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Transportation by 2030: Trends and Perspectives

Drive Trains, Fuels And Technologies For Heavy Duty Vehicles In 2030 And Beyond

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Abstract

This article analyses common technology trends for drivetrain-fuel combinations. Two scenarios up to year 2040 for the transport fleet development of heavy duty vehicles (HDV) in Germany are created. It is investigated how new technologies would dispread into HDV for urban and transregional transport fleets and what will that cause relating to energy demand and greenhouse gas emissions. The methodology approach comprises freight modelling, vehicle technology assessment, scenario technique and fleet modelling. Finally, some policy recommendations are given to address the reduction of greenhouse gas emissions of road freight transport.

Keywords: *road transport, heavy duty vehicles, drivetrains, alternative fuels, policy.*

1. Introduction

Today (2013), 35.6 million commercial vehicles are registered in Europe. France has by far the biggest fleet of commercial vehicles with approx. 6.5 million vehicles, while Germany is with about three million commercial vehicles in 6th place (EC, 2015). All European commercial vehicle fleets are dominated by the light duty vehicles up to 3.5 tonnes gross weight. Poland, Italy and Germany operate the largest fleets of HDV over 3.5 tonnes gross weight with more than 800,000 vehicles registered in each of these countries.

Further, the new commercial vehicle registrations heavily depend on the economic situation. Most recently (2015), approx. two million new commercial vehicles were registered in Europe per annum. In contrast, before the financial and economic crisis, the new goods vehicle registrations in the EU amounted to approx. 2.5 million units (ACEA, 2016).

The United Kingdom and France show the highest numbers of newly registered vehicles across all commercial vehicle classes. With a new registrations share of more than 25 %, Germany plays an important role in the EU with regard to HDV over 3.5 tonnes. In 2016, a total of 2,995,166 commercial vehicles are registered in Germany (KBA, 2016). The vehicle fleet development is characterised by the light duty vehicles whose numbers have tripled to approx. 2.3 million units since the early 1990s and which amount to approx. three quarters of the total fleet numbers. Next in line are the tractor vehicles.

It has also to be considered the high dependency of road transport from crude oil resources because most commercial vehicles are driven by drivetrains fuelled by diesel. This high dependency rely on diesel fuel with an expected increase of price and the still increasing greenhouse gas emissions of HDV represent two main risks for a future-proof development of road transport. It is necessary to update the technologies in road freight transport to come to terms with increasing transport prices and policy measure to regulate and reduce the environmental impact.

This article describes the most important trends for drivetrains, fuel and energy supply as well as vehicle technologies and the mode of operation have to be investigated using a medium-term evaluation of common technology development. This investigation focuses on the three drivetrain and fuel combinations of diesel, gas and electric for HDV. The aim is to show what could be forecasted concerning energy consumption, greenhouse gas emissions in German road transport related to the use of new, more efficient and alternative drivetrains, as well as alternative fuels and other vehicle technologies for HDV. It is considered that the further development will continuously take place and the number of new HDV with alternative drivetrains in the transport fleet will need time to grow due to economic conditions and the timeline to make alternative fuels available all over EU countries.

With regard to the deployment areas, in principle, a distinction is made between urban driving profiles and long road haulage. Urban driving profiles are characterised by numerous start-and-stop processes and shorter distances. Long road haulage implies long-distance deployment with its continuous vehicle operation and higher average speed. Different user expectations due to daily tour planning could cause different solutions for drivetrains and energy sources. These expectations determine a more heterogeneous fleet with new requirements to the energy suppliers and their infrastructure in the future. Total costs of ownership, different technology readiness leading to availability of series-production vehicles of different manufactures, service and energy supply are reasons why the HDV transport fleet will become more heterogeneous in the future.

Based on these expectations it is described how new efficient an alternative drivetrains and alternative fuels could be implemented into HDV transport fleet. There is analysed the fleet development, the expected mileage of this fleet and the expected energy consumption. Based on these results the political objectives to reduce greenhouse gas emissions are compared.

Final conclusions consider pros and cons and the necessary adjustments of framework conditions to bring sustainable drivetrain-fuel combinations into the market. This provides the basis for further adjustments of regulations of the road transport sector.

2. Drive Trains, Fuels And Technologies For HDV

2.1 Methodology

The following results are based on data of transport volume that is forecasted for German road transport (BVU et al., 2014). Based on a four step macroscopic freight transport model for Germany – with 431 inland and 170 traffic cells abroad related to origin-destination relations of 24 commodity groups and all transport modes – the transport performance and the mileage were calculated and allocated to the different commercial vehicle classes. The focus of this article is given to the HDV transport fleet due to the high energy consumption and the main risks for a future-proof development. One solution to reduce these main risks is the shift to more efficient and alternative drivetrains and alternative fuels in this HDV vehicle classes.

In the first step the most important trends of current technologies for drivetrains, fuel and energy supply as well as vehicle technologies and the mode of operation are investigated using a medium-term assessment of technology development. This investigation focuses on the three drivetrain-fuel combinations of diesel, gas and electric. The drivetrain-fuel technology developments are assessed with regard to typical areas of application using relevant selection criteria for commercial vehicle technologies by experts of Shell Oil Germany and DLR in a common project (Shell, 2016). The results are visualised using network diagrams. The assessment criteria include the (i) technological maturity which is classified using the NASA Technology Readiness Levels (TRL) 6 (prototype) to 9 (standard product) (NASA, 1995), the vehicle (ii) user costs (total costs of ownership), the (iii) availability of energy or fuel, further (iv) user preferences as well as the (v) emissions balance. Further technological improvements of new HDV are considered by improved drivetrains (including hybrids), aerodynamics, light weight construction, rolling resistance, and driving assistance systems (e.g. predictive cruise control, platooning).

In a second step, scenario technique and fleet modelling by trend exploration are used to investigate future developments of drivetrain technologies, fuels, energy demand and derive the greenhouse gas emissions for HDV transport fleet in Germany (including also HDV coming from other EU and non-EU countries) up to 2030 and beyond. Two scenarios are defined to distinguish between one scenario that implements a further diesel focused development and a scenario that emphasise alternative drivetrain-fuel technologies for HDV. The trend exploration is based on data of new registrations and fleet data of HDV published in official German statistics (KBA, 2016) Further a fleet modelling is applied, that considers assumption who the implementation of more efficient and alternative drivetrains and new vehicle technologies will be realized, The final steps are to calculate the average fuel consumption per kilometre, to forecast the energy consumption based on the modelled mileage and to derive the greenhouse gas emissions by factors (JEC 2014).

2.2 Drivetrains, Fuels And Vehicle Technologies

Diesel drivetrain is the most widespread concept, and as such it provides both the technical and economic benchmarks for all other drivetrains in HDV transport fleets. Further substantial potential for efficiency improvements is observed in the following areas (Hoepke and Breuer, 2013; Süßmann and Lienkamp, 2015; UBA, 2015):

- Improvement of the efficiency of engine and transmission,
- waste heat recovery,
- electrification of accessories as well as (mild) hybridisation,

the latter mainly for vehicles used in urban areas. In the EU, Germany and France are the biggest diesel fuel markets, both exceeding 40 billion litres of diesel sales (EU-COM, 2015). Diesel fuel is an energy carrier with a high energy density of nearly 36 mega joules per litre (MJ/l) or more than 43 mega joules per kilogram (MJ/kg). In fact, more than 99 % of the diesel fuel sold in the EU is B7, i.e. it consists of up to 7 % biodiesel.

Diesel is easy to handle and the most easily available of all fuels. Also, it can be supplemented or replaced by lower-emission biogenic, paraffinic or Power-to-Liquids fuels (EU-COM, 2015). The network diagram (Figure 1) shows that the diesel drivetrain-fuel combination represents the reference technology for HDV transport fleet, mainly with regard to technical, economic and user criteria. The technological maturity, user costs, availability as well as user preferences achieve the highest level (5). However, the diesel technology shows potential for improvement with regard to the emissions, in particular with respect to local emissions. Nowadays, comparatively old duty vehicles with low exhaust gas emission standards are used in urban areas. Therefore it might be possible to solve the emissions issue (at least partially) by using alternative liquid fuels in existing vehicles.

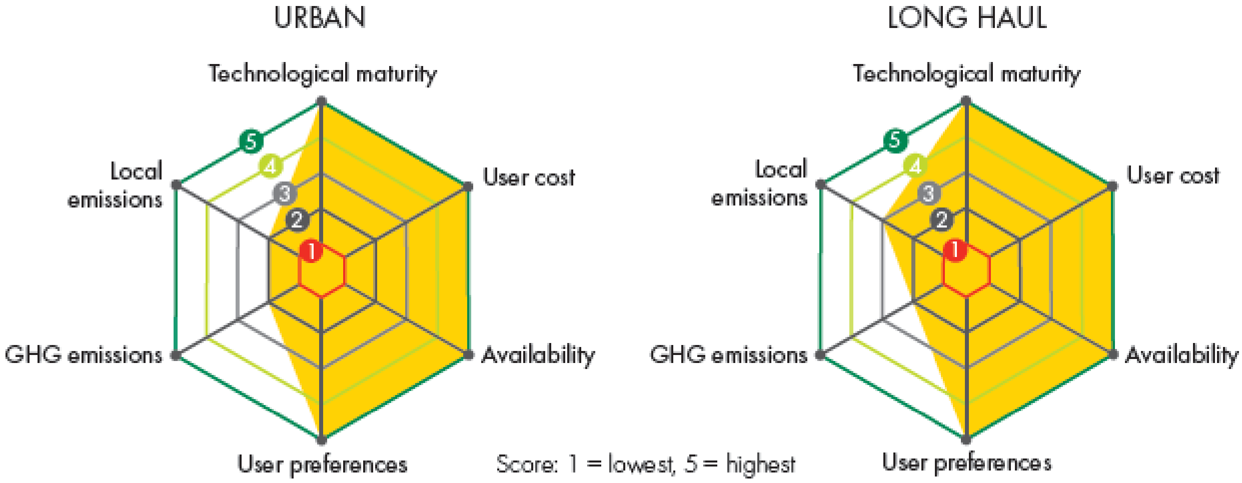

Figure 1 Medium-term assessment of diesel technology

Most recently, natural gas drivetrains have become a relevant drivetrain and fuel alternative for commercial vehicles. HDV have been available in combination with Compressed Natural Gas (CNG) for quite a while in urban transport. Following the global natural gas availability the use of Liquefied Natural Gas (LNG) has still become a further option e.g. in China and North America with high potential and tendency to rise in the EU. The most common internal combustion engine for gas is the Otto engine principle by external ignition. A relevant important drivetrain innovation is dual fuel technology for HDV for long haul road haulage freight transport. It applies the diesel principle, and its efficiency is therefore similar to that of diesel drivetrains. Dual fuel drivetrains can be predominantly operated and Otto principle drivetrains entirely operated with natural gas. As a new technology in dual fuel, High Pressure Direct Injection drivetrains are developed by vehicle manufacturers that enable a similar efficiency as diesel drivetrains.

The advantage using LNG in comparison to CNG is the smaller volume of vehicle tanks that leads to longer distances that could be covered without refilling. Therefore LNG is more suitable for long road haulage and has the potential to compete with diesel drivetrains for HDV.

LNG is a low-emission fuel with an energy density of 21 mega joule per litre closer to that of diesel fuel with 39.6 mega joule per litre or approx. 60 % of the volumetric energy density of diesel fuel (EC/DGM 2014).

Up to now there exists a CNG filling station infrastructure in many European countries, while a LNG infrastructure is under design and construction based on the EC regulation for alternative fuels infrastructure (EC 2014). Only Spain (29), The United Kingdom (14), Fance (10) and The Netherlands (22) possess already of a relevant number of LNG refilling stations (NGVA, 2017). Since LNG is only an option for transregional deployment, a small number of large filling stations in the motorway and highway network would be sufficient to guarantee a safe supply. LNG and CNG can be easily supplemented or replaced by biogenic or electricity-based gaseous fuels (Power-to-Gas). The network diagram (Figure 2) shows that natural gas HDV have reached technological maturity. However, they do not score as high as diesel vehicles in most of the user criteria.

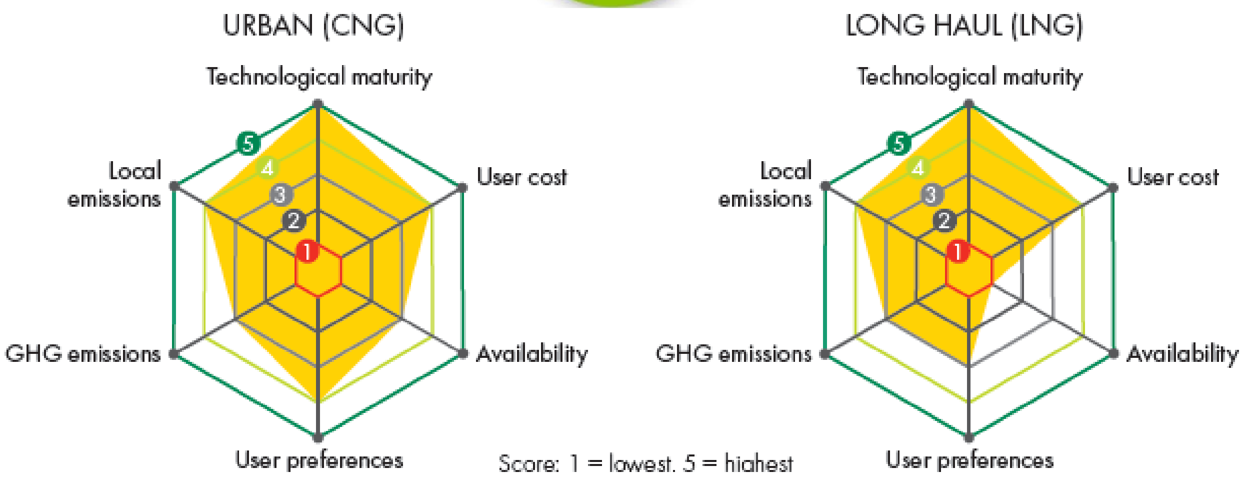

Figure 2 Medium-term assessment of natural gas technology

Similar to the passenger car sector, the industry is also developing concepts for the hybridization or electrification of the commercial vehicle fleet. Electric mobility means that the sole drivetrain or main drivetrain is electric. These drivetrains include, in particular, plug-in hybrids (PHEV), battery-electric vehicles (BEV) and hydrogen-powered fuel cell electric vehicles (FCEV). On the other hand, mildly hybridised vehicles, which are mainly propelled by internal combustion engines, are not (yet) electric vehicles.

The biggest potential for electric mobility is still seen for passenger car-like light duty vehicles as well as vehicles with urban driving profiles, such as vans or city buses. At the current time, there are not any commercial approaches to the electrification of long haul HDV with a high mileage, but first concept studies are developed in the North America (lastauto omnibus, 2017). The core element of electro-mobility is the battery technology as well as the fuel cell for fuel cell-powered HDV. The crucial factor for commercial HDV applications is the low density of energy stored in batteries. Presently, the gravimetric energy density of batteries is between 0.3 to 0.9 mega joule per kilogram, whereas the volumetric energy density is between 0.5 to 2.4 mega joule per litre. Therefore, in order to store about 30 litres of diesel fuel – which is equivalent to the specific fuel consumption per 100 kilometres of an energy-efficient HDV – today a battery with a weight of approx. 2 tonnes would be required. However, the problem of the low density of electricity stored in batteries might be partially solved by storing compressed gaseous hydrogen (CGH2). Apart from an improved battery technology, the prerequisites for nationwide electric mobility are powerful quick-charge options and a hydrogen filling station infrastructure. Only electric vehicles (BEV and FCEV) allow completely local emission-free mobility. However, as both the electricity and the hydrogen are secondary energy carriers, their method of provision is the key with regard to sustainability. The network diagram (Figure 3) shows that only plug-in hybrid electric vehicles have reached technological maturity, battery electric commercial vehicles still haven't. And PHEV score as high as natural gas vehicles regarding user criteria, while BEV don't. PHEV are fit-for-purpose in regional as well as transregional transport, BEV are only an alternative for regional applications with a daily low mileage and an existing charging infrastructure. The main advantage of electric vehicles is zero-emission transport. However, for transregional use, plug-in hybrids have to be operated in combustion mode in order to comply with relevant user criteria.

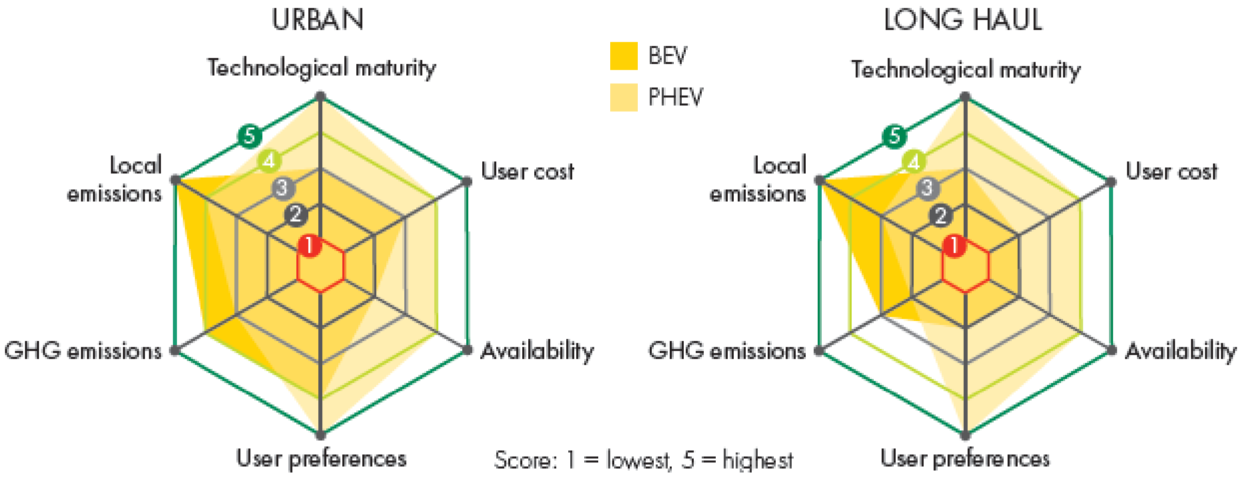

Figure 3 Medium-term assessment of battery-electric and plug-in-hybrids technology

FCEV (hydrogen and fuel cells) is a promising zero-emission technology but the technology has to be further developed to reduce costs as well as renewable hydrogen has to be produced by efficient electrolyses based on renewable energy by Power-to-Gas. It is considered that this technology is not suitable to contribute to reduce greenhouse gas emissions of HDV over the next decade due to significant higher costs. But FCEV technology could highly contribute to reduce greenhouse gas emissions beyond 2030 in case the total costs of ownership will become competitive in relation to existing technology options.

In addition to the drivetrain technology and fuels, the energy consumption and the emissions of HDV can also be improved by developing the non-drivetrain-related vehicle technology. The main lever is the reduction of the vehicle's driving resistance which is mainly composed of its air, rolling, acceleration and gradient resistance. The main beneficiary of aerodynamic improvements due to optimised vehicle shapes is the long-distance transport with its high average speeds (FAT, 2012).

The rolling resistance is heavily influenced by the tyre technology (low-resistance tyres, optimum tyre pressure) (Goodyear Dunlop, 2013). The reduction of the vehicle weight by using a lightweight-design not only affects the payload, but also the rolling, acceleration and gradient resistance, and these have a positive effect particularly on urban driving profiles. Finally, additional potential for efficiency savings can be realised by optimising the way of driving/mode of operation and the scheduling of commercial transports. The optimisation range from driver assistance systems (e.g. predictive cruise control) to platooning and automated driving could be implemented for all drivetrain-fuel combinations assisted by state-of-the-art information and communication technologies.

2.3 Scenarios For Commercial Vehicles In Germany Up To 2040

Based on the described analyses of the drivetrains, fuels and vehicle technologies and the outlook how these technologies will be further developed, scenario technique and fleet modelling are used to investigate future developments of energy demand and greenhouse gas emissions for HDV transport fleet in Germany up to 2030 and beyond. The assessment of the technologies are used to define the efficiency of HDV and estimate the average fuel consumption per kilometre for HDV based on current average fuel consumption data. Further it is considered the potential of reduction related to different technological components like hybridisation and drivetrain optimisation waste heat recovery, using tires with optimized rolling resistance, light vehicle construction, driver assistance by predictive cruise control and other technology components.

Initially, two different technological driven scenarios for future HDV are developed; a trend scenario and an alternative scenario. The key drivers of these different development paths are the framework conditions as specified by society and policy, the purchase decisions made by users and companies that depend on environmental regulations and total costs of ownership, the technical progress of the drivetrain and vehicle technologies as well as developments with regard to availability and prices of the energy and fuel supplies. The size of the fleet and the mileage are the same for both scenarios.

The trend scenario updates the most important developments of the recent past and is based on stable framework conditions including moderate technology improvements. The efficient and further improved diesel drivetrain and liquid fuels remain by far the most economical option for almost all HDV to improve its efficiency and to produce less greenhouse gas emissions. In the trend scenario, the alternative drivetrains (PHEV, BEV) in HDV will not achieve a substantial market share by 2040. HDV will further based on diesel technologies besides some niche applications. In the HDV transport fleet of the trend scenario, the alternative drive-trains will tend to remain the exception.

In the alternative scenario, new drivetrains, vehicle technologies and fuels, especially electric drivetrains as well as gas drivetrains and gas fuels, will increasingly penetrate vehicle and fuel markets. The alternative scenario is driven by ambitious regulations by policy measures that trigger the technology progress of alternative drivetrains. Then, the HDV transport fleets are developed according to different drivetrain technologies and own assumptions concerning the expected efficiency improvements.

In the alternative scenario, alternative drivetrains – LNG for the long haul heavy duty vehicles – will outnumber the new diesel registrations in HDV class by 2040, except for HDV with gross weight between 3.5 and 12 t. Thus about 13 % of HDV transport fleet in 2030 can be driven by gas drivetrains and about 28% in 2040. It will take time to dispread the alternative drivetrain into the market. Anymore it has also to be considered that HDV from other EU countries and non-EU countries will hesitantly adapt the new technology due to lack of funding or other cost structures. In parallel the part of renewable fuel of gas will arise by 20%. Table 1 summarises the main assumptions for the both scenarios.

The results of the trend scenario shows an increase of the energy demand of HDV – calculated on the basis of average fuel consumption and respective mileage of vehicles – from about 670 peta joules (PJ) in 2014 to the an peak of 750 PJ in 2030. After that it will decrease to 700 PJ by 2040. Alternative fuels will not account in this scenario (Figure 4).

Table 1 Modifications of core scenario parameters in relation to basis year 2014

	Trend scenario		Alternative scenario	
	Year 2030	Year 2040	Year 2030	Year 2040
General increase of HDV mileage in Germany (based on an official transport forecast)	26%	39%	26%	39%
Share of Diesel-HDV in the fleet	99.2%	98.7%	85.8	69.7
Share of CNG/LNG-HDV in the fleet	0.7 %	1.1%	13.4	28.5
Share of BEV and FCEV-HDV in the fleet	0.1%	0.2%	0.8%	1.8%
Increase of efficiency (drivetrain, vehicle technologies, planning and assistance.) of new[1)] diesel HDV	16%	27%	34%	41%
Diesel: share of renewables	12%	20%	10%	
Increase of efficiency of new[1)] CNG/LNG HDV	18%	28%	35%	43%
CNG/LNG: share of renewables	20%		20%	
Increase of efficiency of new[1)] BEV/FCEV HDV[2)]	12%	18%	12%	18%
Share of renewable electric energy for BEV and for production of hydrogen	39%	53%	54%	74%

[1)] New HDV that will be new registered in the respective year.

[2)] The increase efficiency up to these values is related to HDV with frequent stops at a tour like in urban areas.

In the alternative scenario, the energy demand will have continuously decreased by 8% (or to 615 PJ) by 2040 despite the simultaneous mileage increase by 39 % during this period. In the trend scenario, diesel fuel with its share of more than 99 % will virtually remain the only relevant energy carrier, whereas in the alternative scenario the diesel demand will almost be halved, mainly taken over by gas fuels (LNG) and, to a lesser extent, also by electricity. HDV consume by far the most energy of all commercial vehicles. In case of Germany that will be more than 80 % in 2040 in both scenarios.

All measures for reducing the energy demand of HDV are facing the following challenge: New technologies with improved efficiency and alternative fuels will need a long period to become relevant in the HDV fleet and in parallel the mileage will further increase significantly. That is why in the trend scenario, the entire well-to-wheel emissions of HDV will go on increasing until 2030 (7.5%) and will have gradually decrease to approx. 6% in 2040 based to year 2014 due to a higher share of renewable fuels and further increased efficiency of HDV. Only the alternative scenario, well-to-wheel greenhouse gas emissions will perceptible decrease to 18% in 2040. The reasons for this reduction include the declining energy demand as well as the introduction of natural gas fuels and – to a lesser extent – also to electric mobility.

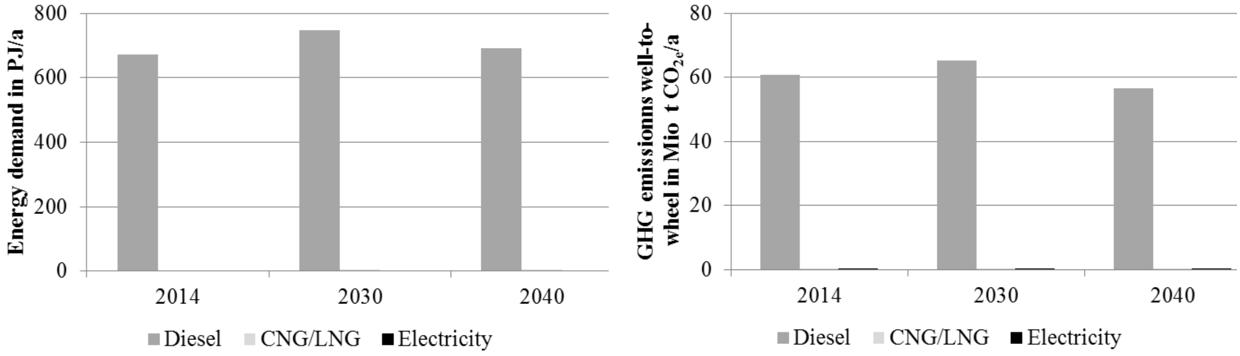

Figure 4 Energy demand and greenhouse gas emission of the trend scenario

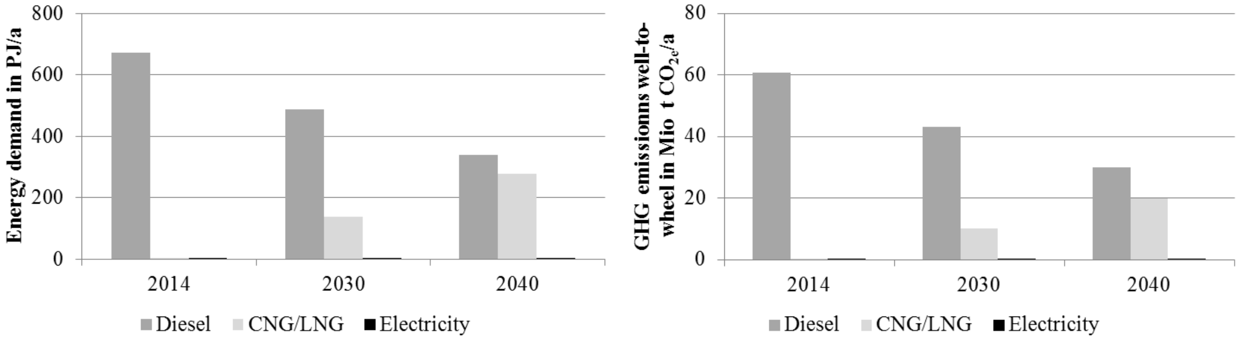

Figure 5 Energy demand and greenhouse gas emission of the alternative scenario

2.4 Policy Recommendations

The German energy transition targets are as follows: A national cross-sector greenhouse gas reduction target has been set – direct greenhouse gas emission should decrease until year 2050 on the basis of year 1990 at least for 80%. The climate protection plan 2050 of the German Federal Administration demands the transport sector to reduce the greenhouse gas emissions until 2050 to zero [BMU 2016].

As a first step, the direct or tank-to-wheel greenhouse gas emissions of the transport sector are to decrease by at least 40% until 2030 based to 1990.

The HDV transport fleet could contribute to the national objectives for climate protection by higher energy efficiency and using LNG as an alternative fuel besides diesel. Otherwise, the contribution of changes in the HDV transport fleet will not be sufficient to gain the objectives in the transport sector until 2030 and probably beyond. This is caused by the necessary transition process, that could start not till LNG refilling infrastructure will provide a service security and TCO will be similar compared with diesel HDV. Further, technological progress of vehicle technologies and renewable fuels has to be forced including electric drivetrains based on better batteries or fuel cells for HDV to continuing decarbonisation of the road transport.

The use of battery electric vehicles (BEV as well as PHEV) to deliver goods in urban areas is a first step to implement environment friendly technology in the road transport sector. That should be supported by policy measures and funding to realise competitive total costs of ownership for transport service providers.

The core problem will be to decarbonise the HDV for the long road haulage. Technologies have to be developed ready for serial production for these HDV or sufficient renewable fuels have to be produced over the next decades to meet the zero emission objective. Therefore, policy measures should be aimed to realise framework condition to shift more transports from road to rail or to inland waterways as the next step. These transport modes cause less greenhouse gas emissions and in case of rail electric traction work also very efficient. Investments in intermodal equipment and rail-road-transhipment concepts and infrastructure should be stimulated to realise suitable pre-conditions to prefer intermodal transport solution. Improved business models based on modernized rail freight equipment have to be realised for better rail transport services for the shippers.

The technology has to be further developed to enable renewable energy and fuels for HDV in a parallel way. One promising technological way is to realise fuel cell HDV that could be driven by renewable produced hydrogen. Technologies to improve efficiency of the production of renewable fuels (methane or diesel) are a second option to get new technologies for HDV beyond 2030. It is an open question which technological path for HDV will become the best from nowadays perspective.

3. Conclusions

Two scenarios of the development of the HDV transport fleet in Germany show which reduction of greenhouse gas emissions until 2030 and beyond could be expected based on current technological progress on the one hand and the forecast of freight transport volume and mileage on the other hand. The alternative scenario is suitable to realize greenhouse gas reductions of about 12 % until 2030 and about 18 % until 2040. The trend scenario shows that the perspective of more efficient diesel drive tannin and vehicle technologies will not be sufficient for HDV transport fleet to contribute to the reduction of greenhouse gas emissions until 2030. One reason is that in the German forecast the transport volume and mileage of road transport will further increase. That leads to increasing energy consumption of the HDV transport fleet and the technology improvements will be compensated.

Therefore the use of the available drivetrain technology of LNG for HDV will be an advisable step to use this potential in the next decade. Further renewable fuels (methane and diesel) and fuel cells are essential to decarbonise the HDV transport fleet as a whole and technologies have to be further developed for the period beyond 2030.

For transport policy both scenarios show further that short term reductions of greenhouse gas emissions based on available technology components for HDV transport fleet could not be sufficient to meet the greenhouse gas emission targets. Otherwise efficient and alternative drivetrains and alternative fuels will slowly penetrate the HDV transport fleet and a transition period is necessary to change the HDV transport fleet and reduce its dependency from crude oil. Therefore, policy should also force intermodal transport concepts to use more energy efficient modes like rail and inland waterway in short term concept to meet their own greenhouse gas reduction objectives until 2030 and beyond.

Policy measures and supporting instruments should also foster the use of battery electric drivetrains in HDV mostly used in urban areas and LNG as well fuel cell technology and renewable hydrogen for long road haulage.

Further, it needs mid and long term concepts with framework conditions to define stable conditions for investments in alternative fuels and technology components for energy supply and HDV that enable a zero-emission HDV transport fleet until 2050.

4. Acknowledgements

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