5

FREIGHT TRANSPORT: INFRASTRUCTURE REQUIREMENTS AND DECARBONISATION

This is a translated version of the original German-language chapter "Güterverkehr zwischen Infrasturkturanforderungen und Dekarbonisierung", which is the sole authoritative text. Please cite the original German-language chapter if any reference is made to this text.

KEY MESSAGES

↘ The increasingly poor condition of road and rail infrastructure in Germany is acting as a drag on economic growth and requires higher levels of capital spending.

↘ Shifting freight transport from road to rail is only possible to a limited extent owing to capacity constraints and largely separate markets for road and rail freight transport.

↘ To ensure that road freight transport can be decarbonised quickly and efficiently, policymakers should first focus on building the necessary charging infrastructure for battery electric trucks.

EXECUTIVE SUMMARY

The **poor condition of Germany's transport infrastructure is** increasingly causing congestion on motorways and poor reliability in rail transport, thus impairing freight transport and economic activity. The foreseeable growth in transport volumes will place an increasing strain on infrastructure, which will **require extensive upgrading**. At the same time, **freight transport** must be **decarbonised.**

The **modernisation** and expansion of transport infrastructure in Germany should be **financed to a greater extent by the users** of this infrastructure**, e.g. in the form of mileage-based car toll.** Allocating fixed amounts of funding to investment promotion organisations could stabilise infrastructure spending and ensure planning certainty. Non-monetary obstacles such as administrative and planning barriers must be removed. A **stronger focus on quality in public procurement procedures** could help to improve such processes.

Shifting freight transport from road to rail in order to accelerate decarbonisation **is only possible to a limited extent**. The potential for this should be strengthened and utilised. Irrespective of this, the capacity and quality of the rail network must be increased. Strict separation of an infrastructure company from the other parts of the DB Group could strengthen the incentives for this. **European coordination of rail freight transport**, e.g. through the Europe-wide introduction of digital automatic coupling, **would increase the efficiency of cross-border freight transport**.

Trucks will remain the dominant mode of transport even in carbon-neutral freight transport. The national carbon price and the CO_2 component of the truck toll – and in future the EU ETS II (EU Emissions Trading System II) – create technology-neutral incentives to switch to alternative drive systems. Battery electric trucks have the greatest market maturity. They can already reduce emissions with today's electricity mix. The **focus should** therefore **initially be on accelerating the market penetration of battery electric trucks**, as this is the only way to achieve significant progress in the decarbonisation of road freight transport by 2030. **This will require the rapid development of the charging infrastructure.** In order to incentivise private investment in this infrastructure, public spaces for the construction of truck charging points in particular – as well as timely digital information on the network capacity of potential charging locations – must be made available quickly and unbureaucratically.

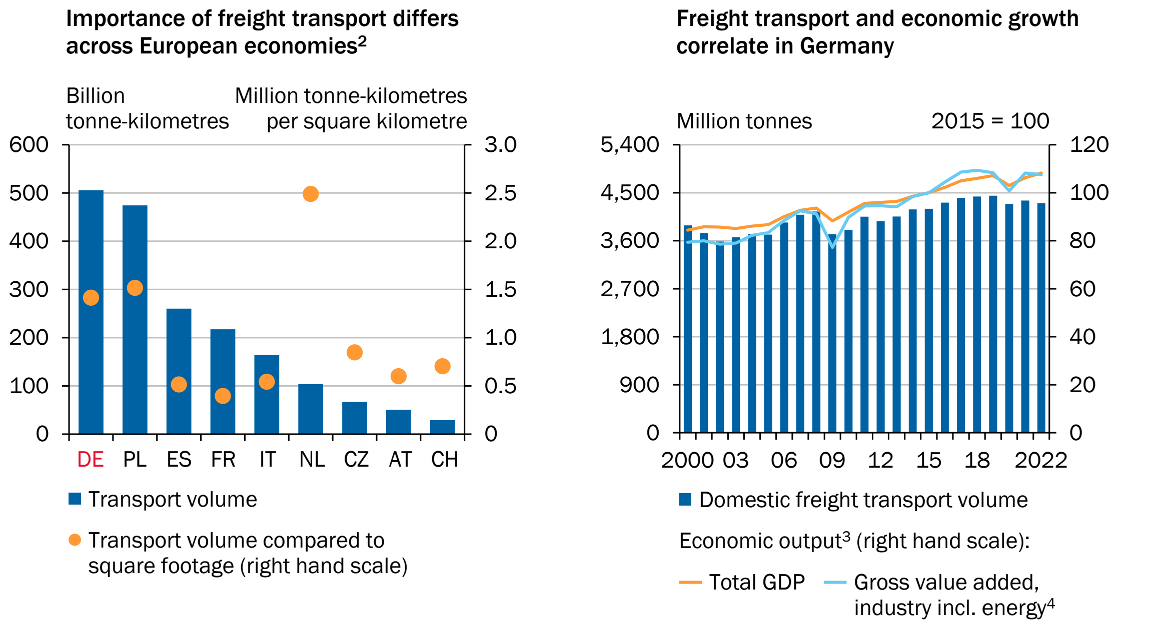
I. INTRODUCTION

425. Inexpensive, fast and **reliable freight transport is essential for any modern economy based on the division of labour** and involving complex value chains (Hummels, 2007; NCFRP, 2012). It therefore makes a major contribution to the productivity of an economy. ↘ BOX 28 Changes in freight transport volumes over time are closely linked to economic development in general. ↘ CHART 96 RIGHT

426. **Lots of freight is transported in Germany** – both in absolute terms and **in relation to the country's geographical size.** ↘ CHART 96 LEFT The importance of transport for an economy depends on the structure of the economy on the one hand and on the size of the country and its geographical location on the other. In economies with a strong service sector, such as Japan and the United Kingdom, freight transport plays a comparatively minor role in value creation. In Germany, on the other hand, where manufacturing and associated intermediate products account for a relatively high proportion of value added, freight transport is more significant. ↘ ITEM 440 ↘ BOX 28 In 2022, the transport and storage sector accounted for 4.9 % of Germany's gross value added. In the European Union (EU) it was slightly higher at 5.2 % in the same year, which is due to the particularly high proportions of gross value added in eastern European countries.

↘ CHART 96

Economic importance of freight transport[1]



1 – Includes domestic, cross-border and transit freight. 2 – DE-Germany, PL-Poland, ES-Spain, FR-France, IT-Italy, NL-Netherlands, CZ-Czechia, AT-Austria, CH-Switzerland. Average values for the years 2017 to 2021, except for Spain (until 2020). 3 – Price-adjusted values, chain index. According to the Classification of Economic Activities, 2008 edition (WZ 2008). 4 – Excluding construction.

Sources: BMDV, FAO, Federal Statistical Office, OECD, own calculations

427. Overcoming **two challenges** is essential to ensure reliable and efficient freight transport in Germany in future. Firstly, the country's **outdated transport infrastructure needs to be modernised and expanded**. And, secondly, **freight transport** must be **decarbonised**. The requirements of carbon-neutral freight transport must therefore be factored into the urgent need for capital spending to maintain and expand the country's transport infrastructure. Given its central geographical location alongside many economically strong neighbours, Germany is also a key transit country for freight transport within Europe. It is therefore important that the process of building the charging and refuelling infrastructure for trucks ↘ ITEMS 505 FF. and the rail infrastructure ↘ ITEMS 549 FF. APPENDIX is coordinated with neighbouring countries.

428. **Transport incurs external costs.** ↘ BOX 26 Freight transport is responsible for one third of greenhouse gas (GHG) emissions from transport and thus for around 8 % of total GHG emissions in Germany. To date, GHG emissions have risen in line with the increase in transport mileage. **In order to achieve the goal of carbon neutrality** by the middle of the century, this correlation must be broken. ↘ ITEM 445 **Three complementary strategies** are conceivable for freight transport, although they hold varying degrees of promise.

Firstly, transport could be **avoided altogether**. However, empirical evidence shows that demand for road transport is not very price-sensitive (de Jong et al., 2010; Musso et al., 2013; Wang and Zhang, 2017; Blechschmidt et al., 2022) and there is a close correlation between freight transport performance and economic development, which is why large-scale avoidance is not to be expected. ↘ BOX 29 ↘ CHART 96 **Secondly**, freight transport can **be shifted** from the roads **to less emission-intensive modes of transport** such as rail. ↘ ITEM 436 However, the demand-side modal shift potential is limited, as trucks serve a fundamentally different transport market than rail and inland waterway vessels. ↘ ITEMS 458 FF. There is also a lack of rail capacity. ↘ ITEMS 463 FF. Forecasts therefore suggest that even carbon-neutral freight transport will still be dominated by trucks. ↘ ITEM 441 ↘ CHART 124 APPENDIX **Thirdly, switching to low-emission drive technologies in road freight transport** can reduce GHG emissions per tonne-kilometre (tkm). ↘ ITEMS 467 FF. Under current conditions this strategy offers the greatest leverage for decarbonising freight transport. Even this, however, involves major challenges, such as the building of a suitable charging and refuelling infrastructure, including the associated network expansion. ↘ ITEMS 481 FF.

429. **Market-based control instruments** such as the national price of carbon emissions in the transport sector (national emissions trading system, nETS), which will be incorporated into the expanded European emissions trading system EU-ETS II (EU Emissions Trading System II) in future, ↘ ITEM 450 and the carbon-based truck toll ↘ ITEM 452 **aim to internalise the external effects of freight transport** and provide technology-neutral incentives for its decarbonisation. This requires the design of these instruments to provide a sufficient incentive to achieve carbon neutrality. Climate targets are likely to be missed under the price corridor defined in the nETS to date (Rickels et al., 2023). Although higher prices could materialise in the EU ETS II in future, there is a general lack of planning

certainty about the future price of carbon emissions in the transport sector (SVR Wirtschaft, 2023). ↘ ITEM 451

Even if the price of carbon emissions corresponds to the external costs of GHG emissions, various **market imperfections** can **slow down decarbonisation**. For example, network externalities and coordination problems can slow down or even prevent the building of a charging and refuelling infrastructure and the switch to low-emission drive systems. ↘ ITEM 516 In addition, research and development (R&D) into new drive systems typically gives rise to knowledge externalities that lead to inefficiently low R&D expenditure. Government intervention should focus on addressing such market imperfections in a targeted way, e.g. by government agencies taking on a coordination role or promoting research activities.

430. Germany's **outdated transport infrastructure** must be **modernised and expanded to ensure efficient and future-proof freight transport**. To this end, the funding for much-needed capital investment must be secured ↘ ITEMS 492 FF. and planning and approval procedures must be simplified. ↘ ITEMS 494 FF. Where there is **potential for a modal shift from road to rail**, this can only be achieved if the capacity and efficiency of rail freight transport is increased. ↘ ITEMS 496 FF. The **removal of disincentives** when **carrying out maintenance work on rail infrastructure** represents an important lever in the sustainable improvement of this infrastructure. ↘ ITEM 501

431. **The biggest obstacle to the ramp-up of alternative drive technologies** in road freight transport is the **lack of charging and refuelling infrastructure for low-emission trucks**. Monetary and non-monetary barriers are restricting its construction. ↘ ITEMS 505 FF. The regulatory framework for private investment in charging infrastructure could be improved by making public spaces available quickly and unbureaucratically and by providing information on suitable locations and network capacity digitally and free of charge. ↘ ITEMS 507 FF. Government funding could address coordination and network externalities ↘ ITEM 516 and thus accelerate the nationwide building of charging and refuelling infrastructure. The reorganisation of the Climate and Transformation Fund (KTF) in the wake of Germany's Federal Constitutional Court (BVerfG) ruling has led to a reduction in public funding for the construction of charging and refuelling infrastructure. ↘ BACKGROUND INFO 20 It is therefore now particularly important to prioritise available funding and to target it at areas where it can achieve a particularly large leverage effect.

432. There are various reasons why **available planning capacity and public funding should initially be concentrated in the short term on** facilitating the direct use of electricity in road freight transport for broad market segments and **ensuring the needs-based construction of charging infrastructure for battery electric trucks (BE trucks)**. BE trucks currently have the greatest market maturity in road freight transport. Given the huge technological advances made in battery and charging technology, it should be possible for BE trucks to cover all application profiles of road freight transport in the future with the exception of just a few niche applications. ↘ ITEM 469

The **widespread use of other low-emission drive technologies** such as fuel-cell electric trucks (FCE trucks) and overhead-line hybrid trucks is **technically possible** but is **not expected in the near future owing to the technological and market barriers that** still exist. ↘ ITEM 470 ↘ BOX 31 **By contrast**, given the ranges and charging technologies available **today** and at today's energy prices, **BE trucks can provide** local and distribution transport – which accounts for **a large proportion of road freight transport – more economically than diesel trucks** ↘ ITEMS 473 FF. and can already realise emission reduction potential using today's electricity mix. ↘ ITEM 471 To ensure economically efficient decarbonisation, this comparatively readily available potential should therefore be exploited as a matter of priority. There are also considerable synergies to be reaped from ramping up BE trucks and expanding the network for charging facilities along motorways. It is therefore a **no-regret measure** to give top priority to the ramp-up of BE trucks in both the private and public spheres.

433. **Where the technical and market barriers to a market ramp-up are even higher** than for BE trucks, especially for FCE trucks and the use of synthetic fuels, however, the focus should be on **technology-neutral research funding** and the **testing of applications in road freight transport that are difficult to electrify**. This leaves open the option of using these drive technologies in parallel with BE trucks at a later date, should this be necessary for technical reasons in certain application profiles or for reasons of economic efficiency. ↘ ITEMS 469 AND 473 FF. However, setting up a publicly funded nationwide hydrogen refuelling infrastructure for FCE trucks for such applications in the short term would not be very effective. There is still too much technical and market uncertainty here. ↘ BOXES 31 AND 33 In addition, such niche applications that are difficult to electrify could also be served by mobile hydrogen filling stations or company filling stations, for example, or decarbonised by synthetic fuels that can make use of the existing refuelling infrastructure. As the ramp-up of the charging and refuelling infrastructure for low-emission drive systems must be coordinated at European level, Germany should support a reassessment of the requirements placed on the infrastructure for alternative fuels regulated by the AFIR, which provides for the nationwide construction of a hydrogen refuelling infrastructure for trucks by 2030, as part of the interim evaluation of the EU Regulation on the deployment of alternative fuels infrastructure (AFIR) at the end of 2024. ↘ ITEM 524

II. CURRENT SITUATION: FREIGHT TRANSPORT IN GERMANY AND EUROPE

434. The foreseeable increase in freight transport in Germany ↘ ITEM 441 poses **two major challenges**. Firstly, the already **overstretched infrastructure** will be **put under even greater strain** than before. This transport infrastructure must therefore be modernised and expanded. And, secondly, the **external costs of freight transport** are likely to increase owing to the higher volume of traffic. In particular, GHG emissions will rise unless efforts are made to decarbonise. ↘ ITEM 446

1. Structure of existing freight transport

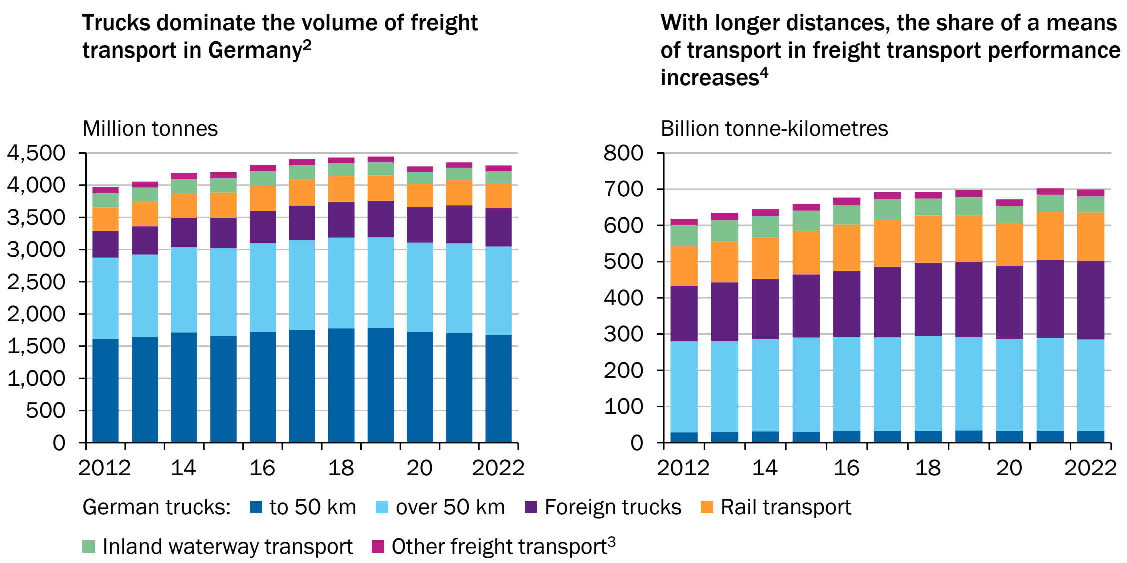
435. **Road** is **by far the most common mode of freight transport**. Around 70 % of the total volume of freight ↘ BACKGROUND INFO 16 was transported by truck in 2022. ↘ CHART 97 LEFT Roughly 14 % of the total volume of freight was transported by foreign trucks. This share has increased by around 3 percentage points over the past ten years. As foreign trucks travel longer distances than German trucks, their share in terms of freight transport performance, i.e. the volume of freight transport per distance travelled, is higher and has grown more sharply. ↘ CHART 97 RIGHT More than half of the freight transported by German trucks (measured in tonnes) in 2022 was moved less than 50 km. In 2022 only 9 % of the total volume of freight was transported by rail and less than 5 % by inland waterway. As rail and waterways serve longer transport routes, their share is higher in terms of freight transport performance.

↘ BACKGROUND INFO 16

Terminology: freight transport in Germany

Freight transport includes the transportation of goods by road, rail, waterway, air and pipeline. In transport statistics, the **modal split is defined** as the distribution of freight transport volume (in tonnes) or freight transport performance (volume per distance travelled, expressed in tonne-kilometres) across different modes of transport. Freight transport in Germany comprises all transport routes that are travelled within Germany; this includes domestic, cross-border and transit freight. Road freight transport is typically divided into **local freight transport** (up to 50 km), **distribution transport** (between 50 and 150 km) and **long-distance freight transport** (over 150 km). The transportation of freight by road is carried out by trucks. A distinction is made between light trucks (up to 7.5 tonnes), medium trucks (up to 13.5 tonnes) and heavy trucks (up to 40 tonnes). Light and medium trucks are mainly used for local and distribution transport, while heavy trucks are mainly used for long-distance freight transport.

↘ CHART 97
Freight transport volume and freight transport performance by means of transport[1]



1 – Excluding maritime shipping. 2 – Includes domestic, cross-border and transit freight. For the distance in kilometres, only the routes travelled within Germany are taken into account. 3 – Air transport (freight and airmail, including double counting in transhipment) and pipelines. 4 – Refers to the distance travelled within federal territory. Transport performance from the border to the point of destination abroad and from the point of origin abroad to the border of the Federal Republic of Germany are not included here.

Sources: BMDV, own calculations

436. **Depending on the type of freight, different modes of transport are prioritised.** ↘ CHART 98 The energy transition is likely to reduce demand for bulk goods such as coal, oil and coke, which are mostly transported by rail or inland waterway (Repenning et al., 2023). This is likely to free up capacity on railways and waterways (Blechschmidt et al., 2022). ↘ CHART 98 However, this capacity is likely to be needed in future for significant growth in the transportation of other bulk goods such as ammonia and hydrogen (Arlt et al., 2023; DWSV, 2023; Reiner, 2023).

437. The majority of freight is transported by road. ↘ CHART 98 **Most freight** in Germany and Europe is transported **over distances of less than 200 km** (75 %) and involves consignment weights of up to 30 tonnes (85 %) (Blechschmidt et al., 2022). ↘ CHART 123 APPENDIX In most cases, transport by rail rather than by truck is either not possible or is currently not very competitive (UBA, 2022). Only a few firms have direct access to the rail network. Transport over the last mile must therefore take place by truck (DB, 2022). Rail freight transport and road freight transport should therefore be regarded as separate markets (Bundeskartellamt, 2005).

438. **There are considerable differences in modal splits between the EU member states.** ↘ BACKGROUND INFO 16 According to Eurostat, rail freight transport accounted for 17.1 % of total freight transport performance (in tonne-kilometres) in the EU in 2022, while road freight transport accounted for 77.8 %. The modal split in Germany is around the European average, with rail freight transport having a slightly higher share. ↘ CHART 99 In rail freight transport the share of cross-

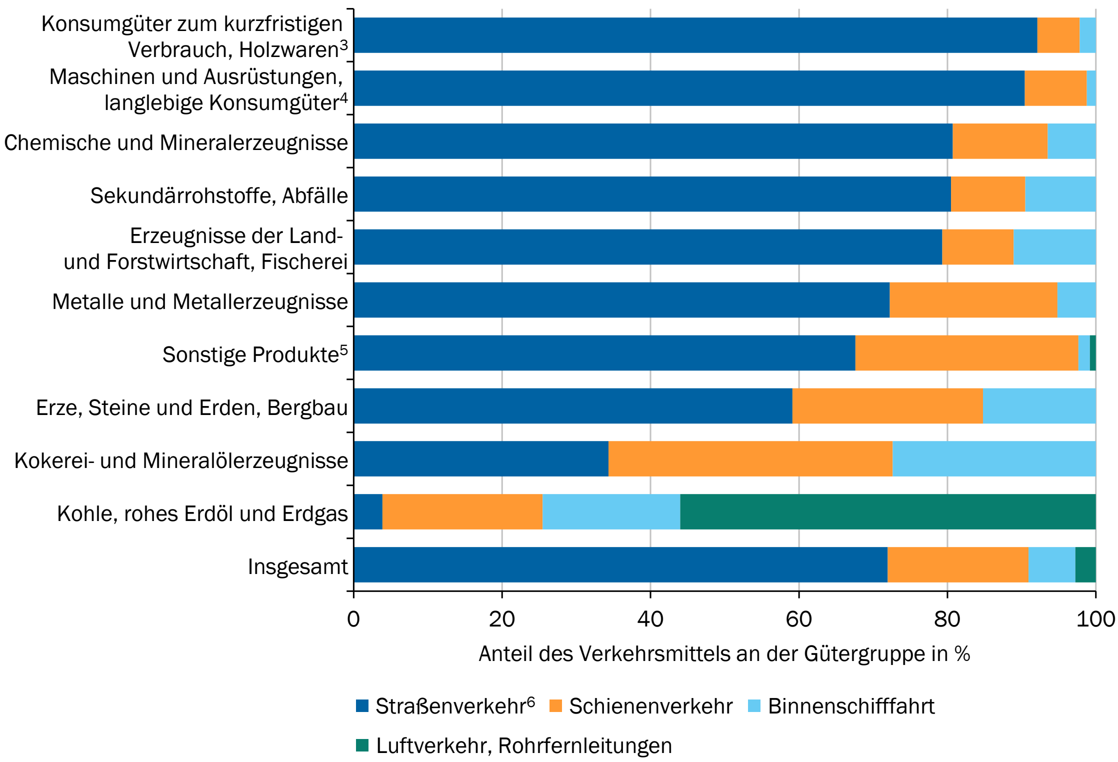
border consignments and transit transport in Germany in 2022 was 51 %, according to Eurostat, compared with an EU average of 50 %. Cross-border and transit freight transport accounted for 40.9 % of road freight transport in Germany (BMDV, 2023a).

439. Although **freight transport** is essential for the geographical division of labour in value chains, it **places a burden on the environment and society**, e.g. through climate-damaging GHG emissions, local air pollution, noise, accidents and traffic congestion (Board of Academic Advisors to the BMVBS, 2009; Leisinger and Runkel, 2023). These external costs are currently only partially internalised by policy frameworks, as are the costs arising from the wear and tear on infrastructure (Kopper et al., 2013). ↘ BOX 26

↘ CHART 98

Verkehrsleistung[1] nach Verkehrsmitteln und Gütern[2] im Jahr 2022

Transportmittelwahl heterogen – Straßentransport dominant



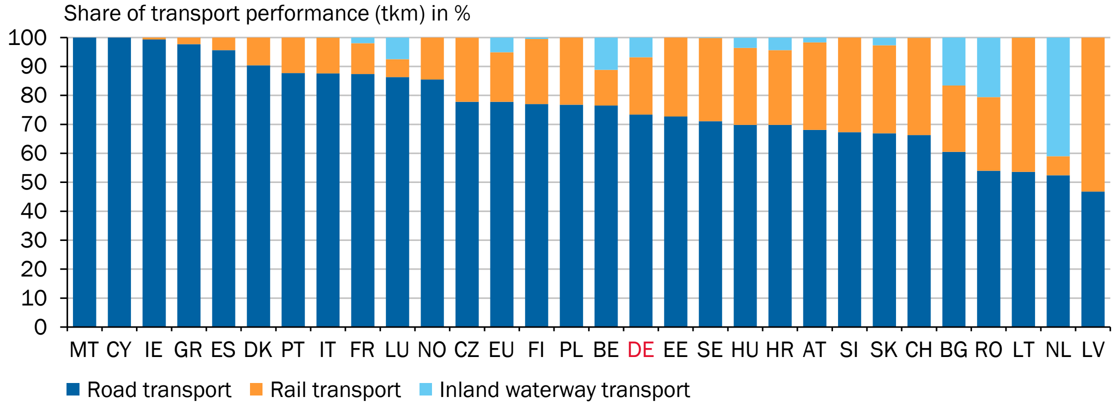
1 – Basierend auf der auf dem Bundesgebiet erbrachten Verkehrsleistung in Mrd Tonnenkilometern (ohne Seeschifffahrt). 2 – Gemäß dem Einheitlichen Güterverzeichnis für die Verkehrsstatistik (NST 2007). 3 – Nahrungs- und Genussmittel, Textilien, Bekleidung, Leder und Lederwaren, Holzwaren, Papier, Pappe, Druckerzeugnisse. 4 – Maschinen und Ausrüstungen, Haushaltsgeräte, Fahrzeuge, Möbel, Schmuck, Musikinstrumente, Sportgeräte. 5 – Post, Pakete, Güter und Material für die Güterbeförderung, Umzugsgut und sonstige nichtmarktbestimmte Güter, Sammelgut, Gutart unbekannt, sonstige Güter. 6 – Die Verteilung auf Gütergruppen wird vom BMDV nur für inländische LKW veröffentlicht, die Verteilung für ausländische LKW wurde mithilfe von Daten des KBA (2024) geschätzt.

Quellen: BMDV, KBA (2024), eigene Berechnungen

↘ CHART 99

Modal Split in domestic freight transport[1] in Europe in 2022

Road freight transport dominates in almost all European countries[2]



1 – Delimitation according to the territorial principle. Includes total freight transport volume on the territory of the respective country by domestic and foreign nationals (incl. cross-border freight transport and transit traffic). 2 – MT-Malta, CY-Cyprus, IE-Ireland, GR-Greece, ES-Spain, DK-Denmark, PT-Portugal, IT-Italy, FR-France, LU-Luxembourg, NO-Norway, CZ-Czechia, EU-European Union (27), FI-Finland, PL-Poland, BE-Belgium, DE-Germany, EE-Estonia, SE-Sweden, HU-Hungary, HR-Croatia, AT-Austria, SI-Slovenia, SK-Slovakia, CH-Switzerland, BG-Bulgaria, RO-Romania, LT-Lithuania, NL-Netherlands, LV-Latvia. Estimated data for Belgium, Switzerland and the European Union.

Source: Eurostat

↘ BOX 26

Background: externalities and cost internalisation in freight transport

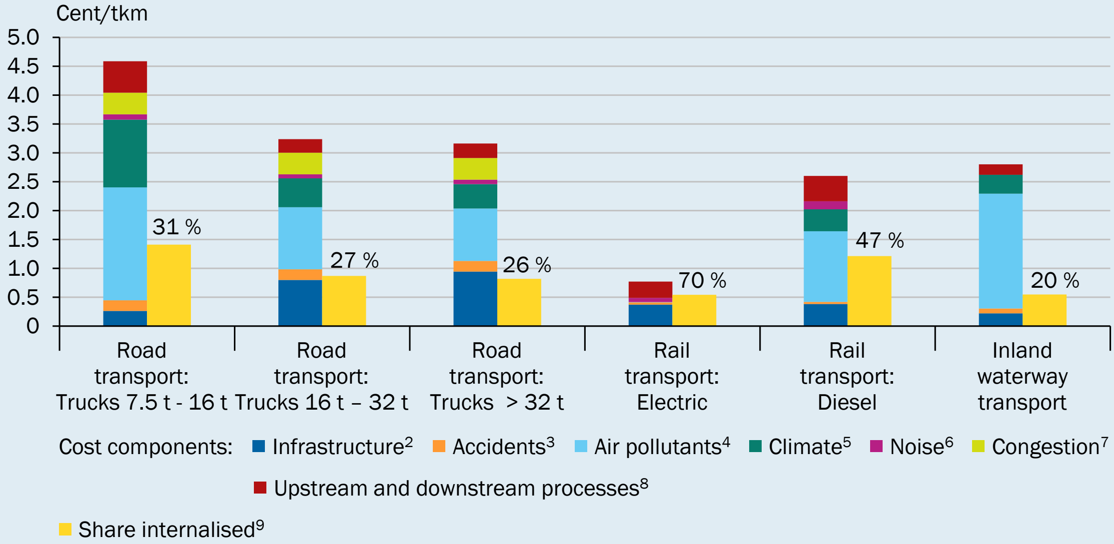
In addition to the costs incurred directly by the transport company, freight transport causes costs in the form of wear and tear on infrastructure and external costs, e.g. through environmental and noise pollution. The total external costs of domestic freight transport in Germany were estimated to be 32.5 billion euros in 2017, which is around 1 % of gross domestic product (GDP). The costs of climate impacts and local air pollution are particularly high, accounting for a share of 37 % (Bieler and Sutter, 2019). **If external costs are not internalised** through an appropriate policy framework, neither transport companies nor their customers will factor them into their decisions. Consequently, **the volume of freight transport can be inefficiently high** and – if external costs and their internalisation vary – the choice of mode of transport may be distorted (Leisinger and Runkel, 2023). Very few recent studies attempt to record and quantify the external costs of freight transport for the EU (European Commission, 2019a, 2020) and Germany (Bieler and Sutter, 2019; UBA, 2020a). The studies conducted by the European Commission (2019a, 2020) are the most comprehensive and are the only ones to report a degree of internalisation of the costs of externalities and infrastructure.

Measured in terms of average costs (Bieler and Sutter, 2019; UBA, 2020a) and marginal costs ↘ GLOSSARY (European Commission, 2020), **road freight transport has higher negative externalities than other means of transport.** Transporting an additional tonne-kilometre by road incurs external costs of between 3.2 and 4.6 euro cents, depending on the truck's load capacity. ↘ CHART 100 Climate pollution and air pollution account for more than half of these costs. The marginal cost of transporting one tonne-kilometre by electrified train is significantly lower at around 0.8 euro cents. More than one third of these marginal costs are attributable to upstream and downstream processes, which include the provision of energy for electrification.

↘ CHART 100

Marginal external costs and their internalisation in freight transport in 2016[1]

The degree of internalisation for rail transport is significantly higher than for other modes of transport



1 – Data basis from 2016, in 2023 prices (calculated using the consumer price index). 2 – Costs for new construction, expansion, maintenance and repair. 3 – Personal injury, medical costs, administrative costs, consequential economic loss, property damage and other consequential accident costs. 4 – Damage to health, crop failures, material and building damage and loss of biodiversity. 5 – Costs due to rising sea levels, loss of biodiversity, water management problems, extreme weather events and crop failures. A CO_2 price of 100 euros per tonne was used as a basis. 6 – Physical and psychological impact of noise. Noise costs can only be reliably estimated for road and rail freight transport. 7 – Costs due to delays and congestion. Congestion costs can only be reliably estimated for road transport. 8 – Costs of generating, converting, transporting and transmitting the required energy. For energy generation in rail freight transport, the electricity mix specific to rail transport is assumed. Other life cycle costs such as production, maintenance or disposal of the means of transport are not taken into account. 9 – Share of variable taxes and charges in marginal external costs; for details see items 190 ff. Appendix.

Sources: European Commission (2019a), Federal Statistical Office, own calculations

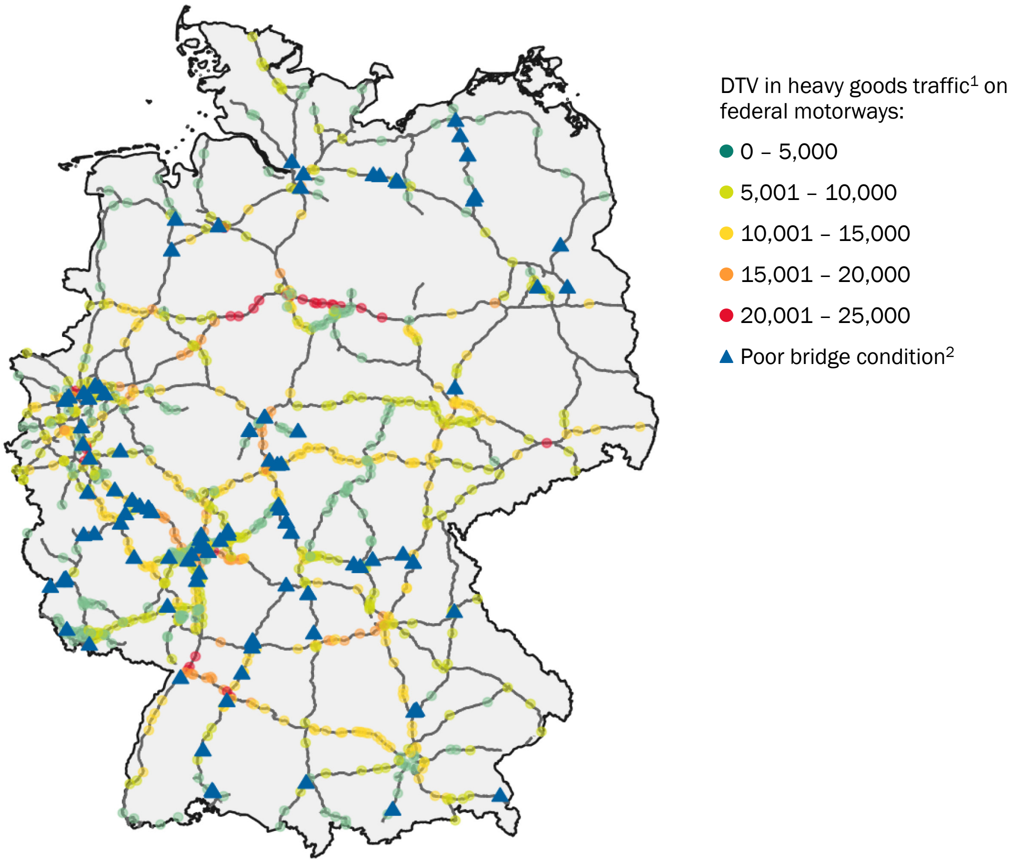
The **degree of internalisation for electrified rail freight transport** is **significantly higher than for other means of transport.** ↘ CHART 100 The external marginal costs shown in the chart and their internalisation were calculated for 2016. Various regulatory changes have occurred since then. In particular, a national carbon price ↘ ITEM 450 and a carbon-based truck toll ↘ ITEMS 452 FF. are now levied in the transport sector. According to estimates by the GCEE, these measures are likely to have increased the degree of internalisation for trucks weighing up to 16 tonnes by around eleven percentage points and for heavy trucks weighing more than 32 tonnes by around seven percentage points. ↘ ITEMS 555 FF. APPENDIX The degree of internalisation for electrically powered freight trains is likely to have increased slightly overall. The carbon price in the EU ETS has risen almost tenfold since the 2016 reporting year, causing a significant increase in internalisation. By contrast, the abolition of the EEG surcharge on electricity and the German government's subsidising of railway line charges has had a dampening effect. ↘ ITEMS 454 F.

2. Challenge: transport infrastructure

440. **Germany plays** a key role in European freight transport owing to its **central geographical location** and proximity to the three most important seaports in Europe (Rotterdam, Antwerp and Hamburg). ↘ CHART 121 APPENDIX There are also international rail freight connections with direct links to inland waterways (Duisburg) and airports that are crucial for freight transport (Frankfurt am Main and Leipzig/Halle). However, the condition of this infrastructure has deteriorated on all transport routes in recent years. ↘ CHART 101 ↘ BOX 27 The introduction of traffic restrictions or even the closure of bridges in very poor condition – as has been the case with the A45 Rahmede viaduct since 2021, for example – has serious consequences for the economy. ↘ BOX 28

441. **Freight transport performance** has risen sharply since the post-war period, ↘ CHART 102 TOP particularly in road freight transport and, since German reunification, in rail freight transport. ↘ CHART 102 BOTTOM The future trajectory of freight transport can be estimated using **various forecasting models** at global, European and national level, which are a key component of infrastructure planning. ↘ BACKGROUND INFO 17 Based on its global transport model, the OECD expects freight

↘ CHART 101
Average daily traffic volume (DTV) on the federal motorways in 2021
Many dilapidated bridges on heavily used motorway routes



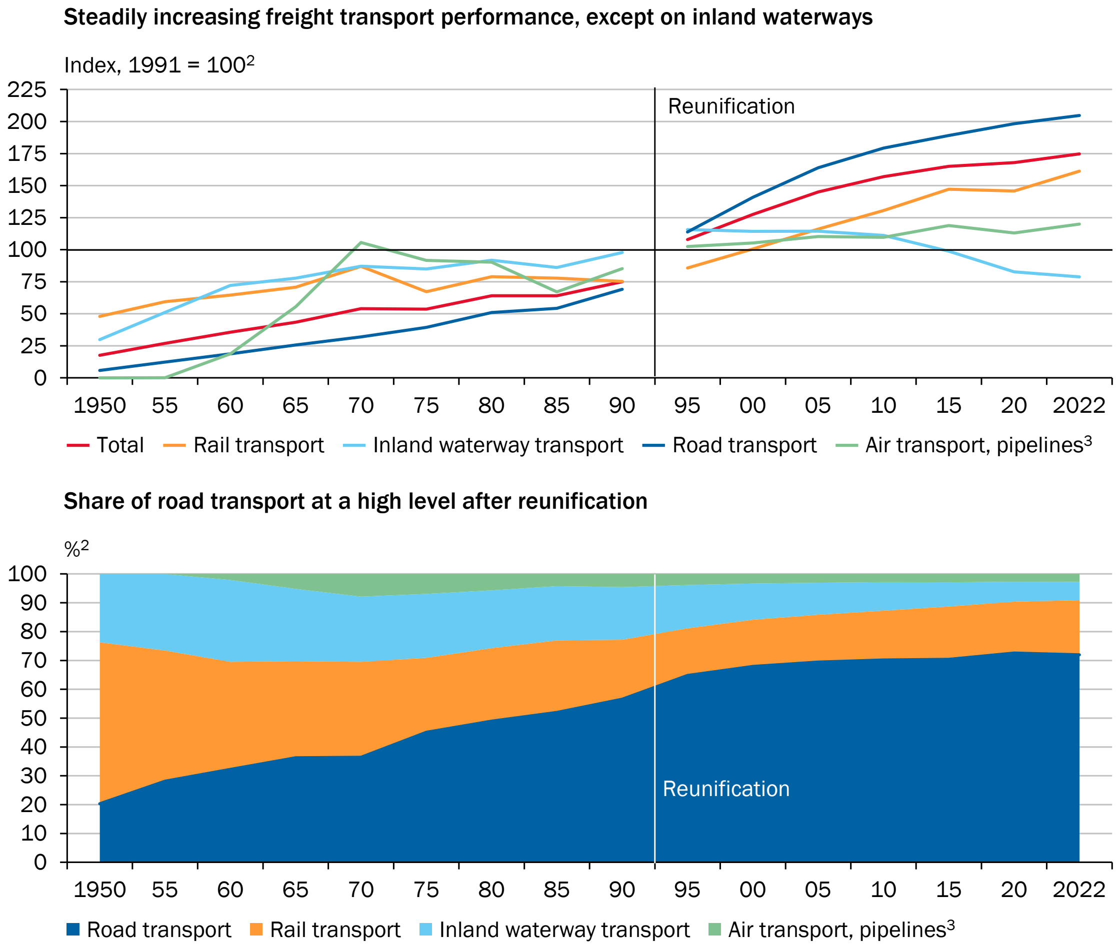
1 – The figure shows the average daily traffic volume for heavy goods vehicles travelling in both directions on all days of the week. 2 – Bridges with the worst condition score in the range of 3.5 – 4.0.

Sources: Federal Highway Research Institute, GADM, © OpenStreetMap contributors (2024), own presentation transport performance in Europe to increase by 71.6 % by 2050 compared with 2019 (ITF, 2023a). The EU's model assumes lower growth of only 50 % compared with 2015 (De Vita et al., 2021). The moving long-term forecast by the Federal Ministry for Digital and Transport (BMDV) predicts a 46 % improvement in freight transport performance for Germany by 2051 compared with 2019 (Intraplan and Trimode, 2023). What all models have **in common** is that **they forecast an increase in freight transport performance**, particularly **in road freight transport**. In Germany, for example, freight transport performance is expected to grow more sharply by road (up 54 %) than by rail (up 33 %) or waterway (0 %) (Intraplan and Trimode, 2023). According to this forecast, rail's share of the modal split could fall to around 17.3 % in future.

442. **Large parts of the infrastructure in Germany are not designed to cope with today's freight traffic**. Freight transport performance per kilometre by both road and rail has doubled since reunification. ↘ CHART 103 The age profile of

↘ CHART 102

Freight transport performance and modal shares in Germany[1]



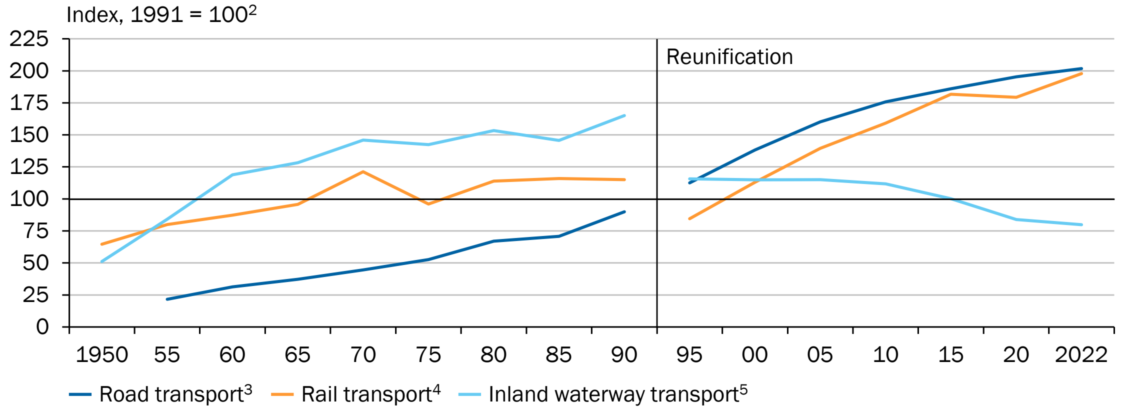
1 – Excluding maritime shipping. Until 1990: former territory of the Federal Republic of Germany. 2 – Calculations based on freight transport performance in tonne-kilometres (tkm). This includes domestic, cross-border and transit freight. For the distance in kilometres, only the routes travelled within Germany are taken into account. 3 – Air transport includes freight and airmail without transhipments.

Sources: BMDV, own calculations

↘ CHART 103

Freight transport performance per km of transport route[1]

Since reunification, the load on the road and rail network has increased significantly



1 – Excluding maritime shipping. Until 1990: former territory of the Federal Republic of Germany. 2 – Calculations based on freight transport performance in tonne-kilometres (tkm). This includes domestic, cross-border and transit freight. For the distance in kilometres, only the routes travelled within Germany are taken into account. 3 – Interurban roads, including through roads. No data available for 1950. 4 – Operating length of the Deutsche Bundesbahn and Reichsbahn or DB AG. Until 1960 without Saarland and Berlin-West. 5 – Federal inland waterways, excluding the routes delegated by the federal government to the Länder for administration (Hamburg, Ems-Jade Canal).

Sources: BMDV, own calculations

bridge structures is a growing problem in view of the increasing loads involved (GCEE Annual Report 2019 chart 88). ↘ BOX 27 The infrastructure on all transport routes is already in poor condition. ↘ BOX 27 Much of it will have to be replaced or upgraded in the near future. This will affect all transport routes and will make it more difficult to shift transport from road to rail or waterways.

↘ BOX 27

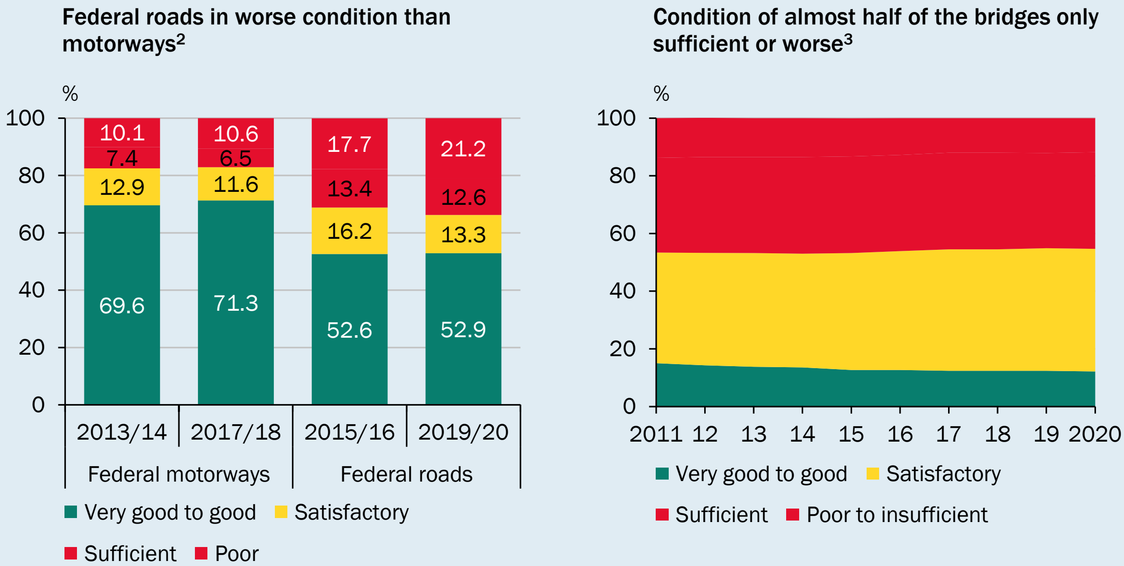
Background: state of the transport infrastructure in Germany

The **condition of the road and rail infrastructure** is **assessed at regular intervals,** which serves as the data basis for maintenance management purposes and the planning of maintenance work. The condition ratings range from 1 (very good / new) to 5 (very poor / deficient). They indicate whether maintenance work is necessary, but they do not allow any conclusions to be drawn as to whether the structures are unsafe for traffic. Structures with poor condition ratings can still be used with certain restrictions (BMDV, 2023b, p. 178 ff.; DB InfraGO, 2024a, p. 9 ff.).

The condition of federal trunk roads can be seen from their asset values and utility values. Their **asset values** show that **federal motorways** are **in a comparatively good condition in contrast to federal highways and municipal roads.** ↘ CHART 104 LEFT Traffic restrictions (e.g. lower speeds, vehicle-distance regulations) are being examined or have already been introduced for 10.6 % of federal motorways and 21.2 % of federal roads. Their **utility values**, on the other hand, which reflect the driving comfort of the road rather than its structural condition, are **significantly better.** This **suggests that maintenance work is** primarily **focused on restoring a good road surface** without improving its structural substance (Scientific Advisory Board to the BMWi, 2020).

↘ CHART 104

Condition[1] of roads and bridges on federal roads



1 – The information is taken from the transport investment reports of the Federal Ministry for Digital and Transport for the respective years. 2 – Summarised five-stage substance values. The categories very good to good correspond to the grades 1 to 2.5, satisfactory 2.5 to 3.5, sufficient 3.5 to 4.5 and poor 4.5 to 5. From a grade of 3.5, the warning value is exceeded and intensive monitoring and analysis is initiated, as well as the planning of measures if necessary. 3 – Summarised six-stage substance values. The categories very good to good correspond to the grades 1 to 1.9, satisfactory 2.0 to 2.4, sufficient 2.5 to 2.9 and poor to insufficient 3.0 to 4.0. From a grade of 3.0, the warning value is exceeded and repair measures must be taken in the near future.

Sources: BMDV, Deutscher Bundestag

The condition of bridges on federal trunk roads is also deteriorating. ↘ CHART 104 RIGHT A large proportion of today's bridges in former West Germany were built during the 1970s (GCEE Annual Report 2019 chart 88). The traffic load models used were based on the gross vehicle weights and axle loads permitted at the time. However, these have increased during the interim decades, which is why the older bridges built before 1985 in particular are only designed for significantly lower loads (BMDV, 2022). ↘ CHART 104 RIGHT When the Rahmede viaduct on the A45 motorway was planned in the 1960s, for example, it was projected to have a daily traffic load of 25,000 vehicles by 1980. When the bridge was completed in 1968, the permissible total weight was 38 tonnes. Most recently, however, the load on the bridge was 64,000 vehicles, of which around 13,000 were trucks (Autobahn GmbH, 2024). In addition, the current permissible total weight for trucks is 40 tonnes, which is higher than it was back then, and data from truck weighing systems on other bridges confirms that even this weight is regularly exceeded (Land.NRW, 2019). Based on their current service life of 100 years, this means that many bridges have already reached the halfway point in their life cycle. However, the sharp increase in freight traffic is putting greater strain on them than originally planned, ↘ CHART 102 TOP which is why their actual service life is likely to be shorter (BMDV, 2022).

The state of the rail infrastructure was assessed for the first time in 2021 as part of the Network Condition Report, which used a rating system similar to that used for roads. **The rail network's overall score** of 3.01 in 2022 has **deteriorated further** compared with the previous year (2.93). ↘ CHART 105 More than half of assets are considered mediocre or worse and therefore potentially need to be repaired or replaced, or even have a backlog. 16.2 % of assets in the overall network have a heightened probability of operational impairment. **Punctuality-relevant assets such as signal boxes, level crossings, track and points receive the worst ratings.**

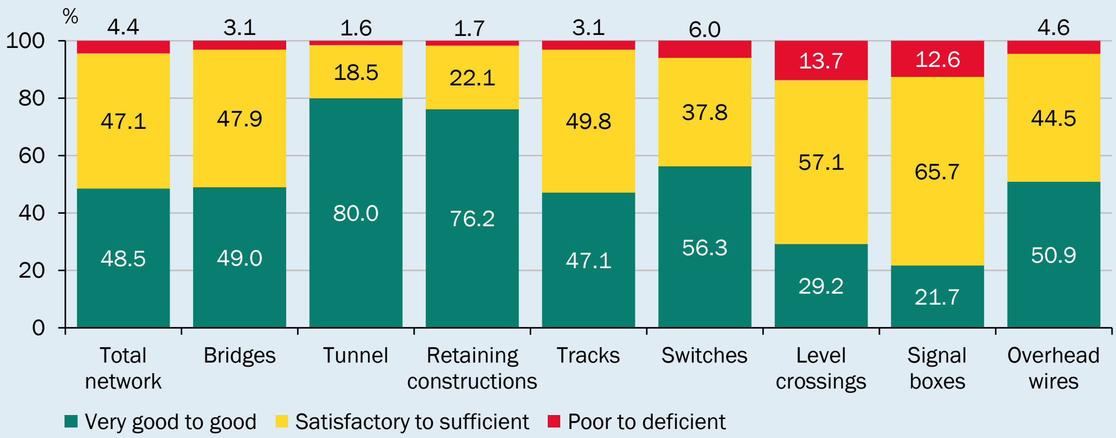
More than half of railway bridges are in poor condition and at least require maintenance work and the simultaneous planning of replacement investment. ↘ CHART 105 5.8 % or 1,485 railway bridges need to be completely rebuilt (DB InfraGO, 2024a). The main reason for the poor condition of many types of assets is their age and their associated susceptibility to malfunction (DB InfraGO, 2024a). The number of infrastructure defects has therefore recently increased and the targets set in the Performance and Financing Agreement (LuFV) have been missed by a long way (DB, 2024a).

The condition of bridges over the canal waterway network is also poor. Almost 50 % of all bridges and 85 % of locks are only in an adequate or worse state of repair (BMVI, 2015a, 2020). ↘ ITEM 460

↘ CHART 105

Condition grades[1] by asset type for the entire railway network in 2022

Signal boxes, level crossings, tracks and switches in poor condition



1 – Summarised status grades based on the grading scheme of the network status report. The categories very good to good correspond to grades 1 to 2, satisfactory to sufficient 3 to 4 and poor to deficient 5 to 6 (restrictive).

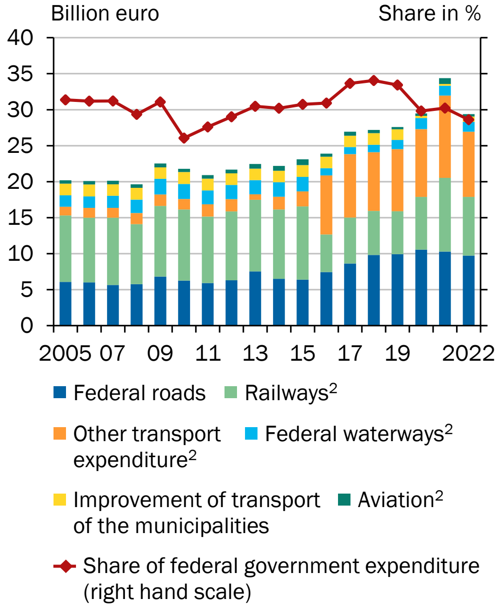
Sources: DB InfraGO (2024a), own calculations

443. The German government's expenditure on transport infrastructure remained largely constant on a price-adjusted basis during the years from 2005 to 2015. ↘ CHART 106 LEFT Measured as a share of the total federal budget, transport spending actually fell significantly after the financial crisis. It has only been rising noticeably again since 2016. The railways in particular have benefited from this. Funding for waterways and federal trunk roads has also increased. **Currently, however, the sharp rise in prices is dampening growth** in real expenditure. Transport spending accounted for 5.7 % of the total federal budget in 2022. 60.1 % of this was spent on capital investment and 39.9 % on maintenance. Capital expenditure is defined as maintenance work that goes beyond normal repairs, as well as replacement construction and new building. However, the level of capital spending is insufficient to maintain the value of the infrastructure. ↘ CHART 106 RIGHT Only in the case of railways has the loss of value, i.e. the decline in the degree of modernisation, been halted recently.

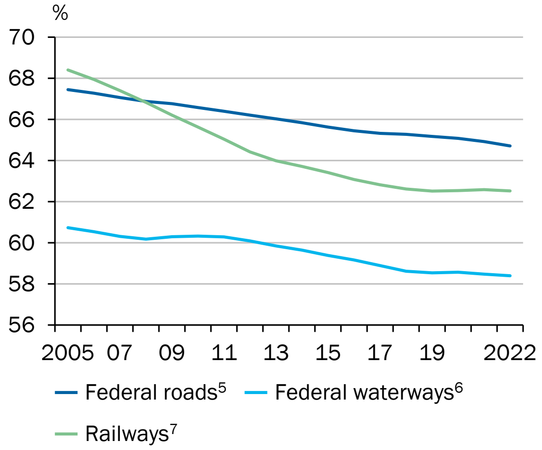
↘ CHART 106

Development of federal transport expenditure and modernity level

Rail and road are the drivers of increased transport expenditure[1] since 2016



Modernity level decreases[3]: Investments are too low to maintain value[4]



1 – Price-adjusted transport expenditure with the average development of the construction price indices in building construction and civil engineering. 2 – As part of a comprehensive modernisation of the budget and accounting system in 2016, administrative services and special assets were reclassified to other transport expenditure. 3 – Net fixed assets in relation to gross fixed assets. Year- end balance without land acquisition. 4 – Provisional values for the years 2020 to 2022. 5 – Excluding administration. 6 – Up to the sea border. 7 – Traffic routes; Deutsche Bahn Group until 2012. Changed data basis from 2005. From 2013 railway system group.

Sources: BMDV, Federal Statistical Office, own calculations

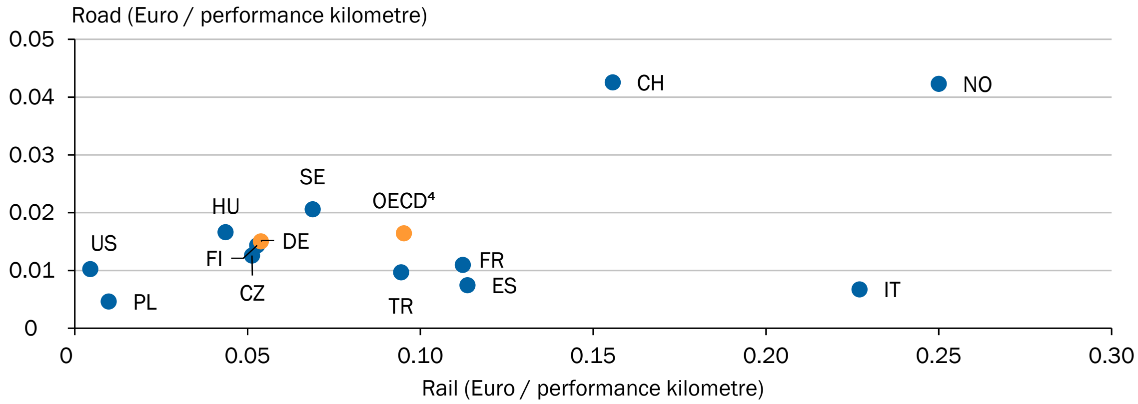
↘ BACKGROUND INFO 17

Background: the Federal Transport Infrastructure Plan (FTIP) as a key instrument of transport infrastructure planning

The **FTIP** is a **collection of projects aimed at the maintenance, replacement, expansion and rebuilding of transport infrastructure.** It covers a period of 15 years but does not constitute a planning or funding commitment (Deutscher Bundestag, 2023a). The FTIP adopted in 2016 **currently** applies **until 2030 and** includes €141.6 billion for maintenance and replacement and €63.6 billion for expansion and rebuilding. The need for maintenance and replacement is calculated on the basis of the current condition of buildings and structures and their expected wear and tear based on previous traffic volumes, and it has been fully adopted for the first time in the form of the FTIP 2030 (Maerschalk et al., 2017). Expansion and rebuilding projects can be submitted by the commissioned transport infrastructure managers and by private actors. Taking into account the anticipated traffic volumes (2030 traffic forecast), these are then assessed in terms of their economic viability, environmental impact and spatial planning and urban development aspects. Only projects with favourable cost-benefit ratios are included in the FTIP. The prioritised projects are placed on a legal footing by means of the expansion legislation and requirement planning adopted by the German Bundestag and are funded out of the federal budget. The BMDV draws up five-year investment plans for their realisation. These plans are reviewed every five years to determine whether they need to be adapted in line with the latest traffic volumes (BMVI, 2016).

444. **Viewed on an international comparison, Germany** was a **middle-ranking** OECD country in terms of its capital spending on **rail and road transport** in 2020. ↘ CHART 107 Standardised to transport performance, around 1.5 euro cents per kilometre (passenger-kilometre and tonne-kilometre) is spent on road transport and just over 5 cents on rail transport by the public finances. Countries such as Norway, Switzerland and Sweden invest significantly more than Germany in both their rail and road infrastructures.

↘ CHART 107
Infrastructure investments[1] per performance kilometre[2] in 2020 in international comparison[3]
Germany's road and railway investments below average



1 – Infrastructure investments include expenditure on new construction and improvements to existing transport routes.
2 – Performance kilometres include freight transport performance in tonne-kilometres and passenger transport performance in passenger-kilometres. 3 – CH-Switzerland, CZ-Czechia, DE-Germany, ES-Spain, FI-Finland, FR-France, HU-Hungary, IT-Italy, NO-Norway, PL-Poland, SE-Sweden, TR-Turkey, US-USA. 4 – Unweighted average of the countries shown.

Sources: OECD, own calculations

↘ BOX 28

Focus: overall economic impact of the state of infrastructure

Four out of five firms in the manufacturing and service sectors in Germany state that their business processes are regularly impaired by infrastructure deficiencies (Puls and Schmitz, 2022). Transport infrastructure is particularly important for manufacturing industry in Germany. This is due to both the necessary transportation of intermediate products to production sites as well as the delivery of finished goods to wholesalers, export (air) ports and consumers. This means that **freight transport is relevant not only at the beginning of value chains**, where they are most fragile (Costinot et al., 2013; Demir et al., 2024). **Rather, it is used several times during the production process**, as value creation typically takes place in several steps and in different firms at different locations. Over the past two decades the structure of production has become increasingly fragmented into (global) value chains and has switched to just-in-time delivery processes (Baldwin, 2022). This has meant that even a small additional step or delay in the transportation of goods can have a significant impact on manufacturing industry. Examples of this were the disruption to supply chains owing to backlogs in port clearance procedures following the major lockdowns during the COVID-19 pandemic in 2020 and 2021, the blockade of the Suez Canal at the beginning of 2021, and the low water levels in the Rhine and other major inland rivers in Germany, e.g. during the summer of 2018 (Ademmer et al., 2019, 2023; Stamer, 2021; Meier and Pinto, 2024). Given that manufacturing has accounted for around 20 % of the value added in Germany over the last ten years, such disruption can be significant for the overall economy (OECD, 2024).

The fundamental **importance of transport infrastructure for value creation** can be recognised using structural models of the regional value-added structure. For example, total welfare was 16.1 % higher in 1974 as a result of the expansion of the West German motorway network than it would have been without the motorway network (Santamaría, 2022). Real income was 4.6 % higher than in the baseline situation.

This is confirmed by simply comparing regions with one another. Gaus and Link (2020) use a panel regression for Germany to estimate the relationship between regional transport infrastructure and regional gross value added at the district level. **Equipping a district better with both motorways and federal highways increases regional gross value added.** However, the density of road networks in neighbouring regions also has a strong positive impact on regional growth. In contrast, the poor quality of federal roads can have a growth-inhibiting effect.

The **macroeconomic elasticity of overall economic output in relation to infrastructure investment** was estimated at between 0.05 and 0.39 in early studies (Stephan, 2001, 2003; Kemmerling and Stephan, 2002; Wieland and Ragnitz, 2015). An increase in infrastructure capital stock of 1 % could therefore boost overall economic output by between 0.05 % and 0.4 %. Accordingly, high capital investment in transport infrastructure is required to trigger noticeable growth in GDP (Wieland and Ragnitz, 2015). Assuming depreciation rates of 10 % and long-term real interest rates of 4 %, however, the marginal returns on this type of capital expenditure can be as high as 16 % (Bom and Ligthart, 2014). This is consistent with the general literature on the impact of public investment on aggregate economic output (Bom and Ligthart, 2014; Belitz et al., 2020; Ramey, 2021). A meta-study has shown that the elasticity of private output, i.e. the production of manufacturing and services, in relation to capital investment in core infrastructure, i.e. roads, railways, airports, energy and water supply, is 0.083 in the short term and up to 1.22 in the long term (Bom and Ligthart, 2014).

Infrastructure restrictions such as traffic congestion or bridge closures due to their poor condition ↘ BOX 27 **can hinder production.** Gaus (2023), for example, shows that bridge closures push up local production costs, as detours occur during transport. Poor navigability of waterways also raises production costs. Water levels on the Middle Rhine briefly fell to historic lows in 2022, which is why three times as many transports were occasionally needed to transport the same quantity (Ademmer et al., 2019, 2023; FAZ, 2022).

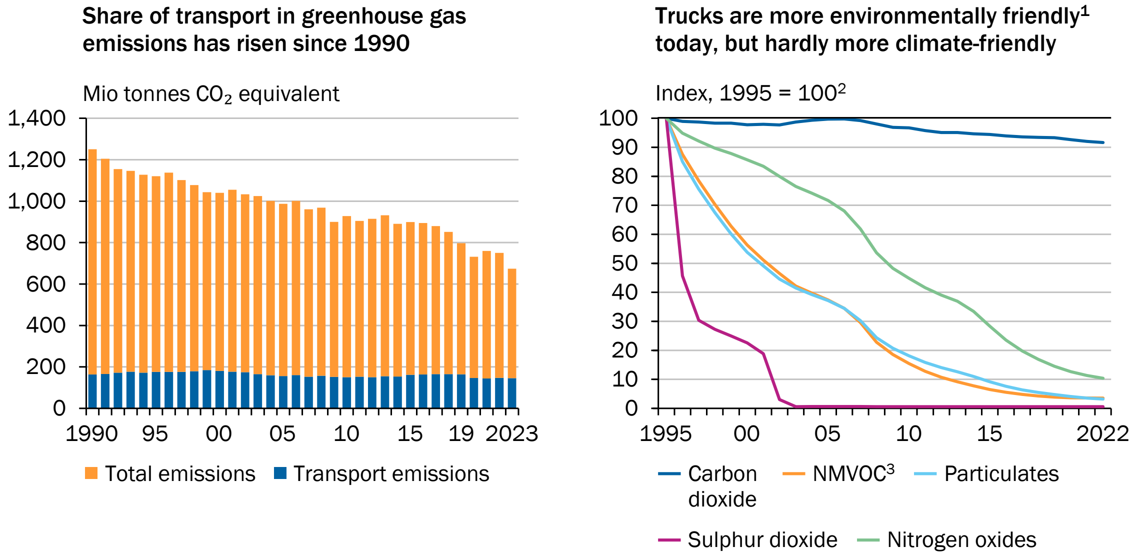
3. Challenge: decarbonisation

445. **Germany and the EU are aiming to achieve carbon neutrality by the middle of this century**. The Federal Climate Protection Act stipulates the interim target that total GHG emissions must fall by 65 % by 2030 compared with 1990 levels. The European Climate Law requires member states to reduce their net GHG emissions by at least 55 % by 2030, and by 90 % by 2050, compared with 1990 levels.

The latest **amendment to the Federal Climate Protection Act** will make annual **emission limits for the transport sector less relevant**. However, the **carbon reduction targets of the EU's** European Effort Sharing Regulation (ESR) **continue to apply**. Consequently, Germany must **cut** its **emissions** in the areas of transport, buildings, agriculture and waste **by 50 % by 2030 compared with 2005 levels**. The Federal Environment Agency's projection report (Harthan et al., 2023) states that Germany is at risk of emitting more in these sectors from 2026 onwards than is permitted under the ESR. In this case, Germany would have to purchase additional certificates from other member states by no later than 2033 to offset these emissions (Council of Experts on Climate Change, 2024). It is difficult to estimate the cost of purchasing emissions certificates from other EU member states as certificate prices partly depend on how far other member states fall short of achieving their targets. However, some estimates put the resulting costs for Germany at billions of euros (Kurmayer, 2023).

446. Around 20 % of GHG emissions in Germany are generated in the transport sector (UBA, 2024a). GHG emissions in Germany fell by 46 % overall between 1990 and

↘ CHART 108
Emissions from transport



1 – In terms of locally effective pollutants. 2 – Specific emissions from trucks (direct emissions per kilometre driven in g/km) standardised to 1995. 3 – Non-methan volatile organic compound.

Source: German Environment Agency (UBA)

2023 (UBA, 2024b). Emissions in the transport sector, on the other hand, remained almost constant. **Transport's share of total emissions has** therefore **risen** from around 13 % in 1990 to 21.6 % in 2023. ↘ CHART 108 LEFT The COVID-19 pandemic led to only a temporary decline in GHG emissions in the transport sector. One third of GHG emissions from the transport sector and the resulting negative climate impact ↘ BOX 26 are caused by freight transport. Commercial vehicles' share of total transport emissions has risen in recent years. ↘ CHART 109

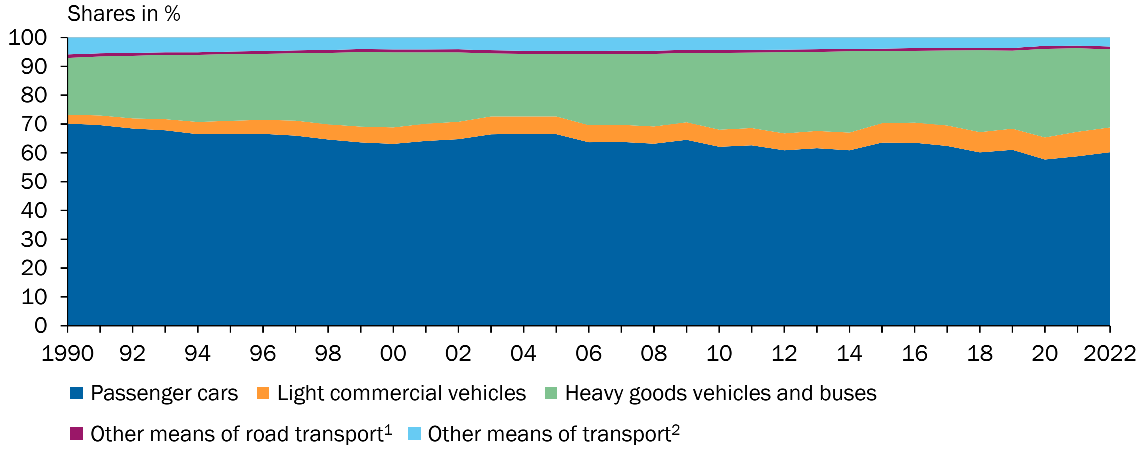
447. Thanks to better engines, improved exhaust technology and higher fuel quality, emissions from trucks per kilometre have fallen since 1995. ↘ CHART 108 RIGHT Emissions of localised air pollutants in particular have fallen. Air pollution from sulphur dioxide emissions, for example, has fallen by more than 98 % compared with the baseline year. GHG emissions per kilometre have declined by only 10 %. Total GHG **emissions from road freight transport** actually **rose** by 23 % between 1995 and 2021 **owing to the sharp increase in freight transport performance** (UBA, 2023a). Road freight transport is therefore responsible for around 98 % of the GHG emissions emitted by domestic freight transport (DLR, 2022).

448. Light commercial vehicles with a gross weight of up to 3.5 tonnes account for around 75 % of the commercial vehicle fleet but are only responsible for around 20 % of GHG emissions in the commercial vehicle sector (Timmerberg et al., 2017). The **majority of GHG emissions in road freight transport are emitted by** heavy commercial vehicles weighing 3.5 tonnes or more, especially **articulated and non-articulated trucks**, which are mainly used for long-distance transport (Göckeler et al., 2023). Assuming typical consumption levels and annual mileage, the decarbonisation of such a truck corresponds to that of 52 cars (Marker, 2024). This therefore provides a particularly strong lever for decarbonising the transport sector.

↘ CHART 109

Development of transport's share of emissions by mode of transport

Utility vehicles with a rising share in greenhouse gas emissions of the transport sector



1 – Motorcycles and other means of road transport. 2 – Rail, sea, air and other transport.

Sources: Eurostat, own calculations

449. Electrified **rail freight transport emits significantly fewer GHG emissions than road freight transport.** ↘ TABLE 20 APPENDIX Waterway transport also offers advantages over truck transport from a climate protection perspective. In terms of the balance of air pollutants, however, inland waterway transport is significantly worse than other modes of transport (UBA, 2020b).

4. Regulatory framework for the decarbonisation of freight transport

450. The **price of carbon emissions is** the **key instrument for achieving climate targets** in the EU (UBA, 2023b; GCEE Special Report 2019 items 107 ff.). Carbon emissions from industry, the energy sector and aviation are currently priced using the European Emissions Trading System (EU ETS). The EU is planning to introduce a second European emissions trading system (EU ETS II) in 2027, which will include the transport and construction sectors not yet covered by the ETS. To date, these sectors have been covered by the national emissions trading scheme (nETS) in Germany. Germany then intends to transfer the nETS to the new European trading system (Deutscher Bundestag, 2023b). **Carbon emissions from freight transport are therefore subject to different** emissions trading schemes and, consequently, different **carbon prices**. The portion of freight transport that is powered electrically is subject to the EU ETS. This applies to both rail freight transport and road freight transport. 97 % of rail freight transport was powered electrically in 2020 (Pro-Rail Alliance, 2024). ↘ ITEM 449

451. Over the coming years it is **uncertain whether the price signals given in the transport sector will be sufficient to achieve** the necessary **reduction in overall emissions** in conjunction with the sectors covered by the EU ETS (GCEE, 2023). The marginal abatement cost of achieving carbon neutrality throughout the EU by 2050 could require a price of €200 to €300 per tonne of CO2 in the transport and construction sectors (Kalkuhl et al., 2023). However, the price actually realised also depends on the scope of additional climate protection measures in the form of standards, bans and subsidy programmes. A recent evaluation of various studies on future prices in the EU ETS II shows a wide range of prices varying from €60 to €380 per tonne of CO2 (Günther et al., 2024). To a certain extent, this range can be explained by different modelling approaches, but it is also partly due to the effectiveness of complementary policy measures (Pahle, 2024). Overall, there is therefore a high degree of uncertainty about future prices of carbon emissions in the transport sector.

CO_2-specific regulation of road freight transport

452. Heavy commercial vehicles have had to pay a toll on German motorways and trunk roads since 2005. Half of the revenue raised is invested in federal trunk roads and half of it in railways. The EU has decided that in **future** the **truck toll** must be **linked to the vehicle's carbon emissions** (EU Directive 2022/362). This was implemented in Germany through the latest toll reform. A carbon surcharge of €200 per tonne of CO2 has been levied in Germany since 1 December

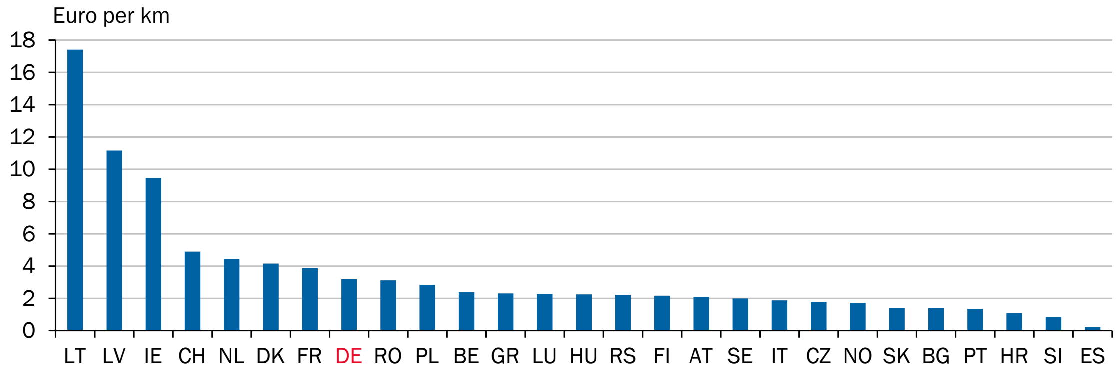
2023. This corresponds to the maximum amount stipulated in the EU Directive (Bundesregierung, 2023a). ↘ BOX 29 This means that the toll is made up of four cost components relating to infrastructure, air pollution, noise pollution and carbon emissions. Depending on vehicle class, the partial toll rate for carbon emissions is between 4.0 and 16.2 euro cents per kilometre. **This should internalise a large proportion of the climate costs on toll roads** (UBA, 2020a). ↘ BOX 26 Zero-emission trucks will be completely exempt from this truck toll until December 2025. Subsequently, only the partial toll rates for air pollution and noise pollution will have to be paid in full. The partial toll rate for infrastructure costs will be reduced by 75 %, and no partial toll rate will be charged for carbon emissions. The German government's CO2-based toll revenue is expected to amount to €6.8 billion in 2024, accounting for around 45 % of total toll revenue in 2024 (Bundesregierung, 2023a).

453. At the same time, **manufacturers of heavy commercial vehicles** are also obliged to decarbonise their fleets. In 2019 a European regulation was adopted that sets **fleet carbon limits** (in grams of CO2 per tonne-kilometre) **for manufacturers of heavy commercial vehicles** (European Parliament and Council of the European Union, 2019). This regulation requires them to reduce their fleet's carbon emissions by 15 % from 2025 onwards compared with the baseline year 2019. Otherwise they will have to pay substantial fines. The tightening of the fleet targets for the years after 2025 was recently decided. From 2030 onwards, carbon emissions must be reduced by 45 % – instead of the previous 30 % – compared with the reference value. The reduction target will rise to 65 % from 2035 onwards and then to 90 % from 2040 (European Commission, 2023a). This regulation is fundamentally technology-neutral. It is up to manufacturers to decide how to achieve the fleet targets.

↘ CHART 110

Track access charges for rail freight transport in European countries[1] in 2021

Track access charges in Germany not particularly high by European standards



1 – LT-Lithuania, LV-Latvia, IE-Ireland, CH-Switzerland, NL-Netherlands, DK-Denmark, FR-France, DE-Germany, RO-Romania, PL-Poland, BE-Belgium, GR-Greece, LU-Luxembourg, HU-Hungary, RS-Serbia, FI-Finland, AT-Austria, SE-Sweden, IT-Italy, CZ-Czechia, NO-Norway, SK-Slovakia, BG-Bulgaria, PT-Portugal, HR-Croatia, SI-Slovenia, ES-Spain.

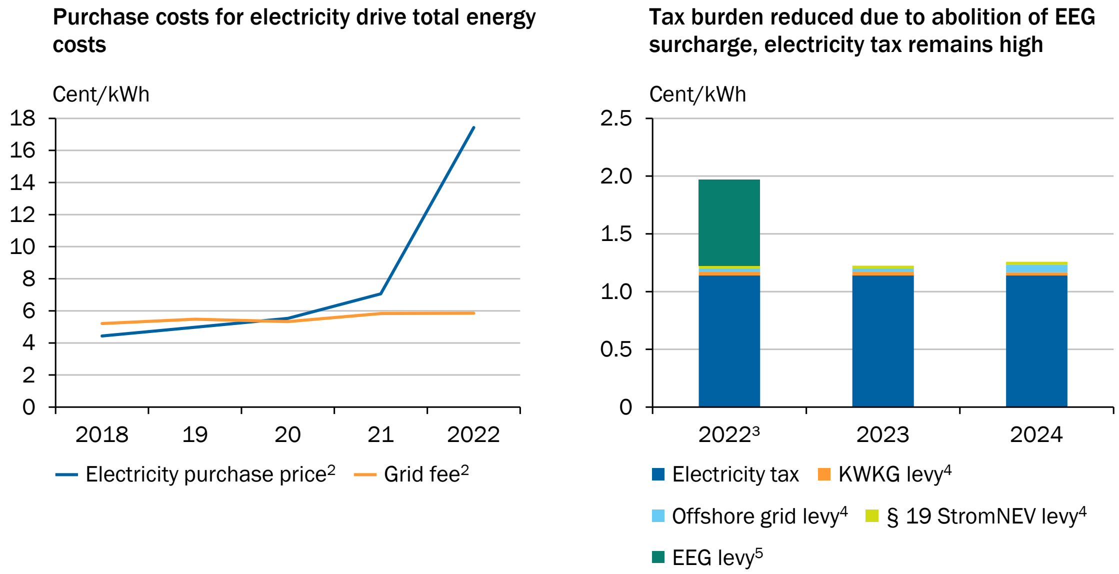
Sources: IRG-rail, own calculations

Costs of infrastructure utilisation and energy in rail freight transport

454. Transport companies must pay **track access charges to the rail infrastructure operators to use the rail infrastructure**. These charges are based on EU-wide principles, which stipulate that the transport companies must bear at least the marginal costs directly attributable to them. On the whole, the **track access charges payable for rail freight transport in Germany are not unusually high by international standards.** ↘ CHART 110 In addition, track access charges for transport companies are currently being reduced by 31.5 % thanks to a German government funding programme (DB InfraGO, 2024b). Charges are also payable for the use of service facilities such as freight terminals and sidings. The overall cost of using infrastructure accounted for around 10 % of rail freight transport revenue in 2022 (BNetzA, 2024a).

455. In addition to infrastructure charges, rail transport companies must bear the **electricity costs incurred in operating their railways**. These consist of the purchase price of traction current, railway electricity grid charges, electricity tax and other surcharges. ↘ CHART 111 The purchase price of traction current roughly tripled between 2020 and 2022 but is likely to have fallen again slightly in 2023 (BNetzA, 2024a). ↘ CHART 111 LEFT The abolition of the EEG surcharge on 1 July 2022 led to a significant reduction in the tax burden. ↘ CHART 111 RIGHT Traction current also enjoys considerable preferential treatment in terms of electricity tax and surcharges. For example, its electricity tax is only 56 % of the standard rate, while

↘ CHART 111
Traction current costs[1] in rail transport



1 – Excluding value-added tax. 2 – Net, excluding taxes and levies. 3 – Additional switch-off load levy of 0.003 cent/kWh.
4 – Levy for electricity volumes of one gigawatt hour or more. A higher levy rate applies to electricity volumes below this.
5 – EEG surcharge limited to 20 % in accordance with Section 65 EEG, abolished on 1 July 2022.

Sources: customs, DB Energie, Federal Network Agency, netztransparenz.de, own calculations its surcharges are between 3.9 % and 10 % of the respective standard rate (BAFA, 2023; netztransparenz.de, 2023a, 2023b, 2023c; Zoll, 2024, §9 StromStG).

↘ BOX 29

Focus: macroeconomic effects of decarbonising freight transport

The decarbonisation of freight transport is likely to incur higher costs in the logistics sector in future. Costs are likely to arise, for example, from the increase in toll costs, higher energy costs of electricity in the medium term (owing to the capital investment in the charging and network infrastructure that needs to be amortised) and the higher acquisition cost of trucks with low-emission drive systems. ↘ ITEM 473 The **toll increase** ↘ ITEM 452 is likely to **significantly push up transport costs.** Toll costs have traditionally accounted for an average of around 11 % of truck transport costs (G+S Magazin, 2021; Trimode, 2022; Transporeon, 2023). This share could rise to around 18 % over the course of this year (Transporeon, 2023). Apart from Germany, only Austria is introducing a CO_2 component to the truck toll in the short term, which is significantly lower than the German carbon component. This could lead to differences in transport costs within Europe and put Germany, as a pioneer, at a competitive disadvantage.

Higher transport costs result in **negative productivity effects** (Branco et al., 2023). Logistics companies are likely to pass this cost increase on to their customers in their fixed costs and variable costs per transport kilometre. The effects of this cost pass-through and the proportion of the cost rise that will be passed on are uncertain at present. However, transport costs make up only a small proportion of the total cost of a traded product. ↘ ITEM 454 As the distances travelled within Europe account for only a fraction of the total transport distance to **non-European sales markets**, rising costs are unlikely to have a significant impact on the **international competitiveness of** German exports. Increases in transport costs are likely to even out within Europe over the long term if, for example, the CO_2 components in the toll are harmonised or the EU ETS II uniformly prices carbon emissions in the transport sector. ↘ ITEM 450 **Demand for road transport is not very price-sensitive** (Musso et al., 2013; Blechschmidt et al., 2022). For example, price elasticity is estimated to be –0.02 for the transportation of foodstuffs and –0.19 for chemicals and fertilisers, which means that if the price of road transport rises by 1 % per tkm, demand for the transportation of foodstuffs (chemicals and fertilisers) in tkm falls by 0.02 % (0.19 %). By contrast, demand for road transport of particularly heavy freight (100 tonnes or more) reacts much more strongly to higher costs and exhibits an elasticity of –2.9. The overall impact that the introduction of the CO_2 component and the associated average truck toll increase has on mileage is likely to be low.

III. STRATEGIES FOR DECARBONISING FREIGHT TRANSPORT

456. **Various strategies** can be pursued in **order to decarbonise freight transport**: **avoid transport** and thus GHG emissions, **shift transport** to lower-emission modes of transport, ↘ ITEM 436 or **change the drive systems** used in road freight transport. ↘ ITEM 467 Given the close relationship between freight transport and economic development, no substantial reduction in freight transport is expected. ↘ ITEM 425 Although efficiency improvements – particularly by avoiding running empty trains, increasing the degree of capacity utilisation and using more long trucks for large-volume goods – can help to decarbonise freight transport, the potential for this is likely to remain limited. The other two strategies – a modal shift and a change of drive systems – are examined in more detail below and their prospects of success in decarbonising freight transport are assessed.

1. Shift freight transport onto rail and waterways

457. As road transport currently causes the highest carbon emissions per tonne-kilometre, **greater use** of **rail transport and inland waterways** could **reduce such emissions**. ↘ TABLE 20 APPENDIX Rail freight transport's share of total freight transport performance has largely stagnated, amounting to around 18 % in 2022. ↘ ITEM 435 The share accounted for by inland waterway transport is actually declining. The German government's target – as formulated in the coalition agreement – that **rail freight transport should account for 25 %** of the modal split by 2030 is **unlikely to be achieved at the current rate** (SPD, Bündnis 90/Die Grünen and FDP, 2021). ↘ CHART 113 LEFT ↘ ITEM 441

Low demand-side potential for modal shifts

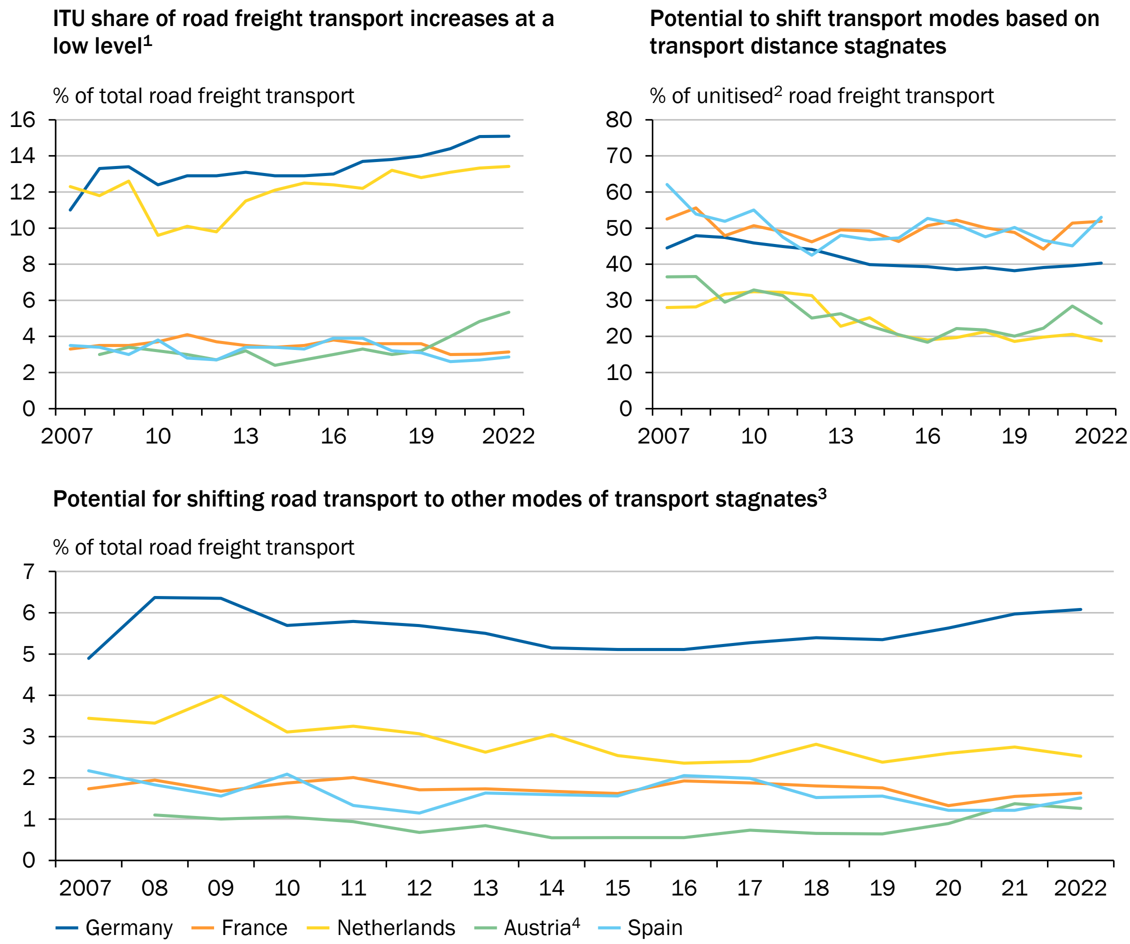
458. The **factors determining which mode of transport to choose** are **accessibility** (e.g. whether a rail connection exists or an inland port is available in the region), the **transport distance**, the **characteristics of the goods and merchandise** to be transported, the **size of the load**, and the desired **transport time** (Tavasszy and van Meijeren, 2011). As loading from one means of transport to another is time-consuming, intermodal transport by rail is usually only used by customers who are not dependent on time-critical transport. As the delivery time is more critical for many goods and intermediate inputs (BNetzA, 2022a), however, the proportion of total transport volumes for which a shift from road to rail transport makes economic sense will remain low for the foreseeable future (Kreutzberger, 2004; European Court of Auditors, 2016; Puls, 2022; BNetzA, 2024a).

459. In addition, **most goods** are **not transported in standardised transport containers**, known as intermodal transport units (ITUs), which can be easily loaded between modes of transport. Instead, much more flexible containers such

as cardboard boxes and pallets are used – partly owing to the small overall shipment size. ↘ CHART 112 TOP LEFT Around 40 % of road-based ITU shipments in Germany are suitable for potentially being shifted from road to other modes of transport owing to the distances involved (over 300 km). ↘ CHART 112 TOP RIGHT As ITU transport accounts for only 15 % of all road transport, however, the total potential for a modal shift determined in this way in Germany is 6 %. This share is high compared with other European countries and is increasing slightly over time. ↘ CHART 112 BOTTOM Innovations in the refinement of ITUs, such as smaller sub-containers ('city boxes'), and their handling only have the potential to enhance the appeal of ITU transport in the medium term, which is partly because of time-consuming barriers to market penetration (van Binsbergen et al., 2014; European Commission, 2022a; Kiani Mavi et al., 2022).

↘ CHART 112

Freight transport in standardised transport units and potential to shift transport modes



1 – Share of total road freight transport (in tkm) transported in Intermodal Transport Units (ITU), i.e. standardised transport units suitable for transport by different modes of transport. Such ITUs include containers, swap bodies and other standardised packaging (in terms of size) that can be moved with simple equipment (e.g. cranes). 2 – Shift potential in unitised road transport as a percentage of unitised road freight transport. "Unitisation" expresses the proportion of total transported goods that is transported in ITUs. 3 – The modal shift potential indicates the share of unitised road freight transport that could potentially be shifted as a percentage of total road freight transport. 4 – The ITU share for Austria in 2007 given by Eurostat appears implausibly high over time (24.6 %) and is therefore not shown in the chart, as is the modal shift potential in total road freight transport (9 %).

Sources: Eurostat, own calculations

460. **Shifting substantial volumes of transport** – especially time-critical small goods (courier, express and parcel services, food, consumer goods) – **onto rail will not be efficient** in the long term either (Pinto et al., 2018; Puls, 2022). Although such a shift is at least theoretically possible, there is a lack of intermodal hubs to facilitate combined freight transport and permit more complex logistics chains (Nothegger, 2023).

461. Rail freight transport is particularly important in cross-border transport owing to the markets it serves. **However, there are** historical **incompatibilities between** the national railway networks (Stoll et al., 2017). ↘ ITEMS 549 FF. APPENDIX The EU has set itself the goal of creating a single European railway area. In order to strengthen this area, it is necessary to expand Europe's railway corridors within the Trans-European Transport Network (TEN-T network). ↘ ITEM 496 Intermodal hubs already exist for this transport, e.g. at sea ports, inland ports and other transhipment centres. **However,** the **liberalisation of rail (freight) transport within the EU during the** 1990s and 2000s **has brought about only minor changes in traffic volumes and in the modes of transport chosen** (Eisenkopf et al., 2006). Given the different markets served by rail freight transport and truck logistics, ↘ ITEM 437 it will require more than just stiffer competition and falling relative prices compared with road transport for rail freight transport to achieve a modal shift.

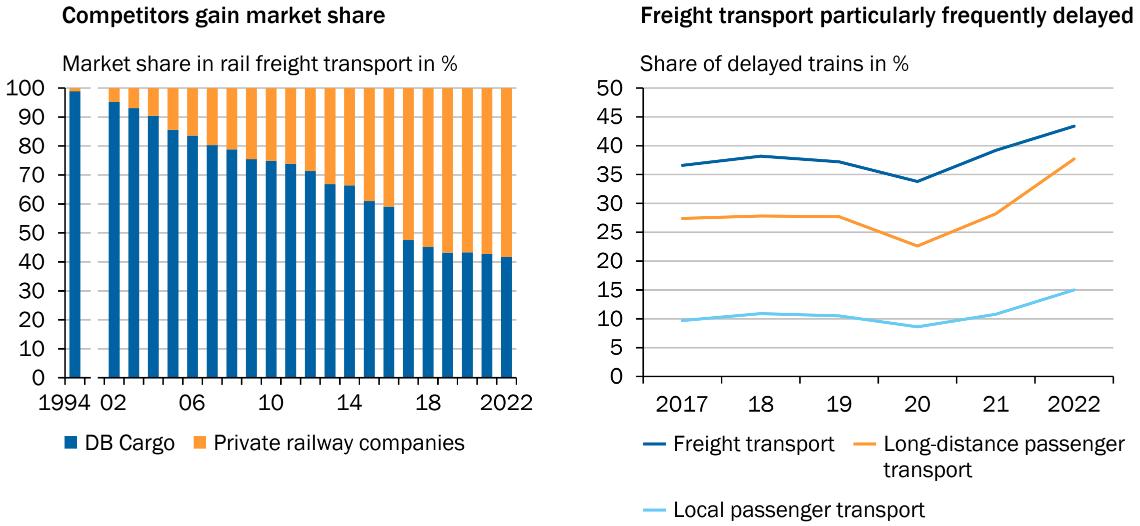
462. With **single-wagonload transport** ↘ GLOSSARY, rail freight transport **also offers the option of transporting smaller quantities of goods by rail**. Customers can have freight transported by rail in ITUs without a direct rail connection. Within Germany, only DB Cargo AG currently offers nationwide single-wagonload transport (DB Cargo, 2024a), although this **line of business has been loss-making for years** and accounted for around half of DB Cargo's total losses in 2022 (Cordes, 2023). At the same time, customers are dissatisfied with these transport costs (BNetzA, 2022a) which, given the lack of competition and the high deficits, indicates that this type of transport is too expensive to generate sufficient demand compared with truck transport. ↘ ITEM 563 APPENDIX

Modal shift possible to only a limited extent owing to low capacity and poor efficiency in rail freight transport

463. Even in the case of journeys for which rail transport could offer an alternative to road transport, ↘ ITEM 459 the actual potential for any modal shift is limited for other reasons. For example, the existing **rail network has reached its capacity limits** (DB, 2023a), which prevents any significant expansion of rail freight transport (DB, 2023b, 2023c). Rail capacity is being squeezed by **inefficient** train route allocation **processes**. ↘ ITEM 465 Above all, the many delays caused by faulty points, for example, mean that trains have to be rescheduled. This is still done manually as there are no automated systems or connectivity between trains and control centres (Moosbrugger, 2008; Meirich, 2017; Eurailpress, 2023). ↘ ITEM 560 APPENDIX

464. In addition, **rail transport is currently significantly** slower than road transport and is associated with longer average delays. ↘ BOX 30 ↘ CHART 113 RIGHT At

↘ CHART 113
Competition and punctuality in rail transport



Sources: DB, Federal Network Agency

43.4 %, the proportion of delayed freight trains in 2022 was even higher than the corresponding proportion in long-distance passenger transport at 37.7 % (BNetzA, 2024a). ↘ CHART 113 RIGHT Customer dissatisfaction with general transport times and punctuality is particularly high in single-wagonload transport (BNetzA, 2022a).

Deutsche Bahn cites engineering works as the main reason for the more frequent delays in rail freight transport in 2021 (Bundesregierung, 2022a). However, delays have been increasing for years. **Switching to rail transport may** therefore **require changes in production processes** that raise operating costs (just-in-time and just-in-sequence approaches would have to be replaced by more warehousing and additional buffer times). However, the many delays are an endogenous problem of the poor state of infrastructure and high capacity utilisation. Significantly improving and expanding this infrastructure could reduce delays and resulting inefficiency.

↘ BOX 30
Background: Deutsche Bahn AG

Deutsche Bahn AG (DB AG) dominates rail transport in Germany. In 2022 it accounted for 66 % of local passenger transport and 96 % of long-distance passenger transport. Its subsidiary DB Cargo AG operated around 41 % of rail freight transport (BNetzA, 2024a). The infrastructure divisions DB Netz AG and DB Station und Service AG were merged into the public-service provider DB InfraGo AG on 1 January 2024. DB InfraGo AG operates around 85 % of Germany's public rail network, which corresponds to an operating length of more than 33,000 km (BNetzA, 2024a). The organisation claims that its business activities will be geared towards achieving three political goals: doubling performance in rail passenger transport, increasing rail freight transport's market share to 25 % and implementing the Deutschlandtakt project (DB InfraGO, 2024c).

The **German government is the sole owner** of DB AG **and is constitutionally obliged to maintain and expand the rail network** (Article 87e of the Basic Law). While the German government bears the cost of replacement investment, DB AG pays **the cost of maintenance.** This dichotomy creates perverse incentives for DB AG to delay maintenance investment until replacement investment becomes necessary, which then has to be funded by the German government (Deutscher Bundestag, 2019). The result is disruption and delays. Whether DB AG sufficiently meets its maintenance obligations and uses the federal subsidies granted for replacement investment in a sustainable manner is reviewed on the basis of quality indicators as part of the LuFV, whose superficial and imprecise design also creates perverse incentives (Monopolies Commission, 2019, 2023a). It is unclear to what extent the planned supplement to LuFV III and the new LVInfraGO, which is due to come into force on 1 January 2025, will address these perverse incentives (Bundesregierung, 2023b). DB Netz AG received investment grants totalling €9.2 billion from public funds in 2023. These grants were used to implement infrastructure investment totalling €12.7 billion in the same year (DB, 2024b).

Although non-state-owned railway companies have gained market share in freight transport over the years, this trend has stagnated since 2018. ↘ CHART 113 LEFT DB Cargo AG's largest private competitor, Captrain Deutschland, had a market share of 6.1 % in 2022 (mofair and Die Güterbahnen, 2023). ↘ CHART 113 DB Cargo AG has been making losses for some time, which totalled €583 million in 2023 (DB Cargo, 2024b). ↘ ITEM 462 These losses are covered in full and indefinitely by DB AG under a profit and loss transfer agreement (DB Cargo, 2024b). As this could give DB Cargo an unfair advantage over competitors, the European Commission launched an investigation in 2022 (European Commission, 2022b). ↘ ITEM 563 APPENDIX The return on revenue for non-state-owned freight transport companies as well was negative in 2022 owing to higher energy and personnel costs. However, they had always managed to achieve a positive return on revenue of between 2 % and 4 % in previous years (BNetzA, 2024a). Nevertheless, the vertically integrated group structure of DB AG continues to create barriers to free competition on the railways. As the DB Group is both the main owner and user of the rail infrastructure, other transport companies could be at a disadvantage when it comes to providing information about planned engineering works, for example (Monopolies Commission, 2023a).

465. **Passenger transport** usually takes **priority over freight transport** when it comes to the allocation of train routes. Freight trains often travel on routes that are also used by much faster long-distance trains. The allocation of train routes in the timetable is normally only carried out according to priority rules if train routes have been double-booked. These rules stipulate that top priority is given to synchronised and integrated traffic ↘ GLOSSARY, followed by cross-border traffic and, finally, rail freight traffic (DB Netz, 2024). **Accordingly, integrated cross-border freight transport is given top priority**, which primarily concerns the TEN-T freight corridors. ↘ ITEMS 461 AND 549 FF.

Rail freight transport therefore merely appears to be at a disadvantage, as it enjoys equal status with passenger transport, especially in synchronised traffic, i.e. on regularly used routes. **On the route itself**, i.e. after train routes have been allocated in the timetable, **no fundamental priority rule** applies to the different modes of transport (DB Netz, 2024). However, the frequent need to reschedule trains following disruption means that the slower rail freight traffic has to give way to other trains, which can result in delays and subsequent disruption (BNetzA, 2015). ↘ ITEM 499

466. The potential for **shifting freight transport onto inland waterways** is **limited** for similar reasons to the case of rail transport. For example, the goods markets and transport markets served differ greatly from typical truck transport (UBA, 2022). Transport costs are only lower than in road transport if inland waterway vessels are fully loaded and distances of over 200 km are involved. In addition, the waterway network is regionally restricted and the potential for expanding waterways is limited (BMVI, 2020). At the same time, marine diesel is particularly emission-intensive in terms of particulates and nitrogen oxides ↘ TABLE 20 APPENDIX, and seasonal uncertainty about the navigability of waterways is increasing owing to climate change. ↘ BOX 28

2. Decarbonising road freight transport

467. Making freight transport completely carbon-neutral by 2045 will require a **steep market ramp-up of low-emission commercial vehicles over the coming years**. By launching its 2030 climate protection programme, the German government (Bundesregierung, 2019a) aims to ensure that one third of the mileage in heavy goods road transport ↘ ITEM 448 is achieved using electricity or electricity-based fuels by 2030. However, today's road transport continues to be dominated by diesel trucks, which account for 97 % of new truck registrations (ACEA, 2024).

BE trucks have the greatest market maturity for use in road freight transport

468. **Various drive systems are feasible for decarbonising road freight transport,** each of which has specific advantages and disadvantages. These include battery electric drive systems, hydrogen drive systems, overhead lines and vehicles with internal combustion engines powered by synthetic fuels. All of these technologies have different levels of maturity (Lischke, 2023). They also differ in terms of payload, energy efficiency, range, acquisition cost, operating cost, refuelling times and charging times. ↘ BOX 31 In addition, there are various challenges to overcome when scaling the charging and refuelling infrastructure. These include space availability; coordination of rest periods, charging times and refuelling times; expansion of the power supply; and hydrogen availability. Compatibility with the European transformation strategy must also be considered.

469. Given the battery electric truck (BE truck) ranges already available **in local freight and distribution transport** ↘ BOX 31, there is **little doubt about the technological and economic feasibility of the widespread use of BE trucks** – partly owing to their strong synergies with battery electric passenger cars (BE cars; Link and Plötz, 2022; Tol et al., 2022; Winkler et al., 2022; Frieske et al., 2023; NOW, 2023a). As recent studies report, the potential of battery electric drive systems in long-distance freight transport has been underestimated in the past (Hoekstra, 2019; Liimatainen et al., 2019; McKinnon, 2021; Nykvist and Olsson, 2021; Bhardwaj and Mostofi, 2022). The enormous technological advances achieved in battery cells over the last ten years have enabled longer ranges

(Löbberding et al., 2020) and a sharp reduction in charging times (Mukhopadhyay, 2019). The cost of producing lithium-ion batteries has fallen by 85 % in the last decade, and further cost reductions are expected (Orangi et al., 2024). The International Energy Agency (IEA) reckons that further innovation in battery chemistry and production will cut the average cost of lithium-ion batteries by a further 40 % between 2023 and 2030 (IEA, 2024). By 2030 there is the potential to drive volume- and weight-saving innovation by continuing to optimise battery technology, thereby significantly increasing BE trucks' range even further (Thielmann et al., 2020). The use of sodium-ion batteries in electric vehicles offers the potential to reduce reliance on raw materials and achieve massive improvements in performance (IEA, 2024).

Viewed from a technological perspective, powerful charging technology will enable **purely battery electric applications to be used for all application profiles in freight transport** (Jöhrens et al., 2022; Tol et al., 2022; Zähringer et al., 2022; Alonso-Villar et al., 2023; Cheng and Lin, 2024; Plötz et al., 2024). Some particularly sophisticated commercial-vehicle applications – such as in mining, on construction sites, in extreme cold or heat, and for long-distance journeys lasting several days that are difficult to plan – are likely to remain difficult to electrify in future. These might require the use of alternative low-emission drive technologies ↘ BOX 31 in parallel with BE trucks. However, such applications play only a minor role in road freight transport as a whole. ↘ ITEMS 435 FF.

470. Given the higher energy density of compressed hydrogen, fuel-cell electric trucks (FCE trucks) theoretically allow longer ranges and shorter refuelling times compared with BE trucks. However, these **comparative advantages of using hydrogen in trucks compared with battery electric drive systems** – benefits which are often stressed in the current debate – **are** increasingly **being relativised by the development of battery and charging technology**, which makes the widespread use of FCE trucks in road freight transport less and less likely (Plötz et al., 2022; Albatayneh et al., 2023; Orangi et al., 2024). ↘ ITEM 469 Hydrogen fuel options with higher energy storage densities, which could enable future ranges of up to 1,000 km with refuelling times of ten to fifteen minutes, are still at the testing stage. This and other existing technical and market uncertainty around vehicles ↘ BOX 31 and refuelling ↘ BOX 33 is delaying the market maturity of FCE trucks. Other truck drive systems, such as overhead-line hybrid trucks and synthetic fuels, continue to face barriers to being considered for use in road freight transport. ↘ BOX 31 Overall, **BE trucks are** therefore **currently** the drive technology with **the greatest market maturity in road freight transport**.

471. The **emission reduction potential that can be realised in road freight transport by using different drive technologies varies** in the short to medium term at least. Given their considerable mileage, BE trucks allow significant emission reductions over their entire life cycle – despite the comparatively high GHG emissions created during their production process – even with today's electricity mix (Wolff et al., 2020). Hydrogen is currently almost exclusively produced from fossil fuels, and only 5 % of its global production is traded (Hebling et al., 2019). The future availability of green hydrogen in Germany is uncertain (Odenweller et al., 2022). Applications in road freight transport also give rise to conflicts

of use, particularly with industry, where some applications are difficult or even impossible to electrify (Castelvecchi, 2022).

Various meta-studies show an extremely **wide range of estimates for future demand and supply of green hydrogen** in Germany in 2030 and 2050 (Hebling et al., 2019; IRENA, 2022; European Commission, 2023b; Scheller et al., 2023). How much green hydrogen will be available in Germany in future depends, on the one hand, on future domestic production volumes – the economic viability of which will, in turn, be largely determined by future electricity and import prices (Scheller et al., 2023) – and, on the other hand, on whether declarations of intent for import projects (BMBF, 2023) can be realised. Despite ambitious announcements, the ramp-up of the hydrogen industry has recently been sluggish worldwide (IEA, 2022; Niemeier et al., 2024). This **also applies to e-fuels**, which are not yet commercially available. All of the new e-fuel projects announced worldwide up to 2035 would only account for around 10 % of Germany's essential e-fuel requirements (Ueckerdt et al., 2021; Ueckerdt and Odenweller, 2023). Overall, therefore, it is unlikely that these technologies will be able to make a significant contribution to achieving the 2030 emission targets. ↘ ITEMS 445 AND 467

472. The **availability and reliable supply of raw materials is becoming** increasingly important as part of the powertrain transition (Backhaus, 2021). This applies **equally to BE trucks and FCE trucks**. Both types of drive system are based on the use of lithium-ion batteries and electric traction engines as key technologies, which in turn depend on the availability of lithium, cobalt and rare earths (Thielmann et al., 2020). The production of fuel cells also relies on the availability of other critical raw materials such as platinum (GCEE Annual Report 2022 table 24). **There is a strong concentration among the countries** that act as suppliers **for large parts of the value chain**. Companies from China are the dominant suppliers of lithium-ion batteries and electric engines, while suppliers of platinum metals come from South Africa and Russia (Buchert et al., 2023; GCEE Annual Report 2022 items 486 ff.). The various European battery production initiatives that have been launched will enable Europe to strategically position itself more independently of other countries in future (T&E, 2023).

The electrification of truck transport – in the form of both BE trucks and FCE trucks – **enables major greenhouse gas reductions with** comparatively **low additional raw-material requirements** (Buchert et al., 2023). Innovation in the production of key components for the powertrain transition can further significantly reduce dependencies on raw materials (Dühnen et al., 2020; IEA, 2024). Sodium-ion batteries, for example, can be produced without any critical raw materials and offer the potential for value creation in Germany (Fraunhofer IKTS, 2023). Nevertheless, the potential for the recycling and secondary use of key raw materials should be fully exploited as low-emission drive systems are ramped up (Buchert and Sutter, 2020).

↘ BOX 31

Background: alternative drive technologies for trucks

In the case of **battery electric trucks** (BE trucks) a battery storage system is installed in the vehicle and the drive is electricity-based via one or more electric engines. BE trucks' cost-effectiveness and suitability for everyday use depends largely on the development of battery technology. The enormous advances in innovation made in battery development in recent years now enable heavy commercial vehicles to achieve ranges of around 500 kilometres without any significant loss of payload, and further huge advances in innovation are expected. ↘ ITEM 469 BE trucks can already be ordered from all major German commercial vehicle manufacturers.

In the case of **fuel-cell electric trucks** (FCE trucks) hydrogen is converted into electricity for the electric drivetrain. Manufacturers are currently testing vehicles suitable for long-distance freight transport with ranges of up to 1,000 kilometres. This requires hydrogen tanks with greater storage capacity than in the past (Frieske et al., 2023; Zerhusen et al., 2023). There is a need for further research and development in this area (NWR, 2023a; Zerhusen et al., 2023). It is still unclear whether hydrogen in FCE trucks will be used in gaseous or liquid form in future. Commercial vehicle manufacturers therefore do not expect the technology used in FCE trucks to be ready for series production until the end of the decade (NOW, 2023a). Given the conversion processes involved in the production and transportation of hydrogen and the reconversion of electricity in the vehicle, the technical efficiency of FCE trucks is significantly lower than that of direct battery-powered electricity use (Hosseini and Butler, 2020).

Another option for supplying energy to commercial vehicles is the direct provision of **drive system energy from overhead line systems** installed on the carriageway. Overhead-line hybrid trucks use the electricity from an overhead line and cover distances away from the overhead lines by using a battery. They offer the advantage that the battery system can be charged while travelling, which means that downtimes for recharging can be avoided or reduced. The relevant vehicle and infrastructure technology is not yet ready for series production. Commercial vehicle manufacturers believe that this drive technology has **little market potential overall** (NOW, 2023a).

As an alternative to the electrification of drive systems there are discussions about the possibility of running **trucks** with internal combustion engines **on synthetic fuels** from renewable electricity (e-fuels) in future. Synthetic fuels offer the advantage of utilising largely existing drive technology and an established supply infrastructure and can therefore theoretically be used immediately. However, e-fuels have so far only been produced in demonstration facilities and pilot plants and are **still a long way from being ready for widespread use** – partly owing to their high production costs (Ueckerdt et al., 2021). Trucks with internal combustion engines can also run on synthetically produced fuels made from biogenic residual and waste materials (e.g. biodiesel). Their carbon footprint depends on a variety of influencing factors and can range from a large reduction in emissions to an increase in emissions compared with trucks using conventional fuels (Wietschel et al., 2019). Given the limited biomass potential of domestic residual materials, it is unclear to what extent such fuels will be available in future.

Alternative drive systems can quickly become economically efficient compared with diesel

473. Road freight transport is characterised by strong competitive pressures which offer very little leeway in price-setting (Wieland, 2010; DSGV, 2023). **A competitive total cost of ownership (TCO) is** therefore **crucial to the market success** of any drive technology. ↘ BACKGROUND INFO 18

↘ BACKGROUND INFO 18

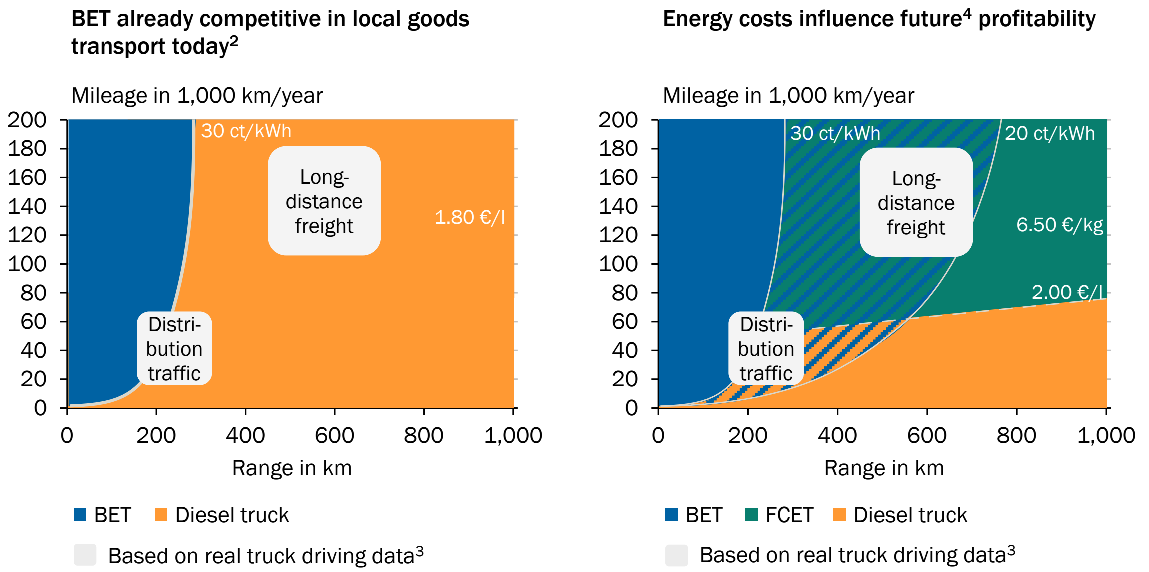
Explanation of terms: total cost of ownership (TCO)

The total cost of ownership (TCO) takes into account not only the cost of purchasing a vehicle but **also all aspects of its subsequent use** such as energy costs, repair costs and maintenance costs over **the vehicle's entire life cycle.** There is no standardised model for calculating TCO. For example, insurance costs, infrastructure costs and vehicle taxes are sometimes also included in TCO calculations. The residual value of a vehicle is calculated in the same way for all alternative drive systems because the level of uncertainty about their subsequent use is equally high for all of them, and this residual value is calculated by depreciating the purchase price at an annual or kilometre-based rate. Battery wear and tear is taken into account separately for BE trucks. Some studies also include government policy instruments such as carbon pricing and truck tolls.

474. A TCO calculation based on today's cost of manufacturing the vehicle components – and including operating and maintenance costs – shows that **local freight transport and some distribution transport** up to a range of approximately 300 km can already be **handled most economically by BE trucks** at today's energy prices. ↘ CHART 114 LEFT This is consistent with the findings of other studies

↘ CHART 114

Total cost of ownership by mileage and range[1]



1 – Total cost of ownership based on current manufacturing costs of the vehicle components (fuel cell 130 euros per kW, hydrogen tank 415 euros per kg and battery pack 120 euros per kWh) and costs for operation and maintenance based on König et al. (2021). The drive system with the lowest total costs is shown. 2 – With a market price for charging current of 30 cents per kWh, a diesel price at the filling station of 1.80 euros per litre and a hydrogen fuel price of 10 euros per kg. In this scenario, the FCE truck does not have the most favourable total cost of ownership for any application. 3 – The "distribution transport" and "long-distance freight transport" application areas shown are based on real lorry driving data from German fleet operators according to Balke and Adenaw (2023). 4 – With a market price for charging current of between 20 cents per kWh and 30 cents per kWh, a diesel price at the filling station of 2 euros per litre and a hydrogen fuel price of 6.50 euros per kg.

Sources: Balke and Adenaw (2023), Wolff and Balke (2024), Wolff et al. (2020), own presentation

(Link and Plötz, 2022). Such use cases account for around 75 % of all truck transport and thus a large proportion of domestic road freight transport. ↘ ITEM 437 The fact that most of today's road freight transport is nevertheless handled by diesel trucks ↘ ITEM 467 is probably largely because the charging infrastructure for BE trucks is not yet available nationwide. In contrast, use cases involving longer ranges and larger mileages are still most economically handled by diesel trucks. Given the current price of hydrogen, the latter is not economically viable compared with diesel trucks even in the case of long ranges and large mileages. ↘ CHART 114 LEFT

475. The national carbon price, the carbon component of the truck toll and, in future, the EU ETS II ↘ ITEM 450 will make the operation of diesel trucks increasingly expensive and unattractive over the coming years. **If the price of diesel rises, BE trucks and FCE trucks will automatically become more economical relative to diesel trucks**, while other technically feasible options ↘ BOX 31 become less appealing. ↘ CHART 114 RIGHT BE trucks will then benefit from local and distribution transport compared with diesel trucks, while FCE trucks will initially become more attractive for very long ranges and mileages, which play virtually no part in freight transport.

476. The relationship between the future market price of electricity compared with that of hydrogen will have a significant impact on what will be the **most economical low-emission truck drive system for long-distance road freight transport** in future. The TCO calculation shows that, assuming a future charging electricity price of 20 cents per kWh, BE trucks could handle practically all long-distance freight transport in Germany more economically than alternative drive systems. ↘ CHART 114 RIGHT If the price of electricity remains unchanged at 30 cents per kWh but the price of hydrogen fuel falls below €6.50 per kg in future, this calculation shows that FCE trucks are the most economical option for long-distance freight transport. These findings are consistent with other studies on TCO parity (Ahluwalia et al., 2022; Basma et al., 2022). However, it should be remembered in this analysis that FCE trucks require around twice as much energy input for the same distance as BE trucks owing to their lower technical efficiency ↘ BOX 31.

477. What generation costs and market prices of electricity and hydrogen actually materialise in future will depend on various factors and is subject to a high degree of uncertainty (World Energy Council, 2021; EWI, 2022; Pehnt et al., 2023; vbw, 2023; Wietschel et al., 2023). The **market price of charging electricity** varies depending on where charging takes place ↘ ITEM 481. Fast charging on motorways is likely to be particularly expensive for trucks in future (Hildermeier and Jahn, 2024). Charging at private depots is likely to be considerably cheaper – partly owing to the available potential for on-site generation of electricity from renewable energy sources ↘ BOX 32. Overall, various studies consider an average market price of charging electricity for trucks of **between 20 and 30 euro cents per kilowatt hour (kWh) in 2030** to be realistic (Jöhrens et al., 2022; Göckeler et al., 2023).

Hydrogen fuel costs today usually range from 10 to 15 euros per kg. According to studies, these **could be reduced to between 4 and 6 euros per kg** over the medium term. **However, such a cost reduction would require economies of scale throughout the value chain, government subsidies** and high capacity utilisation of the supply and refuelling infrastructure (Basma et al., 2022; Zerhusen et al., 2023). This also assumes that the sale of hydrogen at filling stations will continue to be **tax-free and duty-free** and that there will be no internalisation of government costs for building the hydrogen network. In contrast, around half of the market price of electricity assumed above consists of taxes, levies and legally regulated grid charges. Any comparison of electricity and hydrogen prices is therefore distorted in favour of the market price of electricity. If taxes, levies and grid fees are also charged for hydrogen in future, as is the case with electricity, the market price of hydrogen fuel is likely to be significantly higher than the tax-free prices mentioned here.

478. **The secondary market for trucks is also relevant to the economic viability of new drive technologies**. While the majority of used diesel trucks can currently be sold to Africa or southern/eastern Europe, trucks fitted with alternative drive systems can only be effectively used where the necessary infrastructure is available. Given the existing uncertainty, the residual value of diesel trucks is higher than that of trucks with alternative drive systems. ↘ BACKGROUND INFO 18

The **re-use options available for trucks with alternative drive systems remain uncertain**. However, the service life of BE trucks and their key component – the battery – could no longer be synchronised in future, unlike diesel trucks and FCE trucks. New business models aim to continue using BE trucks in the primary market at the end of the battery's service life after they have been upgraded with a new or reconditioned battery (Berylls, 2023). The **residual values of the vehicle and its battery could** then **be considered separately in future**. Second-life applications resulting from used batteries have the potential to significantly improve the total cost of ownership of BE trucks compared with other alternative drive technologies (Lebeau et al., 2019). Finally, the material value of batteries can be utilised by recycling them. The environmental impact of raw-material extraction, production and disposal makes battery recycling worthwhile anyway (Thielmann et al., 2020). ↘ ITEM 472

479. The **competitiveness of technology options** can be **affected by government policy instruments**. For example, the taxes and surcharges levied on electricity generation and transmission in Germany represent a key lever for lowering electricity prices and thus – in addition to rising fossil fuel costs – have an impact on the achievement of TCO parity between BE trucks and diesel trucks (Basma et al., 2021; Bushnell et al., 2021). ↘ ITEM 512 The future role played by BE trucks and FCE trucks in long-distance road freight transport therefore partly depends on the politically imposed regulatory framework, further technological advances and the availability of infrastructure.

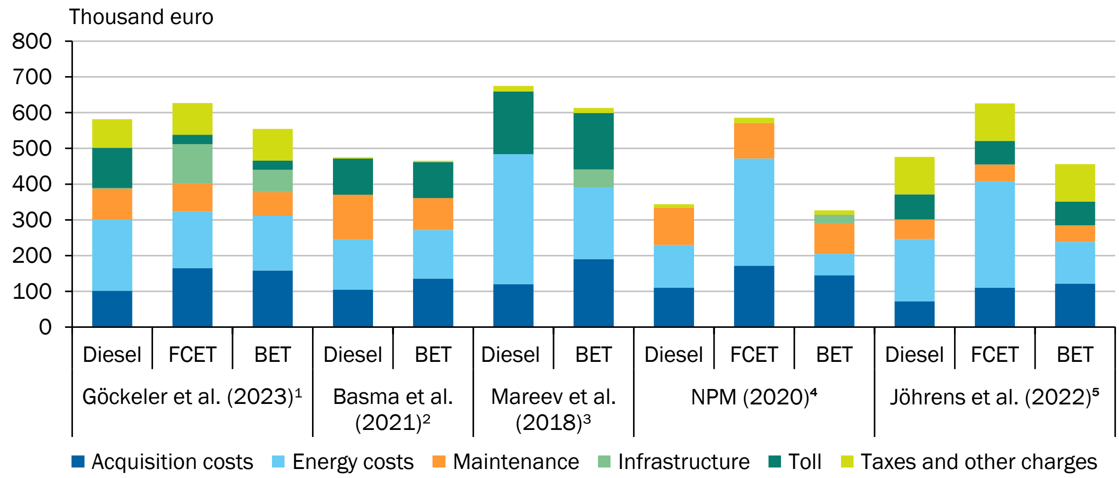
480. If other similar factors – especially the costs of building energy infrastructure, energy efficiency and government policy instruments such as truck tolls – are included, various studies show that **BE trucks** can achieve **TCO parity with diesel trucks in long-distance freight transport by 2030** (Mareev et al., 2018; NPM, 2020; Basma et al., 2021; Wolff et al., 2021; Jöhrens et al., 2022; Tol et al., 2022; Burke et al., 2023). The studies analysed reveal a great deal of heterogeneity in the assumptions made about factors such as application profiles and energy costs in various calculated scenarios. Overall, however, they come to the conclusion that BE trucks will be able to achieve economic viability compared with diesel trucks and FCE trucks in long-distance road freight transport in the near future. ↘ CHART 115

Although these studies show that the acquisition cost of BE trucks is still significantly higher than that of diesel trucks, it is compensated for by lower operating costs. ↘ CHART 115 **FCE trucks**, on the other hand, are associated with comparatively high **acquisition costs and operating costs**, which are likely to remain **higher than those of BE trucks** in future (Tol et al., 2022; Göckeler et al., 2023). ↘ CHART 115 Cost parity with diesel trucks can therefore only be achieved much later than in the case of BE trucks (NPM, 2020; Burke et al., 2023) and, even then, only given optimistic assumptions about the future price of hydrogen (Jöhrens et al., 2022) and for a limited proportion of the application profiles within the EU over very long transport distances (Tol et al., 2022).

↘ CHART 115

TCO-Estimations for truck drives in 2030

Several studies expect a competitive advantage of BET over Diesel by 2030



1 – Total operating costs for a articulated truck (40 tonnes) with an annual mileage of 120,000 km. Year of purchase 2030. BET with a range of 600 km. Scenario "recharge2035" 2 – Total operating costs for a articulated truck (40 t) with a total mileage of 790,000 km after 5 years. Year of purchase 2029. BE truck with 500 km range. Energy costs include the costs for public and private charging infrastructure. 3 – Total operating costs for a articulated truck (40 tonnes) with a total mileage of 939,640 km. Year of purchase 2030. 600 kWh battery capacity. "Average Route", scenarios 1 & 7. 4 – Total cost of ownership for a articulated truck (40 tonnes) with a useful life of 6 years. Year of purchase 2030. Scenario without government control instruments with falling vehicle prices. Without costs for downtime. Only acquisition costs of the private charging infrastructure for BET taken into account. Costs of public charging infrastructure (BE, FCE) not taken into account. 5 – Total operating costs for a heavy commercial vehicle (> 26 t) with a total mileage of 468,100 km until sale. Year of purchase 2030, excluding labour costs and not taking into account the costs of private and public charging infrastructure (BE, FCE).

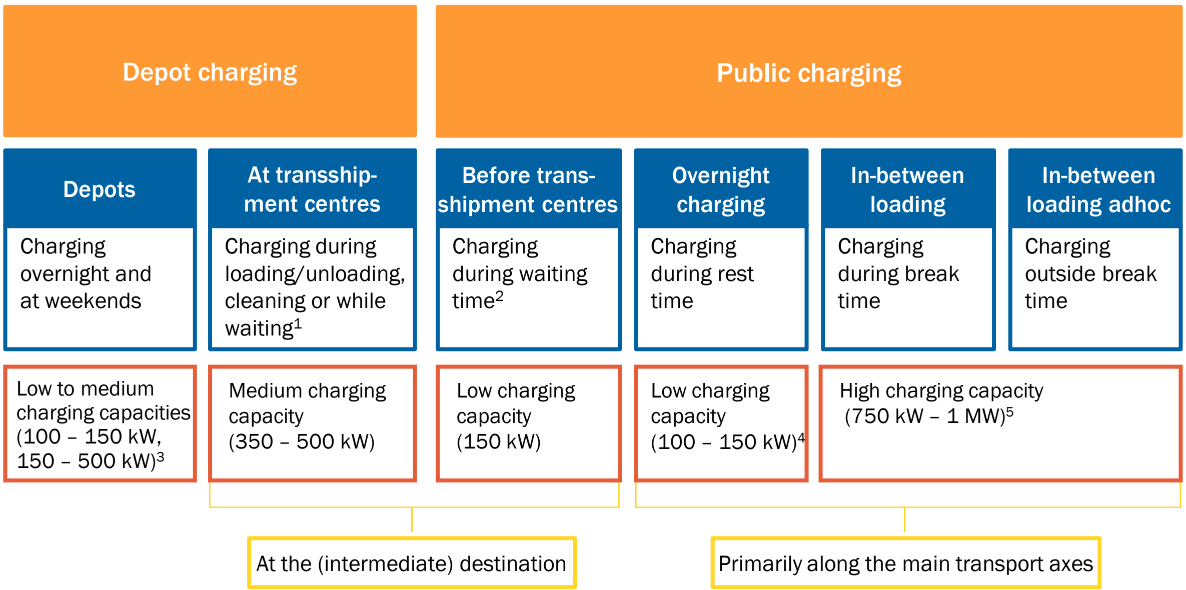
Sources: Basma et al. (2021), Göckeler et al. (2023), Jöhrens et al. (2022), Mareev et al. (2018), NPM (2020), own calculations

Alternative drive systems require an alternative energy infrastructure

481. **A publicly accessible supply infrastructure must be built for low-emission alternatives to diesel trucks**. While FCE trucks rely on a publicly accessible refuelling infrastructure, a distinction must be made between different charging scenarios when building the charging infrastructure for BE trucks, as many of these scenarios can be realised in private depots. ↘ CHART 116 Simulations based on the latest truck driving profiles show that the majority of freight transport in Germany and Europe ↘ CHART 123 APPENDIX can be realised in the medium-term using business charging infrastructure alone (Speth and Plötz, 2024). This is consistent with the findings of comparable studies. Although demand for public charging points is higher in long-distance freight transport, which accounts for the majority of GHG emissions from road freight transport in Germany (Puls, 2022), ↘ ITEM 482 charging at depots dominates in this study as well (Speth and Plötz, 2024).

482. While an existing international standard in the form of the Combined Charging System (CCS) can be used for charging power of up to 500 kilowatts (kW), a new standard is required for scenarios involving higher charging power. Such a standard in the form of the **Megawatt Charging System (MCS)** is already in the process of being standardised. The final IEC standard could be adopted this year (Zeyen, 2024). The installation and operation of the first megawatt charging stations for trucks being piloted has begun. In spring 2024, truck manufacturers Daimler Truck and MAN were each able to independently demonstrate a charging

↘ CHART 116
Charging scenarios with recommended charging power for BET



1 – Primarily for tanker and silo vehicles. 2 – Primary for general cargo vehicles. 3 – Depending on whether parallel or sequential charging is used. 4 – In conjunction with load management. 5 – The megawatt charging system (MCS), which is currently still in the standardisation process, is expected to enable charging capacities of up to 3.75 MW. However, a peak power of around 1 MW should be sufficient to fully charge the lorry within the statutory break time.

Sources: NPM (2021a), own presentation

process based on MCS and put the first charging station for MCS charging into operation at their development centres. Only once the MCS standard is available will the **full range of charging scenarios** required for **battery-electric long-distance transport be available**, as only this standard allows batteries to be charged within the legally prescribed 45-minute journey break, which is required after a driving time of four and a half hours (Article 7 EC 561/2006). However, demand for public MCS charging points for long-distance freight transport is likely to increase only after a while, because vehicles with more regional application profiles and correspondingly shorter ranges are likely to be electrified first, ↘ ITEMS 473 FF. and these vehicles charge almost exclusively in private depots and industrial areas (Jöhrens et al., 2022; Speth and Plötz, 2024).

483. **Challenges** in building a public charging infrastructure for BE trucks arise from the need to **connect charging points to the electricity grid**, ↘ BOX 32 which requires appropriate infrastructure planning and capital investment. The more charging points are clustered locally and the faster charging takes place, the more electricity is required at a particular location at any one time. This often requires an expansion or conversion of the distribution grid. The conditions for grid connection are determined by the local distribution grid operators. They are obliged to connect to the grid in accordance with Section 17 of the Energy Industry Act (EnWG). However, the provision of information on connection options is often time-consuming, as individual inspections and calculations by the grid operator are required for high and medium voltages and for each location.

↘ BOX 32

Focus: interconnection between the electricity system and the ramp-up of electromobility

A significant increase in **electricity generation and** installed **electricity generation capacity** is required **for a broad expansion of charging stations.** There is a gap between the maximum electricity generation capacity and actual electricity generation which, in the case of conventional power plants, is largely determined by demand. As electricity generation from renewable energy depends on external factors, generation capacity must be significantly expanded in order to meet the demand for electricity at all times. The **gap between actual electricity generation and electricity generation capacity** will therefore **widen as** renewable energy's share of the electricity supply increases. Given a scenario in which road freight transport is handled entirely by BE trucks, the GCEE estimates that an additional 100 TWh of electricity per year and, depending on charging behaviour, around 2.85 to 10 gigawatts (GW) of generation capacity would be required. ↘ ITEMS 552 FF. APPENDIX These figures will need to be revised upwards or downwards to reflect future growth in road freight transport and the market share achieved by BE trucks. By way of comparison, total German electricity consumption in 2023 was 456.8 TWh (BNetzA, 2024b) and total installed generation capacity was 232.7 GW (BNetzA, 2024c).

The scenario framework 2023-2037/2045 **approved by the Federal Network Agency** (BNetzA, 2022b), which is based on the long-term scenarios 3 produced by the Federal Ministry for Economic Affairs and Climate Action (BMWK) (Fraunhofer ISI et al., 2024), **assumes massive growth in electricity demand** by 2045, accompanied by an increase in annual net and gross electricity consumption of up to 744 TWh (i.e. 163 %) and up to 770 TWh (i.e. 169 %) respectively. A major expansion of generation capacity is therefore planned: up to 519 GW (232 %) is to be added. In addition, up to 113.4 GW of new PV battery storage systems and 54.5 GW of large-scale battery storage systems are expected (BNetzA, 2022b). In order to prepare the electricity grids for the growing demand from electromobility, grid expansion at the distribution grid level must be carefully implemented. The **amendment to Section 14d EnWG** in 2023 **obliges distribution grid operators to take account of the expected demand for electricity up to 2045 when expanding the grid.**

Compared with the overall planned conversion of electricity systems, which is necessary to achieve carbon neutrality, **the electrification of road freight transport accounts for only a small proportion of expected demand.** The calculations used in the analysis presented here suggest that the energy required for a fully electrified road freight transport system could account for around 8 % of Germany's annual electricity generation in future. Other simulations for Germany come to similar conclusions (Göckeler et al., 2023). This does not necessarily mean that peak demand will have to increase by the same amount. Rather, the extent of the grid expansion required can be reduced if charging is optimised – depending on use cases and subject to suitable regulatory conditions – for example through time-of-use tariffs (Bernard et al., 2022). ↘ ITEM 554 APPENDIX Logistics centres are also attractive locations for photovoltaics. A study shows that there is considerable potential here to meet some of the electricity demand and thus reduce the electricity costs of battery electric commercial vehicles (Biedenbach and Blume, 2023).

484. Auer et al. (2023) evaluate the appeal of public truck parking areas and their potential suitability for truck charging infrastructure in Germany in a comprehensive study. The **realisation periods and capital expenditure required** to connect charging points to the electricity grid **vary greatly depending on the grid connection required**. A connection to the high-voltage grid is usually likely to be required for locations with total charging capacities of 15 megawatts (MW) or more. This is likely to entail realisation periods of around five years (Blume et al., 2023). If connections to the high-voltage grid require the simultaneous construction of a transformer station, realisation periods of up to ten years and investment costs of up to €20 million are possible. Connecting to the medium-voltage grid is usually sufficient for private depots, which means that realisation periods can be reduced to one or two years and investment costs can be cut to less than €100,000 (NLL, 2022a). Active charging management, i.e. spreading the maximum amount that can be obtained from any one charging point across all vehicles charging at the same time, can significantly reduce grid connection costs (Burges and Kippelt, 2021).

485. As charging processes currently take significantly longer on average than refuelling processes and there will therefore have to be more charging points in future than there are petrol pumps available today to supply a similar number of vehicles with power, the ramp-up of low-emission vehicles will be accompanied by a **sharp increase in the space required for parking and charging vehicles** (Monopolies Commission, 2023a). This could become a problem, particularly on motorways, where there are already too few parking spaces for trucks (BaST, 2019; BGL, 2019). In addition, the smooth operation of the logistics sector is likely to require the creation of reservation options for public charging infrastructure so that journeys and arrival times can be planned precisely.

486. **The EU Regulation** on the deployment of alternative fuels infrastructure **(AFIR) provides the framework for the Europe-wide construction of**

charging and refuelling infrastructure for low-emission trucks. ↘ BOX 34 Germany is implementing the requirements for the building of the necessary charging infrastructure as part of the Charging Infrastructure Masterplan II (Bundesregierung, 2022b). The first interim targets must be met by the end of 2025. ↘ BOX 34 The plan is to set up the first AFIR-compliant public CCS and MCS charging network for BE trucks on state-owned land along motorways (initial network). Motorway service stations and publicly accessible private areas are not included. A total of around 4,000 charging points – including 1,800 MCS charging points – are planned for the initial truck charging network.

As with the 'German network for cars', there are **plans to award contracts for the construction and operation of fast-charging infrastructure for trucks by inviting tenders** and to support the construction and operation of charging stations at managed and unmanaged motorway service stations by providing public funding. The necessary **network connections** will be ordered and **implemented by Autobahn GmbH** as part of a **process independent of the awarding of contracts**. They therefore remain the property of the German government. The costs incurred are included in the Climate and Transformation Fund (KTF). However, there are plans to charge the operators of the charging infrastructure for use of the grid connections on a pro-rata basis. Car manufacturer Tesla and charging station operator Fastned have been suing Autobahn GmbH for two years because the latter had signed a contract with Autobahn Tank & Rast Gruppe GmbH & Co KG – the concessionaire for almost all motorway service stations – to set up the necessary charging infrastructure without launching a tendering process (Monopolies Commission, 2023b; Tartler, 2023). Given these ongoing proceedings, only unmanaged motorway service stations can be included in the first stage of tenders.

Although the tendering process should originally have started at the end of 2023 (Bundesregierung, 2022b), it is now **not scheduled to take place until the current year 2024**. Details are still being finalised. As with tenders for the German network, however, the plan is evidently to sign contracts with future operators to ensure that charging stations are installed within a specified period once the contracts have been awarded. In addition, charging station operators will be given instructions regarding the minimum technical and structural requirements for the charging stations to be installed as well as the prices of charging electricity.

487. The AFIR also requires the construction of an **AFIR-compliant initial public network for hydrogen refuelling stations by 2030**. ↘ BOX 34 To this end, the German government has announced that it is devising a master plan for hydrogen and fuel-cell technology in transport (BMDV, 2023c). However, there are still no concrete plans for this. In order to be AFIR-compliant, hydrogen refuelling stations must allow refuelling with gaseous or liquid hydrogen at a certain pressure level. Not all existing hydrogen refuelling stations in Germany meet these requirements. Funding for hydrogen refuelling stations has so far been provided in the form of investment grants. Funding rates of up to 80 % of investment costs were achieved in the German government's most recent calls for funding in 2023. An

examination of whether incentives to expand the hydrogen refuelling station network using a funding mechanism similar to the call for tenders – and equivalent to the charging infrastructure – are possible and expedient has not yet been completed. Given the necessary prioritisation in the KTF, the BMDV is currently not making any statements on future funding options in the area of hydrogen refuelling infrastructure.

↘ BOX 33

Background: hydrogen infrastructure for commercial vehicles in long-distance transport

The **hydrogen refuelling stations** currently **available** in Germany are **only partially compatible with FCE trucks.** Potential transport and delivery options as well as the necessary storage and processing facilities at hydrogen refuelling stations depend on the form in which hydrogen will be used in heavy-duty commercial vehicles in future, although there is still uncertainty about this (Zerhusen et al., 2023). ↘ BOX 31 If gaseous hydrogen is used in FCE trucks in future, the hydrogen's flow rate from the petrol pump to the vehicle would have to be increased in order to refuel heavy-duty FCE trucks within a similar time to diesel trucks (IEA, 2023a; Zerhusen et al., 2023). If, on the other hand, liquid hydrogen is used in future FCE trucks, as currently appears to be the case according to manufacturers, the existing filling stations used for gaseous hydrogen cannot be used or upgraded for trucks. It would therefore be necessary to build a completely new supply infrastructure.

There is, as yet, **no established model** for **supplying carbon-neutral hydrogen to refuelling stations** in future. Hydrogen can be supplied to refuelling stations in various states of aggregation. The delivery of gaseous compressed hydrogen and cryogenic liquid hydrogen by truck is now firmly established. However, delivery by truck is not suitable for larger quantities, for which other supply routes would be required (NWR, 2023a; Zerhusen et al., 2023). The core hydrogen network forms the basis for building a hydrogen infrastructure in Germany. Hydrogen pipelines will successively come into operation by 2032 (BMWK, 2023a). It would be technically **feasible** to **supply hydrogen as a fuel via the core hydrogen network,** although this will not be directly compatible with the refuelling station infrastructure because different pressure levels prevail there. Compressors would therefore have to be used at the petrol pumps, which would require additional energy. Moreover, **a regional distribution infrastructure** would have to be **built from the pipeline of the core network to the petrol station.** The construction of such connecting pipelines incurs high investment costs and requires a great deal of planning (Zerhusen et al., 2023). Alternatively, hydrogen could be produced on-site at the refuelling station by means of an electrolyser (NWR, 2023b; Zerhusen et al., 2023). In order to ensure sufficient production capacity at refuelling stations, however, a considerable amount of space and electricity would be required for the entire plant and an appropriately dimensioned grid connection would be necessary (Zerhusen et al., 2023), which in turn would require substantial capital investment and a certain lead time. ↘ ITEM 484

488. **Europe's first automatic battery exchange station** for BE trucks began **test operations in Germany** last year. This involves a robot replacing an empty battery with a full one. The whole process takes around ten minutes – the same time it takes to refuel a diesel truck. Various studies consider this technology to be a promising addition to the construction of a nationwide charging infrastructure, as lengthy charging breaks can be avoided and there is no need to build network capacity (Vallera et al., 2021; Zhu et al., 2023). However, batteries would have to be kept at stations and are likely to remain a scarce commodity for many

years to come during the ongoing transformation process. Battery exchange stations for cars and trucks are widespread in Asia, especially in China (IEA, 2023a). Almost all major Chinese truck manufacturers have now launched a BE truck model with battery swap capability. The total number of battery swap stations in China was almost 2,000 at the end of 2022, which was 50 % higher than at the end of 2021 (IEA, 2023a).

489. Because freight transport in Europe takes place across borders, the **necessary supply infrastructure** must **be available throughout Europe**. Most European countries have started to build charging infrastructures for BE trucks. Sweden and the Netherlands in particular are making progress here (Mulholland and Egerstrom, 2024). In contrast, overhead lines are (now) of very little significance in other European countries. Hydrogen refuelling stations for cars are being dismantled in several countries because, among other things, they do not meet the latest standards (Everfuel, 2023; Automobilwoche, 2024; FR, 2024). Germany currently has the most hydrogen refuelling stations in Europe. However, some hydrogen refuelling stations have recently been closed in this country (Nicoley, 2024).

↘ BOX 34

Background: European requirements for building the supply infrastructure for alternative fuels

In 2023 the **European Parliament** adopted a supplementary **regulation on the deployment of alternative fuels infrastructure (AFIR)** (European Parliament and Council of the European Union, 2023). The AFIR specifies Europe-wide requirements for building infrastructure for alternative fuels and aims to standardise and ensure the interoperability of charging and payment interfaces. Among other things, it sets out minimum requirements for the construction of a battery-electric and hydrogen-based charging and refuelling infrastructure throughout the Trans-European Transport Network (TEN-T) by 2030 (European Parliament and Council of the European Union, 2023). A charging station with an aggregated charging capacity of at least 3.6 MW is to be installed every 60 km in each direction and a hydrogen refuelling station is to be installed every 200 km throughout the TEN-T core network (6,369 km in Germany) for heavy commercial vehicles. ↘ CHART 122 APPENDIX A charging station with at least 1.5 MW of aggregated charging capacity is to be installed every 100 km in each direction throughout the entire TEN-T network (in Germany a further 5,027 km) (European Parliament and Council of the European Union, 2023). 15 % (25 %) of the charging points throughout the TEN-T core network should be in operation by the end of 2025 (2027). In total, the AFIR aims to install around 2,800 charging stations with a total charging capacity of 7.5 GW across Europe by 2030 (Plötz et al., 2024).

As the AFIR only stipulates a total capacity per charging location, the relevant requirements can also be met by installing CCS charging stations and do not necessarily require a megawatt charging infrastructure. A Europe-wide evaluation of the AFIR concludes that its requirements might be too high in the short term (around 25 % more charging options than the demand forecast in the study) and too low in the longer term (80 % more charging capacity required in 2030) (Ragon et al., 2022). Balke et al. (2024b) calculate that only a public charging network with charging stations every 60 km along the main transport routes and a charging capacity of 1.7 MW per charging point would ensure that long-distance freight transport in Germany can be run with a high degree of certainty, without any loss of time and on low battery capacity. If route planning is adapted more stringently, a charging capacity of 1 MW per charging point located every 100 km might also be sufficient. Strategic placement of charging stations across Germany can significantly reduce the total number of locations required and cover 93.8 % of domestic long-distance traffic in Germany (Balke et al., 2024a). ↘ CHART 122 APPENDIX Although the AFIR should therefore be **sufficient** overall in terms of **network density for Germany in principle**, the **minimum charging capacity specified** in this Regulation is **the absolute minimum.**

IV. MEASURES: REFORM OPTIONS FOR FREIGHT TRANSPORT OF THE FUTURE

490. Given the two major challenges facing freight transport – the condition of infrastructure and the need to accelerate decarbonisation – there is a need for political action. **Monetary and non-monetary barriers are limiting capital investment in transport infrastructure.** ↘ ITEMS 491 FF. In order to provide the most efficient infrastructure possible for the future transport system, its funding must be secured ↘ ITEM 492 and planning and approval procedures must be simplified and accelerated. ↘ ITEM 494 To strengthen rail freight transport, it is important to **maximise the potential for a modal shift**. To this end, rail capacity must be expanded and utilised more efficiently. The decarbonisation of road freight transport requires the **rapid construction of energy infrastructure for alternative drive systems**. The public sector should unbureaucratically make space available along motorways for the building of charging and refuelling infrastructure and remove potential obstacles to the provision of private land. ↘ ITEM 509 Policymakers should reduce uncertainty for private actors regarding the future regulatory framework by making key technology policy decisions, thereby accelerating the market ramp-up of BE trucks. ↘ ITEM 524

1. Removing obstacles to the modernisation of infrastructure

491. The declining level of modernity ↘ CHART 106 RIGHT and deteriorating condition ↘ BOX 27 of **transport infrastructure in Germany** suggest that **more funding should be made available for such infrastructure**. However, there are no reliable estimates of the amount of expenditure that would be required to sustain this transport infrastructure. ↘ BACKGROUND INFO 19 The Federal Transport Infrastructure Plan 2030 (FTIP) defines the aspects of transport infrastructure that will require replacement, maintenance, expansion or total reconstruction in the medium-term. ↘ BACKGROUND INFO 17 However, the actual financial requirements cannot be properly estimated. The prioritisation of projects based on a cost-benefit analysis creates an incentive to underestimate the actual costs (Böttger, 2023). ↘ BACKGROUND INFO 17 Even sharp price increases, such as those that have occurred since 2019, can only be taken into account with a certain time lag. ↘ BACKGROUND INFO 17 This can cause delays and creates uncertainty (Handelsblatt,

2024a). In addition, the cost data available for various expansion and construction projects are not comparable owing to a lack of standardised guidance on how to calculate costs (Bundesrechnungshof, 2016).

↘ BACKGROUND INFO 19

Background: determining the expenditure needed for transport infrastructure

Surveys are often used in Germany **to determine the expenditure required for transport infrastructure**, particularly at municipal level (Arndt and Schneider, 2023; Raffer and Scheller, 2023). However, the **informative value of these surveys** can **be impacted** by selection effects, strategic response behaviour or a lack of delineation of the investment backlog (Christofzik et al., 2019; Gornig, 2019). **Alternatively**, to determine the funding required, it is possible to **calculate how expensive it would be to restore the existing fixed assets to their original condition.** A spending deficit of €3.8 billion per year for Germany was determined in this way for the period from 2006 to 2011, the largest share of which related to waterways and railways (Kunert and Link, 2013). However, this does not take account of future changes in demand in response to economic or demographic trends and new requirements such as the decarbonisation targets set. This drawback could be addressed by estimating the demand for transport infrastructure (Fay, 2001; Fay and Yepes, 2003; Ruiz-Nuñez and Wei, 2015; Branchoux et al., 2018). The FTIP can only do this to a limited extent, as only past traffic trends are factored into the amount of maintenance and replacement investment needed. Changing traffic flows, such as those that may occur in the course of structural changes as a result of the decarbonisation of freight transport, are therefore not considered here. ↘ BACKGROUND INFO 17

492. Around 22.4 % of transport expenditure in 2023 was funded by the truck toll and the rest by tax revenue, mainly from the energy tax (Bundesregierung, 2023c; BMF, 2024). The switch to alternative drive systems means that these tax revenues are likely to fall sharply (UBA, 2021; Board of Academic Advisors to the BMDV, 2022; GCEE Annual Report 2020 item 386). Greater user financing could help to compensate for the loss of tax revenue. In order to ensure that the charges for utilising infrastructure are actually used to maintain and expand it, it is **important** to **use any infrastructure-related sources of funding,** as is the case with toll revenue (BFStrMG Section 11 (3)). The truck toll could cover around 42 % of planned federal transport expenditure over the period from 2024 to 2027 (BMDV, 2023d; Bundesregierung, 2023c, p. 65). In future, therefore, passenger cars should also be used to fund infrastructure in addition to trucks. This could be done using a mileage-based car toll. As heavy vehicles cause more wear and tear on infrastructure than light vehicles, it would make sense to differentiate such a toll according to weight (Agora Verkehrswende, 2022).

493. The GCEE has devised a proposal on how the **scope for debt can be increased by reforming the debt brake** without jeopardising the sustainability of the public finances (GCEE, 2024). Depending on how the debt ratio evolves over time, such a reform could increase the scope for structural debt cumulatively by between €21.6 billion and €57.5 billion by 2027. This should be used to invest in the future. Capital spending on infrastructure that also benefits future generations

who use it represents a valuable investment in this sense and is thus the best possible use of any expanded scope for debt.

494. Above all, however, it is crucial to ensure that the necessary public infrastructure investment is no longer merely seen as a minor item of budgetary policy. According to a proposal by the Scientific Advisory Board to the BMWi (2020), Germany's federal and regional governments could set up **investment promotion companies** (IFGs) for this purpose, whose funding from core budgets is guaranteed over the long term. This could be achieved, for example, in the form of binding contractual or statutory entitlements to constant funding allocations over a period of five or more years, so that clients and contractors can be guaranteed planning certainty. The establishment of investment promotion companies could also help to **overcome administrative and planning obstacles at municipal level** in the medium-term (Scientific Advisory Board to the BMWi, 2020). Key planning competencies and personnel could be pooled at the level of multiple federal states or municipalities. This could yield synergies and cost savings. Examples of such companies include Autobahn GmbH, which manages Germany's federal trunk road network, and DEGES GmbH, which was set up as part of German reunification to build infrastructure in eastern Germany.

495. Extensive neighbourhood and competition legislation offers scope for legal action and causes considerable delays and cost increases in infrastructure projects (BMVI, 2015b; Scientific Advisory Board to the BMWi, 2020). Enforcing construction legislation relating to major infrastructure projects by law, as in Denmark (Roland Berger, 2013, p. 76 ff.; IHK Nord, 2017), can be one way of modernising key parts of infrastructure more quickly. The **Act on the Acceleration of Approval Procedures in the Transport Sector** is a step in the right direction. An overriding public interest was identified for selected rail and road projects, thereby accelerating their planning procedures. Abolishing the need for approval and environmental impact assessments for the renovation of bridges is also a sensible move.

Although **procurement procedures** in Germany **follow** the **most legally secure route possible**, this makes them slow and costly. Starting points for reform include a move away from the strong focus on price and a greater emphasis on qualitative evaluation criteria in the context of functional tenders, as well as the so-called *Mittelstandsgebot*, which can compel the formation of inefficiently small lots (BMVI, 2015b; Scientific Advisory Board to the BMWi, 2020).

2. Strengthening rail freight transport

496. The **potential for shifting** freight transport from road to rail is limited in the medium-term. ↘ ITEMS 463 FF. A key prerequisite for accelerating this trend would be a significant increase in efficiency and capacity in rail transport. ↘ ITEM 497 Strengthening price competitiveness, for example by cutting taxes and surcharges on traction current in rail transport, only promises to be successful if there is sufficient capacity available. ↘ ITEM 455 Where rail already offers efficiency savings compared with road transport – especially **on long, international routes**

↘ ITEM 459 – the conditions for a modal shift should be further improved. ↘ ITEM 563 APPENDIX

Increasing efficiency and capacity in rail freight transport

497. The choice of means of transport for smaller load sizes depends primarily on transport times. ↘ ITEM 458 The **loading time and the time taken to put the train together** also play a **key role** here. In single-wagonload transport, in particular, trains are made up of smaller sections. In many cases this is still done by manual coupling, which requires manpower and is relatively slow (Bundesregierung, 2019b). **The Europe-wide introduction of digital automatic coupling (DAK) could be a decisive improvement** (BMDV, 2021a). However, it requires capital investment in this technology. Given that there are around 54,000 manual coupling operations per day in Germany alone, automated coupling could save a considerable amount of time (DB Cargo, 2024c). However, initial coordinated trials have shown that the DAK system still requires further optimisation before it can be introduced across the board; the first deployments of this technology are planned for the current year (DB, 2024c, 2024d). As soon as these customer deployments have shown that this technology is ready for series production, as many parts of the fleet as possible should be equipped with the technology at the earliest opportunity.

498. The **capacity of the existing rail network** can be **limited by the utilisation of individual structural elements** such as track sections, bridges or stations (Meirich, 2017). Capacity can be increased through **more efficient train route planning** in areas such as scheduling,↘ ITEMS 463 AND 465 (Meirich, 2017). As route utilisation varies greatly from region to region (DB, 2023a), rerouting long-distance rail freight traffic to less heavily used routes could free up capacity and thus help to increase it. However, this could mean considerably longer routes for slower rail freight traffic, which might not be feasible in view of existing employment legislation on things such as returning daily to the home station, and could incur higher transport costs owing to greater wear and tear on freight trains. In future, AI systems could increase efficiency both in train route planning and in scheduling following disruption. ↘ ITEM 560 APPENDIX

499. To increase capacity in mixed operation of the rail network, it is necessary to **provide sufficient passing tracks** to allow faster trains to overtake slower traffic (Muthmann, 2004). For many years now, however, DB AG has actually been reducing rather than expanding its network. Passing tracks in particular have fallen victim to the lack of investment (VCD, 2022). This shortcoming is to be remedied by the Federal Transport Infrastructure Plan 2030, which includes **expansion of the so-called 740m network**, which is a network of passing tracks for trains up to 740 metres long (FTIP, 2018). This will allow rail freight transport capacity to be increased in future. Once this expansion is complete, it will be **possible to use longer freight trains** and move them at faster speeds (DB, 2023c).

Other strategies that could increase the capacity of the rail system – despite **only being** likely to **be implemented in the long term – include the digitalisation** of signalling and control systems, **autonomous (freight) trains**

and the allocation of freight trains to high-speed lines, although these will require technical upgrades. ↘ ITEMS 560 FF. APPENDIX

Improving the competitiveness of rail freight transport

500. Numerous initiatives are under way at European level to create a single European railway area. ↘ ITEM 549 APPENDIX Rail freight transport is profitable in principle, particularly over long distances, and further potential should be exploited. Given its central location, Germany has a key role to play in the **expansion of European** rail freight **corridors**. The procedures for approving new and upgraded lines **should be accelerated**. Incompatibilities in international rail freight transport caused by national regulations and standards should also be further reduced. The introduction of a common European operating language, for example, could help here. In addition, technical incompatibilities such as different track gauges should be standardised in the medium-term.

501. The Federal Rail Infrastructure Expansion Act (BSWAG) creates **perverse incentives to implement maintenance measures in rail infrastructure**. ↘ BOX 30 In the Act's current form, the German government is obliged to fund replacement investment, while DB AG only has to pay for maintenance. Consequently, necessary and economically efficient maintenance measures are delayed and, in the worst case, are not carried out at all until the assets concerned need to be completely replaced. A **revision of the BSWAG** currently being discussed by the mediation committee stipulates that the German government may also have to pay for maintenance costs. This would **only partially solve the incentive problem and would be at the expense of the German government**.

In addition, the Performance and Financing Agreement (**LuFV)** should be **fundamentally revised**. The quality indicators specified in the Agreement cannot adequately verify whether DB AG appropriately uses the federal government subsidies provided for replacement investment and whether it sufficiently meets its maintenance obligations. These indicators need to be revised and expanded for this purpose (Monopolies Commission, 2023a). The GCEE sees the elimination of these incentive problems as an important lever for the long-term sustainable improvement of rail infrastructure.

502. **Decoupling ownership of the infrastructure company from the rest of the DB Group** could help to improve the quality of rail infrastructure. Firstly, this might improve transparency about the use of government investment subsidies for infrastructure investment in rail. ↘ BOX 30 And, secondly, it might prevent inefficient prioritisation of capital expenditure driven by corporate interests. This can happen if investment is geared towards the objectives of the railway's own transport companies rather than towards the objectives of the entire rail network (Monopolies Commission, 2015a). Effective competition could also develop between transport companies. ↘ BOX 30 As a vertically integrated group ↘ GLOSSARY it is in DB AG's interest to maximise its total profit. **Group companies could** therefore **be given preferential treatment over competitors despite** regulatory precautions – for example in terms of **access to rail infrastructure** (Monopolies Commission, 2023a). Strong competition results in lower costs, innovation

and higher quality. This could enhance the appeal of rail freight transport in Germany (Monopolies Commission, 2015a, 2023a). It is currently difficult to assess the extent to which the infrastructure company DB InfraGo, founded as a public service provider in January 2024, will achieve these goals. ↘ BOX 30

However, separation of ownership incurs **transition costs** owing to the creation of duplicate structures. Positive **economies of scope could be lost**. Various empirical **studies** have investigated the effects of vertical separation on costs **but arrive at mixed results**. Cantos et al. (2010), for example, found predominantly positive effects. Mizutani et al. (2015), on the other hand, suggest that railway structures should be chosen according to country-specific circumstances, as they are heavily dependent on transport intensity. Given the efficiencies and competitive advantages described above, however, the positive effects of ownership separation outweigh the negative effects in overall assessments.

503. In order to incentivise rail infrastructure operators to improve quality, a **quality-based component** could be included in **the track access charging system** (Monopolies Commission, 2023a). This would give rail infrastructure operators greater pricing leeway if predefined quality targets are met. If these targets are not met, corresponding discounts would have to be accepted. Suitable quality parameters could include factors such as reliability, rail network size, asset quality, capacity restrictions and service quality (Monopolies Commission, 2023a).

504. To strengthen the price competitiveness of rail transport, there is potential to reduce the amounts of electricity tax and other surcharges on traction current. ↘ ITEM 455 According to the European Commission, the **electricity tax on traction current in rail transport in Germany** is significantly **higher than in other European countries** at 1.14 cents per kWh. Some EU member states, such as Belgium and Sweden, do not levy any such tax at all. They are able to do so because no minimum tax rate has been set for traction current at European level (EU Directive 2003/96/, Article 15). In order to strengthen the price competitiveness of rail freight transport, electricity tax could be reduced either to zero or to the rate of 0.05 cents per kWh applicable to energy-intensive companies.

3. Building the energy infrastructure for alternative drive systems

505. **When building the nationwide charging and refuelling infrastructure for trucks** with alternative drive systems, it may be appropriate to provide public support – possibly even financial support – owing to the necessary coordination involved (GCEE Annual Report 2020 items 454 ff.). This could ensure the rapid construction of charging points and compensate for any initial underutilisation (Monopolies Commission, 2023b). In the past five years, however, investment subsidies covering the construction and grid connection costs of publicly accessible charging and refuelling infrastructure have never been fully utilised (Deutscher Bundestag, 2023c). In addition, only around a quarter of the charging points installed were subsidised (NLL, 2022b; Monopolies Commission, 2023b).

This suggests that there are **primarily non-monetary barriers to the ramp-up of charging and refuelling infrastructure.** ↘ ITEMS 481 AND 483

As BE trucks are expected to become economically viable in the near future ↘ ITEMS 473 FF., there is no reason to assume that this should be fundamentally different when building the charging infrastructure for trucks, especially as CCS charging stations can also be used by BE cars. **However, public funding may be needed to accelerate the market ramp-up of MCS charging infrastructure** on motorways, which is only used by long-distance heavy commercial vehicles, and for **charging stations in private depots**, which are essential for the electrification of local and distribution transport. Nonetheless, such public funding should then be limited to the market ramp-up phase.

↘ BACKGROUND INFO 20

Background: government subsidies for low-emission commercial vehicles

The **Directive on the subsidisation of commercial vehicles with alternative, climate-friendly drive systems and the associated charging and refuelling infrastructure (KsNI) has so far subsidised the purchase of emission-free commercial vehicles** by funding up to 80 % of the additional costs compared with diesel trucks (BMVI, 2021). **Procurement of the charging and refuelling infrastructure required for business operations has** also **been subsidised.** Germany has thus offered the most generous public funding for the purchase of low-emission trucks in Europe (IEA, 2023a). However, the **Climate and Transformation Fund (KTF), which was set up** in response to the Federal Constitutional Court ruling of 15 November 2023, **no longer provides funding for this programme** (Bundesregierung, 2023d). The KTF **still provides a** total of **€1.9 billion to support public charging and refuelling infrastructure** for passenger and commercial vehicle transport (reduced by €0.29 billion; BMWK, 2023b). These funds will primarily be used to build the initial charging and refuelling network for cars and trucks on motorways.

506. Now that the KsNI federal subsidy has ended, the **subsidy for purchasing low-emission commercial vehicles has expired.** ↘ BACKGROUND INFO 20 When making a purchasing decision, it is not only the purchase price that is decisive but also the total cost of ownership over the life cycle. ↘ BACKGROUND INFO 18 In long-distance freight transport in particular, low energy costs and fuel costs and the availability of charging and refuelling infrastructure are the main factors that determine the competitiveness of a technology option (Plötz et al., 2018). Competitiveness with diesel trucks is already likely to apply to local freight transport and aspects of regional transport and will grow from there to cover other use cases as well (NPM, 2020; Basma et al., 2021; Jöhrens et al., 2022; Tol et al., 2022). ↘ ITEMS 473 FF. Various studies show that subsidising car purchases has a considerable deadweight loss effect (Muehlegger and Rapson, 2019; Xing et al., 2021; Qorbani et al., 2024). The phasing-out of this purchase subsidy is therefore to be welcomed. Public funds are better spent on building the charging infrastructure for alternative drive systems (Springel, 2021).

507. **As part of the KTF's reorganisation, public funding** for the **construction of charging and refuelling infrastructure has** also been **reduced.** ↘ BACKGROUND INFO 20 In future these funds will be primarily used to build an initial charging and refuelling network on motorways. ↘ ITEM 486 **Charging infrastructure for BE trucks** will **also be needed outside the initial network** – particularly in car parks, publicly accessible private areas and private depots (Agora Verkehrswende, 2024). ↘ ITEM 481 The public sector has a role to play in resolving coordination problems when building the charging infrastructure. The so-called *FlächenTool*, which the National Centre for Charging Infrastructure (NLL) has set up and manages on behalf of the German government, provides a useful digital information platform that enables available private and public space to be matched quickly and unbureaucratically with corresponding demand. The *StandortTool* enables future demand for charging infrastructure to be regionally identified based on traffic flows, socio-economic data, and spatial and user structures. In addition, e-mobility advice based on the energy advice model could help freight transport companies to adapt their fleet drive systems, plan charging points in depots and submit the necessary grid connection requests, as well as mitigating uncertainty. Consideration should also be given to resuming investment subsidies for the installation of charging stations in private depots during the market ramp-up phase. This should make it possible to exploit the considerable potential for decarbonisation in local and distribution freight transport. ↘ ITEM 474

508. Public tendering is, in principle, a suitable way of ensuring non-discriminatory access to land and funding. It is therefore to be welcomed that the currently planned contract for the initial truck charging network is to be awarded by tender. ↘ ITEM 487 When it comes to the specific **design of tenders,** however, **attention must be paid to their conformity with market and competition standards**. For example, there are doubts about the planned award criteria and whether there are sufficient grounds for the German government to take on the extensive operating and capacity-utilisation risk ↘ ITEM 487 (Monopolies Commission, 2021, 2023b). The NLL justifies this by citing the existence of market failure and its desire to counteract the emergence of dominant regional competitive forces (Hanken, 2024; Pallasch, 2024). However, the intended service and price specifications set regulation-like standards. Given the available options for intervention under antitrust law, it is not clear why these standards are necessary for the building and operation of publicly accessible charging infrastructure, especially since there is no reliable evidence to date that the price of charging electricity in Germany is systematically and abusively excessive (Bundeskartellamt, 2021; Monopolies Commission, 2023b). Rather, the risk of lengthy and bureaucratic processes around tenders arises from petty specifications (Tartler, 2023; Andreae, 2024; von Knobelsdorff, 2024).

509. Even in the run-up to these planned tenders there are various **obstacles that are delaying the German government's provision of public spaces** for the building of the initial charging and refuelling network. ↘ ITEM 486 For example, the motorway locations that have been identified by the NLL and could potentially be considered for the German government's tenders must first go through a time-consuming grid connection application process ↘ ITEM 483. The rapid processing of

these requests should be given high priority by network operators. In addition, the **installation of charging stations at managed motorway service stations is being delayed by** the **proceedings** currently pending **against Autobahn GmbH**. ↘ ITEM 487 This is problematic for the market ramp-up of BE trucks, as electrified long-distance road freight transport is dependent on charging facilities on motorways, and unmanaged motorway service stations are naturally much less attractive for truck drivers during their breaks. A legally sound solution is urgently needed so that the building of car and truck charging infrastructure at managed motorway service stations can continue. This could require the signing of supplementary contractual agreements with the motorway service stations' concessionaire regarding third-party charging point operators' access to motorway service stations and the amounts to be charged for this in the form of concession fees or rents (Monopolies Commission, 2023b).

510. Information on grid connection costs and on the grid capacity of a potential location for charging points must currently be requested individually for each project, which often involves long waiting times. ↘ ITEM 483 It would make more sense if **interactive grid maps** showing connection capacities at the high and medium voltage level were publicly available free of charge and could be used **for site planning when building a nationwide charging infrastructure** in Germany. Digital grid maps are already being used in parts of the United States (Bialek et al., 2023) and Belgium (Verdoodt, 2024), for example. This would enable locations to be selected in advance so that they meet the requirements for current and future grid capacity. In order to create such a map for the whole of Germany, all distribution system operators would have to regularly report information on their grid capacities to a central organisation such as the Federal Network Agency or the NLL. The NLL also has information on suitable areas for car and truck charging infrastructure and where demand from BE trucks could be expected. ↘ ITEM 509 This data could be linked to create a comprehensive information base for potential charging point operators, network operators and policymakers.

511. The minimum charging capacity prescribed by the AFIR on motorways by 2030 is unlikely to be sufficient to electrify long-distance freight transport in Germany (Plötz et al., 2024). ↘ BOX 34 This requires, at least in prospect, the construction of a fast-charging infrastructure on motorways. **Germany should** therefore **exceed the AFIR's minimum charging capacity requirements** wherever possible.

The building of charging infrastructure for BE trucks on motorways cannot wait until the MCS standardisation process has been completed. It is therefore right to press ahead with **construction** of the initial charging network for trucks today **based on the current CCS standard**. In order to increase capacity utilisation and optimise network requirements, ↘ ITEM 484 it makes sense in any case to enable joint use for both MCS and CCS charging at charging locations, for example for overnight charging. ↘ ITEM 481 At least one MCS charging point is currently planned at each location of the initial charging network, and an average of five MCS charging points with high charging capacities are planned at each location. This should result in a total of **1,800 MCS charging points on motorways in Germany**. This provides a sound basis for the ramp-up of BE trucks and could **theoretically**

be sufficient to fully electrify long-distance road freight transport in Germany if the planned roll-out of charging stations by 2030 is successful and the relevant locations are strategically selected (Balke et al., 2024a, 2024b; Plötz et al., 2024). ↘ BOX 34 To facilitate a faster market ramp-up, the construction of an advanced fast-charging infrastructure should already be planned now with a view to the required expansion of the electricity grid and the space required.

512. The **level of market prices for charging electricity** is a **key lever for achieving TCO parity** between BE trucks and diesel trucks. ↘ ITEM 479 Prices vary significantly across Europe – often between locations in neighbouring EU member states – and are driven primarily by differences in grid charges (Hildermeier and Jahn, 2024). There is potential here to reduce the cost of fast charging in Germany in particular (ACER, 2023; Hildermeier and Jahn, 2024). In addition, there is still untapped potential for electricity tax, which could be cut to the European minimum rate (GCEE Annual Report 2020 item 391; GCEE Annual Report 2022 item 196; GCEE Annual Report 2023 item 173). Furthermore, there are **strong synergies** between the **generation of renewable energy on motorways and at truck depots and the expansion of the charging infrastructure network** (Biedenbach and Blume, 2023). ↘ BOX 32 When building charging infrastructure in private depots, combining its construction with photovoltaic systems should therefore be considered. However, the sale of local PV electricity to third-party firms (freight carriers) is difficult for proprietors from a regulatory perspective because they may be required to register as energy supply companies (Next, 2024). Lowering barriers to market entry may strengthen the incentive to invest in photovoltaic assets held in private depots.

513. **In order to secure German and European supplies of hydrogen, an extensive supply network within Europe is required** (GCEE Annual Report 2022 box 26). The construction of such a network makes sense, regardless of what role this technology will play in road freight transport in future. Given the scarce availability of and high demand for green hydrogen, the use of hydrogen will be prioritised where the electrification of processes is particularly difficult (Schreyer et al., 2024). This is particularly the case in the steel industry and basic chemicals, where there are likely to be no economically viable alternatives to using hydrogen (Wietschel et al., 2023).

Remain open to technology; prioritise public funding efficiently

514. Both truck manufacturers and policymakers are currently supporting several potential technological alternatives to zero-emission drive systems in freight transport, with battery electric drive systems at the forefront of truck manufacturers' strategies (NOW, 2023a). Although **pursuing parallel technology paths** encourages **competition** between different technologies, it **raises investment costs** and creates uncertainty for suppliers, users and the public sector (Jaffe et al., 2005; Azar and Sandén, 2011; Krutilla and Krause, 2011; Monopolies Commission, 2015b).

515. **Technology-neutral incentives to decarbonise** freight transport are especially provided by the **national price of carbon emissions in the transport**

sector, the future European emissions trading system **EU-ETS II** and the **CO2-based truck toll**. In order to increase planning certainty with regard to future prices of carbon emissions in the transport sector, Germany should consider introducing a national minimum carbon price (Edenhofer et al., 2019; Scientific Advisory Board to the BMWi, 2019; GCEE Special Report 2019 items 141 ff.). Technology neutrality is also essential in **basic scientific research**, for example in the refinement of drive systems, drive components and energy efficiency as well as the development of re-use concepts for truck components. The resulting knowledge spillovers enable research to make a valuable contribution to creating expertise at an early stage while technologies are becoming established (GCEE Annual Report 2020 items 436 ff.).

516. Market-based incentive mechanisms may remain inadequate owing to market imperfections. Supplementary measures may therefore be necessary (Edenhofer et al., 2019; Stiglitz, 2019). **Network effects make the market ramp-up of low-emission vehicles more difficult in the transport sector** (Li et al., 2017; Springel, 2021; Rapson and Muehlegger, 2023). Switching to low-emission trucks only makes economic sense for companies if there is sufficient charging and refuelling infrastructure available at the same time. **Support for publicly accessible charging and refuelling infrastructure** can help to address such coordination and network externalities and help to ensure that technology-neutral incentives such as the price of carbon emissions ensure a stronger adaptation response.

517. **To minimise the overall economic cost of achieving the climate targets, public funding** should be used **wherever it has a particularly strong leverage effect**. GHG emissions are reduced in an economically efficient way by first utilising the potential that is particularly easy to exploit ('low-hanging fruit') according to the state of the art. Technological progress then makes it possible to achieve further necessary emission reductions more cheaply over time. Focusing public funding helps to mitigate planning uncertainty for private actors and, at the same time, to use the available funds efficiently when budgets are tight. Strict and transparent criteria should be applied to ensure that such prioritisation is not captured by interest groups (Baldwin and Robert-Nicoud, 2007). The probability of a new technology being able to successfully contribute to the social goal of decarbonisation in the near future should be taken into account.

518. Although many solutions for decarbonising road freight transport are probably technically possible in the longer term, not all are equally feasible in the shorter term. Four criteria are particularly important for determining the **likelihood** that a **technology will effectively decarbonise road freight transport in the near future** (ITF, 2023b): firstly, the **maturity of** the technology concerned; secondly, its potential to become **competitive** with diesel trucks and low-emission alternatives; thirdly, its **potential to cut emissions**; and, fourthly, the potential for a **rapid market ramp-up**. ↘ TABLE 18 Taking these criteria into account, we can see that the BE truck is currently the most likely to successfully establish itself on the market by 2030. This technology has either already achieved, or is about to achieve, market maturity. ↘ ITEM 469 ↘ BOX 31 Local and distribution trucks can already be battery-powered at competitive TCOs.

↘ TABLE 18

Alternative truck drives and their contribution to decarbonised freight transport

	Technology readiness[1]	Competitiveness[2]	Emission reduction potential	Fast deployment[3]
BET (short-distance)	TRL 9	Probable	Probable	Probable
BET (long-distance)	Vehicle: TRL 8/9	Probable	Probable	Probable
	Charging with < 350 kW: TRL 8			
	Charging with > 1 MW: TRL 6/7			
BET with battery swap	TRL 8/9	Uncertain	Probable	Uncertain
FCET	Vehicle: TRL 8/9	Challenging	Short-term challenging	Challenging
	High-flow-rate refuelling: TRL 4		Long-term possible	
Overhead line trucks	TRL 8	Possible	Probable	Challenging
Trucks with e-fuels	TRL 6	Improbable	Improbable	Improbable

1 – The ETP Guide to Clean Energy Technologies is an interactive framework in which the International Energy Agency (IEA) provides information on over 550 individual technology concepts and components for the entire energy system that contribute to achieving the goal of climate neutrality. For each of these technologies, the guide contains information on the Technology Readiness Level (TRL). The TRL is a scale for assessing the development status of new technologies on the basis of a systematic analysis. The method was developed in 1988 by NASA for the assessment of space technologies, and has since become established as an assessment standard in other areas of various technology sectors. The IEA uses a scale from 1 ("initial idea") to 11 ("proof of stability reached"). 2 – Competitive total cost of ownership. 3 – Rapid market ramp-up.

Sources: IEA, ITF (2023b), own depiction

↘ ITEMS 473 FF. There is huge potential here for short-term emission reductions in road freight transport, which can be realised using the charging technologies and ranges already available.

519. Given the European climate targets for 2030, the **focus of government action** should initially be **on BE trucks' market penetration**, as this is the only way to ensure the timely success of decarbonisation. The constraining factor at present is the availability of infrastructure. The building of charging infrastructure should therefore be prioritised. Given the shortage of public funding and planning capacity, significant progress in the decarbonisation of freight transport by 2030 can only be achieved if such a focus is maintained. This will also accelerate technology scaling. This policy thus guarantees high utilisation intensity of charging infrastructure. This reduces costs and in turn increases the likelihood that BE trucks will become economically viable. ↘ ITEM 477 **The probability that this capital spending turns out to be a mistake in future is low ('no-regret' measure).** This is especially true as there are strong synergies between the ramp-up of BE trucks and that of BE cars, which have already largely established themselves on the market compared with low-emission alternatives. There are also synergy effects from expanding the network of charging stations on motorways, where public spaces will increasingly be used for renewable energy generation in future anyway (BMWK, 2023c).

520. **The private sector has already embarked on this route**. German truck manufacturers are EU leaders in the sale of low-emission trucks (Mulholland and

Egerstrom, 2024). Europe has also traditionally played a leading role in commercial-vehicle technology worldwide. Europe's largest truck manufacturers (Daimler Truck, Traton Group and Volvo Group) already offer battery-electric solutions for all truck segments, including the heavy-duty class, ↘ BACKGROUND INFO 16 (Daimler Truck, 2024; Traton, 2024; Volvo, 2024). For demanding long-haul road transport, two of these three manufacturers are still keeping open the option that this application profile could partly be covered by FCE trucks in future, ↘ ITEM 469 which is why they are aiming to have the relevant heavy-duty FCE trucks ready for series production in the second half of the decade (Daimler Truck, 2024, p. 12; Volvo, 2024, p. 24). For the other truck segments, which are mainly used in local and distribution transport, these manufacturers do not offer FCE trucks and their corporate strategies do not envisage this for the future either (Daimler Truck, 2024; Traton, 2024; Volvo, 2024). These three truck manufacturers are together driving the construction of charging infrastructure for BE trucks. The Milence joint venture will enable at least 1,700 publicly accessible fast-charging points to be set up on or near motorways and at logistics hubs in Europe by 2027. The fact that manufacturers want **more commitment and investment certainty from policymakers** is demonstrated not least by the recent discussion on tightening the European fleet targets. ↘ ITEM 453 In this debate the BMDV argued that e-fuels should be allowed to count towards fleets' CO2 targets, while truck manufacturers and suppliers called for stricter regulation to be approved regardless of this, as the private sector's focus is on the rapid ramp-up of BE trucks (Handelsblatt, 2024b; Mortsiefer, 2024).

521. BE trucks form the technological basis of FCE trucks. The **remaining uncertainty about** competition between hydrogen and electricity **in long-distance heavy freight transport** can therefore be addressed by an **adaptive policy approach** (Schreyer et al., 2024). As long as the future availability and price of green hydrogen are uncertain, direct electrification by BE trucks should also be preferred for this application, while hydrogen options can continue to be developed, tested and demonstrated.

This will enable us to develop a better understanding of the potential technical limitations of BE trucks in demanding applications over the coming years and to test the practical suitability of emerging fast-charging infrastructure over long ranges. If these make the use of FCE trucks technically necessary or should it turn out that the use of FCE trucks is more cost-effective than BE trucks in future, this approach should be adapted to allow a greater role for hydrogen. The building of infrastructure with long lead times, such as hydrogen pipelines, for which there are strong synergies with industrial hydrogen use, could take this uncertainty into account and be slightly scaled up in order to prepare for optimistic hydrogen scenarios. However, **public funding for hydrogen refuelling stations** and the construction of costly distribution infrastructure for such refuelling stations ↘ BOX 33 should **be avoided for the time being**.

522. Various studies underline the **importance of building public charging and refuelling infrastructure** for low-emission drive systems' market penetration and thus **for the decarbonisation of freight transport**. They set out scenarios for the future numbers of heavy commercial vehicles in the transport sector in

Germany up to 2045. These scenarios do not claim to represent the most likely courses of action but, rather, reflect various assumptions about aspects such as future technological developments and political support, and they highlight the effects that these assumptions have on potential solutions. For example, the long-term scenarios for the transformation of the transport sector (Fraunhofer ISI et al., 2024) ↘ CHART 117 show various drive technologies accounting for different proportions of the numbers of heavy commercial vehicles in 2045, depending on the assumptions used in each case. One scenario (T45-H2) assumes that no publicly available charging infrastructure for BE trucks will be built by 2030 but, instead, that only a public hydrogen refuelling infrastructure will exist at that time. This assumes that there will be a comparatively large number of FCE trucks with high mileage profiles in 2045. This is because, without any public charging infrastructure, only parts of the fleet that can manage without public recharging can be battery-electric (Fraunhofer ISI et al., 2024, p. 27). At the same time, however, these long-term scenarios make it clear that, given the **efficiency benefits and cost advantages of battery-electric drive systems**, the construction of public charging infrastructure for BE trucks will lead to faster market penetration by low-emission trucks and thus faster decarbonisation than the building of infrastructure for hydrogen filling stations (Fraunhofer ISI et al., 2024, p. 9).

523. **Any accelerated expansion of the hydrogen refuelling network by the government for industrial policy reasons seems questionable from a regulatory point of view**. ↘ ITEMS 538 FF. There would have to be compelling arguments as to why, in this specific case, the government is in a better position than companies to predict which technology and thus which business model will or should prevail (‘picking winners’). The fact that BE trucks have already achieved market maturity leaves no doubt that these drive systems will be widely used in future. On the other hand, European truck manufacturers’ development plans for low-emission drive systems give no indication that FCE drive systems will become established anywhere other than in purely niche applications. Building a hydrogen refuelling network in Germany prematurely – before it is even clear what sort of transport and delivery options or storage and processing facilities are required ↘ BOX 33 – also poses the risk of investing in a technology that subsequently proves not to be marketable and thus becomes an investment disaster. This can be observed in the case of existing hydrogen refuelling stations, which are evidently gradually being dismantled both in Germany and several other countries because they no longer meet market standards. ↘ ITEM 489

524. The AFIR ↘ BOX 34 requires parallel charging and refuelling infrastructure for BE trucks and FCE trucks to be built by 2030. Studies have concluded that there is still a considerable backlog in almost all European member states in terms of installing charging stations for BE trucks in order to achieve the AFIR’s targets. According to these estimates, however, hydrogen refuelling stations for the ramp-up of low-emission commercial vehicles are not likely to be needed in Europe until 2035 at the earliest (Ragon et al., 2022; Mulholland and Egerstrom, 2024). The **AFIR** requires **an official interim evaluation** to be conducted at the end of 2024 (European Parliament and Council of the European Union, 2023). This process **will reassess the technological and market maturity of heavy-duty commercial vehicles**. Depending on the outcome of this evaluation,

the EU Commission may submit proposals to amend the AFIR. The German government plans to submit an analysis of the future needs of all AFIR-regulated alternative fuel infrastructure to the EU Commission at the end of this year. The ramp-up of low-emission road freight transport should be coordinated at European level. The interim evaluation of the AFIR provides Germany with the opportunity to coordinate with other European member states and to jointly reassess the potential offered by the various drive technologies for efficient short-term decarbonisation.

A differing opinion: strengthening a broad technology portfolio with a long-term perspective

525. One member of the GCEE, Veronika Grimm, cannot agree with the majority view expressed by the GCEE in the chapter *Freight transport: infrastructure requirements and decarbonisation* on certain points. Her objection relates to some of the explanations and recommendations for action on road freight transport. The presentation and categorisation of the various options available in road freight transport ↘ ITEMS 432 F., 467 FF. AND 505 FF. ignore relevant perspectives and scenarios and focus too strongly on the short- and medium-term. This should be viewed critically, as **long-term developments and industrial policy opportunities should certainly be taken into account when deriving short-term recommendations for action** because:

– The German government's climate targets for 2045 can only be achieved if a variety of technology options can be utilised quickly enough so that they can contribute to cutting emissions by no later than 2045. **Restricting implementation to those technologies that are already mature** at this point in time **prevents implementable opportunities from being discovered** and thus **jeopardises the transformation process**. This can therefore not be justified by reference to the short-term urgency of reducing emissions.

– If Germany and Europe **ignore the long-term prospects for technology development** by focusing entirely on currently mature technologies, **they are putting their competitiveness in key future technologies** at **risk**. Without extensive innovation, after all, neither the global technology and market leadership that Europe aspires to nor a consequent contribution to prosperity growth are conceivable.

– **Furthermore, focusing** too **narrowly on** direct **electrification** in transport can **lead to challenges with practical implementation and create unilateral dependencies**. For example, there could be considerable delays in the full scaling of technology owing to supply bottlenecks for primary products or obstacles to the expansion of infrastructure. In such cases it will be mission-critical to have a range of technology options available rather than just one.

526. Consequently, it does not seem sensible to prioritise preparation of the market ramp-up of other technology options due to the faster market maturity of battery electric trucks (BE trucks). **The ambitious climate targets require forward-looking political action** in the transport sector **that makes the greatest possible use of technological progress** for the transformation precisely because the importance of mobility will increase rather than decrease. The drive technologies used in freight transport are therefore not in competition with each other but complement each other on the pathway towards carbon neutrality.

Traffic scenarios offer guidance but do not provide instructions for specific action

527. In order to be able to base political decisions on the latest assessments of solutions, **potential decarbonisation pathways** are regularly **estimated** as part of system studies and sector-specific analysis (including EWI, 2021; Fraunhofer ISI et al., 2021; Luderer et al., 2021; BCG, 2021; Stolten et al., 2022; acatech et al., 2023; Fraunhofer ISI et al., 2024).

528. The target of carbon neutrality by 2050 as part of the Green Deal presented in 2019 and the bringing forward of the carbon neutrality target for Germany to 2045 by the Climate Protection Act of 2021 has significantly changed the findings of the system studies. In particular, carbon-neutral solutions must now be found for all applications in freight transport as well. As far as road freight transport is concerned, **estimates of the future technology mix derived from scenarios vary widely as there is still major uncertainty** (acatech et al., 2023; Fraunhofer ISI et al., 2024). This applies, for example, to the timely availability of infrastructure (EWK, 2024; Weiss et al., 2024), expected electricity and fuel prices ↘ ITEMS 535 FF. and the cost of vehicles, including re-use options. In addition, switching to 100 % carbon-neutrality scenarios in the studies was only fully implemented after a certain time.

529. The most recent **system studies on Germany** predominantly **project** a **mixture of drive technologies in heavy freight transport,** with direct electrification – i.e. the use of BE trucks – accounting for the largest share in the vast majority of freight transport scenarios. Depending on the scenario, between 0 % and 75 % of trucks in the study results use hydrogen (acatech and DECHEMA, 2022). Scenarios from the dena lead study (2021) and the Kopernikus project Ariadne (Luderer et al., 2021) predict annual hydrogen demand of around 40 to 50 TWh in truck transport by 2050 (acatech and DECHEMA, 2022). Given the tightening of European short- and medium-term carbon emission reduction targets for heavy commercial vehicles, which is expected in May 2024, the National Hydrogen Council (NWR) expects hydrogen demand for trucks and buses to reach around 22 TWh as early as 2030 in its latest demand estimate (NWR, 2024). For the year 2035, by when carbon emissions would have to be cut by 65 % compared with 2019 levels following the tightening of targets for heavy commercial vehicles, the NWR expects hydrogen demand of around 58 TWh for these vehicle classes.

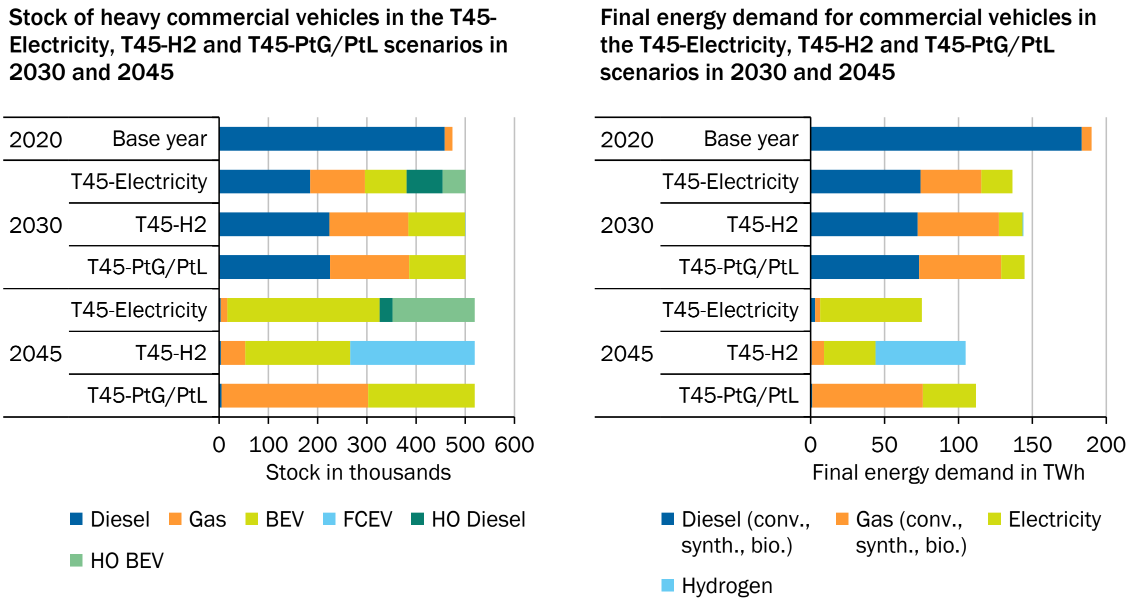
530. The long-term scenarios for the transformation of the transport sector published in February 2024 (Fraunhofer ISI et al., 2024), which were prepared as part of

the project entitled 'Long-term scenarios for the transformation of the energy system in Germany' (Long-term scenarios 3) on behalf of the BMWK, analyse various conceivable developments in the overall system in a series of scenarios so that the **range of options and the advantages and disadvantages of different pathways** can be **examined** more closely. Given the numerous uncertainties and the various complementary fields of action, this approach is extremely useful and, in fact, indispensable.

531. The scenarios, which have been calculated consistently in each case, reflect the fact that very **different technology pathways** are **possible**. ↘ CHART 117 How well they can be realised in each individual case depends, among other things, on **whether various energy sources** are available in sufficient quantities and at reasonable prices and whether the corresponding **infrastructure** is **available**.

↘ CHART 117

Scenarios[1] for heavy goods transport and final energy demand for commercial vehicles[2] in Germany



1 – Long-term scenarios for the transformation of the transport sector (Fraunhofer ISI et al., 2024) from the project "Long-term scenarios for the transformation of the energy system in Germany" (Long-term scenarios 3) commissioned by the BMWK. The scenarios take into account the Climate Protection Act as amended in 2021 with the sector targets for 2030 and the target of greenhouse gas neutrality in 2045. The three scenarios represent "extreme worlds" in order to provide a framework for orientation. T45-Electricity: strong electrification. T45-H2: heavy use of hydrogen. T45-PtG/PtL: heavy use of synthetic hydrocarbons. In order to present the widest possible range of scenarios, the T45-Electricity scenario assumes that a public fast-charging infrastructure for commercial vehicles is established, based on the methodology in Speth et al. (2022). In 2045, this will allow every vehicle to recharge publicly once a day if necessary, doubling the range of the vehicles. In addition, 8,000 km of the road network will be electrified with overhead lines by 2045. However, a hydrogen refuelling station infrastructure is dispensed with. In the T45-H2 scenario, it is assumed that a hydrogen refuelling station infrastructure will be built that will enable the unrestricted operation of hydrogen commercial vehicles from 2030. However, there is no public charging infrastructure available for commercial vehicles. Battery electric vehicles can only be recharged at the private depot infrastructure. 2 – The calculations show the situation at the beginning of the Ukraine war. Despite the fact that gas prices have fallen in the meantime, the regulatory framework for gas-powered trucks has developed unfavourably. As a result, a large proportion of gas energy could continue to be demanded as diesel. The efficiency of both drives is almost identical, meaning that the quantities of energy used would be very similar.

Source: Fraunhofer ISI et al. (2024)

If the commercial-vehicle fleet were to be fully electrified, this would result in annual electricity demand of 69 TWh in 2045. If FCE trucks were also used (scenario T45-H2), annual electricity demand for BE trucks would be only 35 TWh, although 61 TWh of hydrogen would be required – most of it (57 TWh) for heavy commercial vehicles. ↘ CHART 117 RIGHT A scenario in which most heavy-duty mobility uses synthetic hydrocarbons is calculated as a 'fallback' in case the other pathways cannot be fully implemented.

532. The latest academic studies **on European road freight transport** show that, **in addition to battery-electric drive systems, other technology options are also** likely to play **a role in Europe in future**.

- In an iterative coupling of an energy system model with models of traffic volumes over time, driving behaviour and freight transport, Shirizadeh et al. (2024) analyse various pathways to the complete decarbonisation of European heavy freight transport. Three different scenarios on the availability of alternative fuels, infrastructure, energy prices, and changes in freight and passenger volumes over time give rise to various pathways in heavy freight mobility, in which BE trucks always play an important role but other drive concepts are also used – especially for medium and long distances.
- Schreyer et al. (2024), who analyse the direct and indirect electrification of the European energy system based on the REMIND Integrated Assessment Model (IAM) developed at the Potsdam Institute for Climate Impact Research (PIK), come to similar conclusions. In addition to battery-electric drive systems' almost total penetration of passenger transport, a diverse picture emerges for heavy freight mobility across all of the scenarios analysed. FCE trucks, hybrid systems and internal combustion engines also play a role here in addition to BE trucks.
- Carboni et al. (2024) use an agent-based IAM to analyse scenarios for achieving carbon neutrality in Italian heavy freight transport, taking account of various assumptions about technology development, energy prices and political regulation. The result is full electrification for light freight vehicles, whereas battery-electric drive systems play no part in medium and heavy freight vehicles.
- When modelling energy systems for Ireland, Aryanpur and Rogan (2024) come to the conclusion that FCE trucks are also used for heavy loads, especially when considering factors that are not exclusively financial, such as loading time and permissible total weight.

The selection of recent studies considered here suggests that **we can expect a mixture of different technologies**, especially **for medium and heavy loads**, and that there is by no means a clear trend towards one particular technology – neither towards pure electrification nor towards the almost total use of hydrogen – in heavy freight transport.

Taking uncertainty about future regulatory frameworks seriously

533. The **ramp-up of battery mobility and the ramp-up of hydrogen mobility in heavy freight transport** both **face** their own **numerous challenges**. For example, nationwide charging infrastructure is required for BE trucks, which is why the electricity grid must be expanded and – especially on motorways – extensive areas must be made available (Weiss et al., 2024; EWK, 2024; VM BW, 2024). A less dense network of refuelling stations is needed for hydrogen mobility. However, hydrogen must be made available – partly through extensive imports (Bauer et al., 2023; EWK, 2024) – and, above all, agreement must be reached on refuelling technology (NOW, 2023a, p. 26).

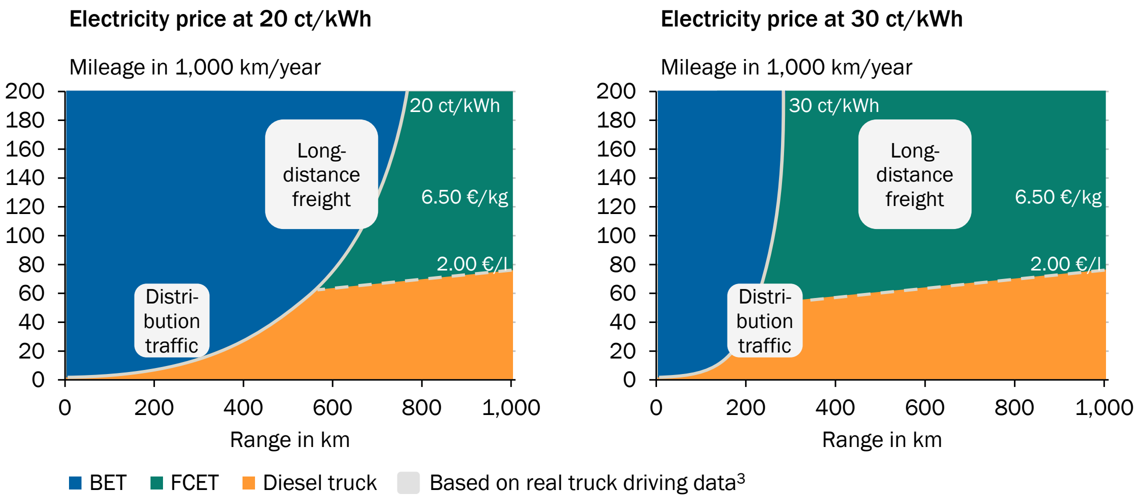
534. It is not yet possible to predict the extent to which purely battery-electric drive systems for trucks will become established (acatech et al., 2023; Fraunhofer ISI et al., 2024; Plötz et al., 2022). As much of the logistics sector is highly cost-dependent, the total cost of ownership will be decisive. **Key factors that** will influence this cost over time are the **availability of charging and refuelling infrastructure**, the **costs of grid expansion**, **electricity costs**, **hydrogen costs**, the **realisation of sufficient hydrogen imports**, **vehicle re-use options** and the **availability of raw materials** for the various technology options. Hydrogen is likely to play a role in use cases with high energy requirements and/or where there is little cost sensitivity, such as heavy freight transport in remote areas or the transportation of oversized and extremely heavy freight (e.g. rotor blades for wind turbines) (Plötz et al., 2022).

535. As far as the total cost of ownership is concerned, there is still a high degree of uncertainty as to whether FCE trucks will have lower total cost of ownership than BE trucks over long distances. This depends, among other things, on the future **price of electricity relative to the price of hydrogen**. ↘ CHART 118 In the political arena the falling electricity generation cost of renewable energy is often cited to argue that electricity will become cheaper and thus electromobility will be more attractive. However, **calculations** determining the average electricity generation cost to meet demand (Grimm et al., 2024) or even future system costs (Ueckerdt et al., 2013; Hirth et al., 2015; Reichelstein and Sahoo, 2015; Shen et al., 2020; Simpson et al., 2020; Loth et al., 2022; Egerer et al., 2022) **do not** generally **suggest** that **electricity will become significantly cheaper** than it currently is.

536. **Estimates of future production costs of green and blue hydrogen** depend on **transport costs** and on the **cost of electricity and natural gas** at **hydrogen production sites**. Hydrogen costs of 2 euros/kg could be achieved at favourable renewable-energy locations (electricity production costs of 20 to 30 euros/MWh) by 2030. Assuming electricity costs of over 100 euros/MWh, however, the full cost of hydrogen production is likely to exceed 10 euros/kg (EWK, 2024, chart 66 and item 256).

537. The latest full-cost indicators for Germany (HydexPlus Green and HydexPlus Blue) have remained within a range of €5.60 to €8.70/kg in recent months, while the Hydrix market price indicator from the EEX is currently fluctuating around €7.50/kg and trending slightly downwards. The S&P/Platts cost indicators for

↘ CHART 118
Energy costs influence future[1] profitability[2]



1 – With a market price for charging current of 20 or 30 cents per kWh, a diesel price at the filling station of 2 euros per litre and a hydrogen fuel price of 6.50 euros per kg. 2 – Total cost of ownership based on current manufacturing costs of the vehicle components (fuel cell 130 euros per kW, hydrogen tank 415 euros per kg and battery pack 120 euros per kWh) and costs for operation and maintenance based on König et al. (2021). The drive system with the lowest total costs is shown. 3 – The "distribution transport" and "long-distance freight transport" application areas shown are based on real lorry driving data from German fleet operators according to Balke and Adenaw (2023).

Sources: Balke and Adenaw (2023), Wolff and Balke (2024), Wolff et al. (2020), own presentation

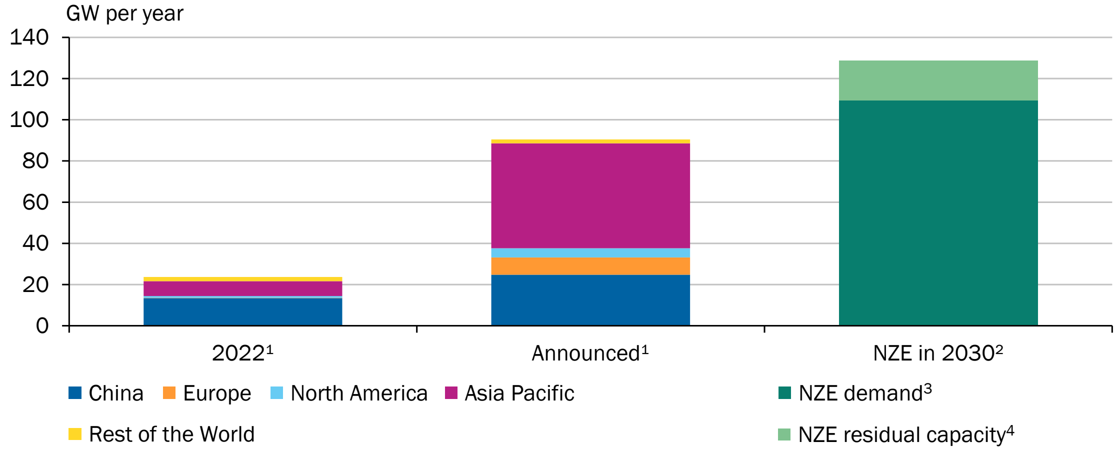
blue hydrogen, as well as the price indicators for green hydrogen from Saudi Arabia, are around €3.50/kg (EWK, 2024, chart 67 and item 257). Transport costs are likely to account for only a small proportion of the cost of purchasing hydrogen in Europe when large volumes are traded over the coming decade (e.g. Runge et al., 2023). Although price expectations cannot be directly derived from these cost indicators, it is clear that **hydrogen prices** are **achievable** that could **make FCE trucks an attractive option for heavy-duty mobility**.

The global market for drive technologies is crucial

538. Seen from manufacturers' perspective and with a view to value creation in Germany and Europe, it is not only the future mix of drive systems in Germany that is important. The focus should also be on **export markets for trucks with different drive systems throughout Europe** ↘ ITEM 532 **and beyond**. Compared with battery development and production, Germany is in a better competitive position when it comes to the manufacture of fuel cells. In terms of both patent applications and industrial players, Germany is one of the leading countries right behind the United States and Japan (Fraunhofer ISI, 2024). In order to **achieve** a **strong competitive position** in the **field of fuel-cell production and as a supplier of FCE trucks and FCE commercial vehicles** over the coming decade, the timely scaling of fuel-cell production in the field of mobility applications and the operation of significant numbers of vehicles in Europe are likely to be necessary.

↘ CHART 119

Production capacities for mobile fuel cells by country/region according to announced projects and the IEA net zero emissions scenario 2050
For 2022 and up to 2030



1 – The capacities in 2022 and the announced capacities include material handling equipment and other transport applications. Announced capacities include existing capacities. 2 – Net zero emissions scenario until 2050. 3 – The production capacity required to meet the projected demand in the NZE scenario (NZE demand) is estimated assuming a utilisation rate of 85 %. The NZE demand for fuel cells is based exclusively on fuel cell vehicles. 4 – The NZE residual capacity represents the production capacity that would remain unutilised on average, which provides a certain flexibility to adapt to fluctuations in demand.

Source: IEA analysis based on data from E4tech and company announcements

539. Back in 2021 the National Platform for the Future of Mobility therefore urgently recommended **expanding activities in the field of fuel-cell technology, as otherwise** – as in the case of battery mobility – **market leadership is likely to be lost** to China (NPM, 2021b). China has recently increased its investment in FCE trucks (IEA, 2023b; Mao et al., 2023) and now has a 95 % share of the global stock of such trucks (IEA, 2023b). However, this is still low in terms of actual numbers at around 8,000 vehicles in mid-2023. The production capacity announced in Europe for fuel cells used in mobility applications currently lags well behind the capacities announced in Asia (IEA, 2023b; Fraunhofer ISI, 2024). ↘ CHART 119

540. **Pure research funding is unlikely to be sufficient** in this situation, as suggested by the Council majority. ↘ ITEM 433 Rather, **a refuelling infrastructure needs to be set up** so that a significant number of vehicles can be operated. The AFIR's requirements (European Parliament and Council of the European Union, 2023) for the construction of hydrogen refuelling stations therefore point in the right direction. The Council majority's proposal that Germany should advocate that the requirements for the expansion of the hydrogen refuelling infrastructure be watered down as part of the evaluation and revision of the AFIR at the end of 2024 ↘ ITEM 524 is not a sensible one. A strategy that initially relies primarily on BE trucks until it becomes clear that these cannot handle all long-distance heavy freight transport (proposal by the Council majority in ↘ ITEM 521) would once again create uncertainty that is likely to cause European manufacturers to lose competitiveness. If FCE trucks are then required for long-distance heavy freight transport

↘ TABLE 19

Strategy and market area of the ten largest trucks manufacturers globally

Company	Head office	Strategy				Market areas
		Battery electric	Fuel cell	Hybrid	PtG/PtL[1]	
Daimler Truck	Germany	X	X			North America, Europe, Asia
Dongfeng	China	X	X			China + X[2]
FAW	China	X	X	X		China + X[2]
Isuzu	Japan	X	X		X	Japan, Asia
Paccar	USA	X	X		X	North America, Europe
Shaanxi/Shacman	China	X	X	X		China, Eastern Europe, Africa
Sinotruk	China	X	X	X		China, Africa, South East Asia
Tata	India	X	X		X	India
Traton	Germany	X				Europe, North + South America
Volvo	Sweden	X	X	X	X	Europe, North America

1 – Synthetic fuels: Power-to-Gas (PtG) or Power-to-Liquid (PtL). 2 – Possibly further market areas.

Sources: Daimler Truck (2024), Dongfeng Motor (2024), H2-Share (2024), Isuzu (2023), Paccar (2024a, 2024b), Shacman (2024a, 2024b), Sinotruk (2023, 2024), sohu (2024a, 2024b), Tata Motors (2023a, 2023b), Traton (2023, 2024), Volvo (2024), Yiyu (2021)

at a later date, Asian or US manufacturers are likely to be used owing to the lack of supply from domestic manufacturers. ↘ TABLE 19

541. With just one exception, the world's ten largest truck manufacturers currently rely on several technology options for heavy-duty truck drive systems. ↘ TABLE 19 The three European manufacturers among them – Daimler Truck, Traton and Volvo – operate worldwide. Asian manufacturers have so far been represented mainly in the Asian and African markets, although some are expanding into Europe and South America. It is likely to become more difficult for European manufacturers to achieve significant market share in FCE trucks in the Asian market unless production and operation of such trucks in Europe is scaled up in a timely manner. **Too strong a focus on achieving the interim targets set for 2030** – with the consequence that the current focus would be primarily on battery mobility, as favoured by the Council majority ↘ ITEMS 432 F. AND 521 FF. – **would cause Germany to fall behind its international competitors** technologically, perhaps permanently, **in the development of fuel cells** for mobility applications (NPM, 2021b).

Reducing dependencies and transformation risk by diversifying

542. It is important to maintain a broad mobility technology base in order to minimise **dependencies on individual technologies and raw materials** in energy supplies and to **diversify relationships for the supply of intermediate products**. As far as energy supplies are concerned, a broad mobility technology base makes it possible to switch to material energy sources (hydrogen, e-fuels) if the full electrification of freight transport is not feasible owing to obstacles in grid expansion or the slow growth of additional generating capacity. The production of batteries and the manufacture of fuel cells require numerous – albeit different

– critical raw materials that are either not domestically available in Europe at all or are not available in sufficient quantities (NOW, 2020, 2023b). In addition, the expansion of Europe's power supply and grids as well as the feasibility of hydrogen imports depend on the availability of raw materials and the existence of robust strategic partnerships.

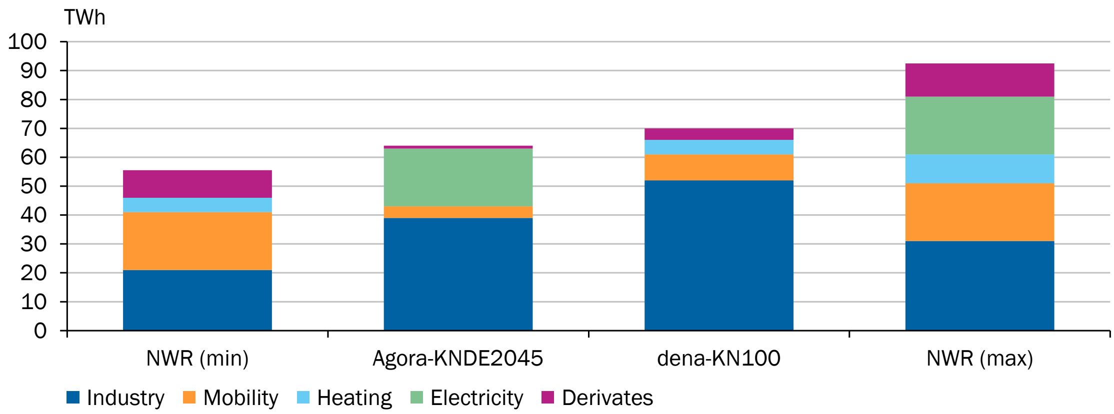
543. The GCEE has therefore emphasised the importance of trade agreements in the past (for example with the Mercosur states or Australia), particularly with regard to the availability of critical raw materials (Grimm and von Rüden, 2022a, 2022b; GCEE Annual Report 2022). If several technology options are used to transform the transport sector, it would be easier to **switch to alternative technologies if certain solution pathways unexpectedly become unavailable or are not scalable as planned**. Obstacles of this kind cannot be ruled out given the current global political situation.

Consider synergies with other fields of action at an early stage

544. The goal of achieving carbon neutrality in Germany by 2045 and in the EU by 2050 requires that the right conditions be created today so that, over the next decade, we can comprehensively transform the transport sector much faster than before. Given the limited budget available, it is undoubtedly important to use this in a targeted way. At the same time, however, it is also important to **make forward-looking decisions** in order to utilise a **broad spectrum of technologies for this transformation process** and to open up **export markets of the future**. After all, only a strong future value-creation base and greater resilience of the (diversified) economic model will lay the foundations for growth and future tax revenues.

545. Hydrogen will be needed in industry and for power generation by 2030. Various recent studies estimate varying levels of demand in these sectors and in mobility. ↘ CHART 120 **When hydrogen is procured**, especially through imports from regions with favourable conditions for production (EWK, 2024, Section 4.4.3;

↘ CHART 120
Forecasted hydrogen demand[1] in 2030 by sector in selected system studies



1 – The hydrogen requirement for the production of derivatives is simplified to 1.67 TWh H_2/TWh derivative.

Source: EWK (2024) based on Prognos et al. (2021), dena (2021) and NWR (2023d)

Runge et al., 2023; Bauer et al., 2023), **the inclusion of demand for mobility is likely to give rise to larger quantity scenarios**. This could fuel competition with other areas of application, which might push up prices. However, larger quantities also enable faster scaling of production, which allows costs to fall more quickly. In addition, larger procurement volumes allow for better diversification of imports, as contracts can be concluded with several suppliers from different regions. There could also be synergies in the building of infrastructure. For example, the National Hydrogen Council recommends considering the hydrogen requirements of various customers, the transformation plans of distribution network operators, and municipal heating planning on an integrated basis when planning the network (NWR, 2023c).

Conclusion: do not focus too narrowly and address technology-specific externalities

546. The arguments cited show why the majority position on the categorisation of drive technologies, ↘ ITEMS 505 FF. especially on the basis of the table ↘ TABLE 18 in the expert opinion, falls short of the mark. The aspects listed there are not sufficient to arrive at any particular prioritisation, and short-term market maturity should not be the criterion for such a decision. In addition, the assessments given in the individual cells of the table are based on only a few studies, so the results and assessments of individual studies are interpreted as guidance rather than the study situation as a whole. Even if most of the available studies were to focus on the benefits of BE trucks, the current market maturity of such trucks should not be placed too firmly at the centre of the action recommended. On the contrary: **giving due consideration to all technologies** that are likely to play **a leading role by 2045** – including those that are still at the earlier stages of development – **is crucial for achieving the climate targets and European competitiveness** in the relevant technology segments.

547. **Given the uncertainty** and the constant need for reassessment, it is likely to be essential to **develop a broad range of technologies with a high level of ambition**. Focusing public funding on supporting battery-electric mobility in freight transport on the grounds that market maturity has already been achieved here, as is positively attested in the main text ↘ ITEM 517, is unlikely to be a sensible option in the case of heavy-duty mobility. This would block the route to technological and market leadership in drive technologies, which will play a key role in the decarbonisation of mobility in the medium and long term. Against this backdrop, the **approach adopted by the long-term scenarios** commissioned by the BMWK (Fraunhofer ISI et al., 2024) – i.e. **presenting a broad range of options in order to keep** a constant eye on these options – **is to be welcomed**.

548. In order to unlock potential for the development and scaling of various mobility options in freight transport, it is important to **internalise network externalities – especially through government action –** in addition to the pricing of carbon emissions in grid-based sectors (GCEE Special Report 2019 item 252; GCEE Annual Report 2020 items 454 ff.). In addition to the ambitious expansion

of the electricity grid and charging network for battery mobility, a hydrogen transportation and refuelling network is necessary **to facilitate larger pilot projects and demonstration projects** and thus quickly gain practical experience in the context of applications. It is therefore to be welcomed that the AFIR (European Parliament and Council of the European Union, 2023) requires hydrogen refuelling stations that can supply both passenger cars and heavy commercial vehicles to be installed at all urban hubs and every 200 km throughout the TEN-T core network by 2030 (e-mobil BW, 2023).

APPENDIX

European rail freight transport

549. The foundations for European rail freight transport were laid as part of **four railway packages with legislative proposals for harmonisation in the European railway area** (BMDV, 2021b). Despite far-reaching regulatory measures having been introduced in recent decades, **many** historically evolved **incompatibilities between the national railway networks** remain. Technical obstacles exist in the form of differences in track gauges, power and overhead line systems, wheel loads and train protection and communication systems. On the operational side, cross-border connections require transnational cooperation. Lengthy **delays** can occur **when trains are handed over at the border** (Stoll et al., 2017). Reasons for this include national network-specific prioritisation, language requirements for train drivers and collectively agreed regulations on working times and rest periods. Back in the early 2000s it was decided to introduce the Technical Specification for Interoperability (TSI) to harmonise the technical and operational requirements for construction and expansion measures (Stoll et al., 2017).

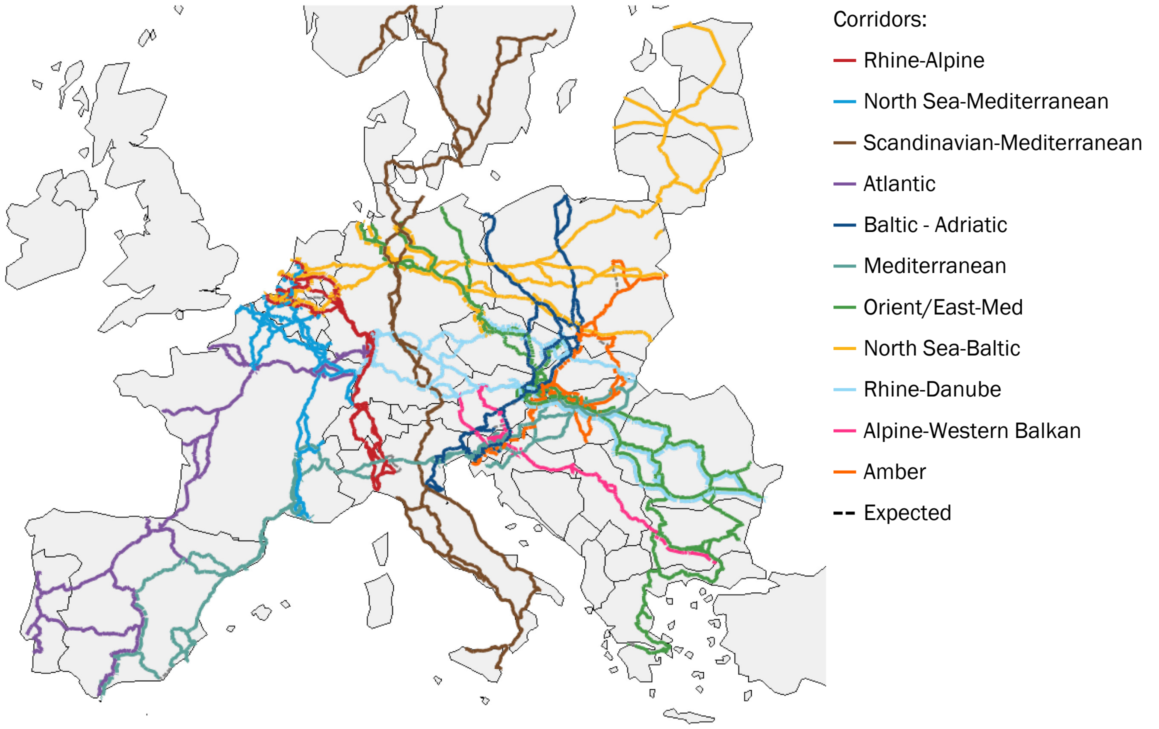
550. A **network of eleven core corridors** is being developed **to promote trans-European rail freight transport**. ↘ CHART 121 This largely overlaps with the corridors of the Trans-European Transport Network (TEN-T). The infrastructure operators of these corridors are obliged to cooperate more closely than before and to offer cross-border train routes. Decision-making authority for each corridor has been pooled in so-called one-stop shops (OSS). This is intended to simplify processes and establish a single point of contact for end users (BMDV, 2021b). In compliance with the EU regulation on the development of the TEN-T network (European Parliament and Council of the European Union, 2013), the **neighbouring countries** have **committed to fully electrifying** these **corridors and equipping them with the European Rail Traffic Management System (ERTMS)** (Stoll et al., 2017). This system will include the introduction of a standardised European Train Control System (ETCS), which will remove the need for the costly exchange of train wagons when crossing borders.

551. Six of the planned core corridors run through Germany. ↘ CHART 121 The expansion of the network comprises several major projects. **While its EU neighbours are ambitiously pushing ahead with these, Germany is lagging behind**. The 64-km Brenner Base Tunnel, which forms part of the Scandinavia-Mediterranean Corridor, could relieve much of the burden on transalpine freight traffic between Austria and Italy from 2032 onwards. **However**, the four-lane expansion of the rail link from the German side – **the Brenner northern approach – is not expected for another 20 years or so** (DB InfraGO and ÖBB Infra, 2024). The situation is similar with the connection to the Swiss section of the TEN-T Rhine-Alpine corridor. Switzerland completed three railway tunnels (Lötschberg, Gotthard and Ceneri base tunnels) totalling 107 km in length between 2007 and 2020 (EDA, 2020). The northern feeder route from Germany will not be expanded to four lanes until 2035 (DB, 2024e).

↘ CHART 121

European freight corridors

Germany is involved in six corridors



Sources: EuroGeographics for the administrative boundaries, RailNetEurope

Background to calculations of the electricity needed for the electrification of road freight transport

552. In a scenario in which **all road freight transport** is **battery-electric** by 2045, electricity consumption would result directly from current final energy consumption. This currently stands at around 640 petajoules (PJ), i.e. around 177.7 terawatt hours (TWh) (Federal Statistical Office, 2022, table 1.2.1.). However, as battery-powered commercial vehicles are more efficient than conventional trucks equipped with diesel engines – the efficiency factor for diesel trucks is approximately 0.45, whereas for electric drive systems it is around 0.8 (Ekberg et al., 2021) – final energy consumption can be corrected downwards using the factor (0.45/0.8) = (1/1.77), which would equate to **gross electricity consumption of approximately 100 TWh in road freight transport**.

In order to reflect expected future electricity consumption, this figure must be **corrected for the growth rate in road freight transport** and for the **potential share of alternative drive systems compared with BE trucks**. These two figures can currently only be forecast with uncertainty. The growth rates in road freight transport stated in various forecasts vary between 30 % and 70 % by 2045. ↘ ITEM 441 In addition, some road freight transport could be powered by alternative low-emission drive systems in future. If BE trucks accounted for only 80 % of carbon-neutral road freight transport, total potential gross electricity consumption would range from approximately 104 to 136 TWh.

553. In addition to the total amount of electricity required, the **distribution of electricity demand over time** is also relevant for electricity systems – in particular the fluctuation in charging demand over the course of the day. Highly concentrated charging requires much more power generating capacity and grid capacity than if demand is spread over time. If, for example, all trucks were to charge for one hour at the same time every day, annual consumption of 1,000 TWh would require around 273 GW of generating capacity to be available for truck electricity. However, such concentrated charging is not expected. Rather, a large proportion of charging is likely to take place in firms' depots or during legally required journey breaks. ↘ ITEMS 481 FF. ↘ BOX 32

554. The **upper limit on how concentrated charging will be** and how much of a strain it will place on electricity systems is therefore likely to be determined **by demand for public charging infrastructure** – particularly mega-chargers. Assuming that this form of charging meets 25 % of charging demand ↘ ITEM 481 – approximately 25 TWh – it will require available generating capacity of between 2.85 GW (if charging is spread evenly throughout the day) and 22.9 GW (if charging always takes place within three hours a day). How much additional generating capacity this requires depends on whether charging times overlap with high residual load, i.e. the times when there is relatively high demand compared with electricity generation from renewable energy. High residual load is likely to occur during the morning and evening hours (Agora Energiewende et al., 2023), i.e. generally not at times when BE trucks are charging (Daimler Truck and TenneT TSO, 2022). It can therefore be assumed that, depending on charging behaviour during public charging, approximately 2.85 to 10 GW of additional generating capacity produced at the right time will be required.

Background to calculations of the degree of internalisation in road freight transport in 2024

555. When calculating the internalisation rate for 2016, the European Commission takes account of the truck toll and the energy tax on diesel. The **truck toll has been reformed several times since then**. In particular, a toll component for carbon emissions was introduced in December 2023. ↘ ITEM 452 In addition, a **carbon price has been** levied **on diesel fuel** since 2021. The GCEE has carried out some analysis to **quantify** how these regulatory changes have affected the **degree of internalisation in road freight transport**. The assumptions used to determine the taxes and charges levied in 2024 are explained below. The inflation rate is used to extrapolate the external cost rates from 2016.

556. The first step is to **estimate** what proportion of **total marginal taxes and charges** calculated by the European Commission **for 2016 is accounted for by truck tolls and taxes**. According to the Commission's own figures, energy taxes in 2016 amounted to around 9.5 euros per 1,000 tkm and tolls to 4.5 euros per 1,000 km (European Commission, 2019b, p. 77). This equates to a ratio of 2:1. As the toll is levied per kilometre driven, the relative toll costs per tkm are higher for lighter trucks than for heavier trucks. This enables us to determine that the ratio of toll share/tax share is 40/60 for small trucks (7.5 to 16 tonnes), 30/70 for

medium trucks (16 to 32 tonnes) and 20/80 for large trucks (more than 32 tonnes). The actual cost shares could be higher or lower.

557. When **estimating the increase in toll charges** since 2016, it should be noted that the vehicle classes in the toll tariffs differ from the European Commission's vehicle classes. In addition, the vehicle classes in the toll tariffs applicable for 2016 and 2024 have changed. For 2016 the toll rate for small trucks will be based on the toll rate for trucks with two axles, for medium-sized trucks on the toll rate for trucks with three axles, and for large trucks on the toll rate for trucks with four axles. For 2024 the average of the toll rates for trucks weighing 7.5 to 12 tonnes and trucks weighing 12 to 18 tonnes will be used for small trucks, the toll rate for trucks with up to three axles and weighing more than 18 tonnes will be used for medium-sized trucks, and the toll rate for trucks with up to four axles and weighing more than 18 tonnes will be used for large trucks. The toll tariffs within the individual weight classes are differentiated according to Euro pollutant classes I to VI. A distinction is also made between CO2 classes (1 to 5) within Euro emission class VI. CO2 class 5 applies to zero-emission trucks. These are not included in the calculations.

The increase in the toll rate is calculated for each vehicle type (differentiated according to weight and axle class, Euro emission class and CO2 class). The average is then calculated for each vehicle class (small/medium/large). This results in a toll cost increase of 124 % for small trucks, 152 % for medium trucks and 158 % for large trucks. This is based on the highly simplified assumption that there is an equal distribution across the various CO2 pollutant class combinations within each weight class. However, it would also be plausible to assume that the proportion of trucks in Euro emission class VI is steadily growing.

558. The **introduction of a national carbon price** has a linear effect on all vehicle classes. The carbon price can be interpreted as a per unit tax per litre of diesel. The energy tax on a litre of diesel was 47.04 cents in both 2016 and 2024 (Section 2 (1) sentence 4b of the Energy Tax Act). The carbon price per litre of diesel will be approximately 14.4 cents in 2024 (Bundesregierung, 2024). This represents an **increase of around 31 % in the tax burden**.

559. According to the calculations presented here, **taxes and charges rose by a total of** 5.2 cents per tonne-kilometre for small trucks, 3.1 cents for medium trucks and 2.2 cents for heavy trucks as a **result of these changes**. This represents **internalisation rates of 42 % for small trucks, 37 % for medium trucks and 33 % for large trucks**.

Long-term options for increasing capacity in rail freight transport

560. **In order to increase capacity on the railways,** there are other technical options that can reduce the **minimum train running times**, i.e. the time that elapses before the next train can arrive after a train has passed through a section of track (block section). It is expected that **digital systems** using new cross-sectional technology such as artificial intelligence **can help to increase rail capacity** (DB, 2024f, 2024g). Greater use of AI could optimise train route allocation

in real time and in traffic itself in future. So far, however, only small sections of the rail network have been prepared for other digital solutions. By the beginning of 2023, for example, only 520 km of DB Netz AG's network of over 33,000 km had been equipped with the European Train Control System (ETCS) (Bundesregierung, 2023e). Preparing larger sections of the rail network for digital control systems, especially high-performance corridors, would require considerable capital investment.

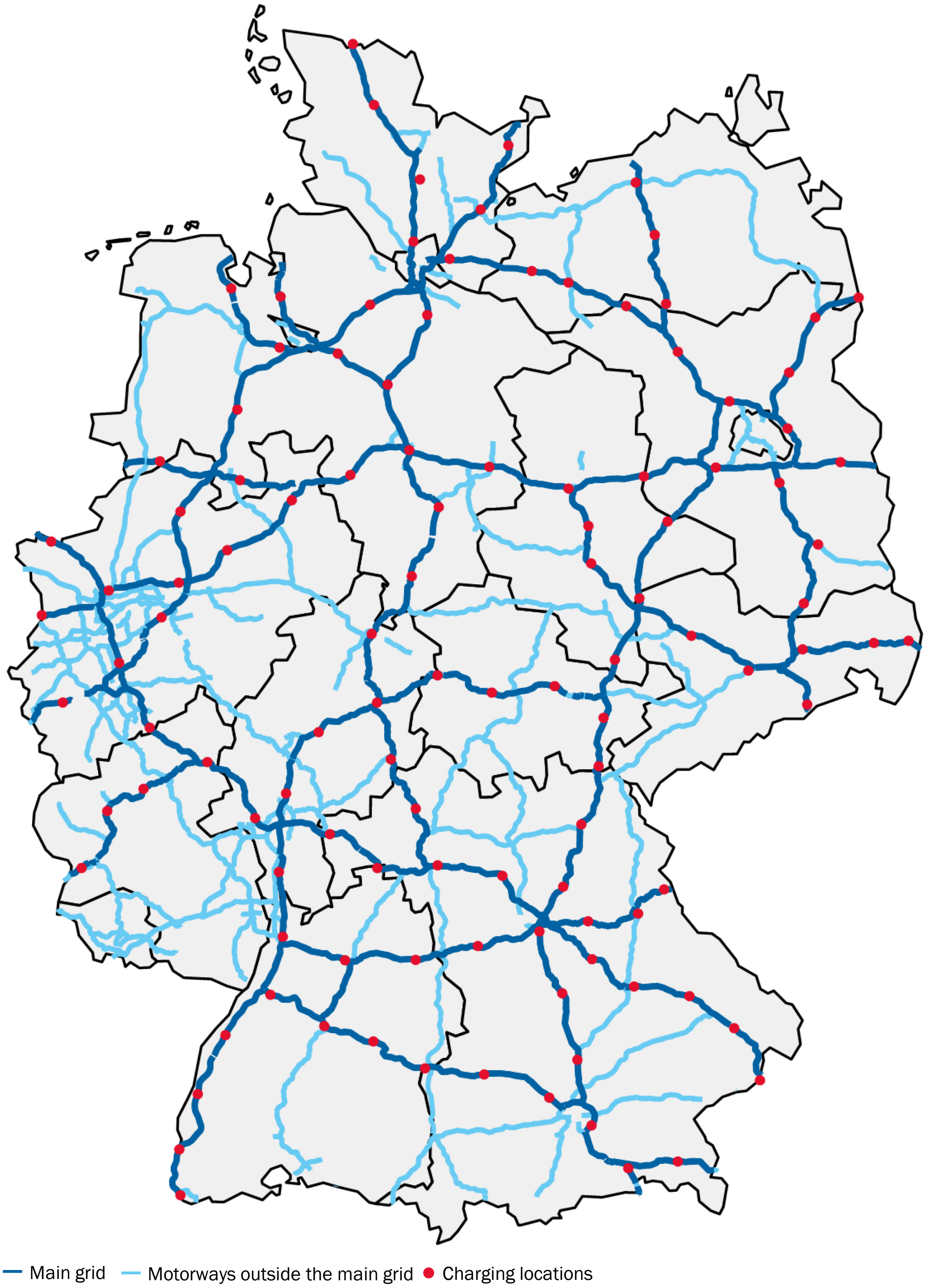
561. **The improved utilisation of high-speed lines by assigning them to rail freight traffic** is also under discussion (Bundesregierung, 2023e). When few or no ICE trains are travelling on these lines – especially at night – they can be made available to freight trains on some routes. However, rail freight railcars still lack the technical capability to travel on high-speed lines. Further capital investment in trains is therefore required for such capacity expansion. ↘ ITEM 497

562. There are further **feasible concepts** that could significantly improve the flexibility and speed of rail freight transport **in the long term**. As the punctuality and speed of rail freight transport are influenced not only by the time and labour required to assemble trains ↘ ITEM 497 but also by the staff changes required ↘ ITEM 498, automated, **autonomous trains** could address this problem. DB Cargo AG, Digitale Schiene Deutschland (DSD), the German Aerospace Centre (DLR) and the Dutch infrastructure operator Pro-Rail B.V. are currently testing autonomous freight trains on the Betuweroute between the port of Rotterdam and the Ruhr region (DB, 2021; EBA, 2021). This trial project will run until 2025 and is intended, among other things, to demonstrate the technical and operational maturity of ATO technology. Testing is still limited to the Dutch section of the route, which is reserved for freight transport (24Rhine, 2021). It is conceivable that these trials will be extended to other routes, which will have to be technically upgraded.

563. **In order to utilise the potential for rail freight transport on shorter routes**, it would make sense to build **intermodal hubs**, even if Germany already has a fairly large number of such transhipment hubs compared with other European countries (ECA, 2023). Transhipment processes can be organised more efficiently **by using digital solutions** such as improved document handovers and freight-tracking systems (Bergstrand, 2020). **Rail sidings at companies** can also shorten first and last mile transport routes by truck (Die Güterbahnen, 2023; VCI, 2024). The construction and maintenance of such intermodal hubs can be handled either solely by DB AG as infrastructure operator, on a business level by large companies or logistics groups, or in partnership between DB AG and other firms. When the rail network is expanded to include further sidings, the funding commitment usually lies with the companies that commission the sidings, while construction is carried out by DB AG.

↘ CHART 122

AFIR-compliant charging infrastructure along the Ten-V main grid[1]



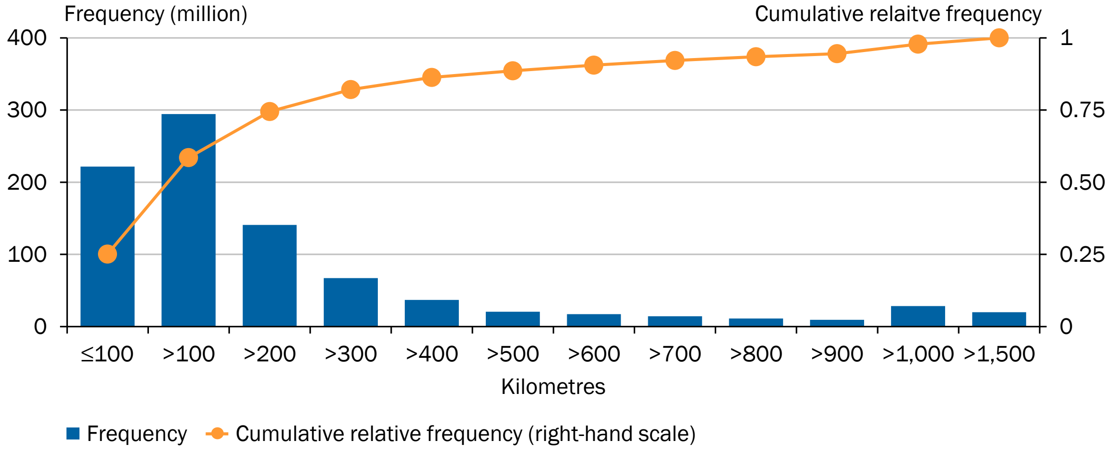
1 – The map shows a possible implementation of the European requirements of the Alternative Fuels Infrastructure Regulation (AFIR) along the trans-European transport network (TEN-T core network) in Germany by 2030. Existing motorways that are currently being upgraded for the TEN-T core network (e.g. A1) are included; motorways that have not yet been upgraded are excluded.

Sources: Balke and Wolff (2024a), own presentation

↘ CHART 123

Distribution of route lengths of truck journeys in the EU in 2030[1]

75 % of European truck transports with distances of less than 300 km



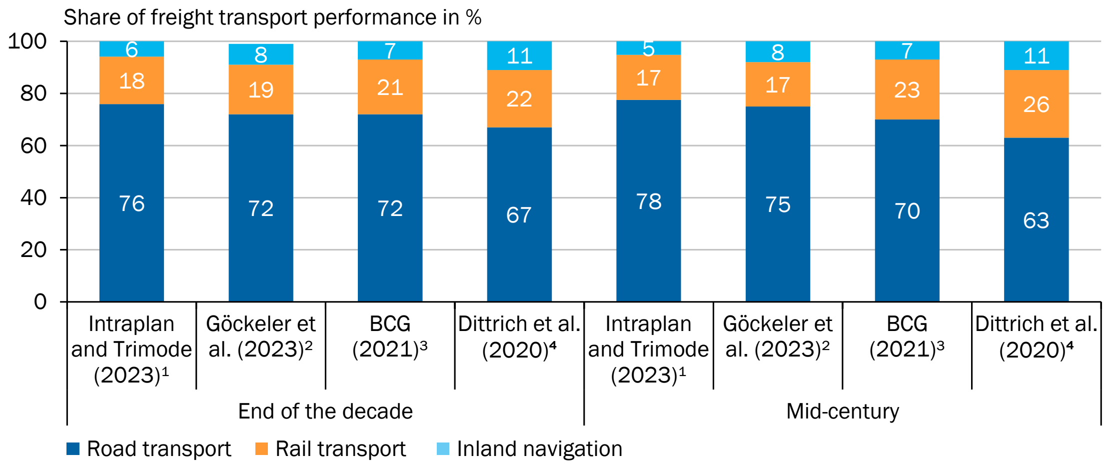
1 – Forecast for 2030 based on the average growth rates of truck freight transport for the years 2010 to 2019.

Source: Speth et al. (2022) based on the ETISplus data set

↘ CHART 124

Forecasts for the future modal split in freight transport

Trucks also the most important means of transport in climate-neutral freight transport



1 – Values for the years 2036 and 2051. 2 – Values for the years 2030 and 2045. 100 % deviation because additional modes of transport were taken into account in the scenario. 3 – Values for the years 2030 and 2045. 4 – Values for the years 2030 and 2050; GreenEe2 scenario.

Sources: BCG (2021), Dittrich et al. (2020), Göckeler et al. (2023), Intraplan and Trimode (2023)

↘ TABLE 20

Means of transport in freight transport differ strongly in their emission intensity[1]

Means of transport	Greenhouse gas[4]	Nitrogen oxides	Particulates[5]
	Gram per tonne kilometres[6]		
Trucks[2]	**121**	**0.198**	**0.010**
of which:			
Trucks from 3.5 to 7.5 tonnes	569	1.775	0.068
Trucks from 7.5 to 12 tonnes	398	1.115	0.041
Trucks over 12 tonnes	253	0.604	0.022
Articulated and non-articulated trucks	103	0.139	0.008
Freight railways[3]	**16**	**0.032**	**0.001**
of which:			
Diesel traction	28	0.242	0.007
Electric traction	15	0.018	0.001
Inland waterway vessel	**36**	**0.415**	**0.011**

1 – Average emissions of individual means of transport in freight transport in Germany in 2022. 2 – Trucks with a gross vehicle weight of 3.5 tonnes or more as well as articulated and non-articulated trucks. 3 – The emission factors for the railway shown in the table are based on data on the average electricity mix in Germany. Emission factors based an company or sector-specific electricity purchases may therefore differ from the values shown in the table. 4 – CO_2, 'CH4 and N_2O indicated in CO_2 equivalent according to AR5 (5. Assessment Report of the IPCC). 5 – Particulate emissions from vehicles originate partly from the exhaust, e.g. soot particles. In addition, particulates are produced by the wear and tear of brakes and tyres. Not including abrasion from brakes, overhead wires, tyres and road surfaces. 6 – Including emissions from the provision and conversion of energy sources into electricity, diesel, liquefied petroleum gas and natural gas

Source: German Environment Agency (UBA)

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