FEV CONSULTING

LOW CARBON PATHWAYS UNTIL 2050

DEEP DIVE ON HEAVY-DUTY TRANSPORTATION

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The European Commission calls for a climate-neutral Europe by 2050 [European Commission, 2018a], which is in-line with the goals of the Paris Agreement [UNFCCC, 2015]. One element of reaching a carbon-neutral economy is to reduce greenhouse gas emissions. Within the economy, the transport sector accounted for 23% of greenhouse gas emissions in 2017, while heavy-duty trucks accounted for 25% of the greenhouse gas emissions in the transport sector [EEA, 2019]. Thus, heavy-duty trucks are important to achieve the greenhouse gas emission reduction.

Yet, it is unclear how heavy-duty vehicles can contribute to this reduction. There are three reasons for this: Firstly, the freight transport demand will likely increase. Secondly, size and weight of the vehicles limit the options to reduce their energy demand. Thirdly, many stakeholders need to be aligned to make change happen: authorities, fleet operators, vehicle manufacturers, technology suppliers and energy providers.

However, we conclude that low carbon pathways for heavy-duty trucks do exist. Figure 1 shows the pathways. We present three low carbon pathways, which achieve greenhouse gas emission reductions of 80% to 95% by 2050 compared to 1990.

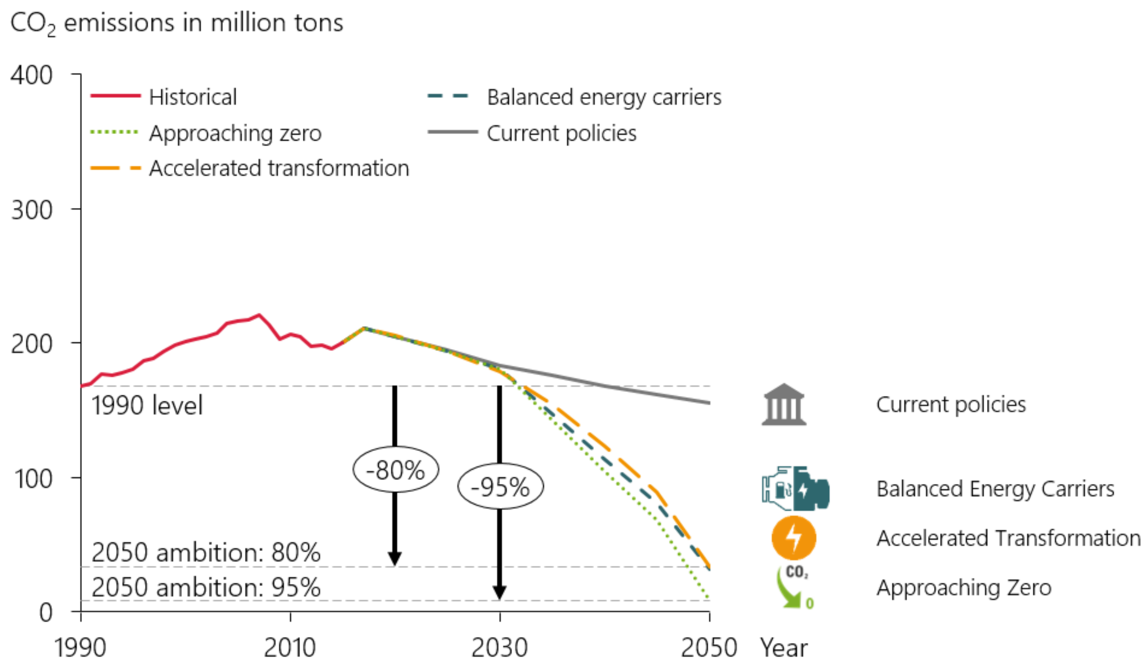

Figure 1: Pathways of the four scenarios modeled in the extended tank-to-wheel balance.

All pathways apply four measures: optimization of usage, electrification of powertrains, efficiency increase of vehicles and adaptation of energy carriers. Our four key take-aways for the measures are:

1. Optimization of usage is an important aspect of the CO_2 emission reduction. It can mitigate the emissions added by the higher transport demand in the future. This is enabled by an uptake of connected and automated trucks which result in an increased truck utilization.

2. Electrification of powertrains includes hybrid, battery and fuel cell electric powertrains. It provides a small CO_2 emission reduction in the well-to-wheel balance. To increase this, more electricity and hydrogen – used in fuel cells – needs to come from renewable sources. All low carbon pathways use battery and fuel cell electric trucks at more than 25% of the vehicle stock.
3. Efficiency increase of the vehicles is a strong contributor to lower CO_2 emissions. This efficiency increase is enabled by improved gliders – reduction of aerodynamic drag, rolling resistance and weight – and improved powertrains – e.g. engine efficiency measures.
4. The adaptation of energy carriers is key. Only with high shares of energy from renewable sources, high CO_2 emission reduction can be achieved in the well-to-wheel balance.

Figure 2 also reflects this. It compares the CO_2 emission reduction and the impact of the four measures in the four scenarios. In the extended tank-to-wheel balance the adaptation of energy carriers contributes the most to the CO_2 emission reduction, followed by the electrification of powertrains. In the well-to-wheel balance the adaptation of energy carriers contributes even more to the CO_2 emission reduction than in the extended tank-to-wheel balance. The adaptation of energy carriers in the well-to-wheel balance also includes the increase of electricity generation by renewable sources. In this balance the impact of electrification of powertrain is low since 2018's energy mix is considered.

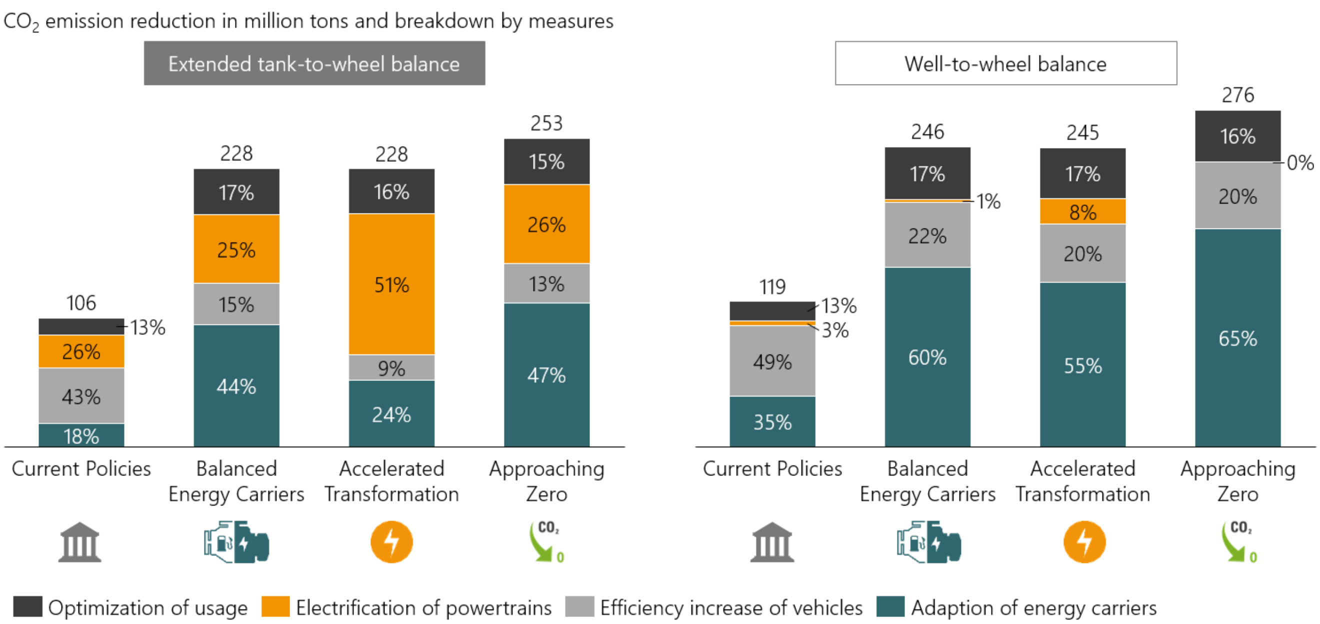

Figure 2: Comparison of the CO2 emission reduction in million tons in the four scenarios and breakdown by the four measures in the extended tank-to-wheel balance (left) and the well-to-wheel balance (right) by 2050 compared to 1990.

In all pathways, battery and fuel cell electric trucks as well as liquid and gaseous fuels from renewable sources are relevant. This requires huge investments and demands swift action. To ensure the measures are developed suited to the desired outcome, authorities need to provide a framework for fleet operators, vehicle manufacturers, technology suppliers and energy providers. Such frameworks could include incentive schemes, mandates, adaptation of taxation and review of CO_2 emission accounting.

The life-cycle CO_2 emissions reduce by about 70% for heavy-duty long-haul trucks sold in 2050 compared to such sold in 2018. This reduction is due to the higher share of energy from renewable sources.

Figure 3 shows the final energy demand of heavy-duty trucks. For reference, the energy demand of heavy-duty trucks in 1990 was about 2,300 PJ. In all scenarios the final energy demand reduces until 2050 compared to 2018 – at up to 37% in the Accelerated Transformation scenario. This is mostly due to optimized usage as well as more efficient vehicles and powertrains.

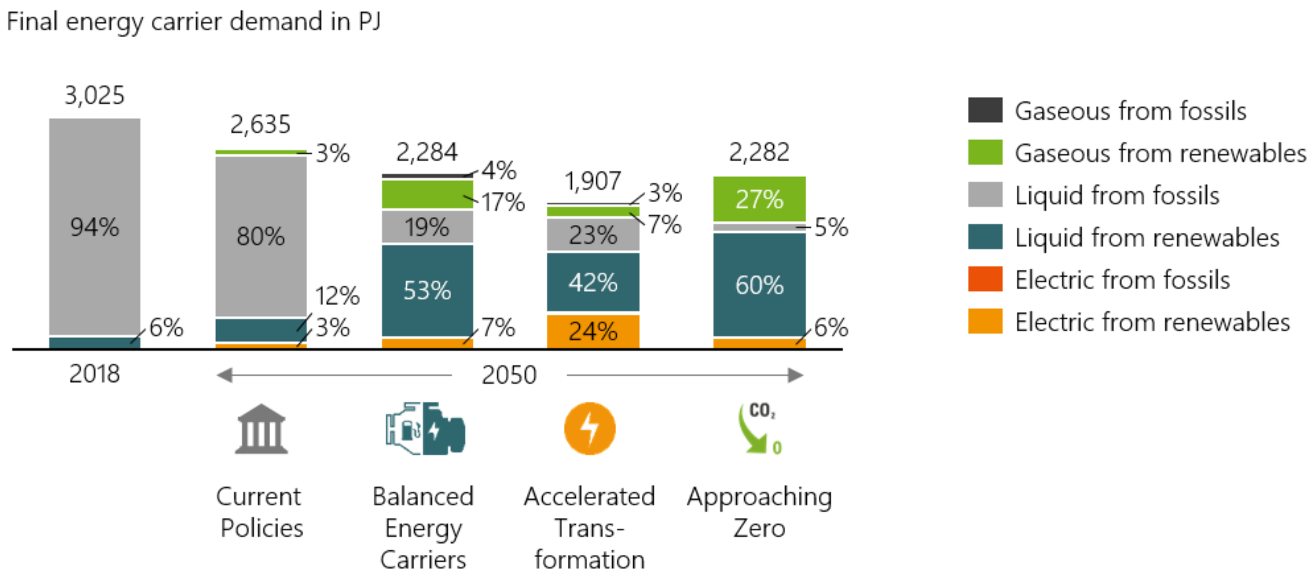

Figure 3: Final energy demand of heavy-duty trucks in Europe in PJ, shown by energy carrier type and source in 2018 and 2050 in the four scenarios. The final energy demand does not include the energy to process the energy carriers.

Also, the source of energy provision moves towards increased use of renewable sources. In the three low carbon pathways – Balanced Energy Carriers, Accelerated Transformation and Approaching Zero – renewable sources account for more than 73% of the final energy demand. In the Approaching Zero scenario 93% of the energy is supplied from renewable sources. This results in 5 billion kg of gases from, 40 billion liters of liquids and 150 PJ of electricity – all from renewable sources.

Furthermore, the vehicle stock changes as shown in Figure 4. The stock size grows in the Current Policies scenario and reduces in the Accelerated Transformation scenario. In both, the Balanced Energy Carriers and Approaching Zero scenario, the vehicle stock size in 2050 is as in 2018.

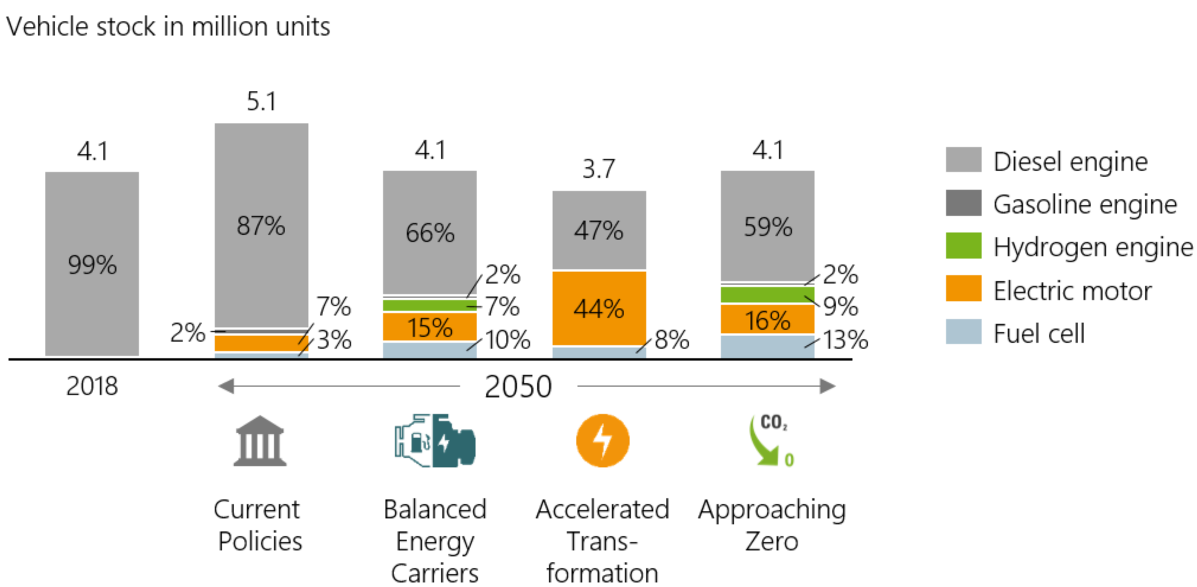

Figure 4: Heavy-duty vehicle stock in million units, shown by main energy conversion system in 2018 and 2050 in the four scenarios.

In all scenarios combustion engines stay relevant and represent at least 47% of the vehicle stock in 2050. Many of these combustion engines in the stock are hybridized: 23%-points in the Balanced Energy Carriers, 27%-points in the Accelerated transformation and 26%-points in the Approaching Zero scenario. Zero CO_2 emission powertrains represent a high share of the vehicle stock in 2050: 52% in the Accelerated Transformation, 38% in the Approaching Zero and 32% in the Balanced Energy Carriers scenario.

The total-cost of ownership for trucks with hydrogen combustion engine, battery and fuel cell electric powertrains increase their competitiveness until 2050. In the Balanced Energy Carriers scenario in 2050, a truck in a long-haul use-case incurs lower total cost of ownership with a fuel cell electric and hydrogen combustion engine powertrain than with a compression ignition powertrain. The total costs of ownership for battery electric and compression ignition powertrain are similar. In a regional-haul truck, battery electric powertrains are cheaper in total cost of ownership already in 2025 and extend this advantage throughout 2050. For a regional-haul truck, the total cost of ownership of a fuel cell electric and hydrogen combustion powertrain are similar to the compression ignition powertrain.

In the Accelerated Transformation scenario, battery electric powertrains are cheaper in total cost of ownership than fuel cell electric, hydrogen combustion engines and compression ignition engines as well for long- as for regional-haul trucks. Due to the more expensive powertrains, the direct manufacturing costs of all vehicles sold are 9.3 billion € higher in 2045 than in 2018 in the Balanced Energy Carriers scenario and 8.8 billion € in the Accelerated Transformation scenario. This is an average increase of 39,000 € per vehicle in the Balanced Energy Carriers scenario and 44,000 € per vehicle in the Accelerated Transformation scenario.

Greenhouse gas emission reduction from heavy-duty trucks of 80%-95% by 2050 requires significant changes and aligned actions

Our analysis of low carbon pathways in the European heavy-duty transportation sector shows that CO_2 emission reduction ambitions of 80% and 95% compared to 1990 can be achieved with enormous efforts of all stakeholders. For that, authorities need to provide a holistic framework for fleet operators, vehicle manufacturers, technology suppliers and energy providers. Authorities should involve all key stakeholders and jointly define boundary conditions driving infrastructural and technology decisions.

Fleet operators, vehicle manufacturers and technology suppliers should enable efficient solutions of transportation resulting in an increased utilization of trucks. Vehicle manufacturers should develop efficient glider and powertrain technologies: aerodynamic drag, weight and rolling resistance reduction as well as automation on glider side, efficient combustion engines, hybrid, battery electric and fuel cell solutions on powertrain side. The energy providers should invest into scaling-up production of electricity, gaseous and liquid fuels from renewable sources as well as into the underlying infrastructure. This includes the electric grid and hydrogen fueling stations.

We identify three key findings for the European heavy-duty transportation until 2050:

1. To achieve the level of CO_2 reduction ambition, a combination of the discussed technology options is required. Additionally, a high share of energy carriers from renewable sources – including gaseous and liquid fuels – is required.
2. The strong interdependency of stakeholders requires an aligned strategy enabling the required shift of the industry.
3. The high CO_2 emission reduction is linked to significant investments for all stakeholders.

We discuss four different scenarios towards 2050. In the Current Policies scenario, announced policies as of today are carried forward until 2050, no further tightening is considered. Evolutions are driven by the competitiveness of market players. The CO_2 emission reduction by 2050 compared to 1990 is below 10%. The Balanced Energy Carrier scenario assumes the electrification of heavy-duty vehicles in selected use-cases only. Efficiency measures will be introduced at the current pace and energy carriers from renewable sources ensure to reach the ambition of an 80% CO_2 emission reduction ambition. The Accelerated Transformation scenario lowers CO_2 emissions by 80% as well. The pathway is characterized by a faster development of automation and battery technology. Charging is cheaper and the infrastructure is built-up rapidly. The Approaching Zero scenario achieves 95% lower CO_2 emissions by 2050 compared to 1990. Developments and trends are like in the Balanced Energy Carriers scenario, but the contribution of electrification and energy carriers from renewable sources is higher.

The reduction ambition is defined in an extended tank-to-wheel balance. This considers carbon capturing from biomass and air as well as the carbon emissions from tank-to-wheel. In a well-to-wheel balance the absolute CO_2 emission reduction is higher.

In the following, we will focus on the Balanced Energy Carriers and Accelerated Transformation scenario.

Figure 5 shows the CO_2 emission reduction pathways towards 2050 on the left for the Balanced Energy Carrier scenario and on the right for the Accelerated Transformation scenario in the well-to-wheel balance.

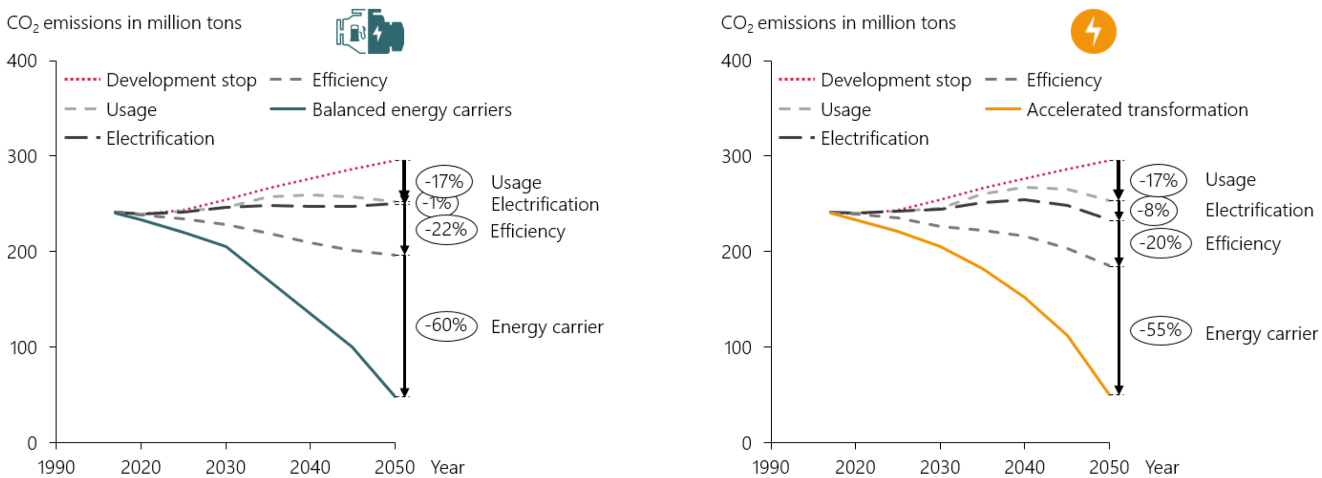

Figure 5: Comparison of CO_2 emission reduction in the Balanced Energy Carriers (left) and Accelerated Electrification (right) scenarios in a well-to-wheel balance.

To understand the different measures and their contribution to the overall CO_2 emission reduction, we isolate the results and distinguish between development stop, optimization of usage, electrification of powertrains, efficiency increase of vehicles and adaptation of energy carriers. The development stop is a common baseline for all scenarios. In this, the CO_2 emission increase is driven by the expected 36% increase in freight demand until 2050. Afterwards, the contribution of the measures is added.

The optimization of usage reduces CO_2 emissions in both scenarios by 17%. This combines shift of freight transport induced by the automation of trucks and a more efficient use of the vehicles due to connectivity and advanced logistics concepts.

The electrification of powertrains includes hybrid, battery and fuel cell electric powertrains. The impact is considerable in the extended tank-to-wheel balance. In this balance most of the reduction comes from battery electric powertrains, followed by fuel cell electric powertrains while hybrid powertrains only have a low impact. In the well-to-wheel balance the impact is low since the increase of renewable sources in the electricity generation is accounted in the adaptation of energy carriers.

The efficiency increase of vehicles combines optimization of the glider and the powertrain. In both scenarios, in 2050 the stock of trucks with a new cabin glider and a hybrid powertrain demands on average about 35% less energy for the same task than the stock of trucks with a baseline glider and a compression ignition powertrain in 2018.

Although the adaptation of energy carriers has a significant influence in both scenarios, their origin is different: In the Balanced Energy Carriers scenario the related CO_2 emission reduction share of 60% is driven at 52%-points by liquid and gaseous fuels from renewable sources. Electricity from renewable sources plays a minor role at 8%-points of the CO_2 emission reduction from the adaptation of energy carriers. In the Accelerated Transformation scenario, the situation is different: The contribution of electricity to the CO_2 emission reduction is much larger at 24%-points of the 55%-points that are attributed to the adaptation of energy carriers. The higher share of electric vehicles in the stock yields the difference and links back to the fundamental boundary condition of earlier and stronger technology developments in electric powertrains. Those include high energy densities and low costs for the battery.

In both scenarios the demand for energy carriers from renewable sources is high. In the Balanced Energy Carriers scenario, 4 billion kg of hydrogen, 35 billion liters of diesel-type fuels and 154 PJ of electricity are required. In the Accelerated Transformation scenario, 2 billion kg of hydrogen, 23 billion liters of diesel-type fuels and 500 PJ of electricity are needed. To supply this much energy from renewable sources, the energy provision needs to change fundamentally. To make this change happen, significant investments are required.

With these figures, it is clear that all stakeholders need to take enormous efforts under the alignment of the authorities to make it happen: bring the European heavy-duty transportation on a low carbon pathway and thus mitigate climate change.

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Disclaimer

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