MARKET POTENTIAL OF CATENARY HYBRID ELECTRIC TRUCKS IN DIFFERENT WORLD REGIONS

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Source: http://www.klimaexpo.nrw/meetup/mitmachen/projekte-vorreiter/vorreitermobilitaet
OUTLINE

1. Motivation and research question
2. Methods, data and assumptions
3. Results
4. Findings & conclusion
Heavy-duty vehicles only have a small share of vehicles in stock...

Figure 11 • Global stock of road freight vehicles, 2015

...but they are responsible for large parts of CO$_2$ emissions in road transport.

Figure source: Kluschke et al. (2018): Decarbonization of heavy-duty vehicles: A literature review of alternative fuels and powertrains, submitted to Energy Reports.
To compare technical solutions, we analyze six drive trains in four world regions in 2030.

What are technical solutions to reduce emissions in heavy-duty transport?

(1) Comparison of **six drive trains**:

I. Diesel  
II. LNG: Liquefied Natural Gas  
III. BEV200: Battery electric vehicle with 200km range  
IV. FCEV: Fuel-cell electric vehicle  
V. CHV Diesel (x% el.): Catenary hybrid vehicle with add. diesel engine and x% driven electrically  
VI. CHV100: CHV with battery and 100km range

(2) In **four world regions**:

- EU: Europe  
- US: United States  
- CN: China  
- IN: India

(3) In **2030**
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We compare drive trains for heavy-duty trucks using total cost of ownership (TCO).

**Calculation of TCO per kilometer:**

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

- **TCO**: Total cost of ownership [km]
- **VKT**: vehicle kilometers traveled [km]
- **I**: Investment [€]
- **i**: interest rate
- **T**: investment period
- **cons\_f**: consumption of fuel f [kWh/km]
- **c\_f**: cost of fuel f [€/kWh]
- **c\_O&M**: cost for operation and maintenance [€/km]

No consideration of taxes (not applicable), insurance or driver cost (not different between drive trains)
We assume equal vehicle parameters across countries and country-specific energy prices.

- Equal vehicle parameters in all countries based on [1].

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Diesel</th>
<th>LNG</th>
<th>BEV200</th>
<th>FCEV</th>
<th>CHV Diesel</th>
<th>CHV100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment 2030 [€]</td>
<td>128,673</td>
<td>135,107</td>
<td>194,477</td>
<td>174,000</td>
<td>152,000</td>
<td>189,200</td>
</tr>
<tr>
<td>Consumption [kWh/km]</td>
<td>2.457</td>
<td>2.781</td>
<td>1.232</td>
<td>2.250</td>
<td>1.600*</td>
<td>1.600</td>
</tr>
<tr>
<td>Cost for O&amp;M [€/km]</td>
<td>.152</td>
<td>.143</td>
<td>.092</td>
<td>.132</td>
<td>.135</td>
<td>.107</td>
</tr>
</tbody>
</table>

- Country-specific energy prices are taken from World Energy Outlook [2].

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


* electric only, in pure conventional mode same consumption as Diesel.
The mean annual mileage and the number of vehicles in stock differ by country.

Distribution of driving from Germany [3] transferred to other countries’ mean annual mileages [4].


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EUROPE: CHV Diesel with some electric driving is cheaper than Diesel.

- CHV Diesel (100% electric) and BEV200 lowest cost solutions.
- LNG, CHV100 are second-best options.
- CHV Diesel (0% electric) slightly worse than Diesel.
- FCEV much more expensive.

Mean annual driving distance EU: 92,000 km. (2030)
**UNITED STATES: CHV Diesel only slightly better than LNG.**

- **BEV200, CHV Diesel (100%), LNG all with similar TCOs**
- **CHV100 only slightly better than Diesel**
- **CHV Diesel (0% electric) slightly worse than Diesel.**
- **FCEV much more expensive.**

<table>
<thead>
<tr>
<th>Variation</th>
<th>Capital Cost [€/km]</th>
<th>Energy Cost [€/km]</th>
<th>O&amp;M [€/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CNG/LNG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEV200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCEV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHV Diesel (100%el)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHV Diesel (0%el)</td>
<td></td>
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<tr>
<td>CHV100</td>
<td></td>
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</tbody>
</table>

Mean annual driving distance US: 112,000 km. (2030)
CHINA: CHV Diesel is best option when some share is driven with electricity.

CHV Diesel (100% el.) and BEV200 lowest cost solutions

CHV100 is second-best option.

CHV Diesel & LNG (0% electric) slightly worse than Diesel.

FCEV more expensive.

Mean annual driving distance CN: 52,000 km. (2030)
**INDIA**: Electric drive trains only have small advantages compared to conventional ones.

- Only small advantages in India for BEV200, CHV Diesel (100% el), CHV100
- Diesel, LNG, CHV Diesel (0%) all within 0.1 €/km
- FCEV with higher cost

Mean annual driving distance IN: 48,000 km. (2030)
Small amounts of electric driving for CHV Diesel necessary to pay off across countries.

- Shown is cost difference of CHV Diesel (100% el) and Diesel vehicle
- Small amounts of electric driving necessary to pay-off = Electric breakeven distance
  - EU: ~30,000km
  - CN: ~40,000km
  - US&IN: ~55,000km
Large shares of vehicles in stock can pay off with little electric driving.

1. 96% of vehicles drive more than 30,000km (=CHV Diesel 100% el)
2. 80% of vehicles drive more than 60,000km (=CHV Diesel 50% el)
3. 55% of vehicles drive more than 90,000km (=CHV Diesel 33% el)
4. 17% of vehicles drive more than 120,000km (=CHV Diesel 25% el)
Using annual mileage distributions shows highest market potentials in Europe and US.

<table>
<thead>
<tr>
<th>Region</th>
<th>Break-Even distance (100% el)</th>
<th>Break-Even distance (50% el)</th>
<th>Break-Even distance (33% el)</th>
<th>Break-Even distance (25% el)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU</td>
<td>30,000</td>
<td>60,000</td>
<td>90,000</td>
<td>120,000</td>
</tr>
<tr>
<td>US</td>
<td>55,000</td>
<td>110,000</td>
<td>165,000</td>
<td>220,000</td>
</tr>
<tr>
<td>CN</td>
<td>40,000</td>
<td>80,000</td>
<td>120,000</td>
<td>160,000</td>
</tr>
<tr>
<td>IN</td>
<td>55,000</td>
<td>110,000</td>
<td>165,000</td>
<td>220,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Region</th>
<th>Amount of vehicles with higher annual mileage</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU</td>
<td>96%</td>
</tr>
<tr>
<td>US</td>
<td>90%</td>
</tr>
<tr>
<td>CN</td>
<td>72%</td>
</tr>
<tr>
<td>IN</td>
<td>37%</td>
</tr>
</tbody>
</table>
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**Findings & conclusion**

- Large variations of energy prices (lowest conventional fuel prices in US) and also driving distances across countries (low driving in CN and IN)
- TCO for LNG in US as low as electric vehicles; CHV Diesel (100% el) and BEV200 lowest cost options
- Large shares of vehicles could drive with low share of electric driving.
- Highest market potentials in EU and US since driving in CN&IN too low.

**YET:**

- Influence of infrastructure and range not explicitly considered.
- Energy price development very uncertain.

**STILL, catenary hybrid electric trucks seem to be a cost-efficient option to decarbonize heavy duty-transport.**
Thank you for your attention!

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Further reading: