Consumption values are regarded as particularly important with a mean value of 1.75. The statement about the trouble proneness of an alternative powertrain has a high standard deviation; respondents evaluate this statement very differently, but tend not to agree with it. In contrast, more than 50 % agree with the statement that alternative powertrains are of particular interest to companies for environmental reasons. The image improvement due to alternative powertrains is also confirmed by more than 50 %, although 17 % were also of the opinion that using alternative powertrains has no effect on image (response: neither nor). A clear majority confirms that both the current infrastructure and the charging or refuelling times of alternative powertrains have disadvantages for the companies.

Infrastructure user requirements

Another important part of the questionnaire targets information on how to design the future infrastructure of alternative powertrains. Information about the willingness to make detours, the minimum engine power of a HDV, maximum duration of refuelling and minimum range of a HDV was obtained using open questions. The median detour drivers are willing to make is around 20 km. 50 % of those questioned gave a value between 10 and 30 km. Extreme values are found at 100 km, and some respondents said their willingness was 0 km (Figure 6). The issue of how long it takes to refuel or recharge is another important criterion when designing the system for alternative powertrains. The sample's median of the maximum duration of refuelling is about 15 minutes. The maximum duration of refuelling mentioned by one person was 60 minutes, and five persons would accept 45 minutes. 50 % of the answers were between 10 and 30 minutes (Figure 7). The median of responses concerning the minimum range of a truck is about 800 km. This is not surprising given the fact that most respondents answered 400-800 km to the question about their daily mileage. 50 % of answers are between 600 and 1000 km, although there are several outliers at the top and bottom. Minimum ranges of 2000 km and 300 km form the upper and lower limits.

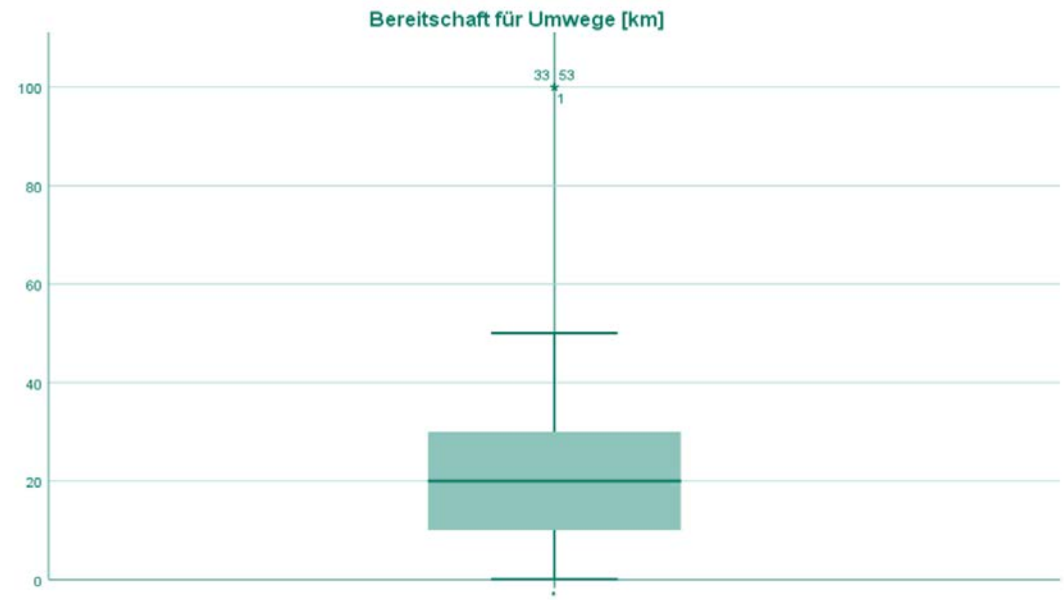

Figure 6: Willingness to make detours in kilometres

With regard to fuelling behaviour, it can be seen that public filling stations are used less often, and that vehicles tend to be filled up more at the start or end of a trip. The company's own filling station is almost uniformly given as the main one used. Spontaneous refuelling seems to be the exception rather than the rule; the filling stations are at least already known ones in most cases and refuelling is almost always planned. Fuelling is mainly done depending on the conditions of the fuel card used. In addition, the downtime periods between shifts are used for refuelling rather than break times. The number of actual fuel dispensers seems to play a rather minor role. With regard to the length of trips, the information given in Section II on average mileage is confirmed: The trips of most respondents are shorter than the range of their current heavy-duty HDV. More precisely, these trips are frequently less than 600 km. The trucks tend to reach their loading capacities due to their limited volume rather than their weight.

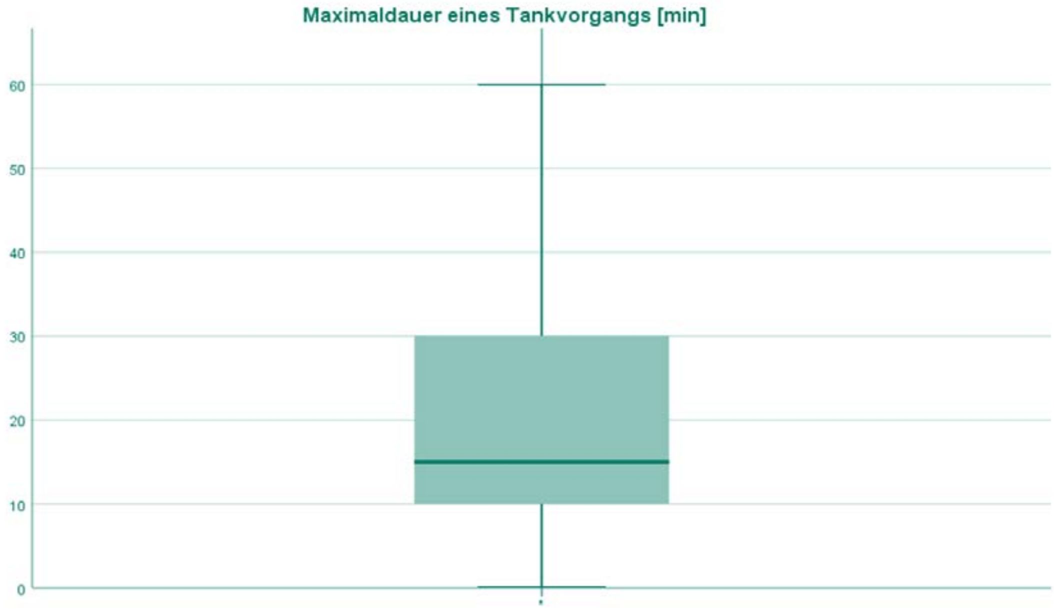

Figure 7: Maximum duration of refuelling in minutes

4.2 Correlation analysis

Correlation and regression analyses were conducted to examine the data for correlations. In particular, a closer examination was made of what influences the willingness to switch to alternative powertrains. Again, these influences and other correlations are presented divided into the three sections of company and fleet characteristics, user vehicle requirements and infrastructure requirements and fuelling behaviour.

When conducting the correlation analysis, several correlations were found between company and fleet characteristics and the willingness to switch to alternative powertrains. The three strongest correlations are presented in the following.

Company and fleet characteristics

There is a positive correlation between company size and the willingness to switch: Larger enterprises seem more willing to switch to alternative powertrains.

This is equivalent to a negative correlation coefficient, because the scale of company size is from (1) small to (6) large and the willingness to switch declines from 1 to 6. The strength of the correlation is clear with a correlation coefficient of -0.4 at a level of significance of 0.01. The second identified correlation is between the average mileage and the willingness to switch: users with higher mileages seem more willing to switch to alternative powertrains. The correlation coefficient is -0.292 and is significant at the level of 0.01. The third correlation is between users' knowledge of alternative powertrains and their willingness to switch: users who know more about such alternative powertrains seem more willing to switch to them. The strength of the correlation varies depending on the type of powertrain, but the general tendency exists for all types.

When looking at the different vehicle user requirements and the willingness to switch to alternative powertrains, the strongest correlation is between the economic requirements and the willingness to switch. The TCO is very strongly related to the willingness to switch, with a correlation coefficient of 0.42 at a significance level of 0.01, followed by reliability with a coefficient of 0.26 at a significance level of 0.05. Technical requirements, on the other hand, do not seem to be closely related to the willingness to switch. With the exception of cabin equipment, there is no significant correlation and even this one is rather weak. Among the ecological requirements, toll classification seems to correlate with the willingness to switch with a correlation coefficient of 0.313 at a significance level of 0.05.

The influence of the different vehicle user requirements on the willingness to switch to alternative powertrains is examined more closely using a multiple linear regression. The dependent (endogenous) variable in the model is the "willingness to switch to alternative powertrains" and the different vehicle user requirements are treated as the independent variables. Of interest here is which type of user requirement has the strongest influence on the willingness to switch. If strong correlations exist, any later modelling of a system must pay particularly close attention to these requirements.

When carrying out the stepwise regression in SPSS with regard to the influence of the different user requirements on the willingness to switch to alternative powertrains, all the exogenous variables are excluded apart from the TCO and the investment.

Testing the model for heteroscedasticity shows a negative result. This was visually checked by plotting the residuals against the predicted (estimated) values of Y. The standardised residuals were examined for dependencies in a scatter plot.

Homoscedasticity can be regarded as given, because no systematic patterns can be identified (Stoetzer 2017, p. 142).

Testing for autocorrelation of the residuals only makes sense in time series analyses. Since the study can be classified as a cross-sectional one and there is therefore no natural sequence of observations, there is no need to test for autocorrelation (Stoetzer 2017, p. 147). There is no multicollinearity. This was checked using a correlation matrix: the correlation coefficients between the variables are all far from 1. Collinearity diagnostics was also performed: The condition number, which is a measure for the proximity of the matrix of observed values to the limiting case of perfect multicollinearity, provides values far below the thresholds of 20 and 30 respectively (Stoetzer 2017, p. 166). In addition, the VIF values (variance inflation factor) have values far below the threshold limit of 5 and provide no indication of collinearity. The histogram of the unstandardised residuals shows only a limited deviation of these from the normal distribution.

The results indicate that the willingness to switch to alternative powertrains decreases with an increasing importance of investment; this is shown by a standardised coefficient of -0.263. At the same time, the willingness to switch increases with an increasing importance of TCO. The standardised regression coefficient equals 0.544. With an adjusted coefficient of determination of 0.21, the regression explains 21 % of the variance; the F-value is 9.326 and has a significance level of close to zero, as does the significance level of the t-values for the variables TCO and investment (t-value=4.315 and -2.088, respectively).

A second linear regression analysis was performed to explore how the willingness to switch depends on the attitude towards alternative powertrains. Here, the dependent variable in the model was the “willingness to switch to alternative powertrains”, and the different answers concerning attitude from section III in the questionnaire were treated as the independent variables. When performing the stepwise regression in SPSS concerning the influence of attitude towards alternative powertrains on the willingness to switch to these, the following exogenous variables were included in the model: variables regarding consumption, climate protection and company image. Once again, the test for heteroscedasticity was negative. Multicollinearity was not found either: the correlation coefficients between the variables are all far from 1. The condition number in the collinearity diagnostics again produced values far below the thresholds of 20 and 30, respectively (Stoetzer 2017, p. 166). The VIF-values were far below the threshold limit of 5 and also provided no indications of collinearity. The histogram of the unstandardized residuals shows a limited deviation of these from the normal distribution.

The results indicate that the attitude towards consumption values, climate protection and company image is positively correlated with the willingness to switch to alternative powertrains. The advantage that alternative powertrains have for the company's image has the strongest influence, with a standardized regression coefficient of 0.403. Consumption values have a regression coefficient of 0.272 and climate protection 0.256. The F-value is 18.253 and has a significance level of almost zero, as has the significance level of the t-values (all t-values are between 2.27 and 3.61). The adjusted coefficient of determination is 0.45 and therefore explains 45 % of the variance.

5 Critical appraisal

5.1 Discussion

The survey results provide several insights into the requirements and willingness to switch of today's users of long-haul heavy-duty goods transport. Some requirements are compatible with alternative powertrains, while other aspects are still strongly influenced by today's diesel standards. The following section summarises and discusses which aspects determine the willingness to switch and which requirements users have and prioritise.

Willingness to switch

The willingness to switch to alternative powertrains depends on company size, among other things. Especially larger companies seem more willing to switch. Unlike medium-sized companies, they are more likely to have the financial means for the higher investments that alternative powertrains currently require. In addition, according to Seitz (2015, p. 94), larger organisations are more likely to introduce corporate guidelines which embody corporate social responsibility and environmental protection.

The willingness to switch is also correlated with knowledge about alternative powertrains. Users who already have such knowledge are better able to judge the opportunities and risks involved. This correlation is confirmed by the fact that 15 % of users intend to purchase a gas HDV and that the highest level of knowledge exists for this type of alternative powertrain. Demonstration and educational projects can help users to gain practical experience and knowledge.

Furthermore, those users citing high average mileages are also more open to alternative powertrains. Operating costs carry more weight if high mileages are involved; alternative powertrains have lower operating costs than diesel-fuelled vehicles, which means they can save users money in the long term (Seitz 2015, p. 211). In principle, the majority of users appear willing to switch.

Vehicle user requirements

On the one hand, the study shows that economic aspects, mainly TCO and reliability, are the most important vehicle requirements for users. Reliability and TCO are strongly dependent on each other, because vehicle shortages due to possible downtimes or repair costs can cause high losses. This shows that transparency and confidence must be created among users so that alternative powertrains are perceived as reliable and practicable alternatives to conventional engines. In addition, the regressions show that, alongside TCO, investments also have a significant influence on the willingness to switch. Investments have a negative influence on willingness, while TCO have a positive one. Although investments are related to the TCO through depreciation, among other things, the level of investment has a separate and scientifically proven influence (Sechtin 2012, p. 115). In this case, users for whom investments are very important are (rather) not willing to switch because of the currently still high investments required for vehicles with alternative powertrains. In contrast, users for whom TCO are very relevant show a higher willingness to switch because the lower operating costs of alternative powertrains means increasing cost savings in the long term (Seitz 2015).

On the other hand, ecological requirements are also important to many users. Above all, environmental protection and toll classification are very relevant for some users. The opinions in this category are particularly diverse, which indicates a shift in requirements is taking place. Previous studies have already shown that environmental aspects are only relevant for “innovators” and “early adopters”, while decisions in the mass market are mainly oriented on costs (Seitz 2015, p. 110). Whether this division also applies to our sample can be examined in the future using cluster analyses.

Infrastructure user requirements

The average mileage of 400 to 800 km and the minimum range of 800 km required by most users are only compatible to a limited extent with today’s alternative powertrains. The current ranges are approx. 175 km for battery-electric HDVs and about 400 km for fuel cell HDVs, assuming that the HDVs are the same size as diesel HDVs and that no weight or volume reduction has taken place (Gnann et al. 2017, p. 904). The range problem is not as important for gas HDVs and has to be considered in a differentiated way for catenary HDVs, because the length of roads without overhead power lines depends strongly on the expansion of the overhead line infrastructure and on the transport task of the users.

The willingness to make a detour, which is around 20 km for most of the users questioned, must be considered critical in view of the current filling station infrastructure for the majority of alternative powertrain types. The EU directive 2014/94 on the development of infrastructure for alternative fuels plans a continuous ramp-up of infrastructure. The directive refers predominantly to filling stations for passenger cars. Heavy-duty commercial vehicles are only explicitly mentioned for the LNG filling station network. According to this, LNG filling stations should be built by 2025 at around 400 km intervals on average along the Trans-European Transport Network (TEN-T) (Directive 2014/94, European Union). Hydrogen infrastructure should be deployed in the form of a network with a maximum distance of 300 km between filling stations (Seitz 2015, p. 115). Up to the end of 2017, 43 public hydrogen filling stations were operating in Germany, but none with sufficient fuel capacity to supply a large number of long-haul HDVs (Kühnel et al. 2018, p. 85). At present, CNG filling stations are also not yet widely distributed for HDVs. The average future distance between CNG filling stations along the TEN-T should be about 150 km by 2025 according to the directive of the European Union. Similarly, the charging infrastructure for battery-electric HDVs is still far from being compatible with the willingness to make a detour of 20 km. In comparison, a large number of charging stations already exist for passenger cars, but none has the charging capacity to meet the high energy demand of heavy-duty commercial vehicles (Kühnel et al. 2018, p. 88).

In addition, about 70 % of users do not fill up predominantly at fuel stations along the motorway, but at the company's own filling station. This significant majority is very probably due to the above-average number of large companies in the sample (see section 5.2). Since primarily small companies have to rely on filling stations along the motorway, and rarely have their own filling station, a different distribution can be expected for the basic population. Nevertheless, when developing a filling station infrastructure for alternative powertrains, funding should be provided for company filling stations as well as for constructing public fuel stations. In its Electric Mobility Funding Guidelines of 09.06.2015, the German Federal Ministry of Transport and Digital Infrastructure (BMVI) plans such support for battery-electric trucks. Accordingly, charging infrastructure is fully eligible for funding without fulfilling the general requirement of being publicly accessible (Bundesministerium für Verkehr und digitale Infrastructure 2016).

5.2 Limitations

There are certain limitations to these research results that are explained below. The sample of the study was not controlled in any way except for ensuring that a wide selection of persons or companies was addressed. Since a complete list of the basic population of users of heavy-duty vehicles does not exist, it was not possible to make a random selection. This makes it difficult to make statements about the representativeness of the study, or to apply inferential statistics. Using the internet to distribute the study can lead to distortions in that predominantly participants are selected who are open to online media and questionnaires. Likewise, it cannot be ruled out that there is a tendency to attract survey participants who are already interested in the topic and who therefore may influence the direction of the results.

In the following, we examine whether our sample corresponds to the basic population with regard to the two characteristics of company size and fleet size.

When comparing the sample and the basic population based on company size, it can be seen that larger companies are slightly overrepresented in the sample (right) and small companies slightly underrepresented (Figure 8).

Considerable differences based on fleet size emerge when comparing the sample with the basic population. While significantly more compares with a fleet of one to three HDVs are represented in the basic population (left), companies with between 11 and 50 HDVs are strongly overrepresented in the sample (right) (Figure 9).

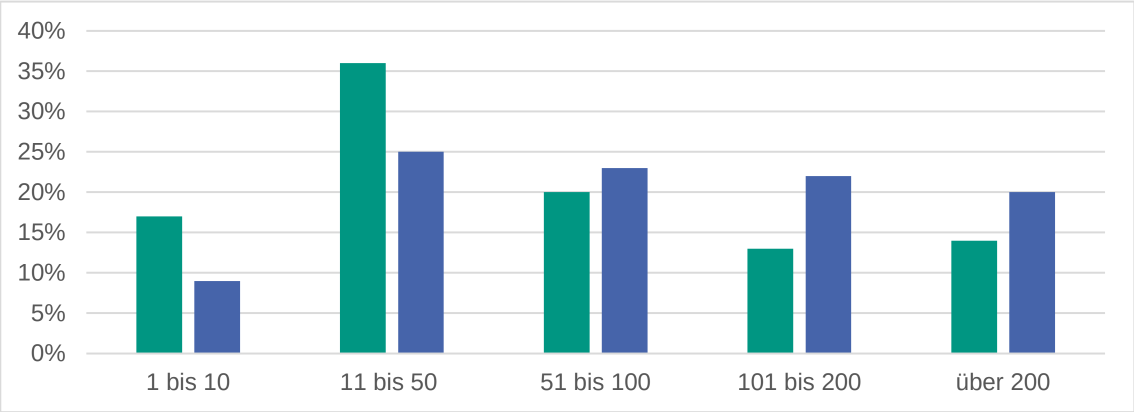

Figure 8: Comparison of company size (based on number of employees) in basic population (in green) and sample (in blue)

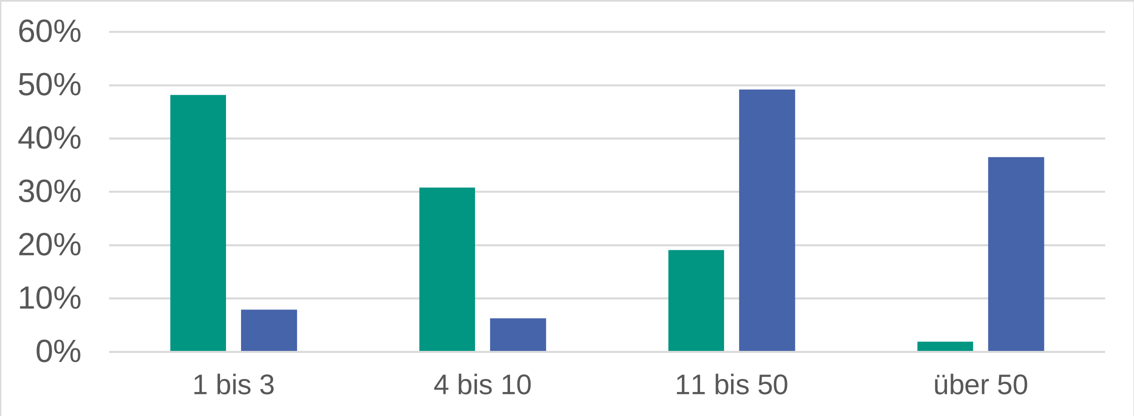

Figure 9: Comparison of fleet size (based on number of HDVs) in basic population (in green) and sample (in blue)

In order to obtain a more holistic overview of how HDVs are distributed, the total number of HDVs is distributed approximately among the vehicle fleets. The assumptions are based on data given in “Struktur der Unternehmen des gewerblichen Güterkraftverkehrs und des Werkverkehrs” (German Federal Office for Goods Transport 2015). According to these statistics, as of the reporting date at the end of October 2015, there were 45,051 commercial goods transport companies in Germany, which had a total of 379,582 vehicles in use (HDVs + semi-trailers, +3.5 %) (Federal Office for Goods Transport 2015, p.7). Under the assumption that the fleet size can be divided on average into 2, 6, 28 and 150 vehicles (as in the sample), the following distribution results (Figure 10): More than 80 % of companies cover only 25 % of vehicles. The majority of HDVs are therefore represented by only a few companies with large fleets.

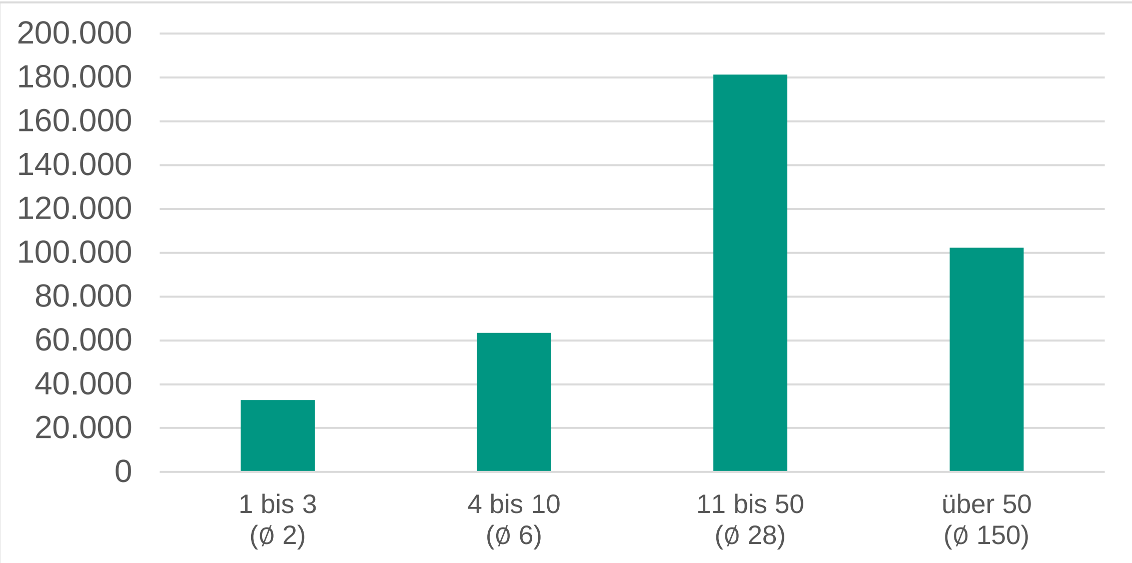

Figure 10: Distribution of all German HDVs (based on average HDV number per vehicle fleet); own estimate

Furthermore, our study is limited to the users of heavy-duty vehicles in Germany. A study with an international sample could provide a more comprehensive picture with regard to the user requirements for HDVs without the influence of national circumstances. In addition, the local sample consists exclusively of members of freight-forwarding and logistics companies, because these were the easiest to reach when recruiting participants. However, users of HDVs are found in other organisations as well. Finally, although the sample size was sufficient for the purposes of this research study, further statistical analyses would benefit from more comprehensive samples.

6 Conclusions and outlook

The following main insights were obtained when considering the study's research question "*What are the current user requirements for road-bound heavy goods transport in Germany concerning vehicles and infrastructure, and what do these requirements look like?*"

On the one hand, the high importance of economic requirements, in particular TCO and reliability, shows that cost considerations are currently still dominant for users. Due to high competition and cost pressure in the freight-forwarding and logistics sector, companies have little financial leeway, especially when it comes to implementing environmentally-friendly measures. Investments and TCO should be regarded in a differentiated way: The regressions show that users are more willing to switch to alternative powertrains if they prioritise TCO. This willingness declines if they give more weight to investments. Correlation analyses additionally show that company size, daily mileage and knowledge about alternative powertrains are all positively correlated with the willingness to switch.

On the other hand, the study shows that ecological requirements like environmental protection are also considered relevant by many users. The opinions were very diverse in this category. Some users are aware of the growing significance of ecological aspects. A slight majority does show a basic willingness to switch to alternative powertrains.

Requirements concerning the infrastructure show that, on the one hand, users are prepared to make detours to find a filling station or charging infrastructure. Longer refuelling times or charging procedures than those needed for conventional vehicles with internal combustion engines are also accepted. On the other hand, the average range required is only compatible to a limited extent with the current ranges offered by alternatively powered HDVs. However, the data obtained about the actual daily mileage suggest that the ranges demanded are rarely needed for everyday operations.

Switching heavy-duty road freight transport to alternative powertrains in the future and thus meeting climate targets can only succeed if the daily users of such vehicles accept them. The results of the study indicate that, for this to happen, the reliability of alternative powertrains and their contribution to reducing TCO must be demonstrated in operation, and ensured through support programmes and political measures. Reducing the required investments can also make a decisive contribution to the spread of alternative powertrains. This can be done either directly through state subsidies, for instance, or indirectly by supporting the development and production of alternative powertrains in industry. On the other hand, direct state intervention seems indispensable for developing infrastructure. In particular, users cannot bear the high initial costs of infrastructure deployment on their own. In the long term, infrastructure can probably be financed without state subsidies. In the industry itself, clients can provide essential support to the spread of alternative powertrains by introducing ecological guidelines. Furthermore, knowledge about alternative powertrains should be increased. Demonstration and information projects can give users the opportunity to gather practical experience of alternative powertrains. These measures should not only consider the requirements of users in freight-forwarding and logistics companies, but involve all the relevant stakeholders such as local residents, as well as fuel and vehicle producers.

As already indicated in the section on limitations, there is the need for further research. To analyse users in more detail and divide them into groups, cluster analyses could be conducted in addition to the regression and correlation analyses. Conjoint analyses could also provide further insights concerning preferences and requirements. When generating a sample, the aim should be to obtain a random as well as a larger sample in order to enable more comprehensive statistical analyses. This or the application of quota sampling can ensure the representativeness of the survey.

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