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Electrification of heavy duty vehicles and development of charging infrastructure – future trends and recommendations for action from the perspective of vehicle manufacturers and charging infrastructure experts

1st subreport of the research project "ELV LIVE - Accompanying research on the use of battery-electric heavy duty vehicles in day-to-day logistics operations"
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Abstract

Road freight transport is the second most important source of CO_2 emissions in the transport sector worldwide after passenger car traffic. Diesel-powered internal combustion engines dominate truck traffic. Numerous scientific analyses, as well as manufacturers' development activities and their forecasts, suggest that battery electric drive systems are also a key technology for decarbonizing road freight transport in heavy duty vehicles. Nevertheless, numerous questions remain unanswered regarding the specific implementation and the required energy supply infrastructure. In addition, the assessments of promising technology paths still differ greatly depending on the stakeholder group. Based on discussions with market players, this paper provides answers to these open questions and presents the various perspectives.

Prospects for e-trucks and necessary charging infrastructure from the perspective of vehicle manufacturers and charging infrastructure experts

This paper first provides an overview of the development of the truck sector in the most important markets worldwide. It then discusses the prospects for alternative drive systems for heavy duty vehicles with a focus on battery electric drive systems in the German and European markets, addresses the necessary charging infrastructure and the associated challenges, and makes recommendations for action.

The results presented are based on the statements of a total of five heavy duty vehicle manufacturers active in Europe, which together cover around 90 % of the European heavy duty vehicle market. The manufacturers' representatives were interviewed in the course of 60- to 90-minute guided interviews. The anonymized results of the interviews and the resulting recommendations for action were discussed in more detail at a joint workshop in June 2024. The interviews took place between the end of 2023 and mid-2024. During the process, discussions were held with manufacturer representatives from DAF, Daimler Truck, Tesla, Traton (Scania, MAN) and Volvo Group Trucks (Volvo Trucks, Renault Trucks). In addition, representatives of the infrastructure company Milence and the German National Organization for Hydrogen and Fuel Cell Technology (NOW) were interviewed with a focus on the necessary design of the charging infrastructure. The statements presented do not necessarily reflect the opinions of the authors.

Trends in the international truck market

The international truck market continues to be dominated by diesel drives. In recent years, however, there has been strong momentum in new registrations of battery electric trucks. At around 92 %, China is by far the largest market for zero-emission heavy duty vehicles. The EU is in second place with Germany as the country with the highest share of new registrations. The key drivers for the momentum in e-truck sales in key sales markets are stricter CO_2 standards for heavy duty vehicles and monetary incentives for zero-emission drives through direct subsidies for procurement and advantages in terms of duties and taxes.

Technical characteristics and prospects of battery electric trucks (BET)

Advances in battery technology are already making it technically possible to use BET beyond regional transport. However, the main application of battery-powered trucks will probably soon shift from regional to long-distance transportation due to operating cost advantages in particular. The availability of charging infrastructure as a key influencing factor and bottleneck at the same time will determine the speed of the market ramp-up.

Technical properties and potential of other drive and fuel alternatives

The H_2 fuel cell provides efficiency advantages over the internal combustion engine, but in view of the lack of market maturity of H_2 fuel cells, the use of hydrogen in internal combustion engines is expected to be the initial approach. At the same time, the fundamental competition for the use of H_2 with other demand sectors is noted. In view of the limited potential for increasing efficiency, the commercial vehicle manufacturers surveyed are no longer pursuing hybridization of the internal combustion engine truck drive as a solution option. Alternative fuels (biofuels, synthetic fuels) were not named as part of the manufacturers' technology strategy.

Manufacturer strategies and expected market ramp-up for e-trucks

The European CO_2 fleet targets are named as the main driver and key point of orientation for product strategy. The forecasts for e-trucks from the BMDV's clean room discussions with heavy duty vehicle manufacturers in Germany in 2022 are confirmed and in some cases an even more dynamic market development is expected. In particular, the introduction of electric long-distance trucks from 2024 is expected to provide a significant boost. The aim is for battery-electric trucks to account for over 50 % of new registrations as early as 2030 and battery-electric drives are seen as the dominant technology for trucks in the long term. Compared to CO_2 pricing (including the truck toll), which is relevant to operating costs, manufacturers consider the promotion of vehicle purchase to be a less significant incentive. Electric truck providers could try to gain market share at the expense of established manufacturers, particularly before the CO_2 target values for 2030 are reached.

Manufacturer strategies for further drive and fuel alternatives

All manufacturers expect battery-electric trucks to dominate road freight transport in the future. At the same time, all manufacturers are also involved in the development of hydrogen-powered drives (in combination with fuel cells and combustion engines). The majority of manufacturers do not believe that hydrogen-powered trucks will be economically competitive in the longer term and only see applications in niche markets, as they do not believe that the hydrogen price level required for the mass market is likely to be achievable without continued subsidies. A single manufacturer mentions a relevant potential for hydrogen-powered trucks in the order of 10–20 % market share. Plug-in hybrid drives and alternative biogenic and electricity-based fuels were not mentioned in any of the discussions as an option for the decarbonization of heavy-duty trucks.

Charging infrastructure for battery electric trucks

General

The availability of a fail-safe charging infrastructure is the key prerequisite for market ramp-up of e-trucks. A lead time for such infrastructure expansion ahead of the planned increase in the number of e-trucks must always be ensured and temporary oversizing is considered tolerable.

Depot charging

The charging infrastructure in the depot is a central component of electrification. However, its importance can only be estimated based on simulations and a few practical examples. Grid connection represents the greatest restriction, both in terms of available connected load capacity and implementation of new or more powerful grid connections.

Public charging

Public (fast) charging infrastructure is particularly relevant for long-distance transport and must be developed primarily along and near the highway network. Charging parks will probably include a combination of CCS and MCS charging options – with an increasing focus on MCS-capable charging points, especially for long-distance transport. The AFIR specifications represent good basic coverage for Europe, but a significantly higher level of expansion is already required for Germany today. A predominantly private-sector implementation of the public charging infrastructure in Germany is expected. In particular, the necessary rapid expansion over the next 10 years is seen as challenging, especially with regard to the requisite grid connections. The lack of suitable sites with sufficient grid connection capacity and the need for longer-term concessions to develop sites economically exacerbate the problem.

Market ramp-up of e-trucks - challenges and recommendations for action

1: Grid connection of charging infrastructure

Limited grid connection capacity and long lead times until grid connection is implemented represent the greatest limitation for the development of high-performance charging infrastructure.

- Forward-looking grid expansion planning based on target conditions is essential, as is the short-term establishment of transparency regarding available grid capacities.

2: Development of private charging infrastructure:

The development of depot charging infrastructure is greatly hampered by location-specific framework conditions and there is little practical experience to date that would allow a reliable forecast of the potential that can be realized.

- Transport companies should be made aware of the sometimes long lead times for expanding the charging infrastructure, funding should be provided for high grid connection costs and the range of advisory services needs to be expanded.

3: Reliable framework conditions in the long term

Regulatory and financial framework conditions that ensure the switch to e-trucks and the development of charging infrastructure for the players concerned are not politically secured.

- Existing framework conditions (including AFIR, CO_2 vehicle standards, CO_2 price) should be updated ambitiously and in the long term and supplemented with additional instruments (e.g. e-truck quota for fleet operators).

4: Development of public charging infrastructure

The AFIR requirements only create basic coverage for public charging infrastructure and do not provide any long-term planning security.

- The AFIR should be updated and the binding nature of the national targets in Germany should be increased by adding suitable sanctioning options. In addition, funding should focus on MCS charging points.

5: Change management for users

The introduction of e-trucks requires transformation processes for numerous players and puts pressure on small transport companies with low margins in particular.

- Advice for transport companies, geared to the specific circumstances, should be expanded.

6: Sites for (public) charging infrastructure

There is a lack of sufficient space for the construction of charging parks along trunk roads and the pressure on existing parking spaces is increasing due to the expansion of charging infrastructure.

- Politicians and administrators should do more to promote the acquisition of parking spaces along long-distance transport corridors and information on suitable spaces should be made publicly available.

Background to this publication

This paper was produced as part of the ELV-LIVE research project[1] , which is scientifically monitoring the early use of battery electric trucks in day-to-day logistics operations in the period from 2023 to 2025. Against this background, it should be noted that this paper primarily represents the perspective of the vehicle industry, even if user-related aspects are also addressed in some cases. In the current research project, findings on the experiences and perspectives of users with alternative drive systems are also being collected through the monitoring of case study partners and standardized survey of transport companies. These will be published in similar publications at a later stage in the project and thus shed light on another important perspective on the transformation of the heavy duty vehicle market.

1 Project website: https://www.erneuerbar-mobil.de/projekte/elv-live

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List of abbreviations

AC	Alternating current
ACEA	European Automobile Manufacturers' Association
AFIR	Alternative Fuels Infrastructure Regulation (AFIR)
BEHG	German Fuel Emissions Trading Act (Brennstoffemissionshandelsgesetz)
BET	Battery electric truck, also referred to as e-truck in this document
BEV	Battery electric vehicle
BMDV	German Federal Ministry for Digital and Transport Affairs
BMUV	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection
BMVI	German Federal Ministry for Digitalisation and Transport Affairs
CCS	Combined Charging System
CO_2	Carbon dioxide
DC	Direct current
EP	European Parliament
EPA	Environmental Protection Agency
ETS	Emissions trading system
EU	European Union
EV	Electric vehicle
FCEV	Fuel cell electric vehicle
FCET	Fuel cell electric truck
H_2	Hydrogen
HDV	Heavy duty vehicle
IRA	Inflation Reduction Act
KSG	German Climate Protection Act (Klimaschutzgesetz)
KsNI	German Funding program "Climate-friendly commercial vehicles and infrastructure"
LNG	Liquefied natural gas
MCS	Megawatt Charging System
MoU	Memorandum of Understanding
NOW	German National Organization Hydrogen and Fuel Cell Technology
NO_x	Nitrogen oxides

OEM	Vehicle manufacturer (original equipment manufacturer)
PHEV	Plug-in hybrid electric vehicle
PC	Passenger cars
PtL	Power to liquid (liquid fuel from electrical energy)
RED	Renewable Energy Directive
TCO	Total cost of ownership
GHG	Greenhouse gases
USD	United States Dollar

1 Introduction

Road freight transport is the second most important source of CO_2 emissions in the transport sector worldwide after passenger car traffic. Diesel-powered internal combustion engines dominate truck traffic (IEA 2024). The majority of emissions in road freight transport are caused by heavy duty vehicles, which are primarily used for long-distance transport and are characterized by particularly high mileages.

Against this backdrop, decarbonization of the transport sector can only succeed if road freight transport is included. This is reflected, among other things, in ambitious targets and stricter regulatory requirements at national, European and international level, which have recently been established and are beginning to take effect.

Numerous scientific analyses now provide a clear picture of how the decarbonization of road freight transport can succeed in the coming decades, which technology paths are particularly advantageous from a technical and economic perspective and which energy supply infrastructures are required. Manufacturers' current development activities and their forecasts on the future market shares of alternative drive systems also provide important information. Nevertheless, numerous questions remain unanswered with regard to concrete implementation and the assessments of promising technology paths still vary greatly depending on the stakeholder group. Based on discussions with market players, this paper provides answers to these open questions and presents the various perspectives.

The following section (Chapter 2) provides an overview of the international truck market and the increasing importance of alternative drive systems in the context of the framework conditions established in the respective market.

The paper focuses (Chapter 3 and 4) on the evaluation of battery-electric truck drives and possible drive and fuel perspectives from the perspective of vehicle manufacturers and charging infrastructure experts. Both the technical characteristics and development prospects of the technology as well as the market ramp-up forecasts (Chapter 3) and the necessary charging infrastructure requirements (Chapter 4) are discussed. Finally (Chapter 5), key fields of action are identified and concrete recommendations for action are formulated from the perspective of the representatives of vehicle manufacturers and charging infrastructure experts involved. These do not necessarily reflect the authors' assessments.

The results presented are based on the statements of a total of five heavy duty vehicle manufacturers active in the European market, which together cover around 90 % of the European heavy duty vehicle market. The manufacturers' representatives were interviewed in the course of 60 to 90-minute, guideline-based interviews. The anonymized results of the interviews and the resulting recommendations for action were discussed in more detail at a joint workshop in June 2024. The interviews took place between the end of 2023 and mid-2024. During the process, discussions were held with manufacturer representatives from Daimler Truck, Traton (Scania, MAN), Volvo, DAF and Tesla. In addition, representatives of the infrastructure company Milence and the German National Organization for Hydrogen and Fuel Cell Technology (NOW) were interviewed with a focus on the necessary design of the charging infrastructure.

In the following explanations, a special focus is placed on statements with a large overlap in the assessments of the interviewees. However, statements that only represent individual opinions or are only shared by some of the interviewees are also listed and marked accordingly. The statements on the assessment of the technology options and market forecast (Chapter 3) largely represent the assessment of the vehicle manufacturers' representatives. The assessments of the charging infrastructure and the central fields of action (Chapter 4 and 5) also includes the perspective of the charging infrastructure experts surveyed.

This paper was produced as part of the ELV-LIVE research project[2] , which is scientifically monitoring the early use of battery electric trucks in day-to-day logistics operations in the period from 2023 to 2025. Against this background, it should be noted that this paper primarily represents the perspective of the vehicle industry, although user-related aspects are also addressed in some cases. In the current research project, findings on the experiences and perspectives of users with alternative drive systems are also being collected through the monitoring of case study partners and the standardized survey of transport companies. These will be published in comparable publications at a later stage in the project, thus shedding light on another important perspective on the transformation of the heavy duty vehicle market.

As part of the predecessor project StratES[3], similar interviews were conducted in 2020 with representatives of vehicle manufacturers and suppliers on the state of technology and development prospects for alternative drive systems and fuels (Göckeler et al. 2020). so that a comparison of the change in assessments over time can be made in this paper.

2 International truck market overview, importance of electric heavy duty vehicles and relevant regulations

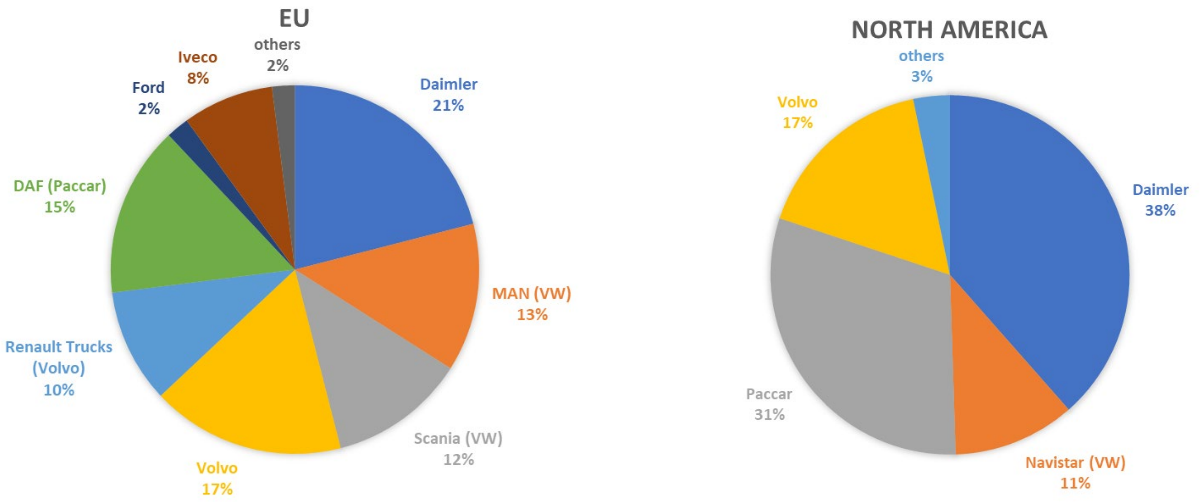
2.1 Global truck market and the role of manufacturers

In 2022, around 6.5 million heavy duty vehicles, i.e. heavy duty vehicles with a gross vehicle weight of 3.5 tons or more, were sold worldwide. Trucks accounted for around 77 % and buses for around 23 % of sales (IEA 2023). The global truck market exceeded the value of USD 250 billion in 2022. By comparison, sales in the passenger car sector amounted to USD 1.55 trillion (Global Market Insights 2023a). Due to the expected future increase in transportation services and the associated growth in truck mileage and truck fleet, the global truck market is forecast to grow to an estimated USD 400 billion in 2032 (Global Market Insights 2023b). Most trucks are currently sold in North America (38 %), followed by the European Union (EU) (30 %) and Asia (22 %) (Global Market Insights 2023b). In the EU, the largest national sales markets are Germany, France, Poland, Italy and Spain (Statista 2023).

The market shares of various vehicle manufacturers (so-called original equipment manufacturers (OEMs)) differ fundamentally between the global sales markets. In China, only Chinese OEMs play a significant role in the truck market (Mao and Rodriguez 2022). In North America (USA and Canada) (see Illustration 2-1), Daimler (38.5 %), Paccar (30.6 %), Volvo (16.6 %) and Navistar (11 %) sell the most heavy trucks (> 15 t) (Buysse 2022). In the EU (see Figure 2-21), there is a more differentiated market for heavy trucks (> 15 t) with Daimler (21 %), Volvo (17 %), DAF (15 %), MAN (13 %), Scania (12 %), Renault Trucks (10 %), Iveco (8 %), Ford (2 %) and others (2 %) as players (Mulholland and Rodríguez 2023). Some of the manufacturers come from the same groups: MAN, Scania and Navistar belong to the VW subsidiary Traton, Renault Trucks to the Volvo Group and DAF to the US company Paccar.

2 Project website: https://www.erneuerbar-mobil.de/projekte/elv-live
3 Project website: https://www.erneuerbar-mobil.de/projekte/strates

Illustration 2-1: Comparison of market shares of heavy trucks from different manufacturers: EU and North America



Source: Öko-Institut, own illustration with data from (Buysse 2022). (Mulholland and Rodriguez 2023).

2.2 Status quo of electric heavy duty vehicles in international comparison

The introduction of electrically powered heavy duty vehicles started with electrically powered buses for local and urban transport: in 2021, buses still accounted for around two thirds of new registrations of zero-emission heavy duty vehicles in the EU, while in China and North America the share was around three quarters in each case (Mulholland und Rodríguez 2023; Buysse 2022). The registration figures for zero-emission buses are currently stagnating or falling (approx. 49,000 worldwide in 2023, -17 % compared to 2022), while the ramp-up of trucks is continuing (approx. 54,000 worldwide in 2023, +35 % compared to 2022).

With a share of around 92 %, China is by far the largest market for zero-emission heavy duty vehicles to date (Buysse 2022). In China, financial support for vehicle purchases led to a massive boost for zero-emission heavy duty vehicles. The gradual, significant reduction in the subsidy amount per vehicle caused registration figures to fall by more than half after the peak in 2016, before stabilizing after 2020.

In China, as well as worldwide, conventional heavy duty vehicles powered by fossil fuels still account for by far the largest share of annual sales figures. The share of zero-emission vehicles has risen from 0 % in 2012 to 4 % in 2021. The absolute number of new registrations of heavy duty vehicles in all other global markets is still only a fraction of that in China. Nevertheless, there is clear momentum, with a focus on the EU in recent years (Mulholland and Rodriguez 2023;).

With the improvement in battery technology and the associated increase in range, battery-electric trucks are now increasingly coming onto the market after city buses. Most heavy duty battery electric trucks were sold in Germany (29 %), France (17 %) and the Netherlands (17 %) in the first two quarters of 2023. In Europe, Volvo (26 %) and Renault (21 %) are pioneers in the market for heavy duty battery electric trucks (Mulholland and Rodríguez 2023). The USA and Canada are the fourth largest market for zero-emission heavy duty heavy duty vehicles (0.9 % of the global market) behind Asia excluding China (2.3 %). Here, the share of heavy battery electric trucks in new purchases is still in the per mille range with 94 heavy battery electric trucks in 2021. The majority of these sales are accounted for by Lion Electric (41 %) and BYD (31 %) (Buysse 2022).

In the second-largest market for electrically powered heavy duty vehicles (Europe, 4.3 % of the global market), battery-electric city buses are now sold exclusively in some countries (Mulholland and Egerstrom 2024). In 2022, 3,000 battery-electric buses were sold in Europe. This corresponds to a 13 % share of the total market for buses sold (Mulholland and Rodríguez 2023). This trend is now also gaining momentum in the truck sector. Sales of zero-emission heavy duty vehicles are expected to continue to grow strongly in the coming years, both in China and in the rest of the world. Battery-electric drive systems are expected to play the main role here (Mao and Rodriguez 2022).

The main drivers of the ongoing development towards zero-emission drives are national laws and international agreements on emissions standards and climate protection. In the case of city buses, for example, the EU has set itself the target of reducing direct CO_2 emissions to zero by 2035 (European Commission 18.01.2024). The regulations in the truck sector are described in section 2.3 in more detail.

2.3 International comparison of truck regulation

2.3.1 Overview

To support the achievement of national climate targets through the market ramp-up of zero-emission trucks, countries have introduced incentives and regulations for battery-electric trucks at national level. 70 % of global zero-emission heavy duty vehicle (HDV) sales take place under the effect of EV policies (IEA - International Energy Agency 2023). The type, target group and scope of the incentives and regulations offered vary between countries (IEA - International Energy Agency 2023). Target groups can either be truck operators on the demand side (freight forwarders, transport companies) or manufacturers of battery-electric trucks (OEMs) on the supply side.

The following section describes general global trends in regulatory and incentive structures. Then, focusing on relevant markets and countries with high sales figures for battery electric trucks, instruments for market introduction are presented and discussed in relation to the size of the respective national markets.

Declarations of intent are a non-binding but relevant instrument for setting the framework: In the "Memorandum of Understanding (MoU) on Zero-Emission Medium- and Heavy duty Vehicles", 36 countries have set themselves the goal of making the sale of new trucks and buses 100 % emission-free by 2040, achieving an interim target of 30 % emission-free vehicles by 2030 and net zero emissions by 2050 (Drive to Zero 2024).

Numerous countries have already adopted such binding targets – so far mainly for passenger cars, but increasingly also for heavy duty vehicles (IEA - International Energy Agency 2023). In order to create planning security with regard to product development and a level playing field, vehicle manufacturers must reach or fall below an upper limit for the average CO_2 emissions of vehicles sold in certain target years. The most relevant vehicle markets in North America, Europe and East Asia in particular now regulate the CO_2 emissions of heavy duty vehicles on the supply side by means of CO_2 standards. This represents a central mechanism for promoting market ramp-up worldwide (European Automobile Manufacturers' Association (ACEA)).

Another common policy instrument is tax breaks for the purchase or ownership of battery electric trucks as well as direct financial support for vehicle purchase or charging infrastructure. The trend here is that high purchase subsidies for zero-emission vehicles are gradually being reduced as electric vehicles gain in importance on the market. As a result, subsidies in the area of charging infrastructure are becoming more important, some of which have already been introduced at the same time. In the area of electric city buses, for example, a high level of market penetration can already be observed, with some countries already having ambitions to only purchase electric city buses from the 2030s (London 2034; EU 2035; Guangdong 2025). The greater availability of zero-emission models and the resulting increase in competition create a more favorable price situation than in the zero-emission truck sector, which in turn makes high purchase subsidies in the city bus sector unnecessary (IEA - International Energy Agency 2023).

In Germany, it can be seen that the taxation of road use and energy sources (CO_2-pricing of fuel, CO_2-component of the truck toll), in conjunction with the CO_2-standards for heavy duty vehicles, is gaining relevance, while the promotion of the purchase of vehicles and charging infrastructure has expired. It remains to be seen whether this trend can be observed throughout the EU as a result of the Green Deal measures relating to HGV traffic, which are only just beginning to take effect.

In addition, industrial policy efforts are being made worldwide to improve the market position of the respective national economy during the market ramp-up of zero-emission vehicles and to benefit from the expected sales. Attempts are being made to locate manufacturing companies (vehicles, batteries, infrastructure, etc.) in their own country and thus achieve a certain degree of independence in terms of supply and a share in the expected profits. China, the USA and the EU use large subsidy packages such as the Inflation Reduction Act (IRA) or the Green Deal Industry Plan (IEA - International Energy Agency 2023).

In the following, the regulation in China, the USA and Europe is presented as regions with relevant sales figures for battery electric trucks and key global markets. In addition, selected measures of the European member states with the highest sales are described.

2.3.2 China

China's President Xi Jinping announced in 2020 that his country would achieve CO_2 neutrality by 2060 (IEA - International Energy Agency 2021) . In order to achieve this goal, far-reaching emission reductions are needed in the transport sector (10 % of national emissions) and therefore also in road freight transport. China currently has the highest sales figures for zero-emission heavy duty vehicles in the world.

China regulates CO_2 emissions from heavy duty vehicles as part of emission standards that specify the energy consumption of new vehicles (Mao and Rodriguez 2022). In addition, China is pursuing the goal of developing and promoting the manufacturing industry for electric vehicles through massive support measures. There are far-reaching supply-side tax breaks, such as exempting car manufacturers from consumption and vehicle taxes. The government also grants loans to manufacturing companies. Demand-side purchase incentives were discontinued at the end of 2022. Tax breaks on vehicle purchases are due to expire by 2027. Support measures for the development of the charging infrastructure are to be maintained for the time being (Yu 2023).

2.3.3 USA

In the US, the Environmental Protection Agency (EPA) has published a proposal for greenhouse gas emission standards (Phase 3) for heavy duty trucks to reduce CO_2 emissions tank-to-wheel to 31 % below 1990 levels by 2050 (Xie and Minjares 2023; Ragon et al. 2023). In addition, the Inflation Reduction Act (IRA) plans USD 369 billion for climate-friendly investments, of which USD 1 billion is earmarked for vehicles and infrastructure in the heavy duty vehicle sector. In addition to the demand-side tax relief on vehicle purchases (up to USD 40,000 per vehicle), the IRA also includes supply-side tax credits for production (IEA - International Energy Agency 2023; Wolf 2023). "Under this scheme, the U.S. government provides subsidies for domestic battery production of up to $ 35/kWh and an additional $ 10/kWh for module assembly. Assuming average battery prices in 2022 of around USD 150 per kWh, these new US production incentives could account for almost a third of the total battery price" (IEA - International Energy Agency 2023).

2.3.4 European Union

In the EU, the **CO_2 standards** are the central policy instrument for decarbonizing heavy duty vehicles. In June 2024, Directive 2024/1610 ((EU) 2024/1610 2024) came into force, which requires manufacturers to reduce the average CO_2 emissions of their new vehicles sold in all relevant truck segments by 45 % by 2030, 65 % by 2035 and 90 % by 2040, in each case in relation to fleet CO_2 emissions in 2019. The vehicle classes are weighted according to their mileage, making long-distance vehicles such as tractor units particularly relevant for achieving the target. Failure to meet the target will result in high fines. There are also considerations to further increase the permissible total weight of zero-emission trucks, beyond the currently permissible additional weight of 2 tons, in order to achieve further range development without restricting the payload in view of the increased battery weight (Westerheide 2024).

On the demand side, the Clean Vehicle Directive ((EU) 2019/1161 2019) – and its respective national implementation, such as the German Clean Vehicle Procurement Act (SaubFahrzeugBeschG 2021) – sets requirements for the procurement of zero-emission city buses and municipal work vehicles, which also has an indirect impact on the development of truck technology. There are also discussions about setting mandatory targets for company fleets to convert their fleets of cars and heavy duty vehicles to zero-emission drive systems. The European Commission is currently conducting a consultation procedure on this (T&E 2024a).

The **development of public charging infrastructure** is the most important task with which the governments of the EU member states are flanking the market ramp-up. Since 2023, this expansion has been regulated by the AFIR Regulation ((EU) 2023/1804 2023) regulated. Binding national targets for publicly accessible infrastructure for alternative fuels and charging electricity are set as minimum standards, which can also be exceeded by national targets. The focus is on charging stations for passenger cars and trucks. For these, minimum charging capacities and maximum distances for charging points are defined, graded according to the relevance of routes and locations (Göckeler et al. 2023). The regulation also defines a network of hydrogen filling stations, albeit to a lesser extent, for all member states.

Road user charges are a relevant lever for incentivizing the use of zero-emission heavy duty vehicles. The Eurovignette/road pricing directive (1999/62/EC 1999) sets the framework for national legislation on toll collection on trunk roads. For example, emission-free vehicles can still be completely exempt from tolls up to and including 2025, after which a limited reduction compared to emission-intensive vehicles is still permitted. The reform of the directive in 2022 obliged those member states that levy a truck toll to integrate a CO_2 component into it.

The stricter air pollutant limits for trucks as part of the Euro 7 standards adopted in 2024 (European Parliament 2024) can also be conducive to the market ramp-up of zero-emission trucks by increasing the costs of combustion vehicles.

The implementation of instruments to promote market ramp-up varies considerably in some member states. There is great diversity in the implementation of EU directives, national subsidies and tax breaks – from Germany, where 80 % of the additional costs will be covered by 2023, to Bulgaria, where there are virtually no subsidies or support. For this reason, the framework conditions in Germany and other European countries with a comparatively high proportion of zero-emission heavy duty vehicles are presented below in order to describe in more detail how the transition path will be structured.

2.3.5 Germany

The basis for emission reduction targets in road freight transport in Germany is the national **Climate Protection Act (KSG)**. This contains reduction targets for each sector. In the transport sector, a reduction to 85 million tons of CO_2 equivalents is to be achieved by 2030, i.e. a halving of GHG emissions compared to the current level. Previously (KSG 2023), binding annual emission levels applied to each sector. The amendment to the Climate Protection Act in May 2024 abolished these in favor of a multi-year and cross-sectoral overall calculation (The Federal Government 2024b). According to the Climate Protection Program 2030, one third of road freight transport mileage is to be covered by electric drives or electricity-based fuels by 2030 (BMU 2019).

Until 2023, **financial support for the purchase** of zero-emission heavy duty vehicles was a key policy instrument for achieving these goals and the highest such support in the EU. In the "Climate-friendly heavy duty vehicles and infrastructure" (KsNI) funding program, 80 % of the additional costs compared to a comparable conventional vehicle and the purchase of the tank or charging infrastructure required for operation were recently funded. However, as part of the consolidation of the federal budget at the beginning of 2024, the federal government decided that there will be no further purchase subsidies.

Since then, the **development of charging infrastructure** has been all the more central to the promotion of electromobility. The German targets require a significantly higher expansion of charging infrastructure than in the AFIR (see section 2.3.4). The federal government addresses the development of charging infrastructure in the Charging Infrastructure Master Plan II (BMDV 2022). In September 2024, a tender is to be issued for the installation of charging points at around 130 unmanaged rest areas, in addition to the planned charging infrastructure at around 220 managed rest areas. The BMDV estimates that this would cover two thirds of the demand for publicly accessible charging points on German highways (BMDV 2024).

In addition, German legislation contains several instruments to reduce the running costs of climate-friendly drive systems for heavy duty vehicles compared to fossil-fueled road freight transport. The approach of using taxation to make the costs per kilometer in freight transport more climate-friendly is also supported by economic experts such as the German Council of Economic Experts (Sachverständigenrat zur Begutachtung der gesamtwirtschaftlichen Entwicklung) (Sachverständigenrat für Wirtschaft 2024) recommended. The focus here is on a **CO_2** price on fuels and the redesign of the truck toll. The former was introduced in Germany in 2021 as part of the Fuel Emissions Trading Act (BEHG). After initially €25/t CO_2, it has stood at €45/t CO_2 since the start of 2024. This corresponds to costs of around 3.6 ct/km for a truck and articulated lorry. The price is set to rise further to €55/t CO_2 in 2025 and will be determined by the market within a narrow corridor from 2026 or, if necessary, replaced by the European Emissions Trading System ETS 2 from 2027 (Die Bundesregierung 2024a; Acksel; Huenges; Kastner 2017).

An important component of the regulation of transport costs is the structure of the **truck toll** introduced in Germany in 2005. The changes that came into force at the end of 2023 (The Federal Government n.d.) to the Federal Trunk Road Toll Act (BFStrMG 2011) represent the implementation of the EU Road Charges Directive (see section 2.3.4). New features include the inclusion of vehicles between 3.5 and 7.5 t (with the exception of so-called craftsmen's vehicles) and the levying of a CO_2 component of 3.7 to 16.2 ct / km depending on weight class and CO_2 emissions. Locally emission-free trucks, including e-vehicles, do not currently pay a toll. From 2026, there will still be no CO_2 component, low rates for noise and air pollution and only 25 % of the infrastructure component of the toll.

The German implementation of the **greenhouse gas emission reduction quota** in accordance with the European Renewable Energies Directive ((EU) 2023/2413 2023) obliges distributors of fossil fuels to gradually reduce the GHG intensity of energy volumes in road and rail transport, whereby the use of electricity in road transport can also be counted towards meeting the target. This has resulted in certificate trading, through which e-vehicle owners and charging infrastructure operators can generate income (Kasten und Jöhrens 2022) with prices falling noticeably in the years 2023 and 2024 (Paulsen 2024).

In addition, e-trucks registered before the end of 2025 are exempt from **vehicle tax** for ten years. However, this only accounts for a small proportion of the operating costs; for a Euro VI tractor unit, it amounts to € 665 per year.

2.3.6 Further examples from selected European countries

In recent years, France has ranked second behind Germany in terms of absolute sales figures for zero-emission heavy duty vehicles in the EU. This was followed by Sweden and the Netherlands, which together accounted for around a third of new registrations of zero-emission heavy duty trucks, although they only account for 5 % of sales of conventional vehicles. Both countries promote these through purchase premiums: 20 % of the purchase price in Sweden and up to 60 % of the surcharge in the Netherlands (Mulholland and Rodríguez 2023; Pölös 2022). In Denmark, the taxation of trucks will be based on the CO_2 emissions of the vehicles from 2025. Norway, a non-EU country, has set itself the target of 75 % of new long-distance buses and 50 % of new trucks sold being emission-free by 2030. These targets have been achieved through a subsidy scheme and a fuel tax for HDVs of around € 200 per tonne of CO_2 (IEA 2022).

What effect various implementations of the CO_2 component of the HGV toll will have in terms of the Eurovignette-/Road Charges Directive (see section 2.3.4) cannot yet be assessed due to the early stage. Implementation is currently heterogeneous in the EU member states, as the initial situation is already very inconsistent (T&E 2024b). In addition to distance-based systems, there are also time-based vignettes. Tolls are levied partly by the state and partly by private concessionaires. Individual countries have introduced, abolished or changed the system in recent years. Several countries such as Austria, the Czech Republic and Hungary with a distance-based system have implemented a CO_2 component based on the German system (Gowans 2024). In many countries with a vignette system or with private operators, the CO_2 component has not yet been implemented (Eurowag 2024).

Trends in the international truck market:

- The international truck market continues to be dominated by diesel drives. In recent years, however, there has been strong momentum in the number of new registrations of battery-electric trucks.
- At around 92 %, China is by far the largest market for zero-emission heavy commercial vehicles. However, the EU is the most far-sighted market for e-trucks worldwide, with Germany as the country with the highest market share.
- The key drivers for the momentum in e-truck sales are stricter CO_2 standards for heavy duty vehicles in key sales markets as well as monetary incentives for emission-free drives through the direct promotion of procurement and advantages in terms of duties and taxes.

3 Alternative drives and fuels for heavy duty vehicles

The market for heavy duty vehicles continues to be dominated by the use of diesel vehicles. Alternative fuels and drive systems have so far played a subordinate role (see chapter 2.2). Until a few years ago, the use of battery electric trucks was not yet being discussed as a serious technology option.

In recent years, however, the development of electric heavy dutyl vehicles has gained significant momentum and there is a clear trend towards the electrification of trucks and buses, which is reflected in both industrial and political strategies (see chapter 2.3). In the following, an overview of the current state of knowledge is provided for each of the available drive and fuel alternatives. The current assessments of the heavy duty vehicle manufacturer representatives surveyed are then presented.

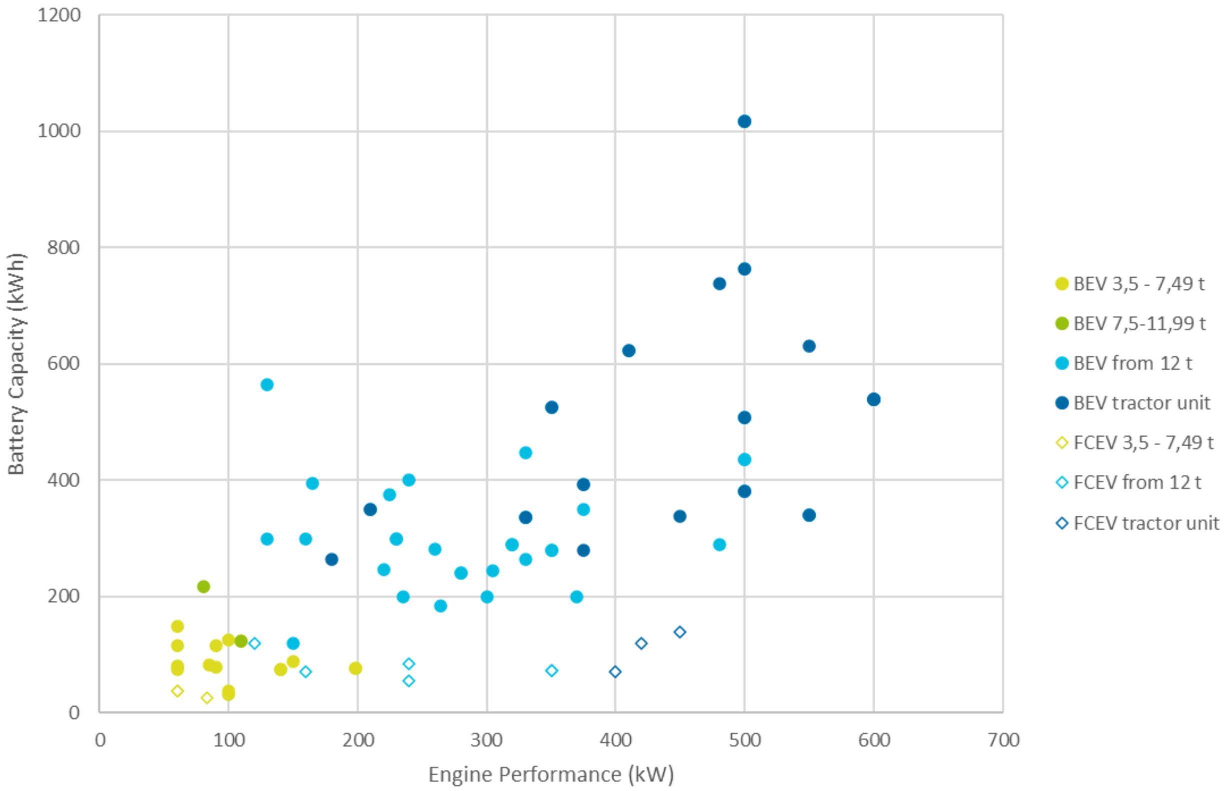
3.1 Properties and development prospects of battery electric trucks

Overview

The high energy efficiency of the electric drive makes battery electric trucks particularly attractive, both in terms of the efficient use of renewable electricity and in terms of the most economical vehicle operation possible. In view of the high performance and high mileage, the main challenge – even more so than for passenger cars – is energy storage. The required battery system incurs considerable additional costs and reduces the vehicle's payload due to its mass.

Thanks to the great progress made in the development of lithium-ion batteries, initially mainly for passenger car applications, heavy duty vehicles for use in regional transport with a range of around 300 kilometers can now be realized without significant loss of payload (Göckeler et al. 2023). An additional weight of up to 2 tons can be tolerated, as this is covered by EU regulations for zero-emission heavy duty vehicles (EP Committee on Transport and Tourism 14.02.2024). E-trucks with a range of up to 300 km were initially mainly offered by converters and other small companies. In recent years, the market has picked up significantly and all major European truck manufacturers have entered into the development and sale of corresponding vehicles (see Figure 3-1).

Illustration 3-1 Overview of available truck models with alternative drive systems, differentiated by drive type, gross vehicle weight, engine power and battery capacity



Source: own illustration

In view of the great importance of long-distance road freight transport and the advantageous kilometer costs of battery electric trucks, their increased use in long-distance transport is in principle obvious. However, this is offset by the need for an even larger battery system and the associated higher investment costs and potential payload losses as well as a particularly powerful charging infrastructure. While a few years ago there was still controversy in research and industry as to whether the battery electric drive could be suitable for these applications in the long term, a clear picture has emerged in the recent past. All European heavy duty vehicle manufacturers have embarked on the development of battery-electric tractor units with a range of more than 500 kilometers for long-distance transport, and all manufacturers are expected to produce series vehicles from 2024. The implementation of corresponding battery-electric vehicle variants is possible with negligible payload losses. The main incentives for the development of these vehicles are their particularly high importance for achieving the European CO_2 standards for new vehicles and the special economic incentives in operation in view of the benefits from the truck toll. This assessment is supported by current scientific analyses (Göckeler et al. 2023; Basma et al. 2022) which confirm the cost advantage of electric trucks in long-distance transport.

Current expert assessments

Against this background, it is remarkable, but also understandable, that the assessment of the main area of application for battery electric trucks has shifted in recent years. Just a few years ago, the focus was on the technical restrictions of the battery and it was concluded that electric trucks would primarily be used in regional transport (cf. Göckeler et al. 2020). Currently, however, the focus is increasingly on considerations of economic operation, which suggest an accelerated use of battery electric trucks in long-distance transport, now that technical challenges have been relativized by technical progress. For example, several manufacturer representatives emphasize that the operating cost benefits of electric trucks in long-distance transport are significantly greater than in regional transport. The introduction of a CO_2-based toll on German highways in December 2023 reinforces this effect.

With regard to the technical maturity of the electric truck drive, particular reference is made to the progress made in battery technology and the energy efficiency of the electric drivetrain in recent years. The adaptation of the battery size to the respective usage profile of the vehicle and the available charging options is seen as an important optimization factor and flexibility for electric trucks. In this context, it is emphasized that heavy duty vehicle production at the established manufacturers is already accustomed to a strong vehicle configuration oriented towards specific customer needs. However, individual manufacturers are also pursuing a strategy of simply offering a standard product in large quantities in order to reduce production costs.

According to the manufacturers' representatives interviewed, it is not possible to make a reliable forecast of the development of purchase prices for electric trucks over the next 10 years. The main influencing factors are the speed of the market ramp-up and the associated process improvements in vehicle production. In view of the fact that batteries are around ten times larger than those in passenger cars, the particular importance of battery costs is pointed out. However, it is also emphasized that the purchase prices of e-trucks also depend on the manufacturer's pricing policy and the extent to which cross-financing is realized from the profit margin of the diesel trucks sold or through the use of risk capital. In view of the stricter emission requirements, it is also assumed that costs will increase for future vehicle models with combustion engines. Compared to fuel cell vehicles, a faster cost degression is expected for battery electric trucks in the coming years. Nevertheless, the remaining surcharge for e-trucks in the coming years is considered less critical by the manufacturers' representatives with reference to the significantly more relevant operating cost advantages compared to fuel cell vehicles, as they already see an overall cost advantage of e-trucks in long-distance transport in the short term and even without vehicle subsidies.

As in scientific analyses, the main challenge for the market success of electric trucks identified by the manufacturers and infrastructure experts surveyed is the availability of the charging infrastructure. For long-distance transport in particular, the future importance of public high-performance charging infrastructure was highlighted.

Technical characteristics and prospects of battery electric trucks:

- Advances in battery technology are already making it technically possible to use BET beyond regional transportation.
- Main application of battery-powered trucks will soon shift from regional to long-distance transport due to operating cost advantages in particular.
- Availability of charging infrastructure as a key influencing factor and bottleneck at the same time determines the speed of market ramp-up.

3.2 Properties and development prospects of other drive and fuel alternatives

3.2.1 Hydrogen-based fuel cell or combustion engine truck

Overview

The use of hydrogen as an energy source enables the emission-free propulsion of trucks as long as the hydrogen is produced entirely with electricity from renewable energies. Two technical solutions are being pursued for the use of hydrogen as drive energy for trucks. On the one hand, these include the combustion of hydrogen in an internal combustion engine in the same way as diesel fuel. Alternatively, the conversion of hydrogen into electricity in a fuel cell to drive an electric motor – analogous to the battery electric drive – is being pursued as a solution. In current vehicle concepts, the fuel cell is designed for around half the engine power. Load peaks and the absorption of recuperation energy are ensured via a supplementary battery system. The hydrogen fuel cell drive in particular has been discussed for many years as a technical solution for emission-free heavy duty road transport.

The additional energy conversion processes in the fuel cell during hydrogen production lead to an energy loss of at least 40 %. The situation is similar for hydrogen production and use in the combustion engine. For this reason, hydrogen-based drive options have a significantly lower overall energy efficiency compared to battery electric drives (Göckeler et al. 2023).

For hydrogen storage in the vehicle, both gaseous and liquid storage is being pursued as a solution option. So far, however, there is no manufacturer-independent definition. The aim is to achieve a vehicle range of 800 to 1000 kilometers by 2030. The comparatively long range and the relatively short refueling time are cited as the main advantages over battery electric trucks.

However, the majority of current studies on technology comparison also assume higher acquisition costs in the medium term compared to diesel and battery-electric trucks, and overall cost advantages over the drive alternatives – including battery-electric trucks – are only achieved under very optimistic hydrogen price assumptions (Göckeler et al. 2023; Basma et al. 2023).

All heavy duty vehicle manufacturers are involved in the development of hydrogen-based truck drives. So far, however, vehicle models are only available from individual manufacturers (Göckeler et al. 2023).

Current expert assessments

The development and market prospects for hydrogen-based truck drives are generally and consistently assessed much more conservatively by the manufacturer representatives surveyed compared to battery-electric trucks. While the feedback on the prospects for battery-electric trucks shows an extremely large overlap across manufacturers, there are differences in the manufacturers' assessments when it comes to hydrogen. Nevertheless, it should be noted that the clear majority of the manufacturers surveyed are also involved in the development of hydrogen-based truck drives and do not rule out the use of the technology – at least in submarkets.

The comparatively high operating costs are cited as being particularly critical for the competitiveness of the technology. However, in view of the still higher purchase prices of fuel cell vehicles, the operating costs for economically competitive use would have to be lower than those for battery electric trucks in order to achieve a relevant market share. The vast majority of manufacturers surveyed believe that the hydrogen price level required for this is not feasible, even in the long term, or at best achievable with the use of continued subsidies. In addition, reference is made to the high level of competition with other industrial and transport applications, which, according to several interviewees, will probably show a higher willingness to pay for hydrogen due to the lack of decarbonization alternatives for these applications.

Individual manufacturers see potential uses for hydrogen-based truck drives in applications where power grid restrictions make the use of battery-electric trucks impossible or only possible at very high cost, or where only very short vehicle downtimes occur for operational reasons that are not sufficient for battery recharging. In addition, off-road applications in the heavy duty vehicle sector are also seen by individual interviewees as possible fields of application for hydrogen.

With regard to the technical variants of hydrogen use in the truck sector, the use of hydrogen in combination with an internal combustion engine drive is initially considered more realistic, taking into account the technological maturity. However, in view of the higher energy efficiency of the fuel cell drive, the use of fuel cell trucks in long-distance transport is considered more advantageous when comparing the two technology options, as this would be associated with significant operating cost advantages. However, fuel cell technology for this area of application is not yet ready for series production. This assessment is shared by several manufacturers.

3.2.2 Hybrid truck

Overview

A hybrid drive is a combination of an internal combustion engine and an electric drive. The vehicle's battery makes it possible to support the combustion engine drive during acceleration and to convert kinetic energy back into electricity and store it in the battery during braking. This drive configuration enables more efficient operation of the combustion engine and saves fuel without the need for external charging of the battery. In previous expert discussions, fuel savings of up to 15 % were considered realistic (Göckeler et al. 2023).

Current expert assessments

In recent years, individual manufacturers have also developed hybrid drives for use in heavy duty vehicles. The high development costs were emphasized in the interview. Future market shares are not seen for the technology, as it is not economically competitive under the changed technological framework conditions due to its significantly lower energy efficiency compared to purely electric drives, among other things, and also cannot claim the monetary advantages of emission-free drives in the truck toll.

All vehicle manufacturers are therefore now focusing on the introduction of zero-emission drives as their main strategy for achieving the European CO_2 fleet targets, rather than on increasing the efficiency of internal combustion engine drives. As a result, only a few hybrid models are available on the market, of which only one has been launched in the last 5 years.

3.2.3 Alternative fuels

Overview

Alternative fuels offer the possibility of continuing to use the combustion engine, but no longer being dependent on fossil diesel fuel and at the same time being able to reduce CO_2 emissions. Against this backdrop, the use of liquefied natural gas (LNG), biofuels and so-called e-fuels are also mentioned in the public debate as possible solutions for the decarbonization of heavy duty vehicles.

Although liquefied natural gas (LNG) is also of fossil origin, its CO_2 emissions per unit of energy are around 25 % lower. Biofuels also cause CO_2 emissions in the combustion process, but remove CO_2 from the atmosphere during biomass production. E-fuels, often referred to as power-to-liquid (PtL) fuels, are created by synthesizing hydrogen with carbon dioxide. If the hydrogen is produced using renewable electricity and electrolysis and the carbon dioxide is extracted from the atmosphere, the CO_2 emissions during combustion in the diesel engine can be climate-neutral. With regard to the fuels under discussion and their importance for the decarbonization of road transport, existing scientific studies point in particular to the limited availability, major competition for use (especially for biofuels and e-fuels), especially with regard to use in air transport, the very high production costs (especially e-fuels) and the negligible CO_2 advantages on a well-to-wheel basis (in the case of LNG) as well as the NO_x emissions that continue to be produced during combustion (Göckeler et al. 2020; Kühnel et al. 2018; Mottschall et al. 2020).

Current expert assessments

In the expert interviews, none of the alternative fuel options mentioned were named as part of the development strategy of the respective manufacturer or as part of a cross-manufacturer future technology mix for the decarbonization of heavy duty vehicles in the European market.

Technical characteristics and potential of other drive and fuel alternatives:

- In view of higher fuel costs, hydrogen-based drives are only expected in sub-markets, if at all, and reference is made to H_2 competition with other demand sectors.
- The H_2 fuel cell shows efficiency advantages, but in view of the lack of market maturity, the use of hydrogen in the combustion engine is expected to be more common initially.
- Hybridization of the internal combustion engine truck drive is no longer being pursued as a solution option.
- Alternative fuels (biofuels, synthetic fuels) were not named as part of the manufacturers' technology strategy.

3.3 Market ramp-up of e-trucks: manufacturer strategies and risks

Overview

Currently, the proportion of new registrations of battery electric trucks in Germany and Europe is still in the per mille to low, single-digit percentage range (see chapter 2.2). In the 2030 climate protection program, the German federal government formulated the goal back in 2019 that one third of road freight transport mileage should be covered by electric drives or electricity-based fuels by 2030 (BMU 2019). In the "Gesamtkonzept klimafreundliche Nutzfahrzeuge[4]" from 2020 (BMVI 2020) outlined possible technology paths for achieving the target and necessary measures. In the "Fahrplan Antriebstechnologien[5]" listed there, path decisions were targeted for the period 2023 to 2026, which should enable promising technologies to be scaled up in subsequent years.

The European CO_2 fleet target values for heavy duty vehicles, which came into force in 2019, already specify a significant increase in efficiency by 2030 and, following the current revision of the regulation

4 concept for climate-friendly commercial vehicles
5 plan Drive Technologies

with a reduction target of 90 % by 2040, already point a clear direction towards zero-emission drives (see Chap. 2.3.4).

In 2022, the European heavy duty vehicle manufacturers communicated their target figures for Germany and Europe for the first time on the basis of confidential and anonymized manufacturer discussions (so-called “Cleanroom Discussions”) (NOW 2023). In the discussions at the time, the manufacturers confirmed that the European CO_2 fleet targets are the key driver for the development and market launch of alternative drive systems for heavy duty vehicles. By 2022, all manufacturers had already identified battery-electric trucks as the central pillar for achieving the targets. This was justified by the technical possibilities that have arisen as a result of the advancing development of battery technology, as well as the particularly advantageous operating costs compared to the drive alternatives. The development and prompt availability of private and public charging infrastructure for heavy duty vehicles was named as a key prerequisite for the targeted market ramp-up.

Interestingly, the manufacturers' announcements in the cleanroom talks in 2022 already significantly exceeded the European CO_2 fleet targets for 2030. The share of new registrations of zero-emission heavy duty vehicles over 12 tons gross weight in Europe forecast by the manufacturers was 53 % for BET and 10 % for FCET. For Germany, a share of 57 % BET and 17 % FCET of new registrations in 2030 was even stated.

In regional transport in particular, battery-powered trucks were considered to be very important in the short term at the time. On long-distance routes, the manufacturers' perspective was less unanimous with reference to the restrictions of the battery in the cleanroom discussions. The importance of hydrogen-based drives was also assessed differently. While some manufacturers considered cost parity to be achievable in long-distance transport, other manufacturers ruled this out. There was unanimity in the assessment that fuel cell trucks would only enter the market in relevant numbers after battery trucks – probably in the second half of this decade. The use of hydrogen-based combustion engine trucks was considered less attractive in the discussions at the time in terms of overall efficiency and residual pollutant emissions.

Current expert assessments

Market ramp-up of battery-electric trucks

The manufacturer representatives currently surveyed expect sales of heavy trucks with battery electric drive (BET) to grow rapidly in the coming years under the current conditions. The forecasts made in the clean room discussions (NOW 2023) on the market development of battery electric trucks are confirmed and in some cases even more dynamic market development is now expected. An S-curve-shaped ramp-up is assumed. In this context, reference is made to the numerous model announcements for 2024, which form the basis for market development. The market launch of long-distance electric trucks in 2024/25 is seen as a significant breakthrough for the electrification of trucks. It is emphasized that there is already great interest in electric long-haul trucks from the transport industry, which makes manufacturers optimistic. A possible second breakthrough could be achieved by 2030, when the proportion of new registrations of electric trucks exceeds the 50 % mark. The available charging infrastructure is seen as the dominant limiting factor. According to individual manufacturers, a market share of e-trucks of well over 50 % by 2030 would otherwise be realistic if the charging infrastructure were fully available. The statement "electric trucks will become the new diesel trucks in terms of market share" is not shared by all manufacturers in this absolute sense, but a development in this direction is expected by the vast majority of respondents.

The European CO_2 fleet targets, to which manufacturers are aligning their product policy, are unanimously cited as the main driver for this dynamic development. Cost-side incentives for users, such as a rising CO_2 price and a CO_2 -based toll, as introduced in Germany, are seen as important instruments for the demand for e-trucks. The introduction of electricity credits as part of the Renewable Energy Directive (EU 2023) in several EU member states and the associated lower electricity costs as well as the revision of EU regulations on dimensions and mass in favor of alternative trucks are cited as further important supportive framework conditions. Government subsidies for vehicle procurement are seen as relevant in the initial phase, as they enable economical operation even for low-mileage truck applications and send an important signal to users about the transformation. At the same time, however, manufacturers consider this funding instrument to be inefficient and poorly targeted and believe it should be of less importance in the future. The short-term reduction in subsidies for vehicle procurement is rated as very unfavorable by those surveyed in terms of its effect on the transport industry, as it runs counter to the planning security required for rapid action and creates lasting uncertainty among users. In this context, the conditions in the transport industry are also cited as a challenge for the market ramp-up. The high number of small companies and low margins make it difficult to introduce new technologies with a changed cost structure. In this context, the remaining residual value uncertainty of e-trucks is also pointed out. In the early market phase, large transport companies are therefore seen as the main target group for the sale of e-trucks.

The potential role of new market participants is interesting. According to individual experts, they could see the time window up to the specified CO_2 target values in 2030 as an opportunity to secure market share early on by offering e-trucks before everyone – including the established manufacturers – has to strive for increased sales of e-trucks to achieve the target values in 2030. With regard to Chinese heavy duty vehicle manufacturers in particular, individual interviewees referred to the tension between unrestricted access to the European vehicle market for foreign manufacturers and the high dependence on critical raw materials and battery technology from China, which suggests a balanced trade policy.

Manufacturer strategies and expected market ramp-up for e-trucks:

- The European CO_2 fleet targets are named as the main driver and central point of orientation for the product strategy.
- The market forecasts for e-trucks from the clean room discussions from 2023 are confirmed and in some cases even more dynamic market development is expected.
- In particular, the introduction of electric long-distance trucks from 2024 is expected to stimulate the market significantly.
- By 2030, battery electric trucks are expected to have a market share of over 50 % and battery electric drive systems are seen as the dominant technology for trucks in the long term.
- In comparison to CO_2 pricing (including the truck toll), which is relevant to operating costs, the promotion of vehicle purchase is considered a less relevant incentive.
- New market players could try to gain market share as suppliers of e-trucks, particularly before the CO_2 target values are reached in 2030, at the expense of established manufacturers.

Market prospects for other drive and fuel alternatives

Although there is broad agreement among the experts consulted about the widespread dominance of battery-powered trucks in future road freight transport, most manufacturers also see other drive alternatives – albeit of much lesser importance – in selected applications. Against this backdrop, it is not surprising that all established manufacturers also refer to their own development activities, albeit mostly to a much lesser extent and particularly with regard to hydrogen-based drives. The use of hydrogen in both fuel cells and combustion engines is being pursued as a strategy. In the opinion of the manufacturers' representatives, hydrogen-based combustion engine truck drives could initially play a more important role in view of greater technological maturity. In the long term, however, manufacturers believe that fuel cell trucks have greater potential – particularly in long-distance transport with high mileages – due to their higher energy efficiency and therefore lower operating costs. It is expected that hydrogen trucks will be represented on the market at least in the short to medium term in view of strong monetary incentives. However, the majority of manufacturer representatives are highly skeptical about the long-term economic competitiveness of hydrogen-based drive options compared to battery electric trucks. Representatives of one manufacturer cite a market potential of 10 to 20 % for hydrogen trucks, which could result primarily from bottlenecks in the energy system and the necessary stationary energy storage. Other manufacturers, on the other hand, point to the economically more efficient stationary reconversion of hydrogen into electricity.

The use of plug-in hybrid drives in trucks was only mentioned by one manufacturer and reference was made to past development activities. However, the future market potential is estimated to be very low.

Alternative fuels such as biogenic or electricity-based fuels (so-called e-fuels) were not mentioned in any of the discussions as a solution option for the decarbonization of road freight transport.

Manufacturer strategies for further drive and fuel alternatives:

- All manufacturers expect battery-electric trucks to dominate road freight transport in the future.
- At the same time, all manufacturers are also involved in the development of hydrogen-powered drives (in combination with fuel cells and combustion engines).
- The majority of manufacturers do not see hydrogen-powered trucks being economically competitive in the longer term either and only see applications in niche markets.
- A single manufacturer mentions a relevant market potential for hydrogen-powered trucks in the order of 10 to 20 % market share.
- Plug-in hybrid drives and alternative biogenic and electricity-based fuels were not mentioned in any of the discussions as a solution option for the decarbonization of heavy-duty trucks.

4 Charging infrastructure for battery-electric heavy duty vehicles

Analogous to the previous discussion of drive and fuel alternatives for heavy duty vehicles, the following section first provides an overview of the current state of knowledge regarding the energy supply infrastructure required for battery electric trucks. The current assessments of the representatives of heavy duty vehicle manufacturers and charging infrastructure experts surveyed are then presented.

Overview

A nationwide and reliable charging infrastructure is – as with electric cars – the central prerequisite for being able to operate electric trucks. Current scenario analyses (e.g. Göckeler et al. 2023) show that the speed of the market ramp-up of e-trucks is essentially dependent on the availability of charging infrastructure and, in particular, on the available public high-performance charging infrastructure and the price of charging electricity there.

While a nationwide public charging infrastructure is already available for electric cars, there are only the first, isolated public charging stations for heavy duty vehicles across Europe so far (Federal Network Agency; Varo Charging; Aral; Milence 2024b; 2024a; Manthey 2024). The e-trucks currently in use are mainly charged at non-public charging stations in the depots of transport companies. The Combined Charging System (CCS) standard available to date allows a maximum charging capacity of 350 kW. However, the actual charging power at existing locations is often still limited by the lower available grid connection power or the technically limited charging power of the available vehicle models. In regional transport use to date, a lower charging capacity often does not represent a usage restriction in view of the fact that charging is usually possible overnight in the depot and the low proportion of e-trucks in the overall fleet.

With a view to long-distance transportation applications and significantly larger battery capacities for such vehicles, battery charging with higher power is becoming increasingly important. In the CharIN initiative, industrial companies are therefore currently developing the *Megawatt Charging System (MCS)* charging standard which, with charging capacities of over one megawatt, should enable large battery systems to be fully charged in 30-45 minutes. This will also make it possible to recharge the battery during the driver's break and thus achieve typical daily mileages in long-distance transport of well over 500 kilometers.

Charging infrastructure can be fundamentally divided into the areas of non-public charging on company premises and publicly accessible charging (Nationale Leitstelle Ladeinfrastruktur 2023). Non-public charging includes charging facilities on the company's own premises (e.g. depot) or on third-party premises that also provide charging infrastructure for other users to charge the batteries of trucks (e.g. at a customer's loading and unloading point) as well as mobile charging points (e.g. for construction site vehicles). Publicly accessible charging includes charging infrastructure at important transshipment points (e.g. freight distribution centers), charging hubs in commercial areas and charging hubs on highways, which enable both high-power recharging during driving breaks and medium-power recharging at night and during longer breaks.

The target states of the charging infrastructure and the future significance of the various charging options cannot be reliably predicted as they depend on a variety of factors and as there are strong interactions between the development of the charging infrastructure and the electrification of the vehicle fleet. For example, the available charging infrastructure influences which vehicles and routes can be electrified at an early stage. And these in turn influence the further expansion of the charging infrastructure. Key influencing factors include the locations at which charging infrastructure can be installed technically (available grid connection capacity) and at competitive costs, which trucks and routes can be technically and economically substituted by electric trucks at an early stage and how the trade-off between battery size and frequency of battery recharging actually plays out in practice.

Despite these uncertainties, studies on the market ramp-up modeling of e-trucks (e.g. Göckeler et al. 2023) and expert assessments indicate the importance of the different charging options. Empirically supported analyses of truck trip chains indicate that, in the long term, over 50 % of energy requirements can be covered by charging infrastructure in depots and with moderate power (up to 150 kW) overnight (Göckeler et al. 2023). The basic prerequisite for this is that charging infrastructure can be installed on the company premises. The battery charging of vehicles that do not return to the depot at the end of the day is likely to take place primarily at publicly accessible charging stations and can also take place with moderate power (150 kW) (Göckeler et al. 2023). CCS charging is particularly relevant for driving profiles whose daily mileage exceeds the battery range and therefore require fast charging during a driver break. MCS charging with a charging capacity of more than one megawatt is mainly used in long-distance transport, where a single charging stop during the driver's break is required to fulfill the daily mileage and a charging capacity of more than 350 kW (CCS) is required for this.

The analyses in the StratES project project (Göckeler et al. 2023) come to the conclusion that, based on representative truck usage profiles, around 80 % of the energy requirement (in the depot and for public night charging) can be covered with a maximum of 150 kW and one charging process per day is sufficient. The energy turnover at CCS and MCS charging stations is much lower in comparison at around 10 % each. However, the importance of the fast-charging infrastructure for the electrification of long-distance transport is significantly greater than the share of total energy sales suggests, as many journeys can only be made on the assumption of a fast-charging infrastructure.

Based on the analyses presented and assuming that the grid connection can be ensured at the respective locations, a future dominance of depot and public night-time charging points can be derived. In the above-mentioned scenario, a need for over 100,000 such charging points in Germany by 2035 is determined, almost a third of which will be in public spaces. The demand for public CCS and MCS charging points is significantly lower at around 4,000 and 2,000 respectively. In a possible public charging network with a grid of 60 kilometers, this means 24 to almost 200 charging points for public night charging and 2 to 10 MCS charging points per location, depending on the regional traffic volume. Similar analyses (Plötz et al. 2020; Burges et al. 2021) arrive at comparable infrastructure requirements, taking into account deviating market ramp-up figures. Compared to the AFIR specifications, the modeled requirements in 2030 are already twice as high and in 2035 are already eight times higher than the minimum available capacity per location specified by the AFIR.

The present analyses illustrate the central importance of the development of charging infrastructure for the market ramp-up of electric trucks. Despite the remaining uncertainties regarding the demand for the use of public charging points and the interactions with vehicle technology (including battery capacity), the simulations show robust requirements for the development of public charging infrastructure for heavy duty vehicles. Taking into account the long planning and implementation periods for grid connections (up to 10 years for the connection to the high-voltage grid), the particular urgency of initiating the development of charging infrastructure at an early stage becomes apparent in order to be able to realize the planned e-truck market ramp-up.

Current expert assessments

Importance of charging infrastructure

The representatives of the vehicle manufacturers and the charging infrastructure experts consulted unanimously emphasized and confirmed the outstanding importance of the charging infrastructure for the market ramp-up of e-trucks. According to their assessment, the development of the charging infrastructure is more important for the market ramp-up than vehicle subsidies and monetary incentives for e-trucks in the truck toll. In comparison to the electrification of passenger cars, the even higher demands on the reliability of the charging infrastructure were pointed out in view of its high economic importance, which must be ensured at an early stage of the market. This is justified by the consequences of a failure of the charging infrastructure when operating e-trucks, which is directly associated with high follow-up costs for the transport company due to the resulting loss of transport services.

In the early market phase in particular, the interviewees believe that charging in depots is very important, as the development of public charging infrastructure requires longer lead times – around 3 years were mentioned – and is therefore not yet available in the short term. However, even under these circumstances, the interviewees believe that there are attractive potential applications for battery electric trucks for initial use cases such as commuter or scheduled services. However, the rapid development of a public charging network along the main corridors is necessary to develop long-distance transport, which is particularly relevant in terms of economy and emissions. In the future, this network must also be expanded beyond the corridors in order to ensure complete network coverage.

The expansion requirements, which were determined by two organizations represented in the interviews, are derived on the basis of the manufacturers' market announcements in conjunction with the targets of the EU CO_2 standards for heavy duty vehicles. The observation is shared that the vehicle target figures have been adjusted upwards in recent years and that in any case it should be ensured that the charging infrastructure development should have a lead time compared to the current demand. The risk of oversizing in the event of a delayed market ramp-up is considered by all interviewees to be negligible or rather tolerable in terms of the development of the charging infrastructure. It is expected that the expansion of the charging infrastructure will primarily be carried out by the private sector. The expansion and connection to the electricity grid as well as lengthy administrative processes are seen as the main obstacles to the rapid expansion of charging infrastructure.

Focus depot charging

The interviewees also rated depot charging as an important component for the electrification of heavy duty vehicles, as this is where a cost-effective energy supply can usually be realized during longer downtimes (especially at night). This explains why the first customers of e-trucks are currently mainly fleet operators who can electrify their depots for the use of the first e-trucks and who see the lower energy costs as a main incentive. In combination with photovoltaic self-supply, additional incentives are already being created for many transport companies and there are efforts on the part of users and manufacturers to further expand cooperation with energy service providers. However, it was also pointed out that due to the different conditions in depots, e.g. in terms of space, truck usage profiles and grid connection capacity, it will not be possible to roll out standardized solutions in the future.

For current applications in regional transport, low charging capacities of 22 kW AC are sufficient for overnight charging and higher charging capacities of 150 to 350 kW may be required for intermediate charging. It was emphasized that there will also be many applications in the future where an output of 100 to a maximum of 200 kW in the depot will be sufficient. For example, even with a significantly larger battery with 500 kWh of usable capacity, an output of 100 kW per vehicle is sufficient for night charging.

Looking to the future, the experts share the results of current simulations, which assume a share of around 80 % of energy sales from charging infrastructure in depots. Individual players, who are primarily targeting customers with depot charging options in the coming years, assume an even higher share. With regard to this aspect, however, numerous interviewees also expressed great uncertainty, citing possible technical restrictions and increased costs for setting up charging infrastructure and connecting to the grid. They point out that previous estimates of the proportion of charging options are mainly based on user surveys and the analysis of journey data. However, the practical experience to date is still a small sample that does not yet allow a robust extrapolation to the overall market. In view of the possible obstacles to the installation of suitable charging infrastructure in depots and their economic operation, some players also consider a significantly higher significance of public (fast) charging infrastructure in the order of 40 to 50 % of total energy sales to be conceivable. In principle, reference is made to the interactions between public and non-public charging infrastructure, which should therefore always be considered in combination for further expansion.

The main challenge for the development of charging infrastructure in depots is the grid connection. In view of the long planning and implementation periods and high costs for grid expansion, it is often necessary to focus on the available grid connection capacity and the current positioning of substations, especially for short-term demand. In this context, reference is also made to the large number of grid operators in Germany, which makes an accelerated grid connection more difficult. France is cited as a positive example, where the strong centralization of grid operation and expansion results in better and uniform coordination and thus faster action. Against this background, opening up suitable depots to third parties is also mentioned as an attractive option for depot charging and the basic idea is outlined that the spatial location of charging infrastructure in commercial areas should initially be geared primarily to locations with a high grid connection power and not necessarily to the current typical locations of the vehicles. In addition to the high costs and the long lead time for connecting to the grid, the lack of expertise and previous experience on the part of both the users of e-trucks and the grid operator is seen as an obstacle to a rapid ramp-up. Particularly with a view to the future scaling of the technology, safety requirements (e.g. fire protection) and space requirements must be taken into account when positioning the charging infrastructure. As the number of e-trucks increases, load management for the charging infrastructure at the depot is considered to be very relevant and incentives should be provided to make electricity demand more flexible.

Focus on public charging

According to the experts surveyed, there is a need for public charging – assuming an available depot charging infrastructure – for journeys beyond the depot of 150 kilometers or more in order to be able to achieve daily driving distances of more than 300 kilometers with the vehicle models currently available. Public charging infrastructure is particularly relevant for the development of long-distance road freight transport, which, according to the experts surveyed, represents the most attractive business case for the use of battery electric trucks. At the same time, however, it is also emphasized that the charging infrastructure required for this is very likely to be the biggest bottleneck for the market ramp-up in the coming years. Similar to existing studies, the assessment is shared that megawatt charging (MCS) will be necessary for this, but that in many cases and especially for night charging in public areas (e.g. at rest areas along long-distance roads) a lower charging capacity will be sufficient and that flexibility in battery recharging will remain in these cases. Against this background, it is also expected that public charging points will be designed for combined use for MCS and CCS charging.

The development of public charging infrastructure in the immediate vicinity of the highway network is seen as analogous to the AFIR specifications and a maximum distance of 3 kilometers or 5 minutes driving time from the highway is considered tolerable. This extended "search area" is also due to the shortage of space and parking spaces along the main traffic routes. The first public charging locations are expected to be built in places with particularly good conditions and these should ensure an early "positive user experience". In addition to the convenient location along particularly highly frequented traffic corridors, which are characterized by a high number of potentially electrifiable journeys, other non-traffic-related framework conditions also play a major role in the development of the sites. A site can only be developed economically if a long-term concession can be awarded that enables long-term development of the site and successive scaling of the charging infrastructure. The currently available grid connection capacity is a subordinate criterion in the search for a location to the longer-term available connection capacity at the respective location.

According to the interviewees, the AFIR specifications provide good basic coverage in Europe. However, they also point out – similar to current studies – that in Germany, based on the forecast vehicle numbers, a comparable network density, but a significantly higher capacity per location should be targeted and is currently being planned. It is also pointed out that the AFIR targets are only satisfactory if depot charging can be comprehensively developed. The target figures from ACEA (2021) on the other hand, tend to be considered too high.

With regard to the costs of high-power charging, several experts paint a rather positive picture. It is true that the investment costs for an MCS charging point are around 3 to 5 times higher than for a CCS charging point, depending on the local conditions. However, due to the high charging capacity at high utilization, a significantly higher energy turnover can also be achieved. Compared to earlier forecasts for MCS charging and in comparison to CCS charging for trucks, significantly lower prices can therefore be offered. A price level of €0.4 per kilowatt hour (net) is cited as a realistic market entry price.

With a view to future developments, reference is made to the high charging losses in the cable between the transformer and the vehicle for high-power charging. The aim should be to reduce the cable connection to a minimum and automated charging connections via the underside of the vehicle or above the cab via pantographs are also seen as possible developments. In view of the shortage of parking space, the experts consulted also believe that space-saving charging solutions will become increasingly important in the future.

According to the experts, the development of the charging infrastructure network will be carried out by the private sector, but this will be significantly influenced by the government framework. It is expected that the market will be characterized by a smaller number of providers compared to the car charging network. The possibility of roaming and cross-provider reservation of charging points should ensure that several players continue to participate in the market in the future and that competition is created that ensures attractive prices for users.

As with depot charging, a high potential for grid-supportive charging is seen, particularly for night charging. Some interviewees also mentioned stationary battery storage systems as a possible interim solution to cover peak loads if the grid connection capacity is initially low. On the other hand, however, other interviewees emphasized that battery storage systems cannot replace a powerful grid connection if fleets are heavily electrified or there are a large number of charging points at one location.

The main challenge is considered to be the necessary rapid expansion of the charging infrastructure over the next 10 years up to 2035, which is the central prerequisite for the planned market ramp-up of battery electric trucks. In this context, it was noted that although technical proof has undoubtedly been provided that charging capacities of 1 MW are easily possible and up to 3.7 MW are conceivable, the standardization process has not yet been completed and therefore only CCS charging stations will be available in the short term. In the future, however, public charging is expected to focus on MCS chargers, which will nevertheless allow charging at lower (CCS) speeds at certain times of demand (especially at night). The reliability of the charging infrastructure for trucks, on the other hand, must be extremely high at an early stage – and significantly higher than for cars – in view of the high costs of transport failures.

In view of the planned rapid market ramp-up of all manufacturers for battery electric trucks, the risk of oversizing grid connections and charging locations is considered to be extremely low. The now clear technology preference in the truck market in favor of battery electric trucks is seen as a positive development, which significantly increases the directional security for infrastructure investments and enables a new dynamic in the market.

Charging infrastructure for battery electric trucks:

General:

- Availability of a fail-safe charging infrastructure is the key prerequisite for the market ramp-up of e-trucks.
- A lead time for the expansion compared to the planned market ramp-up of e-trucks must always be ensured and temporary oversizing is considered tolerable.

Depot charging:

- Depot charging infrastructure is a key component of electrification. However, its importance can only be assessed on the basis of simulations and a few practical examples.
- The grid connection represents the greatest restriction both in terms of existing connected load and the implementation of new or more powerful grid connections.

Public charging:

- Public (fast-charging) infrastructure is particularly relevant for long-distance traffic and must be built primarily along and near the highway network.
- Charging parks will include a combination of CCS and MCS charging options – with an increasing focus on MCS-capable charging points, especially for long-distance transport.
- The AFIR specifications represent good basic coverage for Europe, but a significantly higher expansion must already be realized for Germany today.
- A predominantly private-sector implementation of the public charging infrastructure is expected.
- In particular, the necessary rapid expansion over the next 10 years is seen as challenging, especially with regard to the necessary grid connection.
- The lack of suitable sites with sufficient grid connection capacity and the need for longer-term concessions to develop sites economically exacerbate the problem.

5 Fields of action for the successful market ramp-up of e-trucks in Germany – challenges and recommendations for action

The interviewees are generally optimistic about the long-term market success of electric trucks and a clear focus on battery electric heavy duty vehicles for the German and European market can be seen across all manufacturers in the product strategy. However, considerable challenges are seen for the market ramp-up, particularly in the short to medium term. In a joint workshop with the interview partners, the central challenges were discussed and prioritized in depth and recommendations for action were developed from the perspective of the vehicle manufacturers and infrastructure experts involved. In the following, the challenges rated as particularly high are summarized and presented in descending order of priority, and specific recommendations for action are named from the perspective of the experts involved.

1: Grid connection of charging infrastructure

The challenge

The expansion of charging infrastructure is consistently rated as the most important lever for the market ramp-up of e-trucks. In this context, the sometimes high costs and, above all, the long lead times for grid expansion and connection are seen as particularly critical – both for private and public charging infrastructure. For Germany in particular, the large number of distribution network operators is seen as critical, as this makes it difficult to take a uniform approach and build up knowledge quickly, among other things. According to the respondents, how the future relationship between private and public charging infrastructure develops will probably also be strongly influenced by the technical and economic feasibility of the necessary grid connection at the respective locations.

Recommendation for action

In view of the outstanding importance of grid expansion and connection, forward-looking planning by politicians and grid operators is considered essential. This should consider the requirements arising from the electrification of cars and heavy duty vehicles as well as further expansion requirements from photovoltaics, the heating transition and industry, define target states and take these into account in early expansion planning. In this context, proactive investment in grid expansion by grid operators is also required.

Even in the short term, greater transparency regarding available grid connection capacity is seen as helpful for site planning. In this context, reference is made to France as a positive example, which keeps the available capacities available in public maps.

Grid connection processes should be accelerated, digitalized, simplified and standardized across the large number of grid operators. In this context, a short-term increase in personnel at the network operators is also seen as necessary in order to cope with the increasing number of inquiries and to be able to process them in a qualified manner.

In view of the high grid connection costs, both targeted subsidies for high grid connection costs and an increased allocation of costs to all users are being considered. In addition, monetary incentives for the flexibilization of electricity demand are mentioned as a further field of action.

2: Development of private charging infrastructure

The challenge

It is true that charging at the depot is the most obvious option for the vast majority of use cases. However, the practical implementation is often associated with greater challenges.

Large fleets with a high degree of electrification and intensive truck use with short downtimes in particular require a high grid connection power. In view of the low location flexibility, depots are therefore sometimes more difficult to electrify than potential public charging locations. In addition, safety requirements must be taken into account, which make it difficult to position the depot charging infrastructure. So far, there is little practical experience from users, meaning that the challenges for the future cannot yet be reliably estimated on the basis of a small sample. Whether the predicted potential of depot charging can actually be realized technically and economically is therefore at least partially doubtful.

To make matters worse, the transport industry is characterized by low margins and has so far been reluctant to set up charging infrastructure in view of the limited scope for investment, with small companies in particular continuing to postpone the technology decision.

Recommendation for action

In view of the main challenge of connecting depots to the grid, it is considered important to raise companies' awareness of the sometimes long lead times and restrictions on grid connection capacity. Where grid connection costs are high, unbureaucratic state subsidies should be used wherever possible. In addition, more incentives should be established for charging at night, which places less strain on the grid.

Switching to depot charging infrastructure from other companies is seen as a possible solution in the event of grid connection restrictions. In this context, it is suggested that the regulatory framework should be adapted to enable such usage models. Pilot and research projects could provide important impetus for implementation in this area.

In view of the high implementation costs and the limited capacities of transport companies, consulting companies that provide expertise on the development of charging infrastructure to the companies concerned are considered to be of great importance for the development of depot charging.

3: Reliable framework conditions in the long term

The challenge

The experts believe that the long-term CO_2 fleet targets, the introduction of the CO_2 price via the ETS and – in the case of Germany – the CO_2-based truck toll provide a reliable framework that robustly secures the economic viability of e-trucks and provides planning security for manufacturers and users. The possible less ambitious design and further development of existing regulations in the new European legislative period resulting from the shift in political power following the European elections in June 2024 is seen as a risk for the investment decisions that have already been made.

Recommendation for action

The weakening of existing targets and frameworks as a result of the EU elections in June 2024 was seen as a major risk. The continuation of the CO_2 price and the CO_2-based truck toll in Germany were named as particularly relevant in this context, as these robustly safeguard the overall cost advantage of e-trucks. Their continuation and Europe-wide expansion – in the case of the truck toll – were named as important levers. The continuation of state subsidies for vehicle procurement was considered less relevant and the prospect was held out that e-trucks could be economically viable and dominate the market from 2030 without any subsidies.

Similar to the highly effective regulation of the supply side through the European CO_2 fleet targets, reference is made to the lack of regulatory impetus for the demand side. It is noted that comparable targets for the demand side (e.g. registration quotas for e-trucks for fleet operators) could already have a short-term effect and accelerate vehicle sales.

4: Development of public charging infrastructure

The challenge

The European regulation on the deployment of alternative fuels infrastructure (AFIR) creates planning certainty for all stakeholders regarding the Europe-wide development of a public charging infrastructure for heavy duty vehicles with basic coverage. However, the commitment of the member states to the development varies, so that the area coverage will show greater differences in Europe in the coming years and thus enable the use of e-trucks in Europe to varying degrees. If it is not possible to implement depot charging to the extent forecast – in particular due to restrictions on grid connection – the AFIR targets are considered to be significantly too low. Another uncertainty is the continuation of regulation after the European elections in June 2024, which may stand in the way of the necessary planning security for the expansion of the charging infrastructure.

Recommendation for action

The updating of the European Alternative Fuels Infrastructure Regulation (AFIR) is seen as an important measure for the planning security of all stakeholders involved. The formulation of national expansion plans that go beyond the level of ambition of the AFIR is considered important and necessary, including for Germany. The possibility of sanctions for member states that fail to meet the AFIR targets is also being considered in order to further increase the binding nature of the expansion, although the likelihood of this being implemented is considered to be rather low.

Government funding or support is considered particularly necessary for the development of (MCS) high-power charging infrastructure. Government funding for public charging locations should take into account privately developed locations in order to avoid market distortions between subsidized and non-subsidized locations and to achieve optimal network coverage.

The creation of a standardized and cross-provider data platform for reserving and booking charging stations is considered essential for a public charging infrastructure that is geared towards user needs. So far, however, resistance from charging infrastructure providers has been observed and roaming approaches are seen as possible alternatives. In the future, an intelligent and networked overall system should be created that extends from the route planning of vehicles to the booking of charging stations and intelligent load management.

5: Change management for users

The challenge

The extent of the transformation requires change management among all stakeholder groups. In this context, however, the particular importance of transport companies is highlighted. A rapid technology change can only succeed if the users also actively tackle it. Currently, relevant knowledge deficits and a reluctance to procure vehicles are still being observed, partly due to the high proportion of small companies. For smaller companies in particular, reference is made to the more difficult financing conditions for additional investments in vehicle procurement and the development of charging infrastructure. With regard to the prospects for the technology, vehicle manufacturers are still perceived by users to be skeptical in some cases. The lack of continuity in public funding and the design of further framework conditions with regard to alternative drive systems is seen as extremely counterproductive, as it increases the risks for investments for transport companies. There are fears that delayed action, particularly among smaller companies, could slow down the transformation and, above all, significantly worsen the competitive position of these companies in the future. In view of the changed technological characteristics and cost structure of e-trucks, manufacturers also expect adjustments to the logistics system in the longer term that are optimized for the use of e-trucks.

Recommendation for action

Sound advice for transport companies is seen as particularly important for acceptance and the switch to e-trucks in practice. It is pointed out that it is almost impossible to develop blueprints due to the different framework conditions and that highly individualized advice is required.

It is expected that a consulting network will increasingly emerge that can be used as a service, so that it is not absolutely necessary to build up expertise in the respective transport company. Among other things, tailored route and TCO (total cost of ownership) analyses, advice on the promotion and development of charging infrastructure and the necessary grid connection are mentioned as important contents.

6: Sites for (public) charging infrastructure

The challenge

A high demand for large and efficient charging parks is to be expected along long-distance transport corridors in particular. At the same time, the pressure on space at these locations is already very high and there is already a shortage of parking spaces, which will be further exacerbated by the space required for charging stations. Long-term concession agreements and a secure grid connection are prerequisites for the economic development of space for charging locations. The limited availability of sites that meet these criteria is an obstacle to the rapid development of charging parks, which in turn are essential for establishing battery electric trucks in long-distance transport.

Recommendation for action

Greater political and administrative commitment is considered necessary for the acquisition of additional truck parking spaces along the highway network. In particular, the high demand for public overnight charging should also be taken into account. In this context, it is also mentioned that the expansion of parking space capacities should also be seen as an opportunity to provide attractive and secure parking spaces for transport companies and thus remedy the prevailing shortcomings, even beyond the charging infrastructure requirements.

For the prompt implementation of public charging parks, it is also proposed that more available information on suitable areas, expected charging requirements and grid connection conditions be made publicly available.

Market ramp-up of e-trucks – challenges and recommendations for action:

1: Grid connection of charging infrastructure:

Limited grid connection capacity and long lead times until the grid connection is implemented as the biggest limitation for the development of high-performance charging infrastructure.

- Forward-looking grid expansion planning based on target conditions and the short-term creation of transparency regarding available grid capacities.

2: Development of private charging infrastructure:

The development of a depot charging infrastructure is made more difficult by location-specific framework conditions and little practical experience to date that allows a forecast of the potential that can be realized.

- Raising companies' awareness of the sometimes long lead times for expanding the charging infrastructure, funding for high grid connection costs and expanding the range of advisory services.

3: Reliable framework conditions in the long term:

Regulatory and financial framework conditions that ensure the switch to e-trucks and the development of the charging infrastructure are not politically secured.

- Existing framework conditions (including AFIR, CO_2 fleet targets, CO_2 price) should be updated ambitiously and in the long term and supplemented with additional instruments (e.g. e-truck quota for fleet operators).

4: Development of public charging infrastructure:

AFIR requirements only create basic coverage for public charging infrastructure and do not provide any long-term planning security.

- Updating the AFIR and increasing the binding nature of the national targets through appropriate sanctioning options and the promotion of MCS charging points.

5: Change management for users:

The introduction of e-trucks requires transformation processes for numerous players and puts pressure on small transport companies with low margins in particular.

- Expansion of consulting services for transport companies that are geared to the respective circumstances.

6: Sites for (public) charging infrastructure:

Lack of space for charging parks along highways and increased pressure on existing parking spaces due to the expansion of charging infrastructure.

- Greater commitment on the part of politicians and administration to the acquisition of parking spaces along long-distance transport corridors and public provision of information on suitable spaces.

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