THE POTENTIAL ENERGY USE & CO₂ EMISSION REDUCTIONS OF ELECTRIC TRUCKS POWERED BY OVERHEAD LINES

Patrick Plötz, Till Gnann and Martin Wietschel
Fraunhofer Institute for Systems and Innovation Research ISI

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A drastic reduction of CO₂ emissions is required to reach Europe’s climate targets.

- EU target: reduction of GHG emissions by 80% compared to 1990
- Transport sector has to contribute, but goals not achievable with combustion engines vehicles
- Solutions for Transport required if we want to maintain our present way of life
- It is not about cost compared current technology but most cost-efficient future technology
Heavy duty trucks make up only 5% of truck stock but 50% of truck CO₂-Emissions

- Heavy trucks have high annual mileage and high energy consumption
- For long-term CO₂-neutrality in the transport sector, we need solutions for the heavy truck transport (today Diesel only)
- Batteries not feasible for long-distance trucks
- Possible solutions:
  - Hydrogen FCEV
  - Power to gas, e.g. renewable LNG
  - Overhead line-trucks

### Commercial trucks in Germany

<table>
<thead>
<tr>
<th>Weight Class</th>
<th>Vehicle Stock (1000 veh.)</th>
<th>Billion Vehicle km/a</th>
<th>Mt CO₂/a WtW CO₂ Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 26 tons</td>
<td>183</td>
<td>19.4</td>
<td>19.7</td>
</tr>
<tr>
<td>12 - 26 tons</td>
<td>161</td>
<td>11.9</td>
<td>9.3</td>
</tr>
<tr>
<td>7.5 - 12 tons</td>
<td>77</td>
<td>5.1</td>
<td>3.0</td>
</tr>
<tr>
<td>3.5 - 7.5 tons</td>
<td>262</td>
<td>7.1</td>
<td>3.0</td>
</tr>
<tr>
<td>&lt;3.5 tons</td>
<td>2,000</td>
<td>26.0</td>
<td>6.3</td>
</tr>
</tbody>
</table>
The alternative electricity paths have advantages and disadvantages

<table>
<thead>
<tr>
<th></th>
<th>Direct use of electricity</th>
<th>Hydrogen</th>
<th>Electricity-based hydrocarbons</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td>• Most efficient path</td>
<td>• medium efficiency</td>
<td>• Infrastructure partly exists</td>
</tr>
<tr>
<td></td>
<td>• In many cases cheap</td>
<td>• Can be stored</td>
<td>• Existing storage can be used</td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
<td>• Necessary expansion of grid and possibly storage infrastructure</td>
<td>• Converting infrastructure is complex and expensive</td>
<td>• CO₂ input necessary</td>
</tr>
<tr>
<td></td>
<td>• For high share of fluctuating RE, flexibility measures incl. storage must be expanded</td>
<td>• Path dependency</td>
<td>• Potentials for “carbon-neutral” CO₂ severely limited</td>
</tr>
<tr>
<td></td>
<td>• Energy density too low for some applications</td>
<td></td>
<td>• Expensive (avoidance costs more than 500 EUR/t)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Efficiency today (WTT)</th>
<th>~95 %</th>
<th>~60-70 %</th>
<th>~50-60 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency today (WTW)</td>
<td>85 %</td>
<td>25-35 %</td>
<td>20-25 %</td>
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</tbody>
</table>

RE= Renewable electricity
Different variants and energy connections for electric trucks are under discussion

**Two possible execution variants**

- **Electric motor + 200 kWh battery** → long-term electrification?
- **Serial diesel hybrid with small traction battery as puffer (~10 kWh)** → Today preferred for full flexibility
Potential of overhead line construction

- Car and truck traffic concentrated on some highways
  - Highways with higher loads should electrified first
  - 33% expansion electrify 50% of truck VKT

Expansion of electrification – connected highway sections of high intensity needed

1’000 km of e-highway

Hamburg
Berlin
Cologne
Frankfurt
Karlsruhe

1- 4’000 km of e-highway

Hamburg
Berlin
Cologne
Frankfurt
Karlsruhe
Munich

Heavy trucks within Germany

<table>
<thead>
<tr>
<th>Trucks per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1’000</td>
</tr>
<tr>
<td>1 – 2’000</td>
</tr>
<tr>
<td>2 – 3’000</td>
</tr>
<tr>
<td>&gt; 3’000</td>
</tr>
</tbody>
</table>

electrified

<p>| | | | |</p>
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<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1st</td>
<td>1’000 km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd</td>
<td>1’000 km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd</td>
<td>1’000 km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4th</td>
<td>1’000 km</td>
<td></td>
<td></td>
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</tbody>
</table>
Results from market simulation model ALADIN:
Individual simulation for several thousand duty vehicle driving profiles + TCO calculation + limited availability of new technologies + only German highway usage

Results:
12 – 26 ton GVW:
- e-trucks with 10% Market share in new registrations
- Main fuel remains Diesel

Heavy duty (> 26 tons max weight)
- Only small number of electric trucks
- Natural gas vehicles (NGV) have 60% market shares
Results from market simulation model ALADIN:
Individual simulation for several thousand duty vehicle driving profiles + TCO calculation + limited availability of new technologies + only German highway usage

Results:
12 – 26 ton GVW:
- e-trucks with 15% Market share in new registrations
- Main fuel remains Diesel

Heavy duty (> 26 tons max weight)
- electric trucks with 25% of sales
- Natural gas vehicles (NGV) still important
Regional effects after market diffusion 2030
Relative change in NUTS3 electricity demand by e-trucks

- Noteworthy grid impact at highway intersections in rural area
Overall economic perspective:

- Assumed infrastructure cost of 2.2 million € per km e-highway (one lane in both directions all inclusive)
- Annual cost for the infrastructure (annuity for 30 years of usage at 5% interest rate) vs. annual fuel cost savings (benefits) from the more efficient electric driving
- Net benefit positive up to 2500-3000 km or about 20% of grid
- BUT: calculations for purely German system of the infrastructure and full intake of users' profits

- Some overhead-line infrastructure for trucks could be cost-effective
The usage phase dominates the life cycle emissions with a noteworthy net benefit

- **Comparison to Diesel truck including**
  - Construction of e-highway & additional truck components
  - and e-truck usage
- **Assumed e-truck is diesel hybrid truck** with
  - Fleet of 60’000 heavy duty vehicles (1/3 of stock)
  - 114’000 km annual VKT
  - 65% electric drive fraction and 35% diesel
  - with 190 gCO2eq/kWh (governmental reference scenario for 2030)

- **Results:**
  - Infrastructure GHG emissions negligible
  - GHG savings of 37 t CO2/a per vehicle
  - GHG savings of 2.2 million tons of CO2eq/a in 2030
Electrification of European highways?

- High share of heavy duty transport in Europe is cross-national
- About one third of the European highway grid are approx. 25,000 km
- Trans-European traffic corridors best start
- Alternative fuels infrastructure directive for joint European system
- Debate is still in an early phase and likelihood of European overhead line grid unclear
Energy consumption e-Trucks by country

- Transfer of fast market diffusion to all of Europe leads to noteworthy electricity consumption

<table>
<thead>
<tr>
<th></th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stock</strong></td>
<td>2,000</td>
<td>285,000</td>
<td>837,000</td>
</tr>
<tr>
<td><strong>Stock share</strong></td>
<td>0.2%</td>
<td>18%</td>
<td>49%</td>
</tr>
<tr>
<td><strong>Electricity (TWh)</strong></td>
<td>0.1</td>
<td>29.5</td>
<td>115.0</td>
</tr>
</tbody>
</table>

Overhead line e-trucks are an interesting option for zero emission heavy duty transport

- **First steps in GHG emission reductions: (1) avoid and (2) shift to electric rail**

- **Electric highways are a potential step towards zero emission heavy duty vehicles**
  - Technology readiness level quite high (close to commercialization)
  - pro: high efficiency from direct use of electricity and efficient electric motor (implies lowest use of additional renewable generation) → most efficient heavy duty option
  - con: infrastructure invest and difficult electric driving away from e-highway

- **Some infrastructure could be cost-effective but further solutions needed** for driving off the highway

- **Open issues:**
  - 50% of heavy duty highway traffic in Germany is transit: Full European system would generate higher benefits → political commitment would be required
  - Full energy system analysis (generation, infrastructure etc.) and comparison to import of renewable fuels, e.g. from north Africa or middle east
Thank you!