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Market potential of catenary hybrid electric trucks in different world regions

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Summary

Catenary hybrid electric vehicles (CHV) are one solution for a decarbonization of heavy-duty transport. To this point, research focuses on Germany and Sweden while other regions with large amounts of trucks are neglected. In this paper, the economic market potential of CHV in Europe, the US, China and India are analyzed. We find high market shares for CHVs with diesel engine for large parts of the considered markets.

1 Research Questions

Global warming combined with an increase of road freight transport has risen attention for low-carbon transport solutions for heavy-duty vehicles. Overhead catenary hybrid electric vehicles (CHV) may be one solution for this issue. While there has been lots of published research on the German and Swedish market, the big international markets have been out of focus to this point. For this reason, we aim identifying economic market potentials for CHV in the EU and US as well as China and India in 2030.

2 Methodology

The market potential is determined in a comparison of the relevant total cost of ownership (TCO) of different drive train options. These are calculated by the TCO components that differ between drive trains, such as investment (I), fuel cost (consumption $cons_f$ multiplied with fuel price c_f) and cost for operations and maintenance $c_{O\&M}$. The investment has to be annuitized (with interest rate i and investment horizon T) and divided by the vehicle kilometers travelled (VKT). In this paper, the cost elements are presented kilometer-specific since this is common for truck leasing rates.

$$TCO = \frac{1}{VKT} \cdot I \cdot \frac{(1+i)^T \cdot i}{(1+i)^T - 1} + cons_f \cdot c_f + c_{O\&M}$$

Here, we focus on trucks with a gross vehicle weight of 40 tons and compare vehicles powered with Diesel, liquefied natural gas (LNG), hydrogen (fuel cell electric vehicles, FCEV) and electricity (pure battery electric vehicles (BEV) as well as CHV). Investments, energy consumption and cost for operations and maintenance are considered equal in all countries and given in Table 1. These assumptions are based on [1].

Indicator	Diesel	LNG	BEV200	FCEV	CHV Diesel	CHV100
Investment 2030 [€]	128,673	135,107	194,477	174,000	152,000	189,200
Consumption [kWh/km]	2.457	2.781	1.232	2.250	1.600	1.600
Cost for O&M [€/km]	.152	.143	.092	.132	.135	.107

Table 1: Vehicle-specific parameters for different drive trains. Own assumptions based on [1].

The country-specific energy prices are taken from the New Policies Scenario in World Energy Outlook 2017 [2]. We increased energy prices to also contain the cost for compression for LNG as well as the cost for distribution infrastructure in 2030. Hydrogen is produced from electricity via electrolysis. The resulting energy prices are shown in Table 2.

Energy price [€/kWh]	EU	US	CN	IN
Diesel	.215	.119	.139	.149
LNG	.130	.070	.150	.140
Electricity	.156	.090	.078	.060
Hydrogen	.309	.181	.170	.155

Table 2: Energy prices in 2030. Own calculations based on [2]

A clearly differing factor between countries are annual mileages of vehicles. The authors of this paper were not able to find cross-sectional data for heavy-duty trucks in the four regions under observation. Hence, the distribution of annual driving distances from a German data set [3] is used and projected to the other regions based on the mean annual driving distance and the number of vehicles in the region in [4]. These distributions can be found in Figure 1 as percentage of vehicles and as absolute number of vehicles in stock, the country-specific mean annual mileages and HDV stock in 2030 are given in Table 3.

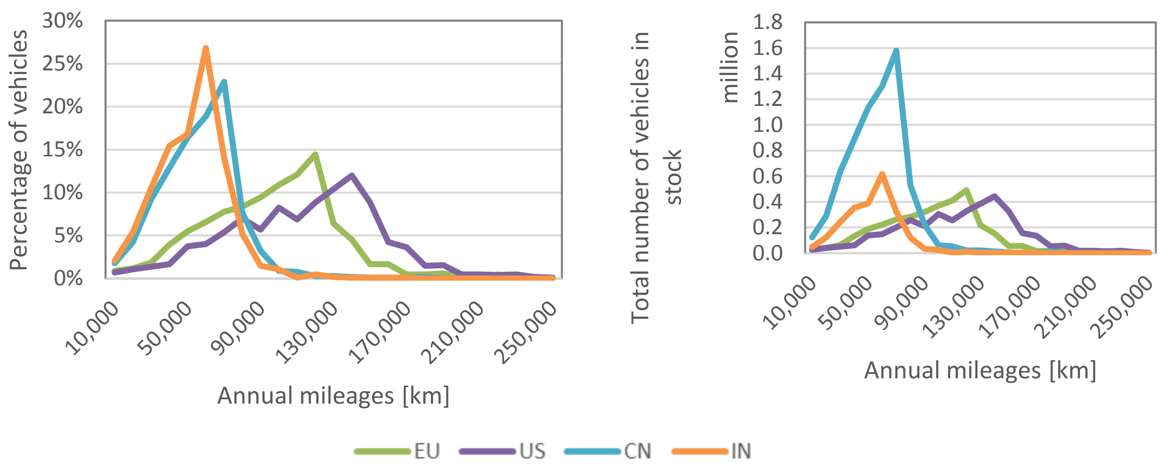

Figure 1: Distribution of annual mileages in different world regions based on [2, 4]

Indicator	EU	US	CN	IN
Mean annual mileage [km]	92,000	112,000	52,000	48,000
HDV stock 2030	3,400,000	3,700,000	6,900,000	2,300,000

Table 3: Mean annual mileages and HDV stock in 2030; Own assumptions based on [4]

3 Results

We show two sets of results. First, we look at different drive train options for average annual mileages to indicate the competing alternative drive train options. Second, we show the cost differences between CHV and diesel for different annual mileages and combine them with the annual mileage distributions from the previous section.

The TCO for different drive trains and region-specific mean annual mileages are shown in Figure 2. Here, capital, energy and O&M cost are distinguished for seven variants: diesel trucks, LNG trucks, BEVs with a range of 200 km, FCEV, CHV with diesel engine as second drive train with 100% and with 0% electric driving and CHV with a 100 km battery.

We find FCEV to have the highest cost in all countries while the other drive trains are all in a range of 0.3 €/km. In all world regions, CHV with 100% electric driving are cheapest option for the average annual mileage. The 0% electric CHV is always more costly, but the differences between all electric and non-electric differ a lot between regions (e.g. 0.28 €/km EU and 0.14 €/km in India). BEV200 and CHV100 are always cheaper than diesel vehicles, yet their range is limited would require high amounts of charging. LNG could be a cheaper near-term solution than diesel vehicles in EU and the US, but already in China and India, their TCO is higher.

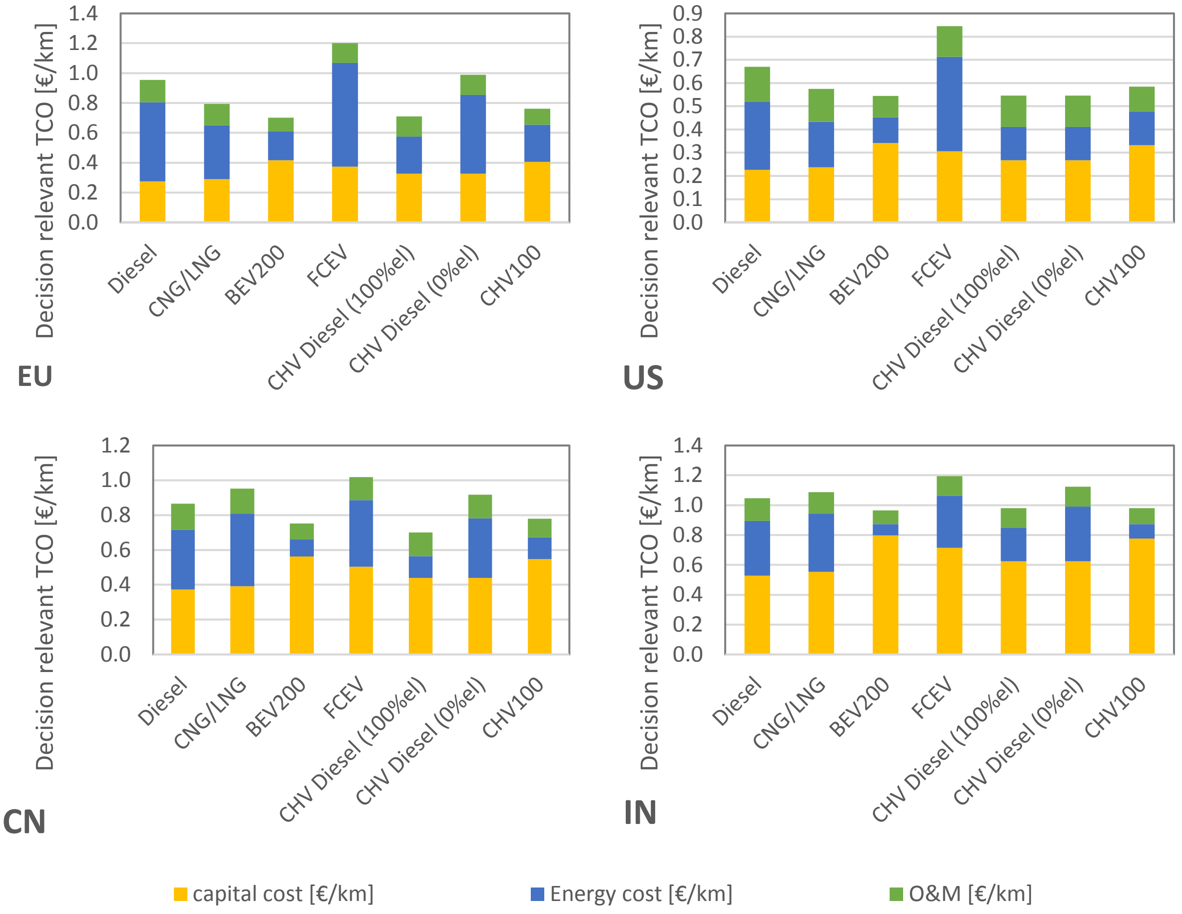

Figure 2: TCO comparison for different drive trains and regions for region specific mean annual mileages. All values shown in [€/km]. Own calculations for 2030.

Average driving distances can help us to get a good first image, but driving distance distributions allow understanding more about the market size and market potentials. In Figure 3, we show the TCO differences between a CHV driving 50% electrically and a diesel vehicle in dependence of the annual driving distances. The TCO differences are shown in €/km for the four different regions.

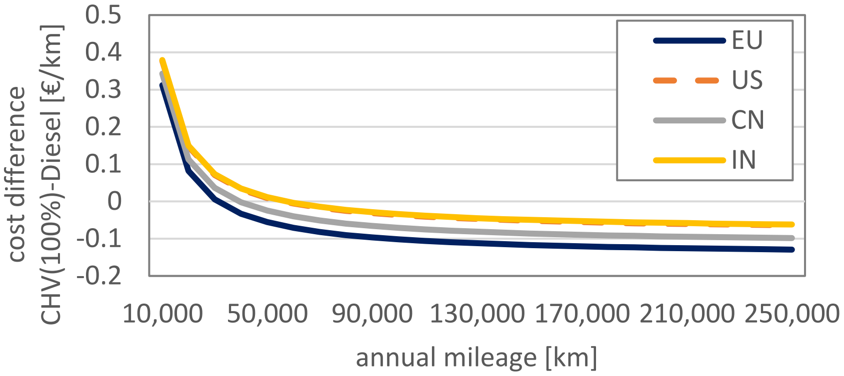

Figure 3: Cost difference for CHV with 50% electric driving and diesel truck in dependence of annual mileage in different world regions in 2030. Own calculations.

We find the highest positive cost differences for low annual driving distances - here, diesel vehicles are cheaper than CHVs. From a certain distance on, CHVs are cheaper, the so-called break-even distance. These distances are at 30,000 to 40,000 km for EU and China and around 70,000 km for the US and India. In Figure 4, we compare these distances to the distribution of annual driving distances for Europe.

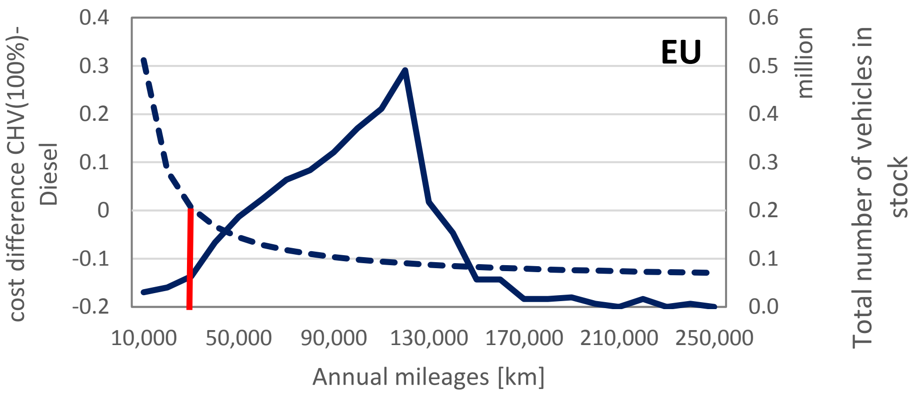

Figure 4: Cost difference for CHV with 50% electric driving and diesel truck in dependence of annual mileage (solid line, primary y-axis) and distribution of annual driving distances (dashed line, secondary y-axis) for EU. Own calculations for 2030.

We indicate the break-even distance with a red line. One may clearly observe that the break-even distance in Europe is left of the driving distance peak, i.e. the majority of vehicles drives more than needed. These results are similar for the other regions. We find the highest relative market shares for Europe (~90%) and the lowest in India (~40%) while the absolute market shares are highest for China (cf. Figure 1).

We can summarize the two main findings of this paper as follows: (1) CHV with a diesel engine and 100% electric driving have the lowest cost in all regions for average annual driving distances. (2) Even with only 50% electric driving, CHV are cheaper in all observed regions in 2030 for the majority of vehicles.

Certainly, these results are subject to a number of assumptions taken from literature. For the presentation, we will also analyze the impact on results of a parameter variation (e.g. energy prices) in a sensitivity analysis.

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