Center for Strategy and Scenario Planning

FUTURE SCENARIOS
for the European heavy-duty truck market

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1 Foreword

"Trying to predict the future is like trying to drive down a country road at night with no lights while looking out the back window." Peter Drucker

Rarely has the outlook for the European heavy-duty truck market been as bleak and uncertain as it is today. What are the implications of the growing need for decarbonization and new technologies such as autonomous driving? How can truck makers deal with supply chain disruptions? Can they emerge stronger? In this study, we seek to answer these questions and provide food for thought not only for managers of heavy-duty truck manufacturers.

Today's business environment is increasingly complex, volatile, and uncertain. Change comes faster than ever, and many developments are impossible to predict. In particular, linear projections from the past are not helpful. Nevertheless, managers must make decisions and commit resources. This is only possible if uncertainty is accepted and made an integral part of strategic decision-making. Traditional strategic planning tools tend to be inadequate under these conditions because they do not take uncertainty sufficiently into account. Scenario planning differs fundamentally from conventional strategy tools in that it attempts to capture a wide range of alternative developments, thus encouraging strategic decision-makers to consider influencing factors that they might otherwise ignore.

Our scenario study of the European heavy-duty truck market helps managers in this endeavor. We have developed four scenarios for the industry in 2030, based on several key uncertainties and key industry trends. We hope these scenarios will inspire you and help you manage the opportunities and threats in this dynamic industry. We wish you an insightful journey through the current situation and potential future of the European heavy-duty truck market.

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2 Executive Summary

Transportation is an indispensable part of today's industrial value chains. Trucks are a key mode of transport, accounting for 77% of goods transported (Eurostat, 2022). However, the global mobility market has been undergoing continuous change over the past decade. Truck manufacturers are facing political and regulatory constraints, strong environmental and social developments, and radical technological disruptions (e.g. autonomous driving, digitalization, connectivity, and green transport), leading to increasing complexity, volatility, and competitive pressure.

In 2018, the entire mobility sector was responsible for about 26% of Europe's total carbon dioxide (CO2) emissions, of which commercial road transport, with more than 188,533 heavy-duty (HD) (>15t) trucks currently in operation, accounts for 39% (Destatis, n.d.; IHS, 2022a). In light of tightening legislation to reduce CO2 emissions, sustainable and cost-effective solutions are needed to transform this sector towards green mobility. New powertrain technologies, such as battery electric, fuel cell (FC), e-fuels, hydrogen (H2), and overhead contact line (OCL) technologies, are still under development with an increasing focus on total cost of ownership (TCO). Sustainable transformation requires a competitive reset and increases pressure on OEMs, suppliers and operators to make long-term decisions about their next generation of vehicles, product portfolios and fleets. At the same time, TCO remains the key purchasing criterion in the commercial vehicle (CV) market (Strategy & 2022).

In addition to powertrain and technology advancements (e.g., cybersecurity, software certification requirements), which are largely driven by TCO, supply chain stability is a growing concern. With the SARS-CoV-2 pandemic and the Russian invasion of Ukraine, rising raw material prices, fluctuating fuel prices, and supply shortages are impacting the value chain. New technologies and emerging megatrends are disrupting the industry, affecting truck OEMs, Tier 1 and 2 suppliers, operators, and consumers alike, and requiring significant research and development (R&D) and infrastructure investments (PWC, 2020).

In essence, the level of uncertainty has increased significantly, making market positioning and decision making more challenging. As a result, companies in the truck manufacturing market must adapt and maintain flexibility to respond to different scenarios and achieve a strategically advantageous position over the long term.

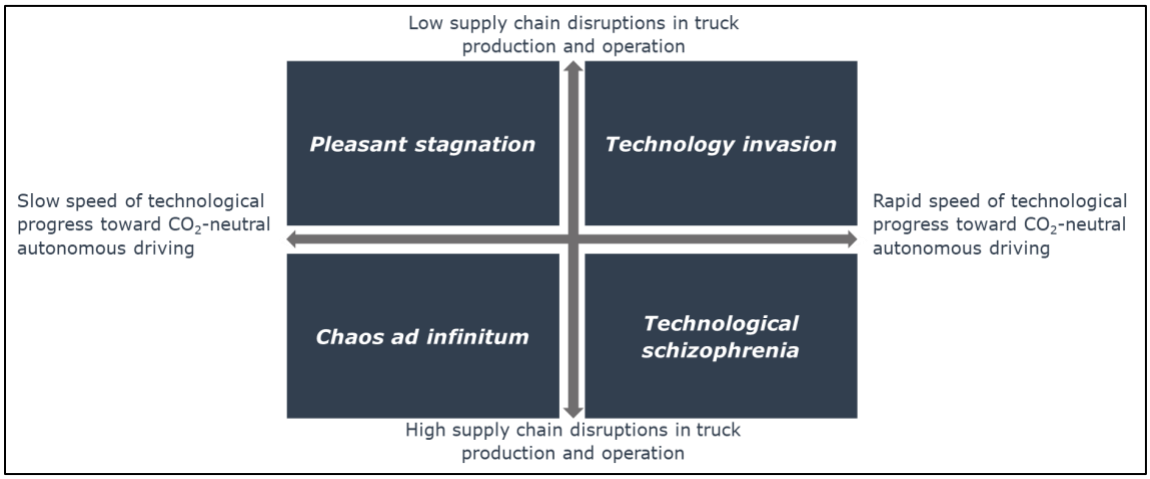
To address these challenges and help managers in the industry plan for the future, we have prepared this study using our innovative approach to scenario-based strategic planning, developed jointly by HHL and Roland Berger Strategy Consultants. Our scenarios are based on extensive research and industry-wide surveys of various stakeholder groups. This has helped us gain a holistic picture of the relevant trends and drivers in the industry and ensures the quality of the scenarios.

The four scenarios we have developed are built around two critical uncertainties identified in our survey of industry experts. These two critical uncertainties, which form our scenario dimensions, are:

- **Speed of technological progress toward CO_2-neutral autonomous driving**
- **Supply chain disruptions in truck production and operation**

Based on these critical uncertainties as well as additional trends and influence factors, four plausible scenarios emerge on how the European heavy-duty truck market could fare until 2030. These four scenarios are the following:

Figure 1: Scenario Matrix for the European heavy-duty truck market



Technology invasion

After a quick recovery in mid-2023 from the recession-like situation associated with the Covid-19 pandemic, Russia's war on Ukraine, supply chain risks and volatile inflation rates, the European commercial vehicle industry shows stable demand growth for heavy-duty trucks. The main drivers are changing consumer needs and strong legislation for CO2-neutral transport in Europe. After huge increases, oil prices and raw material indices (e.g. scrap, iron ore, coking coal) have stabilized at medium-high

levels until 2027. As a result, the share of zero-emission vehicles in the heavy-duty vehicle fleet rises sharply by 2030, as does the share of self-driving trucks in a phased implementation. To optimize the infrastructure for (e-)trucks, the EU is investing heavily in the development of charging infrastructure, electric vehicles (EVs) and autonomous driving technology in this decade.

Technological schizophrenia

Although most European countries have overcome the Covid-19 pandemic following successful vaccination efforts, the European economy has suffered greatly from the recession, supply chain disruptions and inflation. The CV industry has experienced difficulties in accessing raw materials essential for production, as the industry is heavily dependent on supplies from Russia and China, which have been subject to sanctions and export restrictions or have been isolated and in recurrent lockdowns. As a result, raw material prices (e.g., scrap metal, iron ore, coking coal, copper, aluminum, and neo-dymium) will remain extremely high through 2030. Due to these supply constraints, truck OEMs are unable to commercialize their new generations of electric trucks and autonomous driving technologies, leaving the industry in a difficult situation.

Chaos ad infinitum

As a result of two major crises, the Russian invasion of Ukraine and the Covid-19 pandemic, the truck industry has been slow to recover from inflation, energy price increases, supply chain challenges and the general economic downturn. In particular, the semiconductor chip shortage, combined with scarce raw materials and rising prices, has hurt the European CV industry. The raw material price index (e.g. scrap, coking coal and iron ore) and oil prices rose sharply until 2026/27, before finally declining slightly. As a result, total truck sales in Europe decline steadily through 2026, before increasing again to levels still below pre-pandemic levels. However, the global market has recovered more quickly; Asian and U.S. competitors have developed and optimized their zero-emission vehicle and autonomous driving technologies, incentivized by substantial subsidies. Chinese truck manufacturers have begun to enter the European market first, building autonomous driving prototypes in Western Europe and successfully commercializing their new generation of electric powertrains.

Pleasant stagnation

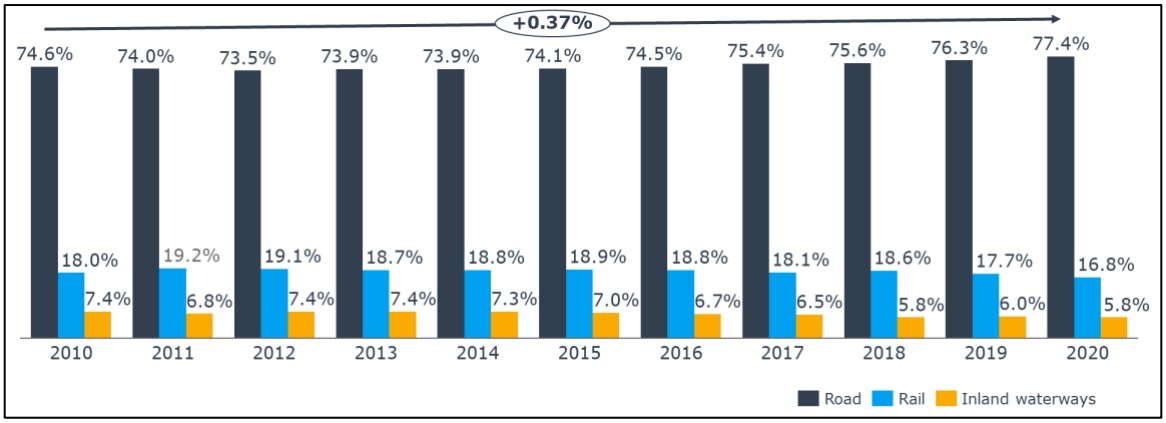
European trucking companies have managed to recover quickly from the significant economic and supply chain challenges caused by the Covid-19 pandemic, the Russian invasion of Ukraine, inflation, semiconductors, and raw material shortages. Oil prices and commodity indexes (e.g., scrap metal, iron ore, coking coal) have stabilized at mid-to-high levels through 2027. The heavy-duty truck industry faces strong growth through 2030, mainly due to rising consumption and e-commerce. However, the share of zero-emission vehicles (ZEVs) in HD trucks is growing slowly and is just about to meet the EU requirements rather than exceeding them. The share of autonomous driving is developing even more slowly. European players generate most of their sales with conventional trucks and have missed out on e-mobility in the heavy-duty truck segment.

3 The European heavy-duty truck market

Introduction and importance of the European truck industry

In 2018, road transport accounted for almost half of the CO2 emissions caused by the mobility sector in Europe (Destatis, n.d.). The modal split of inland freight transport shows that approximately 77% of goods in the European Union (EU) will be transported by road. The remainder will be transported by rail (17%) and inland waterways (6%) in 2020 (Eurostat, 2022). As shown in Figure 2, the share of road transport has been remarkably constant over the last decade, with a slow but steady upward trend at a compound annual growth rate (CAGR) of 0.37%.

Figure 2 Modal split of inland freight transportation of EU countries



Source: Own illustration, following Eurostat (2022).

The market size of the European road freight sector, in which trucks are the primary mode of transport, is approximately €324.5 billion in 2020. The Covid-19 pandemic has had a major impact on this market. Nevertheless, an upward trend remains, and a market size of up to €417 billion is forecast for 2025 (statista, 2021a). This growing trend in market size is in line with the slightly increasing share of road transport in total freight transport (see Figure 2).

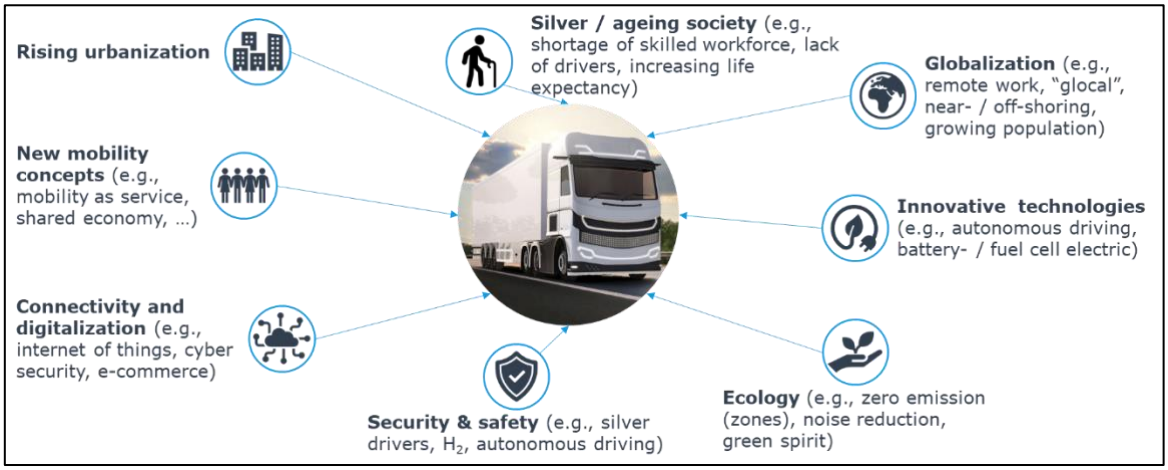
The EU road freight transport industry employed more than 3.2 million people in 2018, representing almost one-third of the EU transport labor market, making it the largest segment within this industry, with Germany as the largest market (statista, 2021b). More than 1.1 million trucking companies currently operate in the European market, but they vary in size. France, Italy and Poland are the top three countries, accounting for more than 40% of trucking companies in Europe (bolddata, n.d.).

Considering the public investment in transportation infrastructure in Germany, for example, the government plans to invest more than €270 billion to rebuild and expand

roads, railways, and waterways over the next 10 to 15 years (Pladson, 2021). In addition, specific sustainable truck projects are being funded, such as the overhead contact line project called eWayBW, which aims to research and test overhead contact line technology on trucks. As a result, the catenaries of specific highway routes will be electrified in order to test hybrid, fully electric and (FC) electric catenary trucks (eWayBW, n.d.). In addition to this specific case, the German government is funding numerous other climate-friendly commercial vehicle and infrastructure projects. Other examples include a subsidy of up to 80% of the purchase price or development costs for retrofitting to low- or zero-emission (ZE) alternatives, the purchase of sustainable commercial vehicles (battery electric vehicle (BEV), fuel cell electric vehicle (FCEV), or hybrid), and charging infrastructure projects (NOW GmbH, 2021). The situation in other European countries is similar.

Figure 3 shows the current mobility (mega)trends in Europe. Landesbank Baden-Württemberg (LBBW) (2021), Zukunftsinstitut (2022a, b), and Gartner (2022) emphasize new technologies such as autonomous driving and digitalization, with a special focus on automotive cybersecurity. The Zukunftsinstitut (2022a, b) includes other megatrends such as increasing urbanization, demographic development, security concerns and the effects of (de)globalization. A study by LBBW (2021) emphasizes the trend toward a shared economy and more stringent environmental requirements, such as CO2 reduction targets or noise limits. The diversity of potential trends affecting the trucking sector underscores the dynamic development of this particular industry.

Figure 3 Overview of potential (mega)trends affecting the truck industry

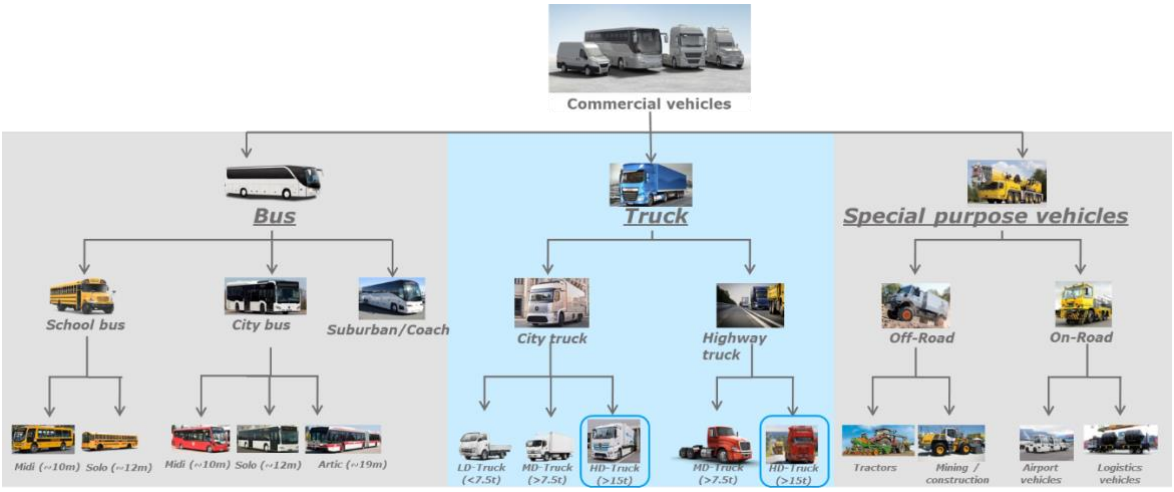


Source: Own illustration, following LBBW (2021), Gartner (2022), and Zukunftsinstitut (2022a, b).

Overview of the European Heavy-Duty Truck Market Structure

The commercial vehicle (CV) market is divided into buses, trucks and special vehicles, as shown in Figure 4. While the first subcategory includes school, city and coach buses of various sizes, the third subcategory distinguishes between on-road (e.g. airport or logistics vehicles) and off-road vehicles (e.g. tractors, mining or construction vehicles). The truck segment is divided into city and highway trucks, which can be further subdivided into light-duty (LD) (<7.5 t), medium-duty (MD) (>7.5 t) and heavy-duty (HD) (>15 t) vehicles.

Figure 4 Structure of the CV market



Source: Own illustration.

Figure 4 describes different HD truck applications that result in different use cases. Urban or short-haul HD trucks have a typical annual range of 40,000 to 75,000 km with relatively low highway usage. In contrast, long-haul vehicles have a high highway application and an annual range of 100,000 km (Roland Berger, 2018).

Furthermore, a variety of powertrain technologies can be distinguished, namely ICE, hybrid, ZEV including BEV and FCEV, ICE with H2 engine, bioliquid natural gas or compressed natural gas. A detailed breakdown of the market data between ZEV and ICE is provided in the chapter "Market size, forest and growth drivers". However, gas and H2-ICE powertrains are not included in this study due to their small current market share and low expected demand in the coming years.

The size of companies operating HD trucks varies from (local) small companies to large multinationals such as DB Schenker, Dachser or Kühne & Nagel (Roland Berger, 2018). More than 90% of European truck operators have less than ten vehicles in their fleet (Mortensen, 2020). In contrast, the OEM market, i.e. the market of HD truck

manufacturers, shows a trend towards consolidation. The top ten OEMs dominate this market segment, accounting for nearly 90% of European sales in 2021 (IHS, 2022a). The CV driveline supplier industry is also moving toward consolidation, as evidenced by several recent mergers and acquisitions (M&A). For example, multinational Cummins acquired U.S. electric (e-)axle supplier Meritor and the CV business of Siemens Group (finan-zen.net, 2022). In particular, the stringent automotive standards and requirements for functional safety and automotive cybersecurity compliance represent significant additional costs that become additional barriers to entry and limit the risk for newcomers in the (e-)powertrain segment (Denk, 2022).

Digitalization, automatization, and future technologies

Compared to other industries, the trucking and commercial road transportation sector has been known for its high labor intensity and manual processes. However, in recent years, the enormous potential for digitalization and automation in production and operations has been recognized, triggering a shift from hardware to software (IBM, 2021; Brown et al., 2021).

The key enabler of digitalization use cases and autonomous driving is vehicle-to-everything communication. This includes communication (e.g., detection and, if necessary, initiation of countermeasures) with pedestrians, other vehicles, infrastructure, and networks. This increases road safety, prevents accidents, and maximizes traffic and road efficiency. However, the legal and insurance policies are still not specified in detail, which creates an unclear and challenging environment for software development (Moubayed & Shami, 2022).

Currently, the digitization and automation of CVs focuses on intelligent planning and route optimization. The underlying software can adjust routes in real time and project the estimated time of arrival accordingly. On the receiving end, operators can accurately track the location of their drivers, as well as the recipient of a package, for example. This smart, connected, and digitized feature helps improve service quality and efficiency (Verkehrsrundschau, 2021). Further software improvements are expected, particularly in the areas of predictive maintenance and operational efficiency.

In addition to these use cases, intelligent software can promote fuel efficiency. For example, drivers can be advised on the optimal time to brake, shift gears, and re-accelerate, which is particularly helpful when driving over mountainous terrain. In some cases, the software takes over the manual process; for example, an intelligent cruise control system can lower the accelerator on downhill stretches to avoid unnecessary fuel consumption (Denk, 2022; MAN, n.d.).

Predictive maintenance is also becoming increasingly important for operators. Truck operators receive notifications for regular or irregular checks, repairs, or upcoming replacements of worn parts if there is a constant connection to the system (Michel, 2022). Prototype software programs are available, such as the MAN software platform. In this case, vehicles send information about traffic, sensor status, battery charge, fluids, and other service-related data to the operator or truck owner via cloud connections (MAN, 2022).

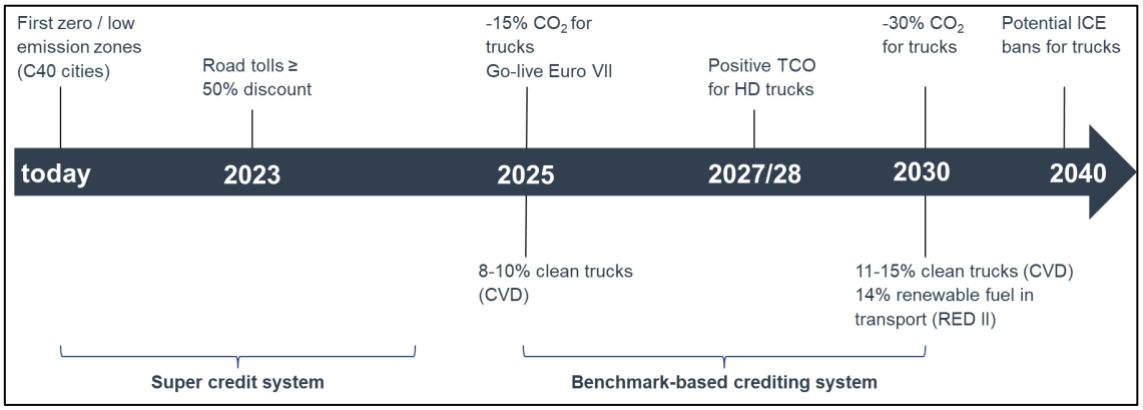
As a major megatrend, autonomous driving is disrupting the CV segment, with a particular focus on HD trucks. This trend would offset the worsening driver shortage, improve operational efficiency and likely have a positive impact on safety, provided the (sensor) technology is mature. In particular, there are six stages on the road to fully autonomous trucks: stage zero defines no automation at all, while stage five describes the full automation scenario. The level of autonomous driving constantly increases from stage one to four, from driver assistance (stage one) to a high degree of automation, where a driver is present but only operates in a non-automated situation (stage four) (Roland Berger, 2016). Today, Daimler Trucks (n.d.) has implemented stage two in its series production and has developed stage four demo vehicles that are partially implemented in specific use cases. Stage three, conditional automation, includes the concept of platooning. The most common and well-known platooning concept is where an operator pairs trucks with matching routes to form a platoon via vehicle-to-vehicle communication. However, a driver is still required as the trucks follow their route to the final destination (Roland Berger, 2016). The benefits of platooning are lower fuel consumption and therefore lower emissions, less space between trucks allowing for more space on highways, and increasing comfort and safety levels with less human interaction. Once level five is reached, driver costs are completely eliminated, which ultimately leads to lower operating costs. MAN and DB Schenker successfully tested the first platooning concept in 2019 (MAN, 2019).

In addition, requirements and purchasing criteria, especially for e-drivetrains, are changing as automotive standards play an increasing role in supplier selection. On top of performance and efficiency requirements, truck OEMs and operators are demanding automotive certifications for production facilities (e.g., IATF 16949), compliance with functional safety (ISO 26262), and automotive cybersecurity (ISO 21434, UN R155). Importantly, these new requirements apply not only to OEMs, but also to most CV suppliers to ensure maximum safety and security in all areas and a minimized risk of cyber attacks (Invensity, 2021). Beyond automotive certification requirements, sustainability is playing an increasing role, as discussed below.

Decarbonization of the logistics road transport segment

Decarbonization is an essential goal of the European Union affecting the truck industry. Figure 5 visualizes the timeline of measures and binding targets designed to force the EU truck industry to move towards this goal (e.g., low or ZE solutions).

Figure 5 Overview of the political and legal regulations for low / ZE trucks



Source: Own illustration, following C40 Cities (2017), European Parliament (2022), Sustainable Truck & Van (2022), European Commission (n.d.), European Commission (2021), NOW GmbH (n.d.)

Several cities have implemented additional local measures such as bans, zero-emission zones, and reduced tolls to reduce particulate matter and nitrogen oxide pollution. For example, the so-called C40 cities have adopted the fossil fuel-free streets declaration that currently applies to buses. Some of these cities have tightened regulations so that by 2025 only zero-emission buses will be allowed to operate within city limits. These regulations will be extended to other vehicles by 2030. The European cities involved include Paris, London, Copenhagen and Barcelona. Although these restrictions do not currently include trucks, they mark the beginning of a shift to ZE policies (C40 Cities, 2017).

The EU is planning further incentives from 2023, such as a discount of at least 50% on road tolls for BEVs or H2 trucks. This incentive has a particularly positive impact on the TCO of electric trucks compared to ICE trucks (European Parliament, 2022; Sustainable Truck & Van, 2022).

In addition, two other EU directives affect trucks: First, CO2 emissions from new trucks must be reduced by 15% between 2025 and 2029. From 2030, the reduction target is 30% on average. The base year for comparison is 2019, and further interim targets may be set for 2035 and 2040. These are binding targets for all new HD vehicles (European Commission, n.d.). Second, the Clean Vehicles Directive (CVD) promotes the use of clean and energy-efficient road vehicles. This regulation primarily applies to buses, but is being extended to trucks, with a target of 8-10% clean trucks by 2025 and 11-15% by 2030, depending on national targets. The CVD applies to vehicle purchase, lease, rental or hire-purchase contracts. A clean vehicle has zero or low emissions, i.e. it uses natural gas, batteries, H2, liquid biofuels, synthetic and paraffinic fuels (European Commission, 2021). Finally, the introduction of the Euro VII standard, which will be implemented in 2025 at the earliest, is expected to tighten emission limits, such as those for CO2, particulate matter, nitrogen oxides, and others. It will also set technology standards to limit air pollution and promote fossil-free transport (ACEA, 2022).

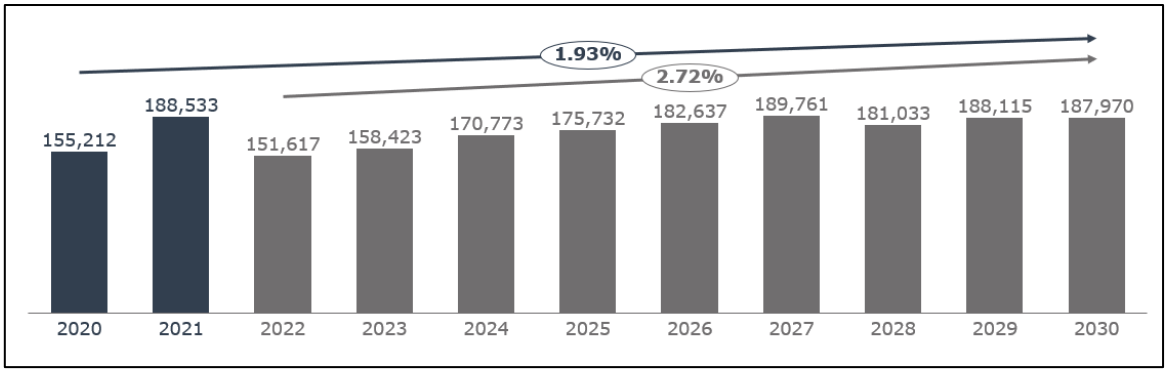
The EU has also initiated the Renewable Energy Directive (RED II). This directive requires a minimum of 14% renewable fuels in the transportation sector by 2030, indirectly accelerating clean vehicle infrastructure (NOW GmbH, n.d.). In addition, OEMs will face penalties after 2025 if they fail to meet CO2 reduction targets for newly registered vehicles. Specifically, the EU plans financial penalties of €4,250 per gCO2 / tkm after 2025, rising to €6,800 per gCO2 / tkm after 2030 (Center for European Policy Network, 2019).

These regulatory pressures are in line with market developments and OEM expectations. For example, Daimler Truck AG has publicly committed to a certain ZEV share in its fleet by 2030 (60%) and 2039 (100%) globally (Daimler Truck, 2021). The Turkish OEM Ford Otosan has committed to new fossil-free trucks by 2040 (Ford Otosan, 2022).

Market size forecast and growth drivers

This subchapter deals with the market size, outlook, and growth drivers for the market under review until 2030. Figure 6 provides an estimation of the development of the HD truck industry in Europe until 2030 in terms of the number of HD trucks sold to European customers. Projected figures declined in 2022 due to the Covid-19 pandemic and the Russian invasion of Ukraine. Further reasons for the decline are rising inflation, shortage of drivers and skilled employees, semiconductor shortages, increasing energy prices, and challenges in maintaining the supply chain (IHS, 2022b).

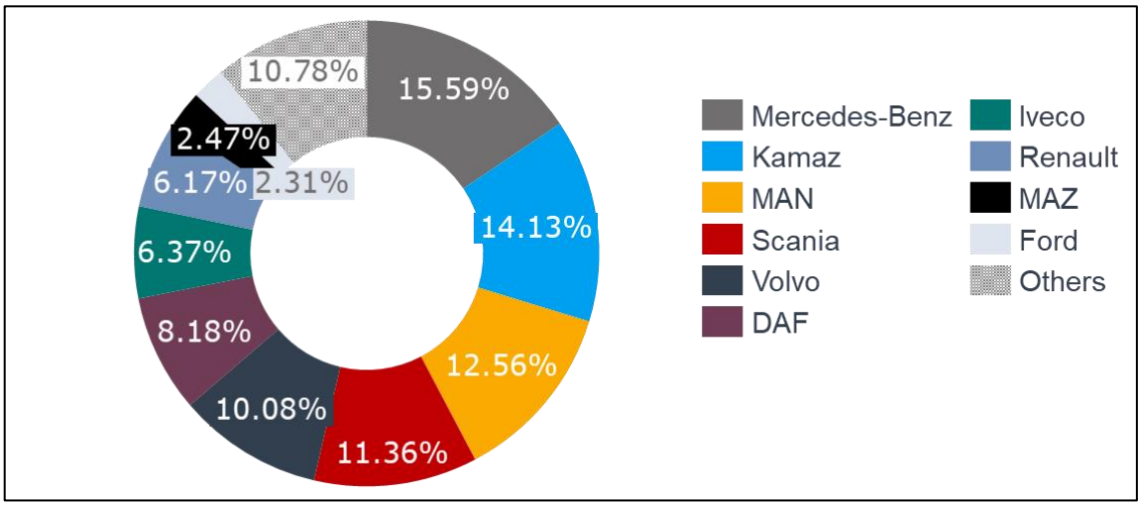
Figure 6 Market size of the European HD truck industry [units] (2020-2030)



Source: Own illustration, following IHS (2022a).

Figure 7 shows the break down of the 2021 truck sales by brands. 89.22% of the total sales volume in 2021, equivalent to 168,205 units, is attributed to the top 10 OEMs.

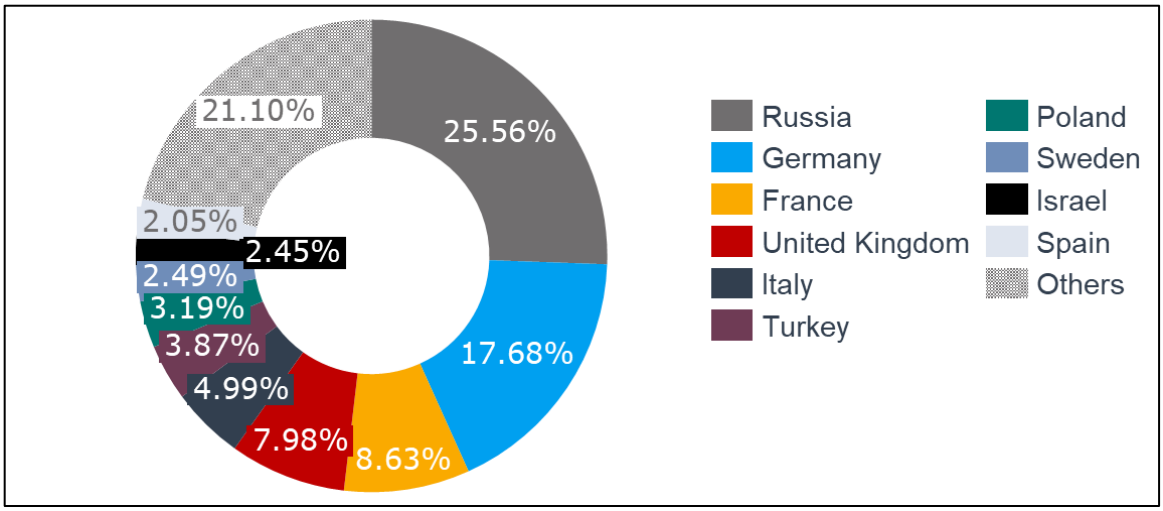
Figure 7 Top 10 sales brands for HD trucks in Europe in 2021



Source: Own illustration, following IHS (2022a).

Figure 8 displays the 10 countries with the highest demand for HD trucks in Europe in 2021. These countries collectively account for nearly 80% of the total sales volume, which amounts to 148,756 units in 2021.

Figure 8 Top 10 countries' demand for HD trucks in Europe in 2021

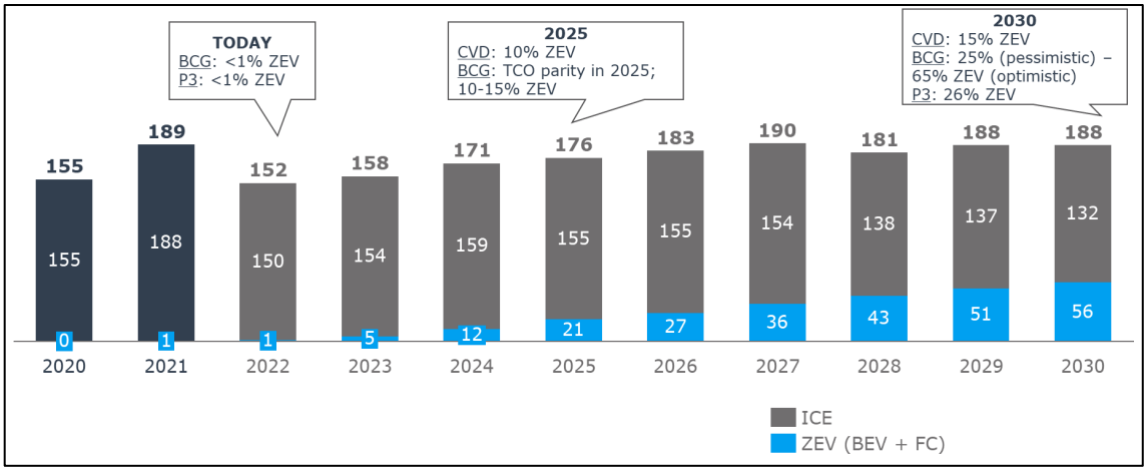


Source: Own illustration, following IHS (2022a)

In addition, these figures can be further analyzed by powertrain technology, such as internal combustion engines (ICE) or zero-emission vehicles (ZEV), which include battery electric vehicles (BEV) and fuel cell electric vehicles (FCEV). Looking ahead to 2030, analysts at the Boston Consulting Group (BCG) predict that the TCO of BEV heavy-duty trucks will be on par with ICE counterparts by 2025, assuming a vehicle weight of over 15 tons and an annual driving distance of 120,000 km. BCG's 2022 forecast also suggests that TCO parity between ICE and FCEV heavy-duty trucks will be achieved in the second half of this decade. These projections are consistent with a study by the International Council on Clean Transportation (ICCT, 2021), which estimates that cost parity will occur between 2022 and 2027, depending on the country within Europe. For example, the Netherlands, France, and Germany are expected to reach cost parity in 2022, while Spain and Italy are expected to reach cost parity in 2026 or 2027, taking into account incentives for ZEVs and penalties for ICE vehicles (ICCT, 2021).

Achieving TCO parity will have a significant impact on the adoption rate of ZEVs, especially in the ramp-up phase. Based on expected TCO parity, decarbonization targets, and insights from various consulting reports, Figure 9 reflects a 30% ZEV share of the heavy-duty (HD) truck market by 2030. This includes both fuel cell electric vehicles (FCEVs) and battery electric vehicles (BEVs), and assumes that countries outside the European Union (EU) would pursue similar ZEV targets in the HD truck sector.

Figure 9 ZEV market size of HD trucks until 2030 [thousand units]



Source: Own illustration, following IHS (2022a), BCG (2022), P3 automotive GmbH (2021).

ZEV development is expected to accelerate rapidly from 2025, with an estimated 12% ZEV share in that year. Both the 2025 and 2030 projections are slightly more optimistic than the CVD regulatory requirements, but are in line with BCG's projections and take into account the positive impact of TCO developments (BCG, 2022). All studies suggest that battery electric vehicle (BEV) technology will dominate the market by the end of this decade, followed by fuel cell (FC) technology.

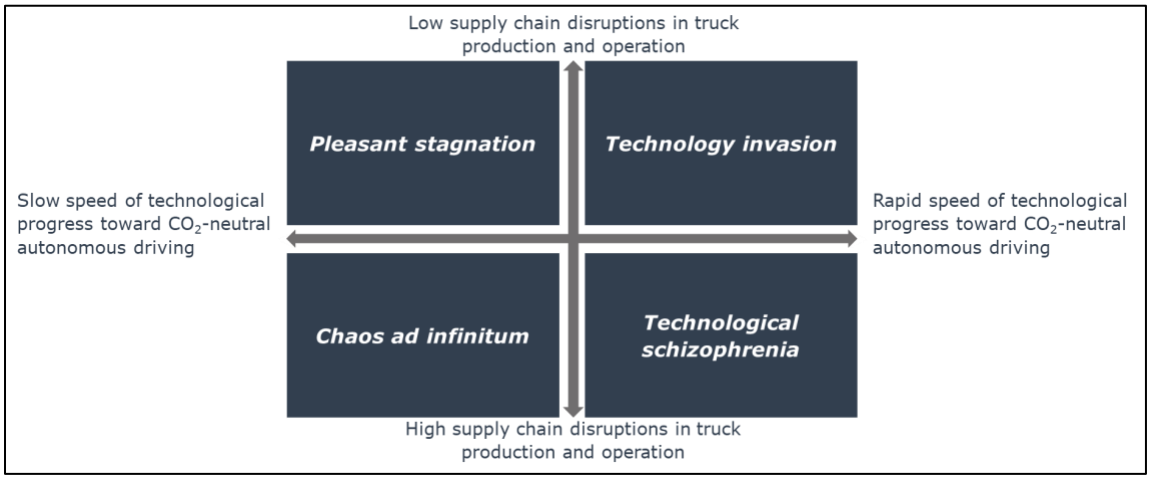
The drivers behind this growth in the ZEV market can be categorized into push and pull factors. Push factors include the need to meet decarbonization targets, the creation of zero emission (ZE) zones, and the rising cost of oil, as mentioned above. In contrast, pull factors include government subsidies and positive TCO developments resulting from the implementation of new, cost-effective technologies and rising oil prices (P3 automotive GmbH, 2021).

In addition to these factors, there are general growth drivers for the HD truck market, such as the growth of e-commerce, the expansion of road infrastructure through public investment, and a return to pre-pandemic economic levels. However, the latter is highly dependent on the outcome of the war in Russia (BCG, 2022). Furthermore, a McKinsey study (2021) found that the commercial vehicle (CV) sector is experiencing a growing level of productivity, which can increase by 1.2% per year until 2024. This increase is closely linked to faster adoption of innovations, particularly automation and digitalization, to improve efficiency (McKinsey, 2021).

4 Scenarios

Based on the market situation and the various trends in the European heavy-duty truck market described above, we have developed four scenarios that present different possible pictures for the industry's future in 2030. These scenarios are determined primarily by the two critical uncertainties, that form the dimensions of our scenario matrix – *speed of technological progress toward CO_2-neutral autonomous driving and supply chain disruptions in truck production and operation.* We have named the resulting scenarios "Pleasant stagnation", "Chaos ad infinitum", "Technology invasion", and "Technological schizophrenia" (see Figure 10). They are described in the following, first briefly and then in more detail.

Figure 10: Scenario matrix for the European heavy-duty truck industry



Overview

Scenario A: Technology invasion

After a quick recovery in mid-2023 from the recession-like situation associated with the Covid-19 pandemic, Russia's war on Ukraine, supply chain risks and volatile inflation rates, the European commercial vehicle industry shows stable demand growth for HD trucks. The main drivers are changing consumer needs and strong legislation for CO2-neutral transport in Europe. After huge increases, oil prices and raw material indices (e.g. scrap, iron ore, coking coal) have stabilized at medium-high levels until 2027. As a result, the share of zero-emission vehicles (ZEVs) in heavy-duty vehicles increases sharply by 2030, as does the share of autonomous trucks in a phased implementation. To optimize the infrastructure for (e-)trucks, the EU is investing heavily in the development of charging infrastructure, electric vehicles (EVs) and autonomous driving technology in this decade.

Scenario B: Technological schizophrenia

Although most European countries have overcome the Covid-19 pandemic following successful vaccination efforts, the European economy has suffered greatly from the recession, supply chain disruptions and inflation. The CV industry has experienced difficulties in accessing raw materials essential for production, as the industry is heavily dependent on supplies from Russia and China, which have been subject to sanctions and export restrictions or have been isolated and in recurrent lockdowns. As a result, raw material prices (e.g., scrap metal, iron ore, coking coal, copper, aluminum, and neo-dymium) will remain extremely high through 2030. Due to these supply constraints, truck OEMs are unable to commercialize their new generations of electric trucks and autonomous driving technologies, leaving the industry in a difficult situation.

Scenario C: Chaos ad infinitum

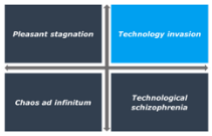
As a result of two major crises, the Russian invasion of Ukraine and the Covid-19 pandemic, the truck industry has been slow to recover from inflation, energy price increases, supply chain challenges and the general economic downturn. In particular, the semiconductor chip shortage, combined with hard-to-find raw materials and rising prices, has hurt the European CV industry. The raw material price index (e.g. scrap, coking coal and iron ore) and oil prices rose sharply until 2026/27, before finally declining slightly. As a result, total truck sales in Europe decline steadily through 2026, before increasing again to levels still below pre-pandemic levels. The global market, however, has recovered more quickly; Asian and US competitors have developed and optimized their ZEV and autonomous driving technologies, incentivized by substantial subsidies. Chinese truck manufacturers have been the first to enter the European market, building autonomous driving prototypes in Western Europe and successfully commercializing their new generation of electric powertrains.

Scenario D: Pleasant stagnation

European truck companies have managed to recover quickly from the significant economic and supply chain challenges caused by the Covid-19 pandemic, the Russian invasion of Ukraine, inflation, semiconductors, and raw material shortages. Oil prices and commodity indexes (e.g., scrap, iron ore, coking coal) have stabilized at mid-to-high levels through 2027. The HD truck industry faces strong growth until 2030, mainly due to rising consumption and e-commerce share. However, the ZEV share of HD trucks is growing slowly and is just about to meet rather than exceed the EU

requirements. The autonomous share is developing even more slowly. European players are mainly generating sales with conventional trucks and have missed out on entering the e-mobility field in the heavy-duty truck segment.

Scenario A: Technology invasion



30.06.2030: European truck players successfully overcame the supply chain challenges in the early 2020s and are renowned for their autonomous driving trucks.

The HD truck market in Europe in 2030

After enduring a recession-like situation for a year and a half, along with the ongoing war between Russia and Ukraine, volatile raw material prices, supply chain challenges, a shortage of semiconductor chips, and the continued Sars-Cov-2 pandemic in 2022 and the first half of 2023, the commercial vehicle industry is finally recovering with stable demand growth for heavy-duty (HD) trucks. According to automotive consultants, the primary factors driving this growth are evolving consumer needs and the stringent legislation for CO_2-neutral transportation in Europe.

Following substantial increases, the prices of oil and raw material indices, such as scrap, iron ore, and coking coal, have stabilized at a medium-high level by 2027. As a result, the zero-emission vehicle (ZEV) share of HD trucks is projected to increase significantly, along with the share of autonomous driving trucks in a phased implementation, until 2030. To optimize the infrastructure for e-trucks, the European Union is investing broadly in expanding charging infrastructure, electric vehicles (EVs), and autonomous driving technology throughout this decade.

"The key to our success is the constant improvement of our technology, ensuring the best fit between the e-motor and inverter, and minimizing the share of rare earth materials. This enables our company to provide customers with the most efficient e-drivetrain solutions, which are also suitable for autonomous driving vehicles," says the Chief Executive Officer of the e-drivetrain technology division for

Developments in the European HD truck industry between 2022 and 2030

After recovering from the recession-like situation associated with the Covid-19 pandemic, the Russian war on Ukraine, supply chain risks, and volatile inflation rates, European governments quickly implement expansionary fiscal policies by 2024 to restore economic growth. Governments have largely lifted travel restrictions during the pandemic after reaching a certain vaccination rate by the end of 2022, and the risk of additional closures and restrictions is low.

However, the Russian invasion of Ukraine has led to severe consequences and export restrictions to Eastern European countries. The truck industry is pulling all business, both customers and suppliers, out of Russia and building alternatives elsewhere. Regarding the gas supply situation in 2022 and early 2023, Russia has stopped the supply of natural gas. With each country's contingency plan, the amount of gas was sufficient to avoid severe economic consequences and blackouts. At that time, (green) alternatives were identified for Germany, one of the countries most dependent on Russia. The political situation in Western and Eastern European countries is relatively stable. In contrast, countries such as Russia, Ukraine, Belarus, Bosnia-Herzegovina, and Turkey continue to show political instability with ups and downs within this decade.

By the beginning of 2024, after years of underinvestment, the majority of EU member states are making substantial investments in education, digitalization, and (road) infrastructure in Europe, amounting to 4.7% of GDP in 2025 and 3.1% in 2030. They are promoting economic expansion and supporting the commercial vehicle industry by optimizing the underlying infrastructure to a sufficient level, as well as offering more subsidies to operators and manufacturers of ZEV and autonomous trucks. These public expenditures have created high confidence in the industry and promoted consumption and corporate investment. Following these measures, the inflation rate in the EU steadily declines from over 7% in mid-2022 to below 2% in 2025. Meanwhile, economic growth (e.g. real GDP growth) rises from around 2.7% in 2022 to 4.3% in 2025 and stabilizes at over 3.3% in 2030. The rapid increase in demand for (HD) trucks reinforces the solid economic upswing in 2025, especially for ZEVs, whose share has multiplied with the increasing supply of subsidies and high fuel prices.

As a result of fiscal policy in the form of growing subsidies, public spending (e.g. debt) has increased significantly in most European countries. The ECB is taking countermeasures to prevent a debt and solvency crisis that would lead to a low interest rate policy by the ECB. Due to the rapid change in inflation and underlying inflation

expectations since Covid-19, the ECB raised interest rates for the first time in 11 years. However, they remain at historically low levels, declining to below 1.0% after 2025 due to the growing public debt from 2024 onwards. Therefore, a combination of fiscal and expansionary monetary policy is the right policy to promote an economic recovery.

After recovering from the supply chain problems of the first half of the decade, European governments and companies are open to international cooperation, far-shoring and collaboration, and are moving towards a free trade approach rather than protectionism.

After large fluctuations and increases in the oil price and commodity index at the beginning of the decade, both indexes stabilize at medium-high levels by 2026 and 2027. The reasons for these price increases are uncertain supply chains, increased scarcity and unclear availability of the required raw materials. From a technological perspective, this scarcity is still prevalent, forcing companies to develop technology that significantly minimizes the amount of rare earths and other materials in their vehicles and (automotive) components. As TCO remains the most critical decision criterion, raw material fluctuations and rising prices have a significant impact on the TCO of EVs in particular. The constantly decreasing prices of batteries and increasing fuel costs compensate for the rising prices of raw materials such as scrap metal, iron ore, neodymium, aluminum and copper, which are relevant for electric motors and inverters. Another critical part of the TCO is the rising cost of truck driver labor. As the number of truck drivers has declined significantly in recent decades, operators need driverless alternatives, for which autonomous trucks are the perfect solution. Despite their likely higher purchase price, autonomous vehicles are attractive from a cost perspective due to the elimination of driver labor costs, the ability to operate 24/7, and the elimination of (human) breaks (except for recharging or refueling). With level four prototypes already in development and some in use before 2022, a phased implementation of autonomous trucks will follow by 2030. Fully autonomous driving (e.g. level five) will first be implemented in internal applications such as transport between warehouses (similar to AGVs, but for larger loads and longer distances). The next use case is public roads with very simple topography and highways with platooning concepts and limited inner-city routes. Driverless applications in cities could be realistic in the long term, around 2040 - until then, the flexibility of such trucks

remains limited. However, the legal situation will have to adapt to technological progress.

In 2022, the UNECE will legally permit the fourth stage of autonomous driving in Europe. Until the implementation of the fifth stage, a Europe-wide mobility concept will be developed, not country by country, in order to avoid regional legal differences and to pioneer a common standard. The new regulation is more complex than the Stage Four legislation, but covers all issues related to data security, safety, legal protection and liability of the vehicle owner. Prototypes of A-samples (car CV categories) will be available by the end of 2023, with further B- and C-samples in the following years. The first final samples will be completed by 2026, while the following year, 2027, the first five autonomous driving e-trucks will be commercialized. An autonomous driving share of 15% is expected by 2030. The share does not include autonomous ICE trucks, as OEMs are not focusing on this type due to increasing CO2 emission restrictions.

Driven by climate change, increasing environmental awareness, and resulting restrictions, these autonomous trucks must be CO2 neutral. In the coming years, governments will tighten ZE and noise requirements as the need to avoid local pollution, especially in cities, increases, leading to more ZE zones. To promote the attractiveness of ZEVs, governments are even increasing the planned Europe-wide tax and toll benefits for CO2-neutral CVs. Further subsidies are being offered for sustainable e-drive and autonomous driving technologies. The underlying technology for BEV and H2 trucks has steadily improved, and OEMs have introduced the first recyclability concepts within this decade. ZEVs are expected to account for 30% of heavy-duty trucks by 2030.

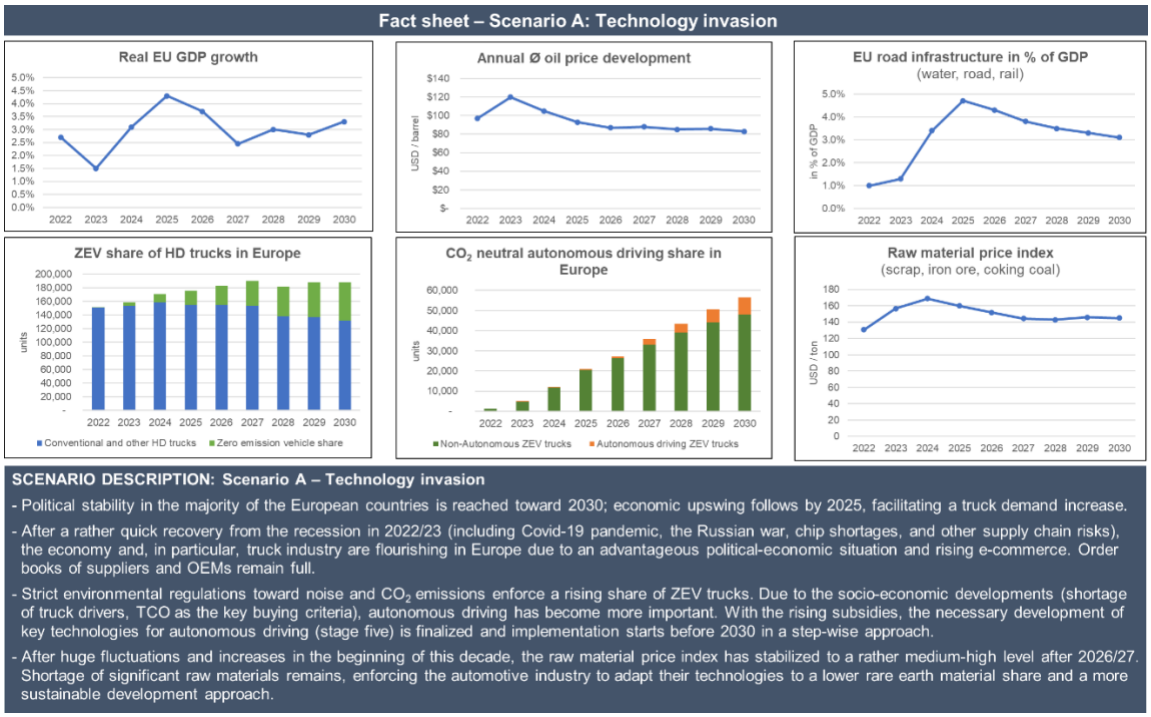
Supported by increasing subsidies, part of the investment is being used to drive digitalization technology in the CV business. As a result, new business models are emerging, such as in the areas of predictive maintenance or connected communication, while maintaining a certain level of safety and IT security. Some new innovative models resemble the principles of a shared economy in the platooning use case. With the increasing implementation of vehicle-to-everything communication, platooning becomes a realistic scenario where operators connect their or other vehicles to save fuel and reduce emissions on highways.

Based on these developments between 2022 and 2030, the technology invasion scenario dominates the European market, with a significant share of CO2-neutral

autonomous trucks replacing a significant share of conventional trucks. The high barriers to entry - due to strict automotive standards: functional safety, cybersecurity and IATF certifications - minimize the risk of entry for new non-automotive players. In this growing, economically improving environment, the trucking industry is rapidly recovering and returning to its pre-pandemic status quo, driven by the significant increase in e-commerce and the associated need for road transportation.

The fact sheet *technology invasion* below illustrates the quantitative development of the most important KPIs over the period under review. This scenario combines the *rapid speed of technological progress toward CO_2-neutral autonomous driving* and *low supply chain disruptions in truck production and operation*.

Figure 11 Fact sheet Scenario A – Technology invasion



Source: Own illustration, following Schwenker & Wulf (2013), p. 118.

Scenario B: Technological schizophrenia

<u>30.06.2030:</u> Major progress in ZEV and autonomous driving technology has been achieved, but the OEMs struggle with implementation due to volatile demand and supply.

Throughout much of this decade, the European economy has endured a great deal of hardship due to the recession and accompanying price fluctuations. Although vaccination efforts have allowed most European countries to overcome the Covid-19 pandemic, supply chain disruptions have continued to adversely affect the commercial vehicle (CV) industry.

Firstly, the truck supplier industry is grappling with difficulties in accessing rare, price-increasing, and fluctuating raw materials that are critical for production. Despite a clear upward trend, the prices of oil and raw material indices, including scrap, iron ore, coking coal, copper, aluminum, and neodymium, remain high until 2030. Secondly, the industry heavily depends on supplies from countries such as Russia and China, which have faced sanctions, export restrictions, or have been isolated due to recurrent lockdowns. Irregular availability and unreliable deliveries from key tier 1 suppliers, particularly in the electric vehicle (EV) business, have prevented truck original equipment manufacturers (OEMs) from commercializing their new e-truck generations in a timely manner, and as a result, they will not meet the expected demand. The same situation applies to the progress of autonomous driving. Consequently, experts have revised their forecasts to predict a 15% ZEV share and an 8% share for autonomous driving.

"Despite the strategic shift toward nearshoring, we cannot avoid delays in the start of production (SOP) of our new e-trucks. Hence, we unfortunately cannot achieve our individual ZEV target for 2030, but we remain optimistic about our interim target for 2035, thanks to our new production facilities, and we can also focus more on our generations of autonomous driving," explained the Chief Technology Officer of a truck OEM.

Developments in the European HD truck industry between 2022 and 2030

European countries are deeply affected by the Covid-19 pandemic from 2020 to early 2023, but most have overcome the crisis with vaccination efforts after three years. However, the Russian conflict and the resulting political instability in some European

countries is having a profound impact on the CV industry. Truck companies are withdrawing operations, suppliers and customers from Russia, resulting in lost sales. However, the heavy dependence on Russia and especially China in the CV sector has a negative impact in the following years. Both countries were sanctioned or periodically shut down due to the zero-carbon strategy. Russia reduced its gas supply from mid-2022 to mid-2023, but the minimum amount was still delivered. Combined with the strict austerity plan of EU governments and sourcing alternatives, sufficient gas supply was secured for the winter of 2022/23. In addition, the shortage and resulting high price of key commodities is becoming another critical supply chain challenge that will affect the entire decade.

Although governments have tried to fight rising inflation, the recession is inevitable and will last longer than expected. As a result, the ECB is raising interest rates to combat inflation from 2022. Nonetheless, the economic recovery is significantly delayed until 2026, with real GDP growth of 2.9%. Towards the end of the decade, in 2029/30, economic growth stabilizes again with an annual real GDP growth rate of 2.5% to 3.2%. At the same time, the inflation rate falls to below 2% by 2030. Expansionary monetary policy is used to support the (late) expansion and stabilization of the market. The ECB switches to a low to zero interest rate policy to stimulate the economy for investment.

Due to severe supply chain problems in the first half of the decade and dependence on risky countries such as China and Russia, European governments promote protectionism. As a result, companies are following a strategic trend of nearshoring and are reluctant to enter into international business relationships in order to become independent and more resilient. However, it could lead to an overproduction scenario if companies start building several new production facilities due to the high uncertainty. This would result in low capacity utilization and economic tensions. Relocating production facilities to or closer to Europe does not solve the inability to deliver in the short term, but only in the medium term.

As a result, European truck sales will decline in 2023 and 2024 compared to last year's levels, and will only grow again in the long term to 156,166 units in 2025 and 187,970 units in 2030, with a five-year CAGR of 3.1%. This is mainly due to the growing share of e-commerce and consumption by the general public by 2025. As a result, the ZEV share reaches the legally required EU interim targets of 10% in 2025 and 15% in 2030, but does not exceed them as originally expected.

Strong protectionist policies prevent foreign players from entering the European truck market, significantly reducing competition and the risk of foreign entry. In addition, the high price volatility and scarce availability of (e-)truck components increase the risk for potential owners. Additional uncertainties arise from possible increases in production costs due to relocation of production facilities and rising raw material prices, which have a significant impact on TCO. The raw material price index (e.g. scrap, iron ore, coking coal) peaks at $196/ton in 2026 and then slowly declines to $165/ton in 2030, still higher than at the beginning of the decade. The quantitative evolution of this index is similar to the evolution of the oil price, reaching a maximum of 142 USD / barrel in 2026 and stabilizing at a high level of 102 USD / barrel at the end of the period.

In addition, labor costs increase as the shortage of truck drivers worsens. Although there is a clear downward trend in battery prices, electricity and fuel costs are rising due to the war in Russia and the raw material situation. As a result, industry and society are expecting higher prices for road freight. As a result of these developments, TCO parity between conventional and electric trucks will be reached later than expected, around 2030 instead of the middle of this decade, resulting in lower ZEV growth than planned. As a result, suppliers' and OEMs' order books are at their highest levels since the 2008 financial crisis, which will last until the middle of this decade. Although demand for trucks is relatively stable, the backlog is growing due to OEM and supplier inability to deliver, volatile raw materials and uncertain supply situation.

In addition to supply chain challenges, environmental factors play a significant role in this scenario. As political, social and industrial awareness of the consequences of global warming and climate change increases, governments are imposing legal restrictions to prevent further damage and local pollution. These restrictions include the establishment of ZE zones, mandatory CO2 emission limits for CVs, ZEV targets per fleet for specific years, and noise limits. Established tax incentives, toll reductions, and subsidies for charging infrastructure, EV technology, and autonomous driving would accelerate the transition to BEVs and FC EVs - if OEMs could ensure the supply of such clean vehicles.

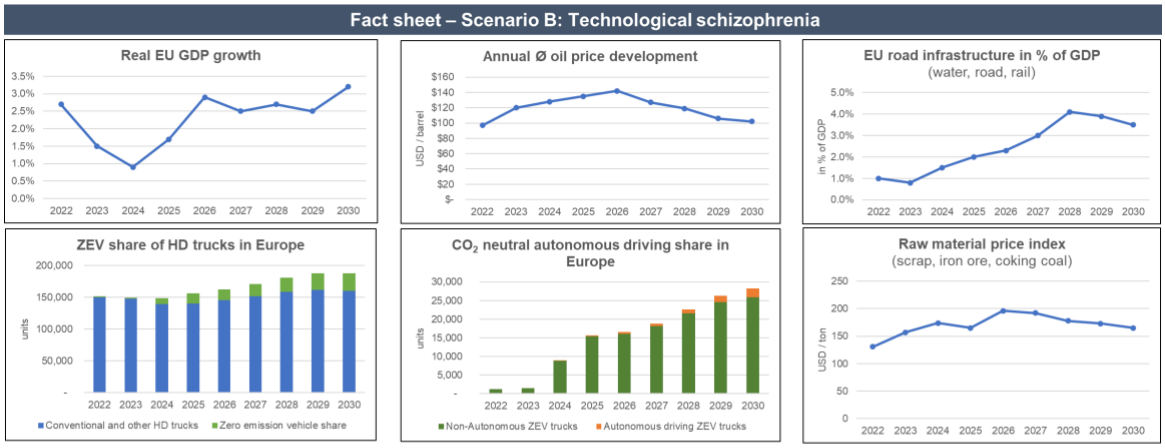
Due to the economic downturn, the level of such subsidies and financial benefits is lower than originally planned and delayed, as is European government investment in transport infrastructure. As a result, the peak investment of 4.1% of total GDP is reached in 2028 instead of 2025.

The real progress will come from increasing the efficiency of electric motors and battery life. By 2030, CV companies are developing the first successful approaches for the circular production of e-drive systems, fully autonomous driving technologies, i.e. Level 5, and related vehicle communication systems. The development of prototypes of such autonomous driving trucks will be significantly delayed due to the inability of suppliers to deliver, so that the first final samples will be commercialized by 2028/29. The penetration rate of autonomous HD e-trucks is relatively low, with an expected 8% share of total ZEVs in 2030. OEMs are not focusing on autonomous ICE trucks due to increasing CO2 emission restrictions. The introduction of such driverless vehicles requires a suitable regulatory approach for the whole continent; current regional standards will be harmonized within a European mobility approach to avoid regional legal differences. This regulation covers the legal protection of the vehicle owner, liability, data security and safety.

The key technologies are developed and ready for the transition to CO2-neutral (and autonomous driving) vehicles from a technological perspective, and the infrastructure is optimized to a sufficient level. However, supply chain challenges make it impossible to achieve the original goals, which hinders and delays actual volume production. With the delayed introduction of autonomous vehicles towards 2030, the first platooning concepts between competing operators and other forms of shared economy are expected after this decade, once the driverless share is significantly higher.

The factsheet of this *technological schizophrenia* scenario shows the quantitative progress and changes of specific KPIs from 2022 to 2030. This outcome consists of the *rapid speed of technological progress toward CO_2-neutral autonomous driving* and *high supply chain disruptions in truck production and operation*.

Figure 12 Fact sheet Scenario B – Technological schizophrenia

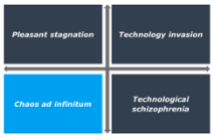


SCENARIO DESCRIPTION: Scenario B – Technological schizophrenia

- Political stability in the majority of the European countries is pending between 2022 and 2030 due to the Russian war, upcoming elections, and delayed economic upswing after the long recession with high inflation. Hence, the truck sales in Europe first decreases before coming back to a pre-war level by 2025.
- After the recession in 2022/23 and other disruptions (pandemic, war, chip crisis, and high priced, rarely accessible raw materials), the economy and, in particular, truck industry are slowly recovering. Order books of suppliers and OEMs are full of high backlogs until 2025/26 due to the unclear supply situation.
- Environmental regulations toward noise and CO_2 emissions enforce a rising share of ZEV trucks. Due to the political-economic developments (shortage of truck drivers, TCO as the key buying criteria), autonomous driving has become more important. With the rising subsidies, the necessary development of key technologies for autonomous driving (stage five) is finalized. However, the implementation of the innovations is enormously delayed as the supply chain is not ensured and constantly disrupted due to missing supply parts.
- After huge fluctuations (2022-2026), the raw material price index has stabilized to a rather high level after 28/29. Shortage of significant raw materials remains and impacts the automotive industry. Even adapting the technology to a lower material share has not evolved into sufficient progress to manage the crisis.

Source: Own illustration, following Schwenker & Wulf (2013), p. 118.

Scenario C: Chaos ad infinitum



<u>30.06.2030:</u> European truck companies have suffered from supply chain challenges for over a decade while Asian and American competitors progressed in autonomous technology.

The HD truck market in Europe in 2030

Over the past four to five years, the European economy has faced significant challenges, including the effects of two black swan events (the Russian war and Covid-19), inflation, and economic downturns. Despite efforts to recover from the recession and supply chain disruptions in the truck industry, progress has been slow. In particular, the shortage of semiconductor chips, as well as the high cost and limited availability of raw materials, have had a negative impact on the CV and automobile sectors. Compounded by the economic downturn, government investments and consumer spending, including e-commerce, have stagnated, resulting in flat demand for trucks.

While the raw material price index (including scrap, coking coal, and iron ore) and oil prices rose to a peak in 2026/27, they have since then decreased slightly but remain at elevated levels of 165 USD/ton and 102 USD/barrel, respectively. "Despite the significant challenges, truck sales in Europe have gradually declined until 2026 before picking up again, but still falling below pre-pandemic levels. Meanwhile, the global market has progressed similarly, but Asian and US competitors have advanced more rapidly, with significant subsidies driving the development and optimization of their ZEV and autonomous driving technology. Chinese truck suppliers were the first to enter the European market, build autonomous driving prototypes in Western Europe and successfully launch their new e-drivetrain generation," according to a CV specialist consultant.

Developments in the European HD truck industry between 2022 and 2030

After overcoming the Covid-19 pandemic from 2020 to early 2023 with sufficient vaccination efforts, the European economies face the subsequent crises and challenges: the ongoing war between Russia and Ukraine, chip shortages, high inflation and the resulting recession. The Russian invasion and the political instability in some European countries with upcoming elections, especially in Italy, France and

the United Kingdom, deeply affect the CV industry. Companies in the industry are withdrawing their business and relationships (suppliers and customers) from Russia, resulting in a detrimental loss of sales. Russia partially cut off gas supplies to Germany, forcing contingency plans to be implemented. With higher supplies from the Netherlands, Norway and Belgium, the winter of 2022/23 can be managed with lower supplies from Russia. Beyond Europe, the dependence of European car companies on China is another major obstacle. During the pandemic, the Chinese government has isolated the country from the rest of the world, following a zero-cover strategy. From 2020 to 2022, the country is in a permanent lockdown with strict regulations on society, international travel and trade. Transactions between China and European countries are possible, but involve extreme delivery delays and other additional burdens. In addition, the difficult access and shortage of key raw materials and the semiconductor chip shortage are disrupting the global CV market.

Although the ECB has raised interest rates above 0% to encourage savings over consumption and reduce inflation, the recession has been inevitable and has affected the economy for longer than expected. With inflation rising above 7% in the EU in mid-2022 and a clear economic downturn with 0.3% GDP stagnation in 2024, the economy begins to grow slowly from 2025 to reach sufficient annual real GDP growth of 2.7% in 2030. At the end of the decade, the inflation rate stabilizes around 2%. Measures to support the expansion of the European economy after the deep recession include the ECB's monetary policy of near-zero interest rates from 2026/27. Another intervention to stimulate investment and consumption is fiscal policy: European governments are increasing their public spending in specific areas through investments, tax breaks or subsidies. However, this action will take place in the second half of the decade - when inflation levels are lower - in order to keep debt levels stable and avoid a solvency crisis.

The shortage of chips and other raw materials for truck production leads to higher prices and worsens the TCO of electric trucks. The raw material price index peaks at $196/ton in 2026, before slowly adjusting to a still-high level of $165/ton by 2030. At the same time, the price of oil increases, peaking at $142 per barrel in 2026 before stabilizing at $102 per barrel in 2030. In addition to these price disruptions, the increasing shortage of drivers and the resulting labor costs lead to further negative impacts on the TCO. In addition, declining battery prices will not be able to offset rising

electricity prices, causing road freight prices to increase. Although the increase in oil prices negatively impacts the TCO of ICE trucks, TCO parity is not reached sooner due to the negative impact of electricity and raw material prices.

Due to severe supply chain disruptions and dependencies on risky countries such as China, European companies have moved their main production facilities to European alternatives and adopted a nearshoring strategy. Due to supply chain and budget constraints, and the fact that they could not switch from far- to near-shoring in the short term, most European truck suppliers are sticking with conventional powertrain technology. The independent powertrain suppliers in Asia and the U.S.-independent because of their strict local content requirements, global presence, and manufacturing footprint-are seizing this opportunity and entering the European market with significant price and technology advantages. They are building prototypes with local OEMs and commercializing their new generation of e-drive systems for HD autonomous trucks.

Overall, total HD truck sales in Europe are flat until the end of 2026, with a slowly increasing ZEV share of 8% in 2030 and an autonomous share of 4%, excluding ICE autonomous trucks. The delayed increase in truck sales is partly related to the decline in consumption and stagnating e-commerce share during the recession. In addition, European truck OEMs have high backlogs due to supply issues on both the supplier and OEM side. As a result, Germany, known for its strong export and automotive position, has been hit the hardest by the temporary decline in trucks and limited foreign trade.

Continuing with the environmental component, global warming and climate change are constantly raising awareness and are key issues for (green) political parties. To prevent local pollution and reduce noise levels in urban areas, the EU is proposing CO2 legislation and specific ZEV targets for cars, buses and trucks. They are offering and planning a range of tax and toll benefits, subsidies for ZEV technology and autonomous driving to facilitate the transition to clean vehicles. However, recent disruptive developments have pushed these plans into the second half of this decade. Worse, the recession shifts the focus from sustainability issues to macro-environmental conditions. The industry fails to meet the interim ZEV truck targets of 10% in 2025 and 15% in 2030, as conventional powertrain technologies are allowed to continue for longer and incentives for a carbon-neutral transition are delayed. After that, OEMs will have to pay penalties if they fail to meet the required CO2 savings. Aggravated by the

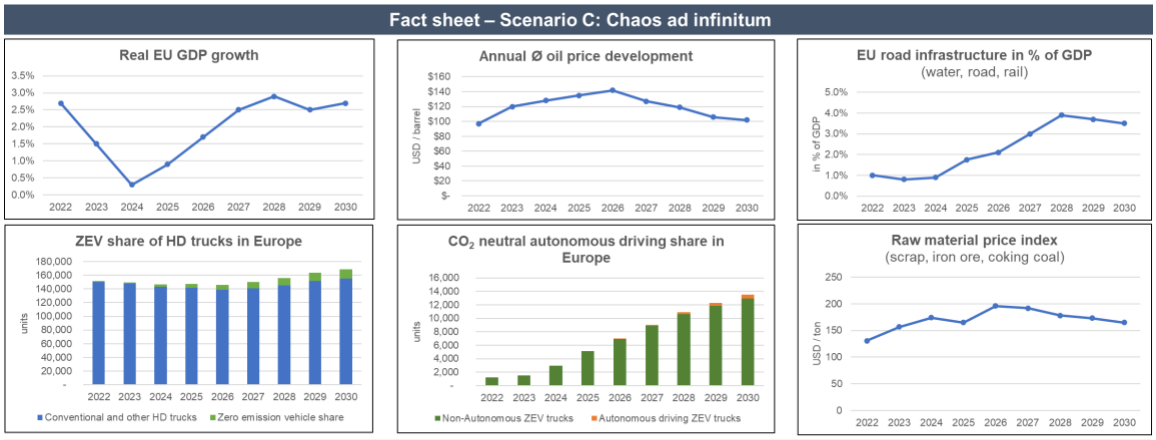
critical supply situation and strong dependence on China, foreign competitors are winning most of the European OEM platforms for e-drive systems. Technological advances in digitalization, recycling, circular production, engine efficiency and batteries are mainly achieved and applied outside Europe. The R&D and strategic direction of European truck companies seems to lack technological foresight, mainly due to economic downturns, limited incentives and strict budget constraints.

Progress on autonomous vehicles is relatively slow. Stage four vehicles are being implemented and their use is steadily increasing, but stage five vehicles, mainly prototypes, exist, with the first commercialization expected towards the end of 2030. Regarding the legal perspective, EU members agree that a pan-European mobility concept is essential for the implementation of such driverless vehicles. However, progress in this area is limited. There are no explicit standards on safety, security, insurance and liability for owners. With the introduction of autonomous e-trucks delayed until 2030, the first platooning concepts between competing operators and other forms of shared economy are expected after this decade. There are no comparable concepts in use during this period.

Last but not least, infrastructure is a critical barrier to the transition to ZEVs in Europe. Significant government investment to expand the charging infrastructure is being delayed, discouraging conservative operators from switching to e-mobility solutions and keeping demand horizontal.

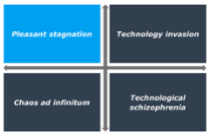
The factsheet of this *chaos ad infinitum* scenario displays the quantitative development of specific KPIs from 2022 to 2030. The x-axis and y-axis of this scenario represent both negative developments of the meta-categories, i.e., *slow speed of technological progress toward CO_2-neutral autonomous driving* and *high supply chain disruptions in truck production and operation*.

Figure 13 Fact sheet Scenario C – Chaos ad infinitum



Source: Own illustration, following Schwenker & Wulf (2013), p. 118.

Scenario D: Pleasant stagnation



<u>30.06.2030:</u> European truckers manage to overcome the supply chain crises but do not progress in implementing autonomous or e-drivetrain technology.

The HD truck market in Europe in 2030

The first half of this decade was marked by significant economic and supply chain challenges, including the Sars-Cov-2 pandemic, the Russian war on Ukraine, inflation, and scarcity of semiconductors and raw materials. However, by 2027, the oil price and raw material indices, such as scrap, iron ore, and coking coal, have stabilized at a medium-high level. Despite these challenges, European truck companies have managed to recover quickly. Mobility experts predict rapid growth of HD trucks in Europe, with 187,970 units expected by 2030, mainly driven by the rising consumption and e-commerce share. However, the ZEV share of HD trucks is only slowly increasing and is expected to meet, but not exceed, the EU's requirements. The autonomous driving share is also developing at a slower pace, with a maximum share of 8% of the total ZEV units achieved in a stepwise implementation in 2030.

"European suppliers have missed the opportunity to enter the electrified HD truck segment, generating sales with conventional supply parts instead. This is mainly due to Asian and American competitors being priced competitively while meeting the minimum automotive standards. In contrast, the established conventional drive system suppliers are struggling with increasing costs due to the uncertain raw material situation," explains a Vice President of a global investment bank focused on the automotive CV industry.

Developments in the European HD truck industry between 2022 and 2030

This decade can be summed up in one phrase: business-as-usual from a technological perspective. European industries had to deal with economic downturns combined with the Russian war on Ukraine, supply chain disruptions (e.g. chip shortages, raw material shortages and fluctuations, sanctions, export restrictions), rising inflation rates, and the Covid-19 pandemic. In view of the partially limited gas supply, especially to Germany,

every European country has established strictly binding contingency plans and identified alternatives to prevent an economic catastrophe. As a result, European governments will implement expansionary fiscal policies through 2024 to stimulate supply and demand activities and improve macroeconomic conditions. Public investments and subsidies will be increased in the mobility sector to facilitate supply and demand. The aim is to optimize the current road, water and rail infrastructure and support the development of new key technologies to limit local pollution.

After the downturn in 2022 and 2023, real GDP growth picks up from 2024 and stabilizes at 3.3% in 2030. The EU inflation rate follows a similar path, rising from 7% in mid-2022 to its peak in early 2023, before slowly declining to a stable level of 2% by 2025/26. To combat inflation, the ECB has raised interest rates in 2022 and 2023. Once the inflation rate returns to low levels, the ECB intervenes with monetary policy by lowering interest rates to 0% to encourage consumption and investment instead of saving. The oil price is similar to the commodity changes: the oil price peaks in 2026 before stabilizing at around $102 per barrel; the commodity index (e.g. scrap, coking coal, and iron ore) peaks at $169 per ton in 2024 and stabilizes at $145 per ton by 2030. Both KPIs stabilize at medium-high levels by 2027.

The EU follows a principle of cross-border cooperation and wants to promote free trade between industries. As a result, the structure of the European truck industry is similar to farshoring. The risk of (new) foreign players entering the European market is high with this free trade approach.

As a result, the scarcity of raw materials has a negative impact on the TCO of conventional and electric trucks. Rising income levels and a worsening shortage of drivers also have a negative impact. Falling battery prices will not offset these negative effects, so that TCO parity between conventional and HD e-trucks will move from the middle to the end of this decade. Consumers are expecting road transport prices to rise, exacerbated by rising fuel and electricity prices.

As most European economies recover and adopt expansionary policies, society regains confidence in politicians and economists and slowly increases consumption. As spending increases, so does the share of e-commerce and the demand for road transport. However, due to the delayed TCO parity, the ZEV share of heavy-duty trucks will increase later than initially expected.

In addition to the supply chain challenges, environmental awareness and the consequences of climate change are important issues for society, industry and politics. Binding interim targets for CO2-emitting industries have been introduced for the truck sector in order to meet the goals of the Paris Climate Agreement by 2050. The EU has introduced CO2 restrictions for heavy-duty trucks to save 15% of CO2 emissions (compared to 2019 emissions) from a fleet perspective in 2025 and a 30% CO2 reduction (compared to 2019) in 2030. Nevertheless, the EU requires specific ZEV targets: 10% in 2025 and 15% in 2030. Governments are also introducing low and zero-emission zones and inner-city noise restrictions, which prohibit conventional vehicles from entering city centers. They are supporting the transition to BEVs and H2 trucks with small subsidies, tax breaks and toll reductions.

European companies entering the e-mobility truck business are late followers. US and Chinese powertrain suppliers have won the first truck platforms in 2022/23. In contrast, most European competitors are struggling to develop a suitable portfolio due to critical and highly disrupted supply chains and dependencies on other countries, such as China with its strict zero-carbon strategy. From a technological perspective, competitors outside Europe are making much better progress in engine efficiency, battery technology, circular production and early recycling concepts.

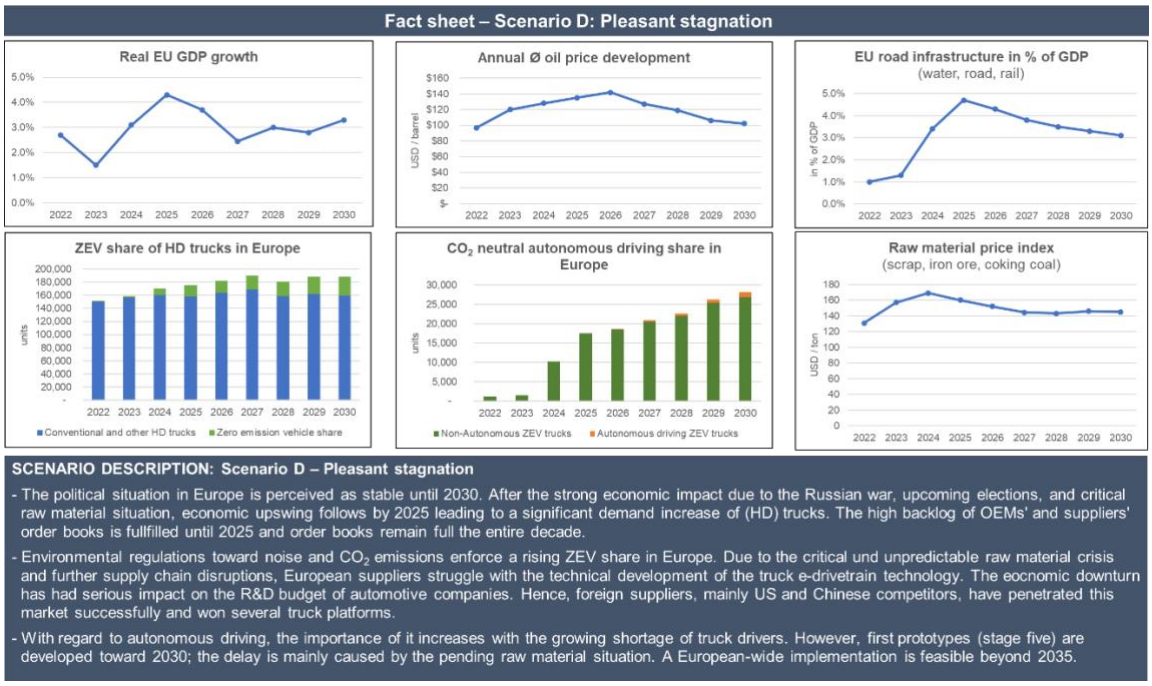
Although the overall demand for heavy-duty trucks increases steadily until 2030, the ZEV share develops more slowly than initially expected, so that the ZEV targets of 10% in 2025 and 15% in 2030 are met but not exceeded.

Similar circumstances apply to the progress of autonomous trucks. OEMs and suppliers have completed Stage Four technology, some of which was in use before the Russian war; these companies have developed Stage Five demonstration vehicles starting in 2026. OEMs commercialize their first stage five platforms after 2030 with a relatively slow ramp-up, so that about 4.7% of ZEV HD trucks are driverless prototypes before SOP. This is due to the critical raw material situation and the unclear regulatory situation. As with powertrain suppliers, progress is coming from OEMs and software providers outside of Europe. The entire vehicle must be digitized and the software adapted to enable autonomous driving with vehicle-to-everything communication. Regarding the legal situation, European economies agree that a pan-European approach to autonomous driving is needed to introduce such an innovation. The first standards for safety, legal protection, information technology security and owner

liability are drafted and discussed, but not finalized. The first truck-sharing platforms or economies are feasible after 2030, e.g. in combination with the introduction of autonomous driving and related platooning concepts.

The *pleasant stagnation* factsheet explains the business-as-usual scenario with the help of specific KPIs from 2022 to 2030. This scenario interlinks *slow speed of technological progress toward CO_2-neutral autonomous driving* and *low supply chain disruptions in truck production and operation*.

Figure 14 Fact sheet Scenario D – Pleasant stagnation



Source: Own illustration, following Schwenker & Wulf (2013), p. 118.

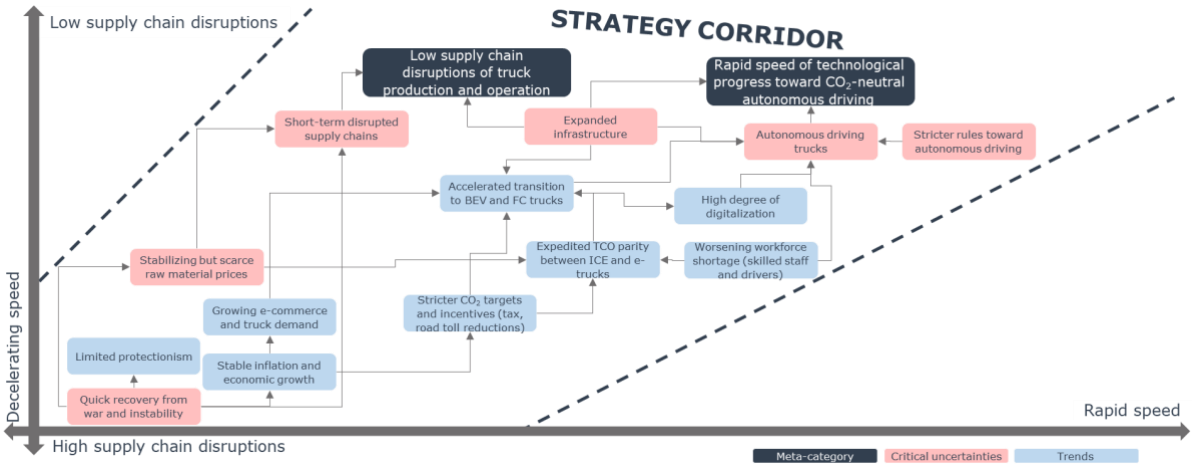
5 Implications

The four scenarios are not intended to predict the future of the European heavy-duty truck market. Instead, they provide realistic alternative views of the industry's future in 2030. The common denominator of all the scenarios is the magnitude of the expected changes. It is therefore essential for HD truck manufacturers to start preparing today. In this chapter, we highlight some of the strategic implications for each player. However, detailed strategy recommendations can only be derived in light of each company's specific situation.

Therefore, the first step is to look for measures that can be implemented in any scenario. This is not trivial for the European HD truck market, as the scenarios are very disjunctive. The second step is to decide which scenario we consider to be the most likely or the most favorable. For this purpose, it is important to critically reflect on the selected scenario dimensions, identify and evaluate the most important "drivers" behind the two dimensions. The core strategy can then be derived.

The core strategy of the European HD truck market focuses on the most favorable scenario: *Scenario A - Technology Invasion* (Schwenker & Wulf, 2013). To develop the core strategy, a strategy corridor was created that encapsulates the trajectory of trends and uncertainties associated with Scenario A. This approach helps to create a core strategy that covers all scenarios and can be further enhanced with scenario-specific options as needed. Figure 15 visualizes this strategy corridor for Scenario A.Figure 15 visualizes this strategy corridor for scenario A.

Figure 15 Strategy corridor based on Scenario A



Source: Own illustration, following Schwenker & Wulf (2013), p. 118.

The following strategic recommendations result from this corridor:

(1) *Adapt portfolio strategy to the latest market trends*. Stringent and ever-expanding ZEV mandates, backed by additional benefits and subsidies, are driving the transition to BEV FC EVs. To avoid financial penalties, OEMs must achieve a significant ZEV fleet share by 2025 and 2030. The year 2025, with the first binding CO2 target, is a critical window of opportunity for EV powertrain suppliers and OEMs. This decade marks the beginning of an e-mobility transformation and the emergence of autonomous driving CVs. As a result, chip suppliers will play a critical role in this development, which may lead to the creation of new software business models.

(2) *Deepen digital know-how and competencies.* Autonomous driving concepts will have an impact on the underlying vehicle software. Therefore, HD truck companies need to be part of this digitalization trend from the beginning, instead of being late followers and observers.

(3) *Build up missing, dedicated resources and enhance employer attractiveness*. This strategic element focuses on enhancing employer attractiveness and addressing knowledge gaps and resource constraints. To bridge these gaps, high-potential employees from traditional product lines can receive sufficient training and onboarding to transition to new product lines. However, companies operating in rural areas may face additional talent acquisition challenges. Convincing experienced employees to move to less prominent and less attractive cities can be challenging, expensive, and often impossible. To overcome this disadvantage, establishing an innovation hub in an attractive city with access to universities specializing in automotive, electrical engineering, and other technological studies could be beneficial. In addition, to attract a larger pool of talented individuals regardless of location, companies should promote hybrid or fully remote work options. Such flexibility is becoming increasingly important for employees in general.

(4) *Embed innovation as the fundamental part of the corporate culture.* It takes more than people and equipment to create innovative, sustainable products. Organization, culture, communication, and processes are also essential.

(5) *Follow an aggressive M&A strategy.* Due to the market dynamics and M&A activities in the CV segment, companies must play an active role in the M&A market, i.e., proactively observe the environment and identify valuable targets, rather than remaining in a passive role and only evaluating companies. With regard

to the e-mobility business, it is essential to become active in the M&A market to close significant technology (knowledge) gaps.

(6) *Achieve independence from (critical) suppliers and a more resilient supply chain*. The years 2020 to 2022 have seen a number of unprecedented challenges that have severely impacted the CV market. These challenges included supply chain disruptions due to factors such as the semiconductor shortage, the Sars-Cov-2 pandemic, and the Russian invasion of Ukraine. These disruptions negatively impacted sales for most market participants. One of the critical issues in this sector is the challenge of changing suppliers within a product generation, as companies must comply with strict automotive standards and certifications. This compliance often leads to lengthy supplier selection and qualification processes, making it impossible to change suppliers on the fly. To address these challenges, three key supply chain changes are required. First, it is critical to identify and build alternatives to all single-source suppliers as potential substitutes. This will help reduce the high level of supplier dependence that is a vulnerability in the industry. Second, logistics and product management departments should evaluate whether critical components can be cost-effectively insourced to limit external dependency. Third, country dependency should be addressed by establishing multiple manufacturing footprints that cater to global operations and different regional markets. By taking these steps, CV market participants can mitigate the impact of supply chain disruptions and ensure continued growth and success in the sector.

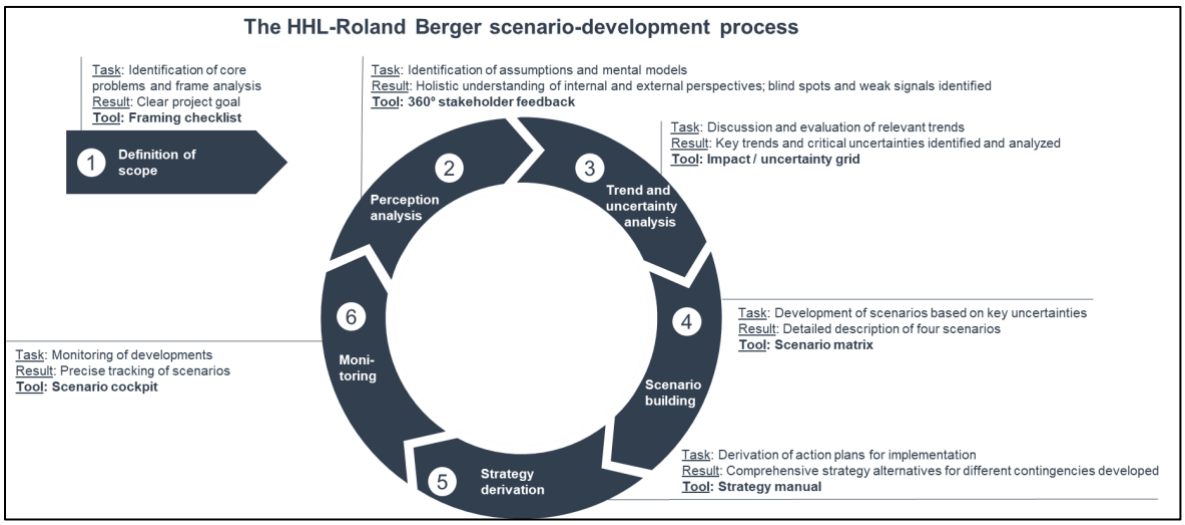
6 Methodology

HHL-Roland Berger Approach to Scenario-Based Strategic Planning

Our scenario study is based upon the approach to scenario-based strategic planning that was jointly developed by HHL and Roland Berger. The approach does not only allow creating scenarios but also enables companies to integrate scenarios into their strategic planning processes.

Our approach consists of six consecutive process steps for each of which we have created a specific tool that eases strategic planning with scenarios in practice. The approach thus enables managers to plan for multiple options. At the same time, it allows managers to integrate and align external and internal perspectives to challenge existing assumptions and mindsets (Schwenker & Wulf, 2013).

Figure 16: HHL-Roland Berger Scenario-Development Process



Source: Schwenker & Wulf (2013).

Description of process steps

Definition of Scope

The first step of the scenario development process is to define the project scope. Experts of our Center for Strategy and Scenario Planning and project partners meet to agree upon the core goal of the project. This includes identifying core problems and framing the analysis. Our Framing Checklist tool makes sure that every important aspect is covered and that all project partners share a common understanding of the steps ahead.

To create the four scenarios for the heavy-duty truck industry we applied the Framing Checklist. We defined the goal of the analysis to be the development of scenarios for the European HD truck market. The present study targets the European HD truck market geographically.

Perception Analysis

In the second step of the scenario development process, we apply our 360° Stakeholder Feedback tool to identify assumptions and underlying mental models of different players in the industry as well as of external stakeholders. This reveals important influence factors, but also possible blind spots and weak signals.

To identify important influence factors for the future development of the European heavy-duty truck market, we sent out two questionnaires to managers as well as external industry experts from research institutions, to consulting companies and to customers to get an overview on their assumptions as well as the trends and factors they considered important for the future of the industry.

After conducting the 360° stakeholder feedback, all factors were consolidated and analyzed. The aim of the so-called trend and uncertainty analysis is to identify the most important driving forces affecting the industry and the corresponding uncertainties behind these factors. These factors were mapped on an impact/uncertainty grid to identify the critical uncertainties.

Trend and Uncertainty Analysis

In the third step of the scenario development process, we determine and analyze trends that are likely to impact the project partner in the future. With the help of our Impact/Uncertainty Grid tool, we cluster the trends according to their degree of impact and their level of uncertainty. Factors which score high on both dimensions are then transformed into 'key uncertainties', the basis of the next step in our scenario development process.

Afterwards, different influence factors that were gathered and rated by the experts in the previous process step were transferred into the Impact/Uncertainty Grid and clustered into critical uncertainties, trends, and secondary elements (Figure 17).

Furthermore, two key uncertainties building the basis for the scenario development in the next process step were identified. For this we clustered six factors into two meta-categories, which we call ‘critical uncertainties’ or ‘scenario dimensions’. The first

meta-category/ scenario dimension is a cluster consisting of three critical uncertainties. These are:

(1) Sufficient infrastructure (battery electric, H_2) (political)
(2) Autonomous driving trucks (technological)
(3) Stricter legislation toward autonomous driving (legal)

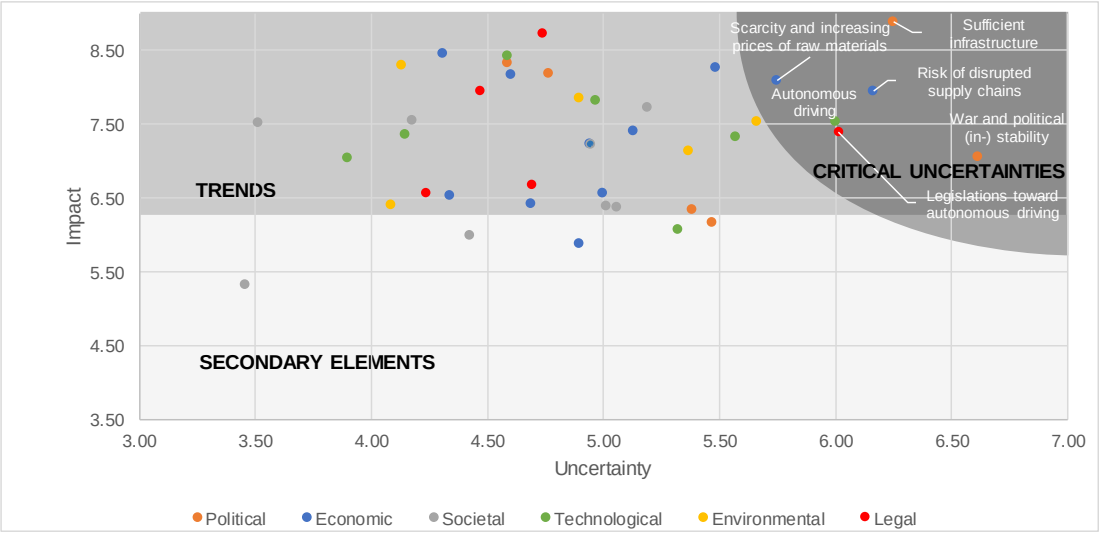
Together they form the scenario dimension **"speed of technological progress toward CO_2-neutral autonomous driving".**

The second scenario dimension, **"degree of supply chain disruptions in truck production and operation"** is composed of three subcomponents. These key uncertainties are:

(4) Risk of disrupted supply chains (economic)
(5) Scarcity and increasing price level for raw materials (economic).
(6) War and political (in-)stability effects (political)

These in total six subcomponents mainly capture the regulatory and economic pressures the heavy-duty truck industry faces.

Figure 17: Impact/Uncertainty Grid



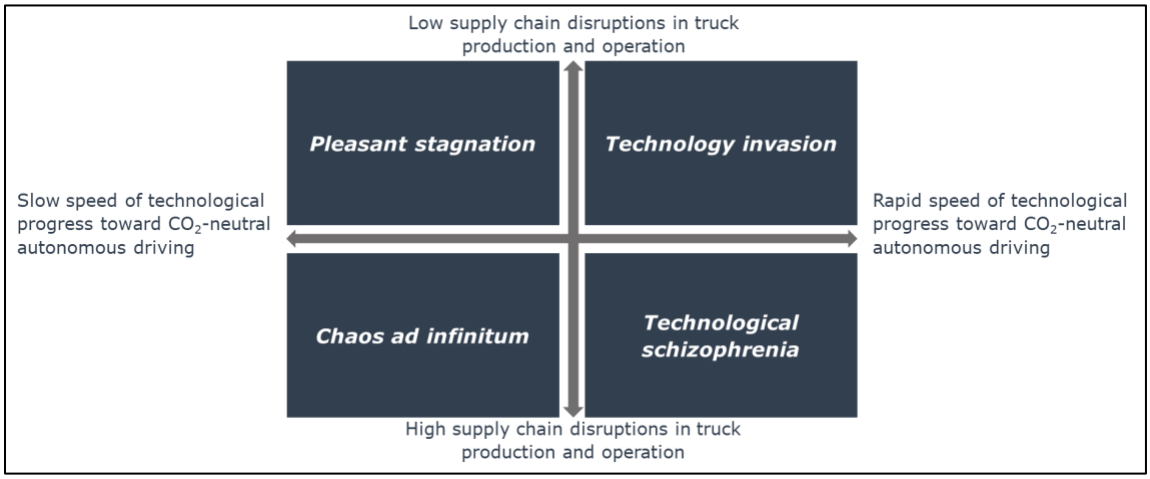
Source: Own illustration, following Schwenker & Wulf (2013).

Scenario Building

In the third step of the scenario development process, the scenarios themselves are created. Using the scenario dimensions determined in the previous step, we derive possible pictures of the future and describe them in detail. Typically, four plausible and

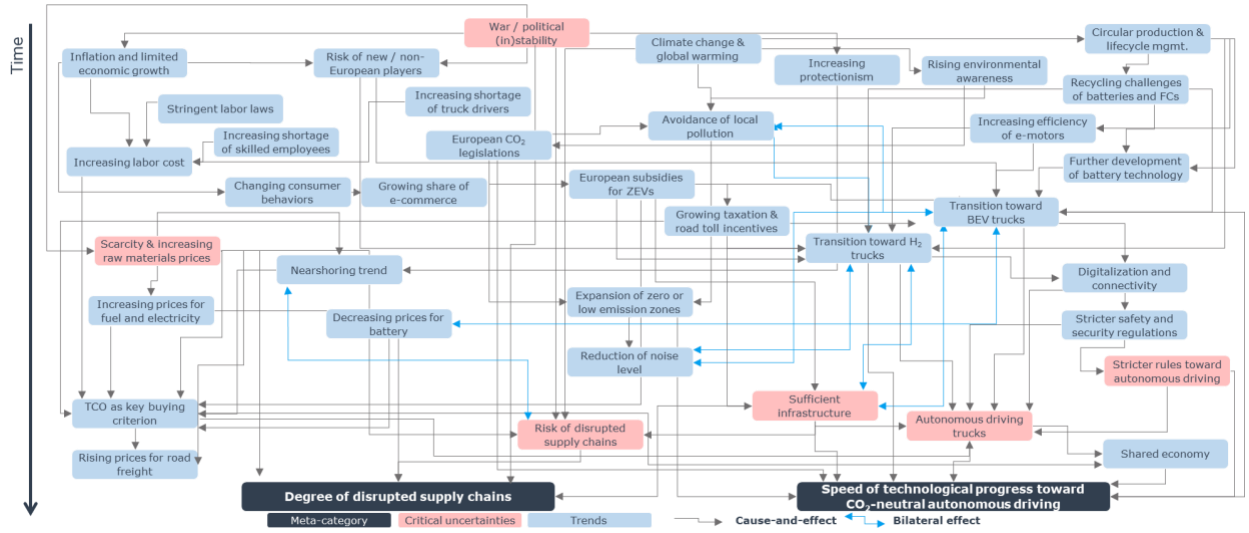
distinct scenarios are developed. Our Scenario Matrix tool guides this process step. To speed up the process and to make the scenarios as accurate as possible, we also use the know-how of global scenario experts assembled in our Scenario network for this step.

Figure 18: Scenario Matrix for the European Heavy-Duty Truck Industry



In the present scenario project, the creation of the scenario matrix resulted in four scenarios for the European HD truck industry as described above (see Figure 18). We named these scenarios ‘Pleasant stagnation’, ‘Technology invasion’, ‘Chaos ad infinitum’, and ‘Technological schizophrenia’. To describe these scenarios in more detail, we created an influence diagram. This diagram displays all trends and critical uncertainties as a chain of causes and effects which lead to the two scenario dimensions. This influence diagram forms the basis for the detailed description of the four scenarios presented above (Figure 19).

Figure 19: Simplified Influence Diagram for the European Heavy-Duty Truck Industry



Strategy Development

The main goal of this step is to develop ideal-typical portfolios businesses or products and services for each of the four scenarios. For the strategy definition we use the scenario-based portfolio matrix as a tool. The scenario matrix serves as a basis for the portfolio matrix. In each of the four quadrants of the scenario matrix, we now display one ideal-typical portfolio that is most adequate for this scenario. To arrive at the ideal-typical portfolios, we first list all existing businesses of the company in question. Then, we go back to the scenarios that we developed. For each scenario we ask two questions:

1. Which of our current businesses, products or services seem particularly promising under the conditions of this scenario?
2. Which new businesses, products or services are promising under the conditions of this scenario?

These two questions are discussed as part of a top management workshop and yield one ideal portfolio for each of the four scenarios. Certainly, specific businesses, products or services can also appear more than once in this portfolio matrix if they fit to different scenarios.

Monitoring

The main goal of this step is to constantly track the development of the company's environment and its influence factors and to allocate or reallocate resources to the most appropriate scenario-based portfolio. For the monitoring step, we use the scenario cockpit as well as scenario-based portfolio management as tools. The scenario cockpit is a strategic controlling tool that comprises several indicators which help us to determine which scenario is most likely to occur. The scenario cockpit lays the essential basis for scenario-based portfolio management. The company's management needs to decide which of the four scenario-based portfolios, which have been defined in step 5, the company should focus on. Scenario-based portfolio management helps to take this decision by answering two questions:

1. Which scenario is the dominant one, that is: which scenario is most likely to occur?
2. How far are we from reaching certain tipping points, that is: Is the transition from the presently dominating scenario to a different one likely?

After having formulated a company's core strategy as well as coping strategies, the scenario planning process supports managers with a monitoring approach, referred to as *Scenario Cockpit* (Wulf et al., 2012). The *Scenario Cockpit* supports the management in identifying critical indicators for changes in the market environment. Based on defined values for each scenario, a regular assessment enables the management to choose the right strategy for the respective developments. Therefore, the senior management must receive reports regularly to align their perception with objectives, focusing on a few objectively measurable indicators to simplify monitoring (Schwenker & Wulf, 2013).

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8 HHL Center for Strategy and Scenario Planning

The HHL Center for Strategy and Scenario Planning creates knowledge and acts as an impetus to change the way decision makers think about the future and organizations plan their future. We provide a platform for the exchange of ideas with leading scenario experts. The Center's activities focus on four areas:

1. Research

We advance knowledge about scenarios by developing new methods and tools for strategic planning, exploring the cognitive and behavioral implications of using scenarios in strategic decision making, and developing new scenarios across a broad range of domains.

2. Teaching

We teach scenario planning to business leaders and strategic planners in executive seminars and workshops, to graduate students in summer seminars, and to MBA and MSc students at HHL studying strategic management.

3. Consulting

We advise corporate, public, and civil organizations on establishing scenario planning structures and processes, reviewing, and adapting existing planning processes, and communicating effectively with all stakeholders in times of uncertainty.

4. Networking

We provide a platform and act as a facilitator to bring together scenario experts from around the world, bridge the gap between theory and practice, and share ideas about what the future will look like.

For more information about the Center, visit *www.scenarioplanning.eu*.

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