HOW TO DECARBONIZE HEAVY ROAD TRANSPORT – A COMPARISON OF ALTERNATIVE FUELS AND DRIVE TRAINS FOR HEAVY DUTY VEHICLES

Dr. Till Gnann

TRB2021 Annual Meeting, International Aspects of Transportation Energy, January, 13th, 2021

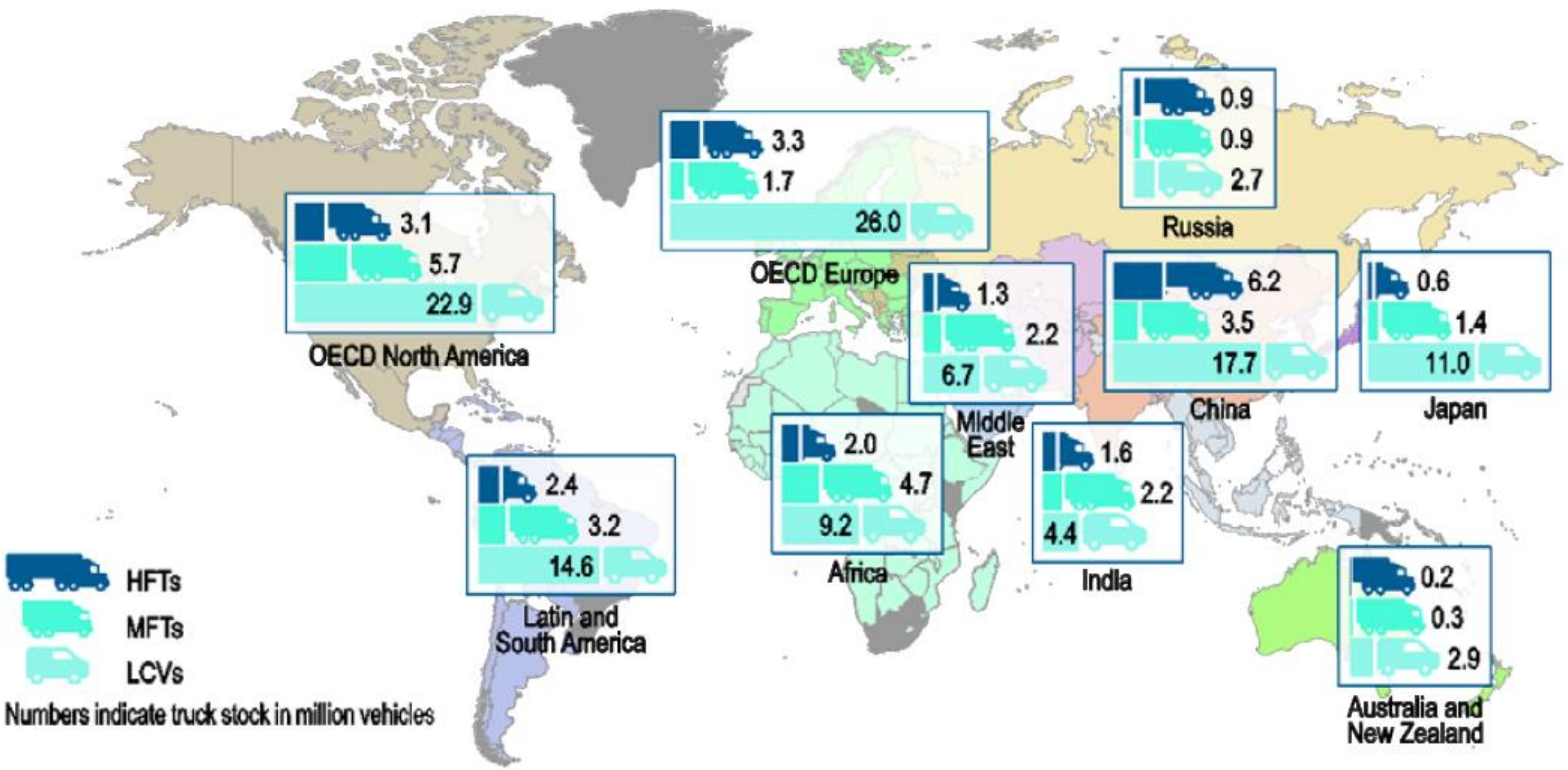
Source: http://www.klimaexpo.nrw/mitmachen/

Outline

1. **Overview, technical solutions and comparison of alternatives**
2. Cost comparison in different world regions
3. Findings, conclusion & limitations

Heavy-duty vehicles only have a small share of vehicles in stock...

Figure 11 • Global stock of road freight vehicles, 2015



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Source: IEA (2017a), Mobility Model, June 2017 version, database and simulation model, www.iea.org/etp/etpmodel/transport/.

Figure source: IEA 2017: The future of trucks: Implications for Energy and the Environment

Fraunhofer ISI

...but they are responsible for large parts of CO_2 emissions in road transport.

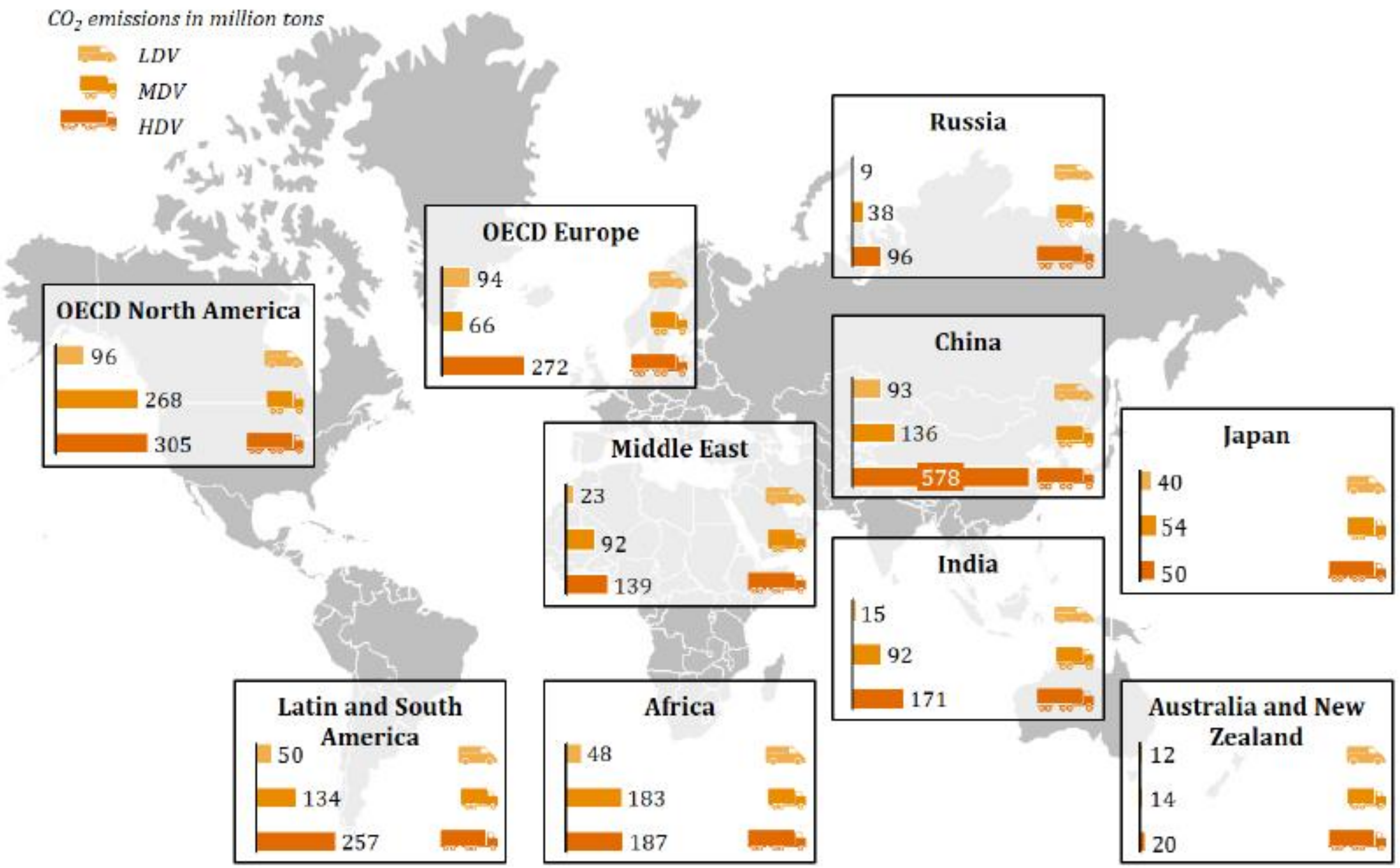
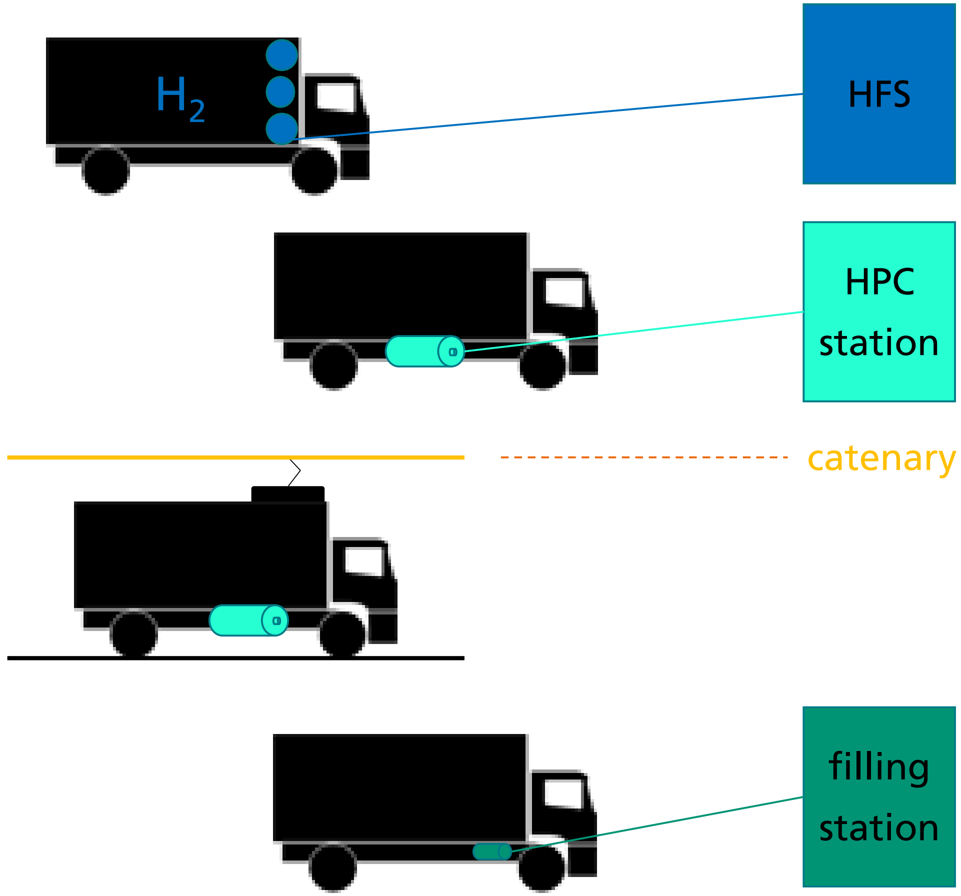


Figure source: Kluschke et al. (2019): Decarbonization of heavy-duty vehicles: A literature review of alternative fuels and powertrains, Energy Reports, DOI: 10.1016/j.egyr.2019.07.017.

There are four main concepts that allow carbon-free trucking.



Long-term solutions for carbon-free trucks

- Fuel Cell Electric Vehicles (**FCEV**) filled at hydrogen filling stations (HFS)
- Battery Electric Vehicles (**BEV**) charged at High Power Charging (HPC) stations
- Catenary hybrid vehicles (**CHV**) charged at a overhead catenary
- Trucks with fuels from renewable energy (Power-To-Gas (**PtG**) / Power-To-Liquid (**PtL**)) fueled at conventional filling stations

Fraunhofer ISI

Comparison of alternative drive trains (1/3)

	Fuel cell (FCEV)	Battery electric (BEV)	Overhead catenary (CHV)	Synthetic fuels (PtG /PtL)
Motors and technology	Electric motor and fuel cell with hydrogen as energy storage	Electric motor and battery as energy storage	Electric motor and power from overhead lines, if necessary with battery as energy storage or additional combustion engine	Internal combustion engine and pressurized gas or liquid tank as energy storage device
Conversion steps Fuel production from electricity	Conversion to hydrogen (electrolysis)	Direct Use	Direct Use	Conversion to hydrogen (electrolysis) and further to carbonaceous fuel

Plötz et al. (2018): Alternative drive trains and fuels in road freight transport – recommendations for action in Germany. Policy Brief. Karlsruhe, Heidelberg, Berlin. Nov, 2018.

Fraunhofer ISI

Comparison of alternative drive trains (2/3)

	Fuel cell(FCEV)	Battery electric (BEV)	Overhead catenary (CHV)	Synthetic fuels (PtG /PtL)
Efficiency today with the use of renewable electricity	Circa	Circa	Circa	Circa
tank-to-wheel	40 – 50 %	90 %	90 %	35 – 40 %
well-to-tank	60 – 70 %	90 %	90 %	50 – 60 %
well-to-wheel	25 – 35 %	80 %	80 %	20 – 25 %
Technological readiness level of vehicles	Several test projects (TRL 6-7)[11]	First commercially available vehicles (TRL 8)[11]	Several test projects (TRL 6-7)[11]	Conventional vehicles
Key challenges	Infrastructure development and increased power requirements due to high conversion losses, cost reduction in fuel production	Limited range, long charging time and payload losses	Infrastructure development, acceptance, integration in logistics processes	Strongly increased power demand due to highest conversion losses, cost reduction in vehicle and fuel production

Plötz et al. (2018): Alternative drive trains and fuels in road freight transport – recommendations for action in Germany. Policy Brief. Karlsruhe, Heidelberg, Berlin. Nov, 2018.

Fraunhofer ISI

Comparison of alternative drive trains (3/3)

	Fuel cell (FCEV)	Battery electric (BEV)	Overhead catenary (CHV)	Synthetic fuels (PtG /PtL)
Power requirement for all German tractor units [TWh]	Ca. 70	Ca. 36	Ca. 36	Ca. 105
User costs vs. diesel truck [€/km][20]	-0.15 to 0.6	-0.1 to 0.2	-0.2 to 0.1	0.2 to 0.6
Infrastructure	High investments, prefinancing necessary	High investments, prefinancing necessary	Very high investments, prefinancing necessary	No high investments, existing infrastructure available
Domestic value added	Generation and distribution plants	Electric motor, power electronics	Infrastructure, pantograph and drive system	Internal combustion engine and generation plants
Import dependency	Low	For battery cells	Low	Import of fuels

Plötz et al. (2018): Alternative drive trains and fuels in road freight transport – recommendations for action in Germany. Policy Brief. Karlsruhe, Heidelberg, Berlin. Nov, 2018.

Fraunhofer ISI

Outline

1. Overview, technical solutions and comparison of alternatives
2. **Cost comparison in different world regions**
    1. **Methods and data**
    2. Results
3. Findings, conclusion & limitations

To compare technical solutions, we analyze six drive trains in four world regions in 2030.

What is the market potential for different alternative fuel vehicles 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**

Fraunhofer ISI

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

- Calculation of decision relevant TCO per kilometer:

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

  - 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)

Fraunhofer ISI

We assume equal vehicle parameters across countries and country-specific energy prices.

- Equal vehicle parameters in all countries based on [1]. All values for 2030.

Indicator	Diesel	LNG	BEV200	FCEV	CHV Diesel	CHV100
Investment [€]	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

- Country-specific energy prices are taken from World Energy Outlook [2]. All values for 2030.

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

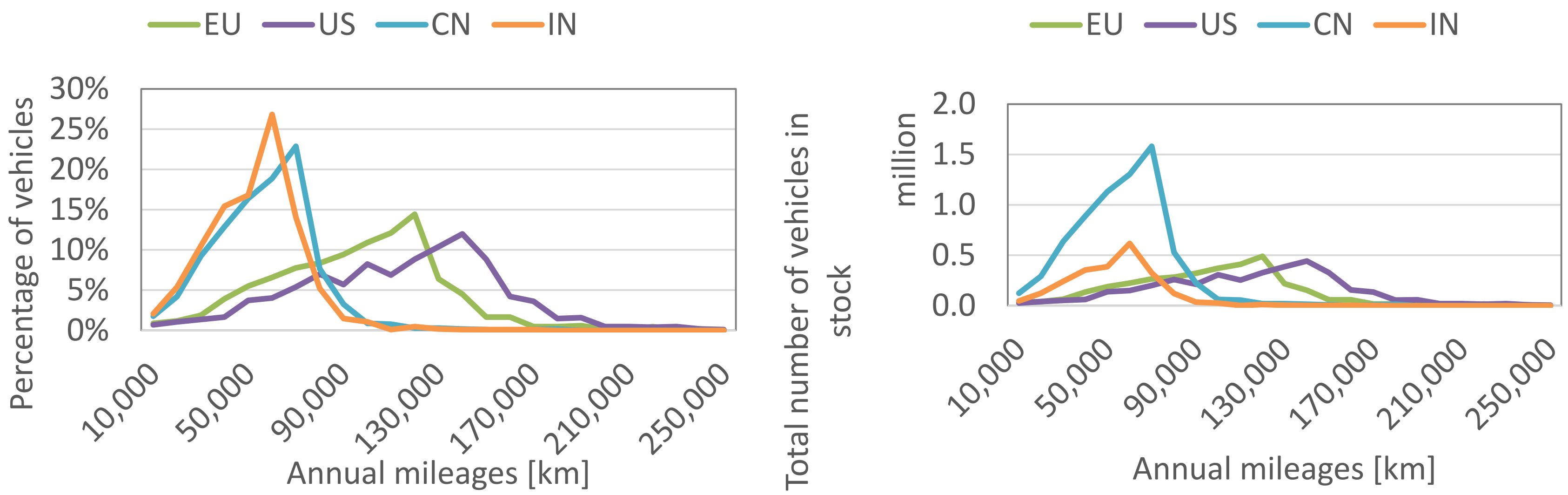
[1] Wietschel, M.; Gnann, T.; Kühn, A.; Plötz, P.; Moll, C.; Speth, D.; Stütz, S.; Schellert, M.; Rüdiger, D.; Balz, W.; Frik, W., Waßmuth, V.; Paufler-Mann, D.; Rödl, A.; Schade, W., Mader, S.: *Machbarkeitsstudie zur Ermittlung der Potentiale des Hybrid-Oberleitungs-Lkw*, Studie im Rahmen der wissenschaftlichen Beratung des BMVI zur Mobilitäts- und Kraftstoffstrategie der Bundesregierung, Fraunhofer ISI, Karlsruhe, Fraunhofer IML, Dortmund, PTV Transport Consult GmbH, Stuttgart, Karlsruhe, TU Hamburg-Harburg, Hamburg, M-Five, Karlsruhe, Germany 2017.

[2] International Energy Agency - IEA. World Energy Outlook 2017. Paris. 2018

* 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].



Indicators [4]	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

[3] *Kraftfahrzeugverkehr in Deutschland 2010 (KiD2010)*. WVI Prof. Dr.Wermuth Verkehrsforschung und Infrastrukturplanung GmbH, Braunschweig, IVT Institut für angewandte Verkehrs- und Tourismusforschung e. V., Heilbronn, DLR Deutsches Zentrum für Luft- und Raumfahrt - Institut für Verkehrsforschung, Berlin, KBA Kraftfahrt-Bundesamt, Flensburg, Germany.

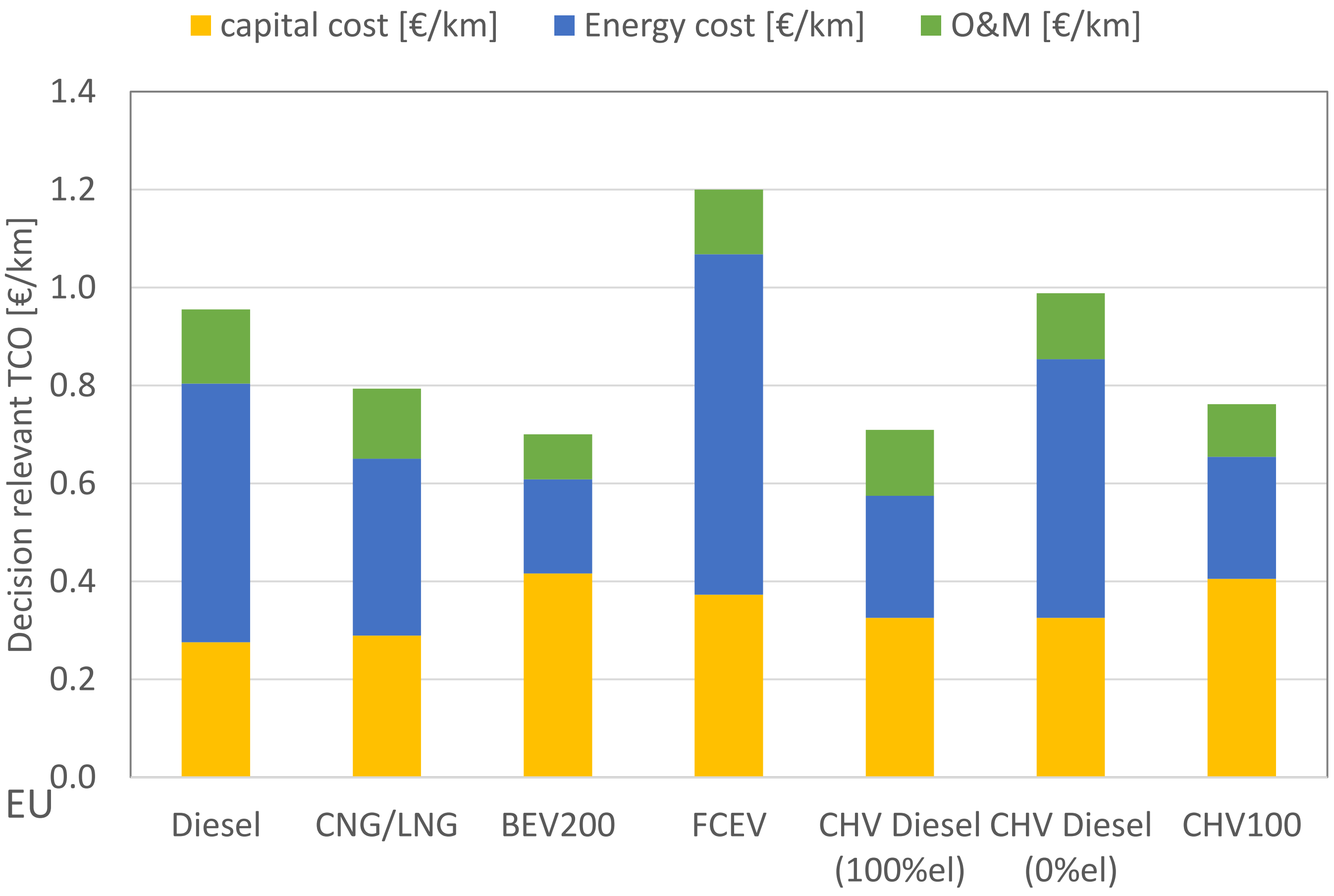
[4] IEA. *The Future of Trucks: Implications for Energy and the Environment*. Paris; 2017.

Fraunhofer ISI

Outline

1. Overview, technical solutions and comparison of alternatives
2. **Cost comparison in different world regions**
    1. Methods and data
    2. **Results**
3. Findings, conclusion & limitations

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

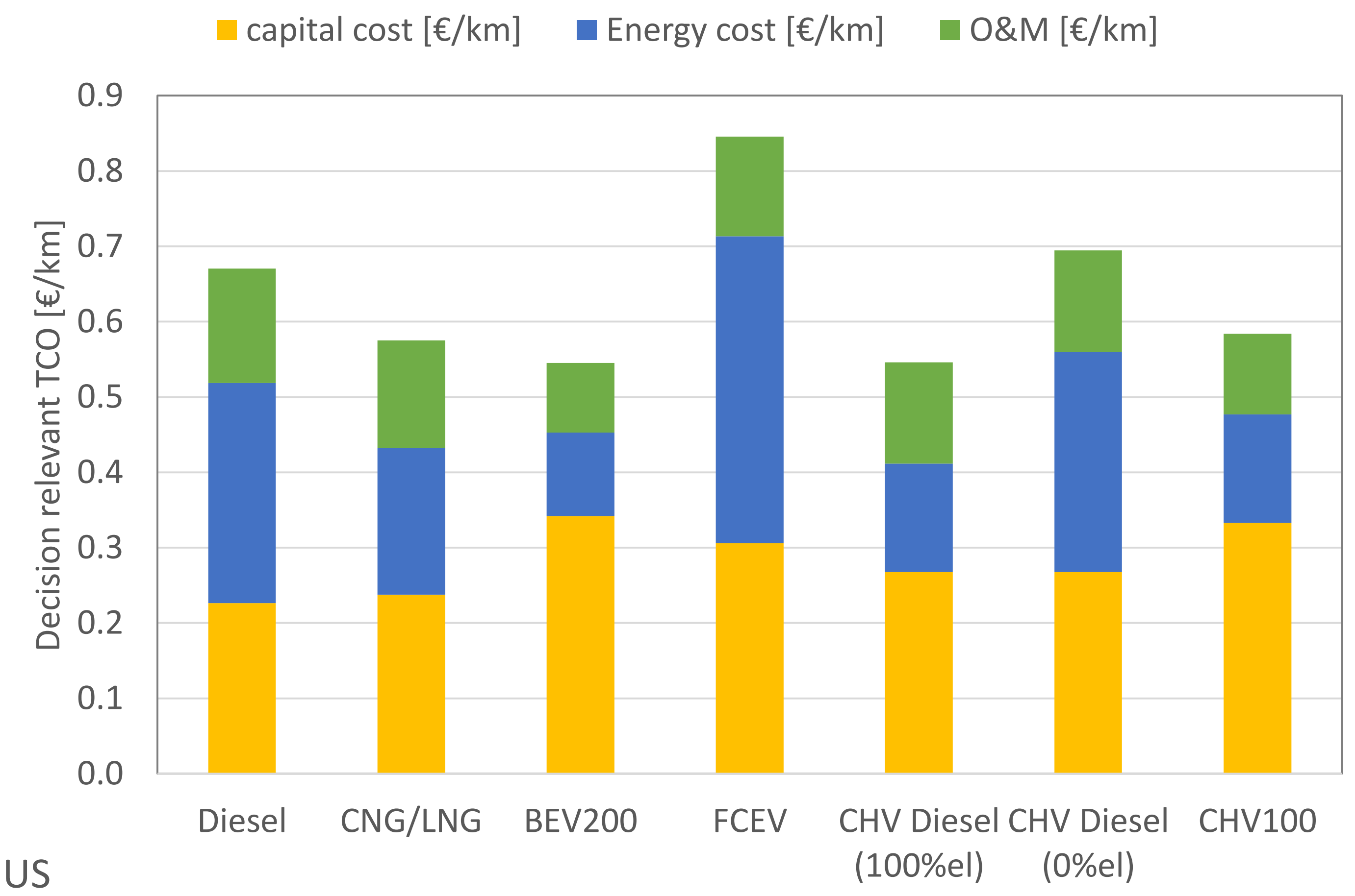


- CHV Diesel (100% electric) and BEV200 lowest cost solutions.
- LNG, CHV100 are second-best options.
- CHV Diesel (0% electric) slighty worse than Diesel.
- FCEV much more expensive.

Mean annual driving distance EU: 92,000 km. (2030)

Fraunhofer ISI

UNITED STATES: CHV Diesel only slightly better than LNG.

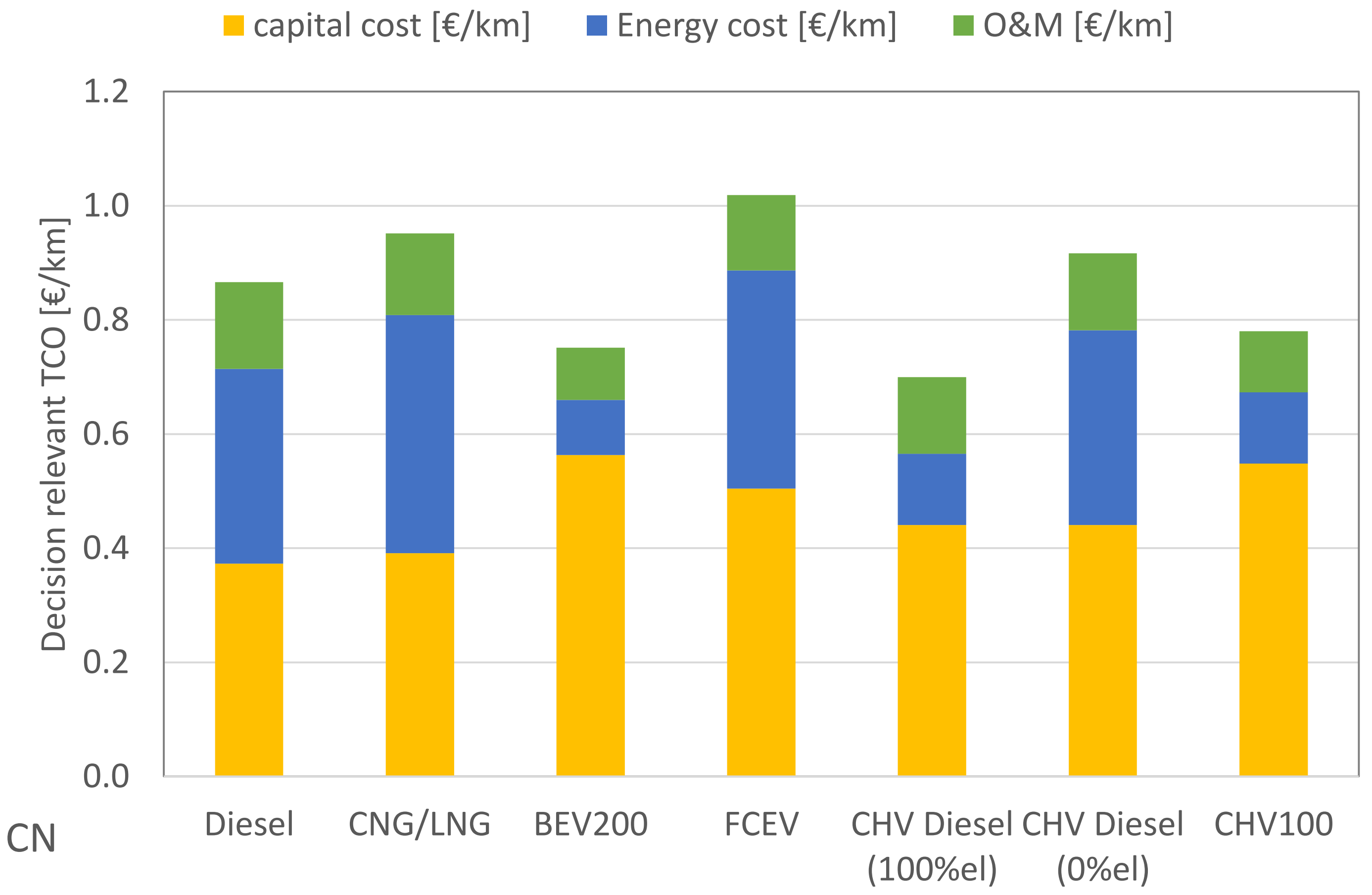


- BEV200, CHV Diesel (100%), LNG all with similar TCOs
- CHV100 only slightly better than Diesel
- CHV Diesel (0% electric) slighty worse than Diesel.
- FCEV much more expensive.

Mean annual driving distance US: 112,000 km. (2030)

Fraunhofer ISI

CHINA: CHV Diesel is best option when some share is driven with electricity.

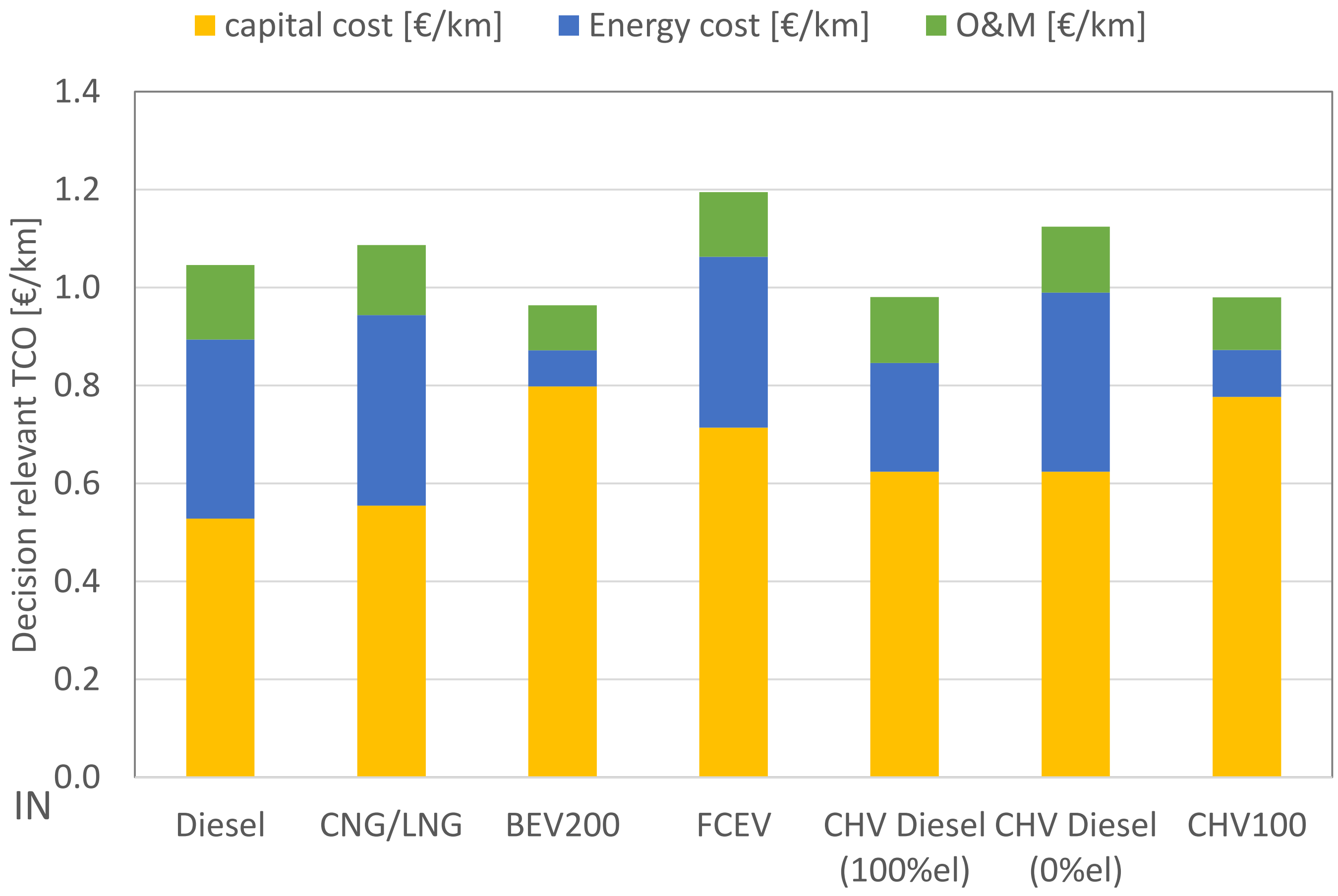


- CHV Diesel (100% el.) and BEV200 lowest cost solutions
- CHV100 is second-best option.
- CHV Diesel & LNG (0% electric) slighty worse than Diesel.
- FCEV more expensive.

Mean annual driving distance CN: 52,000 km. (2030)

Fraunhofer ISI

INDIA: Electric drive trains only have small advantages compared to conventional ones.



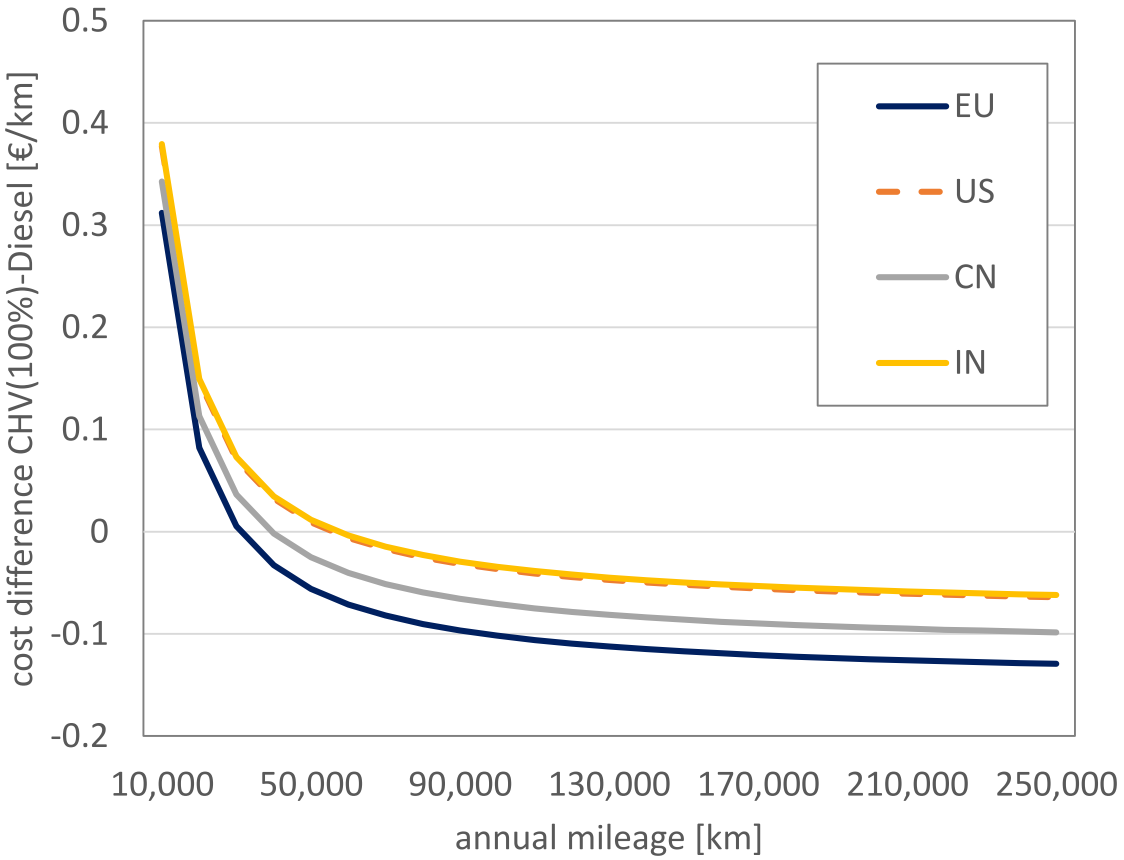
- Only small advantages in India for BEV200, CHV Diesel (100%el), CHV100
- Diesel, LNG, CHV Diesel (0%) all within .1€/km
- FCEV with higher cost

Mean annual driving distance IN: 48,000 km. (2030)

Fraunhofer ISI

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 break-even-distance
  - EU: ~30,000km
  - CN: ~40,000km
  - US&IN: ~55,000km



All values for 2030.

Fraunhofer ISI

Using annual mileage distributions shows highest market potentials for CHV trucks in Europe and US.

Region	Break-Even distance (100% el)	Break-Even distance (50% el)	Break-Even distance (33% el)	Break-Even distance (25% el)
EU	30,000	60,000	90,000	120,000
US	55,000	110,000	165,000	220,000
CN	40,000	80,000	120,000	160,000
IN	55,000	110,000	165,000	220,000

Region	Amount of vehicles with higher annual mileage			
EU	96%	80%	55%	15%
US	90%	54%	8%	2%
CN	72%	6%	1%	.3%
IN	37%	1%	.1%	<.1%

All values for 2030.

Fraunhofer ISI

Outline

1. Overview, technical solutions and comparison of alternatives
2. Cost comparison in different world regions
3. **Findings, conclusion & limitations**

Findings and limitations

General findings

- Large differences in energy demand in complete replacement (Hydrogen = 2 x Electric; PtL = 3 x Electric).
- Varying (initial) infrastructure needs that has to be set up.

Cost comparison

- Large variations of energy prices (lowest conventional fuel prices in US) and 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
- Highest market potentials for CHV in EU and US since driving in CN&IN too low.

Limitations

- Influence of infrastructure and range not explicitly considered.
- Energy price development uncertain.
- Acceptance of users, buyers and politics unclear.

Fraunhofer ISI

Conclusions and policy recommendations

Conclusions

- Electric trucks seem to be a cost- and energy-efficient option to decarbonize heavy duty-transport.
- Their technical limitations are worth to be addressed (e.g. through infrastructure set-up).

Policy recommendations

- The switch to alternative drives requires political action today.
- Infrastructure development can be carried out at limited cost, but must be prefinanced by the state.
- Large demonstration projects help to gain practical experience and create acceptance.

Plötz et al. (2018): Alternative drive trains and fuels in road freight transport – recommendations for action in Germany. Policy Brief. Karlsruhe, Heidelberg, Berlin. Nov, 2018.

Thank you for your attention!

Contact:

Dr. Till Gnann

Project Manager at Fraunhofer ISI

Dept. Energy Technology and Energy Systems

+49 721 6809-460

till.gnann@isi.fraunhofer.de

Further reading:

- Plötz et al. (2019): Impact of Electric Trucks on the European Electricity System and CO_2 Emissions; Energy Policy, Volume 130, July 2019, pp. 32-40, https://doi.org/10.1016/j.enpol.2019.03.042
- Plötz et al. (2018): Alternative drive trains and fuels in road freight transport – recommendations for action in Germany. Policy Brief. Karlsruhe, Heidelberg, Berlin. Nov, 2018.
- Gnann et al. (2019): Market potential of catenary hybrid electric trucks in different world regions. Electric Road Systems Conference (ERS). Frankfurt, Germany. May, 8, 2019.