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What is the best alternative drive train for heavy road transport?

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Abstract

Ambitious long-term green house gas (GHG) emission targets require decarbonisation of the transport sector. For road transport, passenger cars with internal combustion engines need to be replaced by electric vehicles. However, despite its growing share of transport's CO_2 emissions, no clear solution presents itself for CO_2 emission reduction on heavy road transport. Potential CO_2 free options include direct electrification of trucks via batteries, over-head power lines, hydrogen and other power-to-X fuels from renewable electricity. Here, we compare these options with respect to their degree of technological readiness, costs and CO_2 reduction potentials. We use cost assumptions and cost reduction potentials from available literature sources and combine them with today's heavy truck usage data for Germany in 2030. Our results show that the high efficiency in direct usage of electricity from overhead cables implies less installation of additional renewable power compared to fuel cell electric vehicles. Both could be good long-term solutions but require a massive initial infrastructure investment.

1 Introduction

Global warming and the dependence on limited fossil fuels force the world to think about alternative solutions. In the transport sector, plug-in electric vehicles are often discussed as one means to reduce carbon dioxide (CO_2) emissions. However, this only refers to passenger cars and light duty vehicles. The on-road freight transport sector with larger vehicles is often neglected although it is responsible, e.g. for about one third of CO_2 emissions in the earthbound transport sector with only one tenth of the vehicles in Germany [1]. Also, the transport volume is still rising in this sector. If the German goal to reduce CO_2 emissions in the transport sector by 40% in 2030 compared to 1990 [2], the heavy road transport sector has to at least stop to increase its emissions. However, a long-term goal of a CO_2 emission-free transport sector could cause a short- to medium-term increase in CO_2 emissions as well, when electricity is used that is not solely from renewable energies.

This paper aims at showing possible emission-free technology solutions for the heavy road transport sector in a technical, economical and ecological comparison. We compare five drive train technologies for Germany in 2030, but also have long-term goals in mind. The technologies in consideration are: Vehicles powered with liquefied natural gas (LNGV), fuel cell electric vehicles (FCEV), battery electric vehicles (BEV), catenary hybrid vehicles (CHV), methanol (produced via electricity) and diesel vehicles as reference case. Here, we focus on vehicles with a total weight of 40 tons, as they are used mainly on long haul trips with a high share of kilometers on highways. Furthermore, we assume that the electricity is produced by the power plant mix in Germany in which the goals of the German Energiewende in 2030 will be reached.

2 Data and methods

For the analysis of heavy duty vehicles in Germany, we use the data set "Kraftfahrzeugverkehr in Deutschland 2010" (KiD2010) which is a travel survey of about 70,000 vehicles with all vehicle movements on one day of observation [3]. This data set is publicly available and the largest sample of commercial vehicle movements in Germany. The annual vehicle kilometres travelled are peaked at 130,000-150,000 km while there is not such a clear peak for the daily VKT. This implies that vehicles are not used every day or that the frequency of usage is different for the vehicles. In the results section, we will focus on the annual VKT and show cost calculations for the quartiles (q_{25}=81,492 km, q_{75}=141,777 km).

We compare alternative drive trains for heavy duty vehicles in a threefold way: in a technical, an economical and an ecological analysis. For all three analyses the methods are described in the following. In the technical comparison, we compare the Well-to-Wheel (WtW) efficiency for several fuel types that are caused by multiple conversions of electricity to the designated fuel. Furthermore, we use the technological readiness level to respect the different stages of development [EC2015]. The economical comparison comprises a total cost of ownership calculation for the vehicles in 2030 as well as a discussion of the cost for refueling infrastructure. In the ecological comparison, the CO_2 emissions as well as the primary energy from renewable energies needed is calculated.

All technical, economical and ecological assumptions are taken from a large study conducted for the German Federal Ministry of Transportation and Digital Infrastructure [4] and will be discussed in the full paper.

3 Results

Our results from show several aspects that could be considered for a comparison of alternative fuels for heavy duty vehicles. These are of technical, economical and ecological nature. A qualitative summary of these results is shown in the table below. Here, we put "0" if the drive train is equal to a diesel vehicle in the category, "+" if it is better and "++" if it is much better. If it is worse than a diesel vehicle, we put "-" and if it is much worse we take "--".

Table 1: Comparison of drive trains for heavy duty vehicles with different measures

Measure	Diesel	LNG	FCEV	(BEV)	CHV	Methanol
Readiness level	0	0	--	--	-	0
WtW efficiency	0	-	+	++	++	-
Decision relevant operating cost	0	-	--	++	+	0
Infrastructure cost	0	-	--	--	--	0
CO_2 emission	0	+	+	++	+	+
Renewable energy needed	0	0	0	++	++	--

We observe that LNG it is the most competitive solution at the moment that does not need a lot of adaption for users and refuelling stations. LNG has lower CO_2 emissions than diesel as fuel for heavy duty vehicles and vehicles are already available for sale. However, LNG has some disadvantages concerning vehicle cost, infrastructure cost and WtW efficiency. FCEV could be one future solution with several benefits compared to diesel vehicles as their WtW efficiency is higher and CO_2 emission is lower, even if it is powered with the electricity mix in 2030. The main obstacles are the high decision relevant cost (hydrogen price or higher efficiency) and the high cost for refuelling infrastructure. BEV would be the preferred solution from a CO_2 emission, renewable energy needed and WtW efficiency point of view. However, with current technologies, their range is either risible with more battery capacity which significantly reduces the load for transported goods or a charging infrastructure with currently unimaginable power levels. Both options have to be ruled out at the moment. Lastly, CHV offer a solution with several advantages: low renewable energy needed for a complete replacement, lower CO_2 emission, a high WtW efficiency and a compatible decision relevant operating cost. Yet, the infrastructure cost is high and driving along the catenary determines the electric driving and CO_2 emission reduction largely. The advantages of Methanol are low requirements on the infrastructure and some environmental benefits (CO_2 emissions, local emissions) in 2030 compared to conventional trucks. However the overall efficiency is low.

4 Discussion and Conclusions

This comparison of alternative drive trains for heavy duty vehicles is based on a variety of assumptions for Germany in 2030. While the investments for vehicles might differ largely and are unsure, more important are the assumptions for the efficiency of drive trains and the fuel costs which determine the decision relevant cost. All these parameters were taken from literature and discussed in detail in [4]. Furthermore, we focused at heavy duty vehicles with a total gross weight of 40 tons. If some of the technologies diffuse into smaller vehicle size classes or passenger cars, there might be some synergy effects, especially on fuel prices which have been neglected here. There might also be a pluralism of fuels in the long term, e.g. BEV for short-haul and CHV or FCEV for long-haul vehicles, yet we assume that a large infrastructure investment will only be useful for one or two propulsion technologies.

One important question is, if policy makers and industry can agree on a long-term solution or are more short to medium term focussed. In the short to medium term, methanol or LNG could be solutions that are technologically ready and may be competitive soon, especially if methanol is produced in areas with low electricity prices and imported to Germany. However, both solutions have local emissions that may not help for a long-term emission free transport. If the goal is to reduce emissions from transport completely then FCEV or CHV seem to be the only solutions for a locally nearly emission free transport and a tremendous CO_2 emission reduction, if the electricity will be produced via renewables. Both will require an investment in refuelling infrastructure that is probably higher for CHV, yet the additional energy needed for FCEV requires an investment in more renewable energy production. Certainly, more research is needed for both options, before an evidence based decision can be made.

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