Economic Aspects of Battery Electric Buses

DLR | Institute of Vehicle Concepts

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12.12.2018

IEA-HEV Task 33, Helsinki

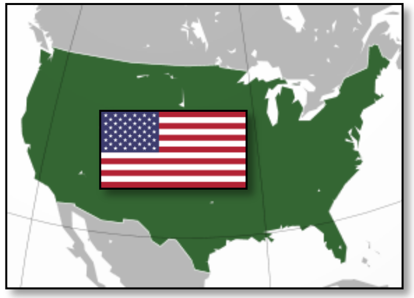
Bloomberg, Wikipedia, BVG, Proterra, Metro-Report
https://www.wiwo.de/unternehmen/dienstleister/3000-e-busse-vier-staedte-wollen-bis-2030-auf-elektro-busse-umstellen/23252304.html
http://www.latimes.com/, https://www.sfmta.com/, https://insideclimatenews.org/
http://www.sustainabletransport.org/archives/5770

When will large bus transit fleets be all electric?
China clearly sets the pace

- **China:** in part already today!
  - 20 % E-bus share in 2017 - but 70 % in sales (2016)!
  - 99 % of the world BEB fleet is located in China
  - Shenzhen has already transferred its whole 16000 bus fleet to BEB


- **Germany**: 2030 (and following years)
  - Transition from demonstration to commercialisation phase
  - 100 % E-buses by 2030 announced by the biggest cities:
    - Berlin, Hamburg, München, Köln, Frankfurt

- **USA**: 2030-2040
  - Los Angeles: 2030
  - San Francisco: 2035
  - New York: all-electric latest until 2040

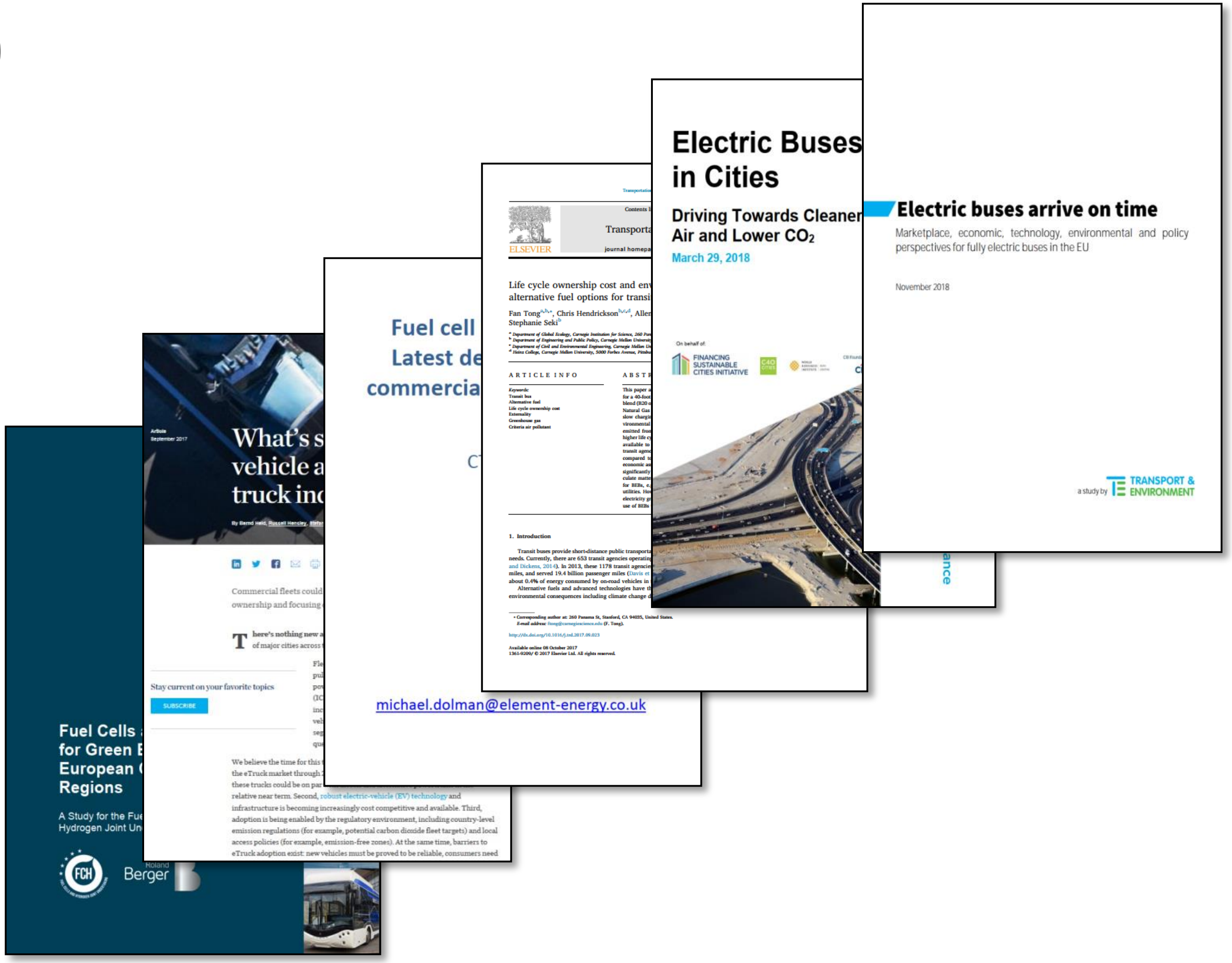



→ **It will be a mix of battery electric buses (BEB), fuel cell electric buses (FCEB) and trolley electric buses (TEB).**

TCO of battery electric buses (BEB)

Analysis of recent e-bus TCO studies

- TE [2018]: Electric buses arrive on time – Marketplace, economic, technology, environmental and policy perspectives for fully electric buses in the EU
  (Transport& Environment)
- BNEF [2018]: Electric Buses in Cities - Driving Towards Cleaner Air and Lower CO_2
  (Bloomberg New Energy Finance)
- Tong [2017]: Life cycle ownership cost and environmental externality of alternative fuel options for transit buses
  (Carnegie Institution for Science)
- Element Energy [2017]: Fuel cell buses in Europe: Latest developments and commerzialization pathway
  (Element Energy)
- McKinsey [2016]: What's sparking electric vehicle adoption in the truck industry
  (McKinsey)
- Roland Berger [2018]: Fuel Cells and Hydrogen for Green Energy in European Cities and Regions
  (Multi-stakeholder study for FCHJU)



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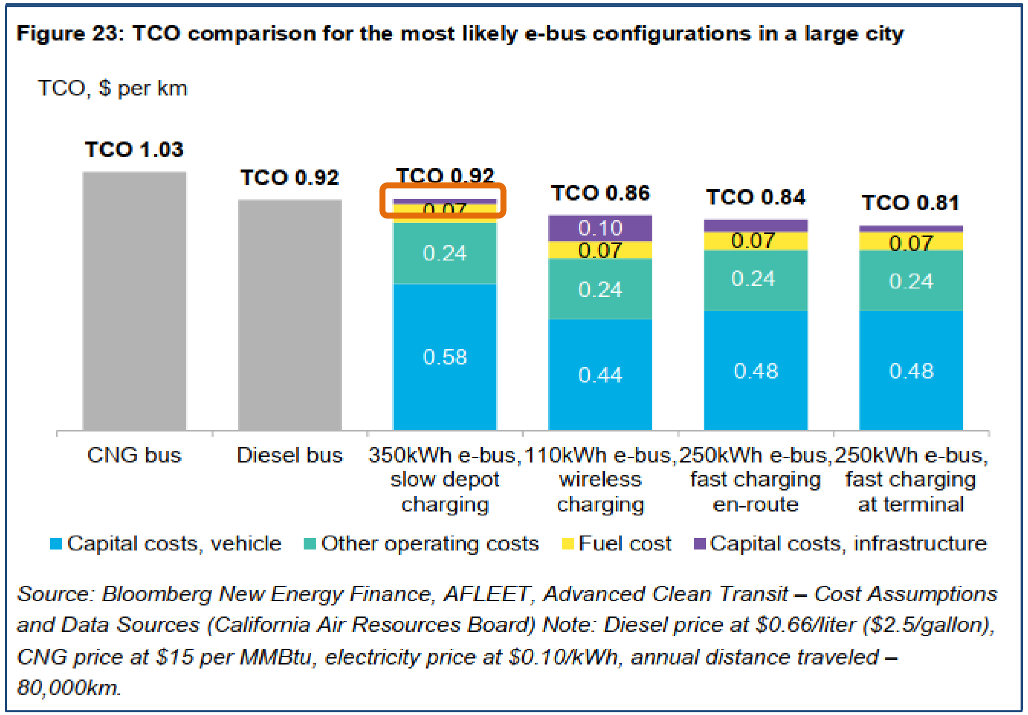
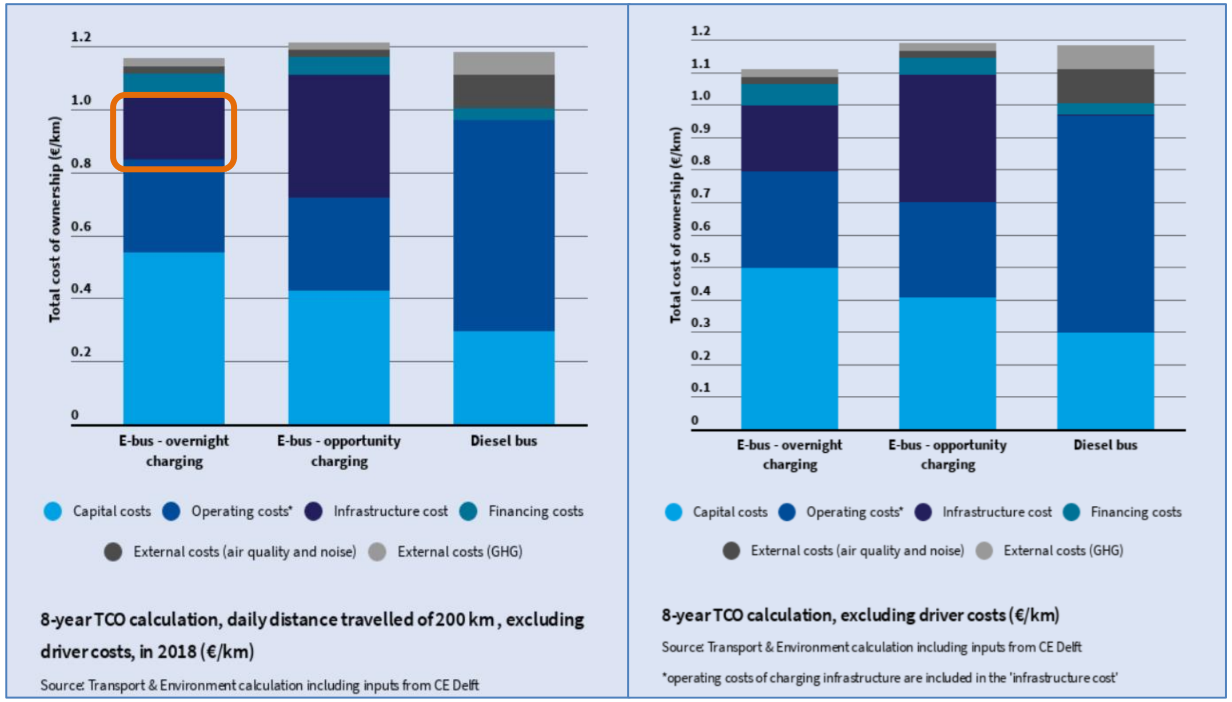
BNEF [2018]



TE [2018]

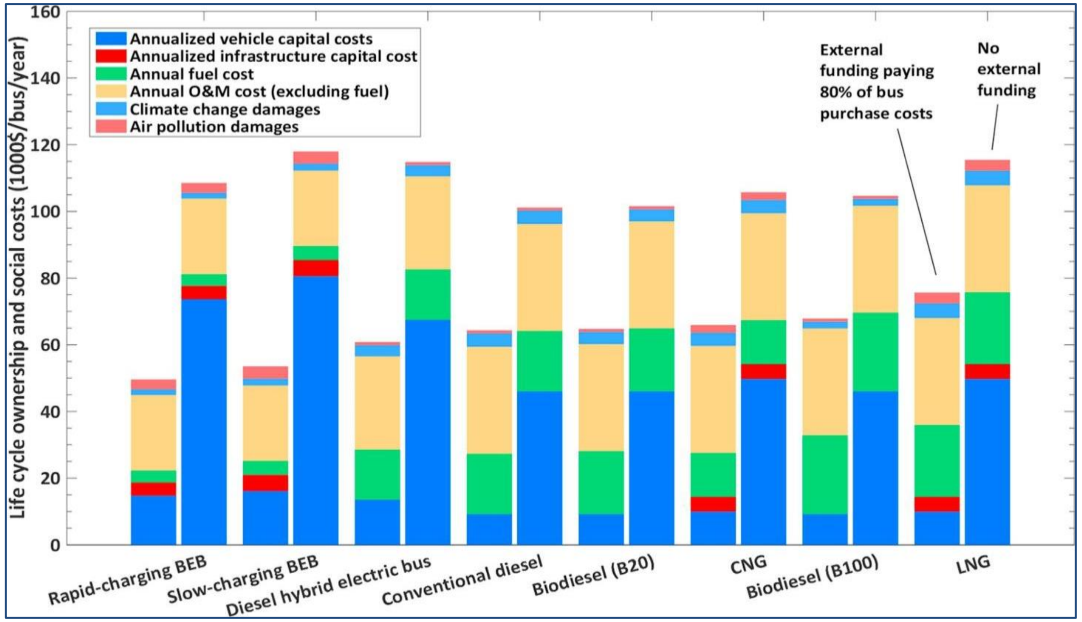


- The most recent 2018 BEB TCO studies of *Bloomberg New Energy Finance (BNEF)*, *Transport & Environment (TE)* and *Tong* (next slide, 2017) suggest **(near) cost parity of BEB and DB**
  -> but at different absolute cost levels!

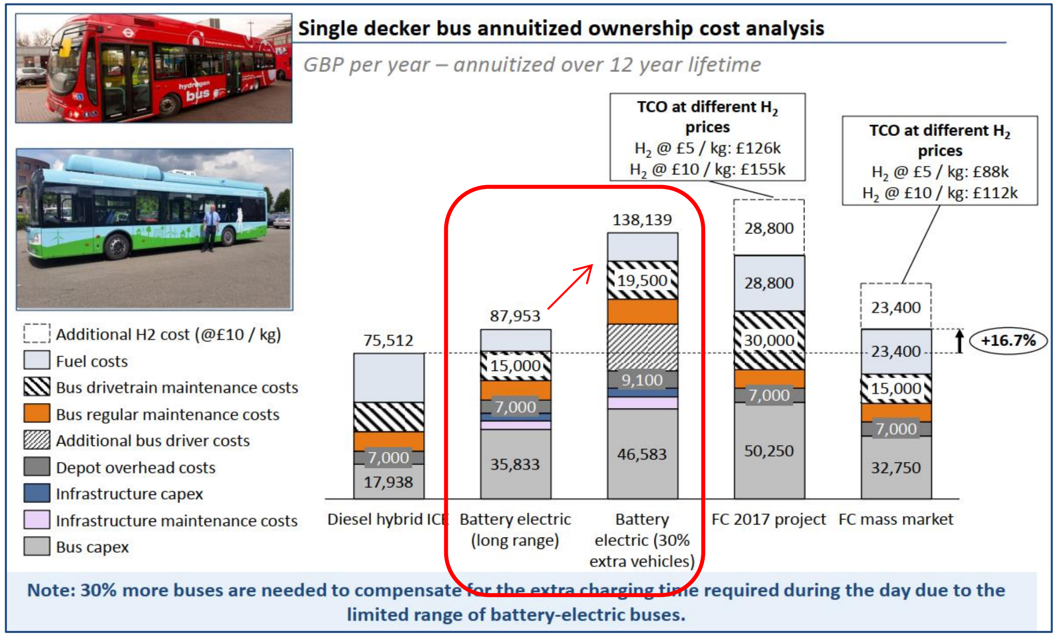
- TCO of *overnight charging BEB* is lower than TCO of *opportunity charging BEB* according to *BNEF* and *TE*
  - but higher acc. to *Tong* (next slide)

- *TE* estimates much higher infrastructure CAPEX than *BNEF* and *Tong*

Tong [2017]



Element energy [2017]



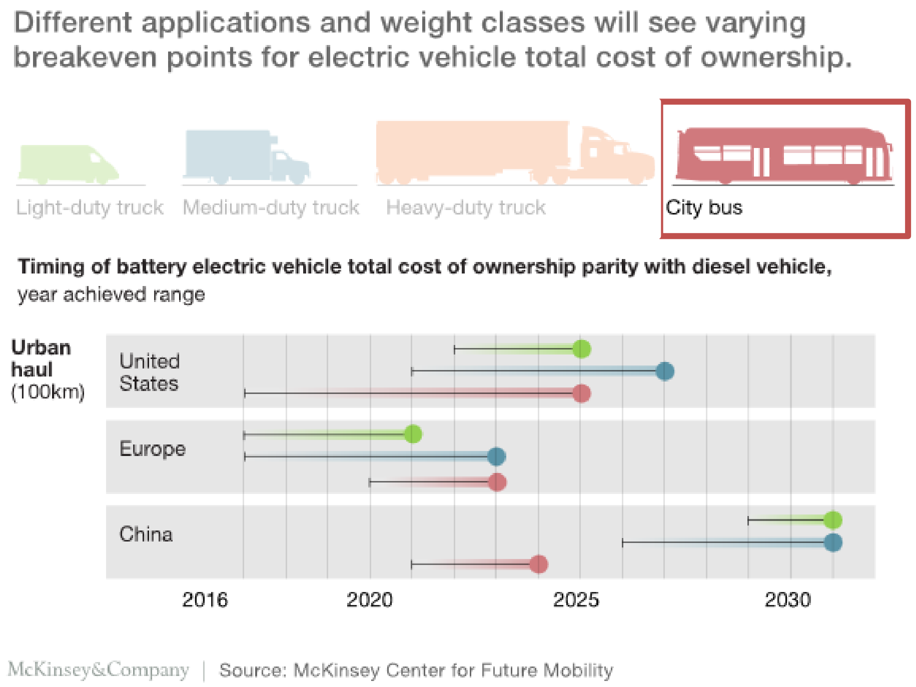
- *Tong [2017]*: If **CAPEX** are **subsidized** to a large degree, BEB outperform DB in terms of TCO

  (e.g. the German federal government funds 80 % of CAPEX markup to DB)

- *Element Energy (Ballard) [2017]* stress potential need of **additional BEB** because of range limitations
  (and thus, the mark-up of FCEB against BEB and DB decreases)

- Some studies also include **external (environmental) costs** which shifts the picture towards BEB
  -> the external cost effect however is not that big on total TCO (ca. 5-10 %)

- *McKinsey [2016]*: **TCO parity of BEB/DB** will be attained between **2023-2025** (earliest in Europe, then in China, followed by the US)



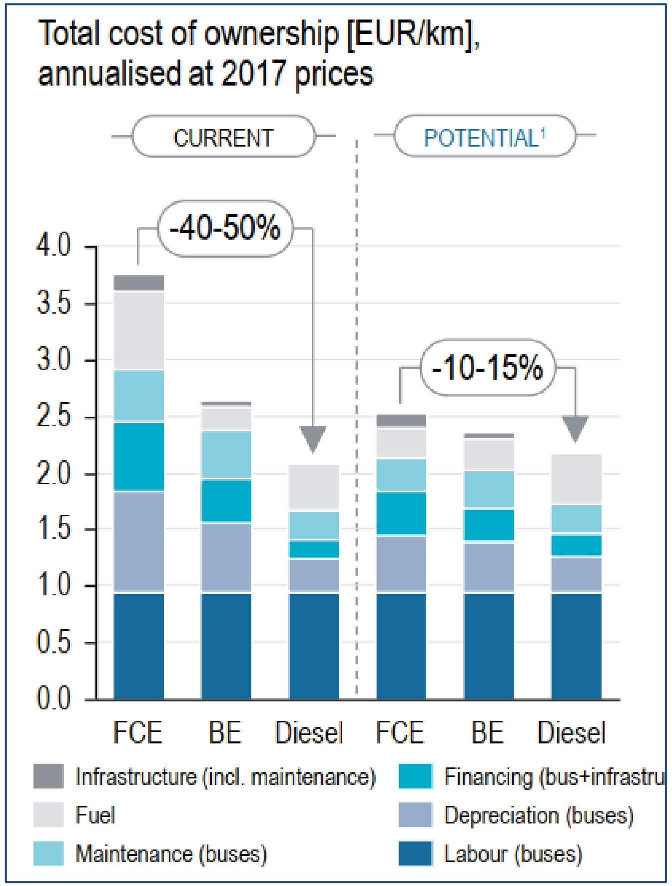
McKinsey [2016]

- *Roland Berger [2018]* claims TCO markups today:
  - 80 % (FCEB vs. DB)
  - 42 % (FCEB vs. BEB)
  - 26 % (BEB vs. DB)

- FCEB TCO markups are projected to decrease down to
  - 16 % (FCEB vs. DB)
  - 9 % (FCEB vs. BEB)
  - 7 % (BEB vs. DB)

→ Robust drop of CAPEX and fuel costs required

- This (FCHJU funded) study estimates much higher BEB costs than the other studies
- 175 cities and industry stakeholders involved



Roland Berger [2018]

BEB CAPEX

- **Economies of scale** will likely reduce BEB costs in the future
  - Batteries
  - Series bus production
- **High** up-front **battery cost** is still major cost driver (2-2.5 times higher BEB price than DB)
  - Battery prices will decrease in the long term provided there are no significant battery production capacity constraints and critical raw materials are available sufficiently

- Unsubsidized CAPEX cost parity with diesel buses between 2023 and 2030 studies say

- **Prices of buses within China** are generally much **lower than in US and EU**: DB: 94 k$, BEB: 250 k$ (Asian Development Bank [2018]) -> but same cost markup factor between BEB and DB

Trends of BEB OPEX

Energy	Maintenance	Component replacement	Driver

• Drivetrain efficiency uptake
• Advanced HVAC systems like heat pumps
 	
• Diesel price increase (taxes, also on CO2… ?); regional price and tax levels differ
 	
• *Diesel* is non-critical in countries with poor infrastructure - whereas *electricity supply* often is
	• Electric drivetrains require less maintenance than diesel drivetrains
	
	Issues:
	• Availability enhancement
	• Decrease of downtimes
		• Battery lifetimes will improve through
		  • LTO-based battery chemistries
		  • cell balancing
		  • improved thermal management
		
		• Longtime goal: no battery exchange during bus lifetime of 12-15 years
			• Driver costs form substantial part of TCO – but are usually not included in the studies
			• Today: additional driver demand (service interruptions)
			
			• If bus operation can be automated (SAE Level 5), driver costs (0.8-1.5 €/km in Germany) can be omitted (at least partly), reducing TCO substantially

Infrastructure

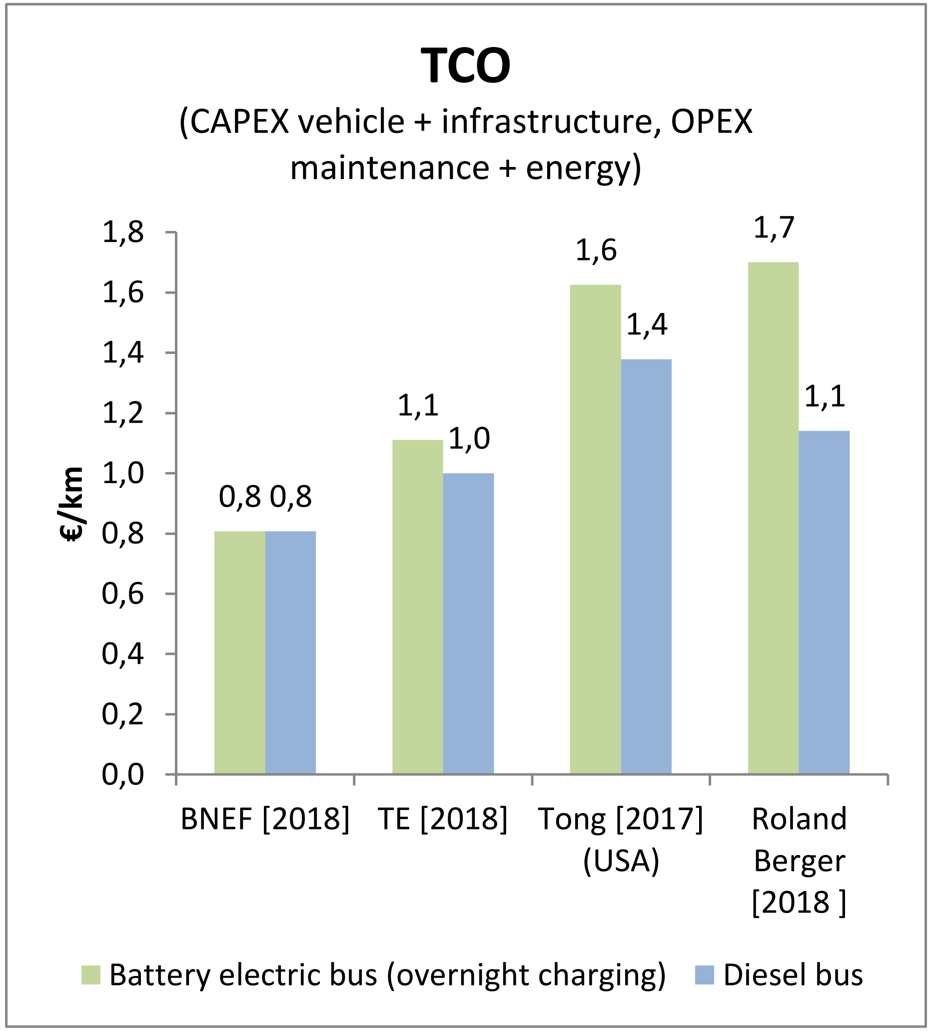
- Charging infrastructure is in absolute terms a big investment position, but becomes less important on a *cost per km* base
- With large fleets, bigger investments into new substations or even grid upgrades might become necessary
- Back-up solutions in case of blackouts? (hydrogen might be better suitable for multi-day energy storage)

https://www.electrive.com/
https://insideevs.com/

BEB TCO - study comparison

- There is a wide TCO span across and within studies depending on the frame conditions
- Also the single cost blocks and assumptions (infrastructure costs, energy and lifetime in particular) differ widely across studies
- BEB have nearly reached cost parity with DB claim three out of four studies
  -> But: additional BEB may be needed due to limited operational flexibility (range)
  -> also: additional risk costs due to availability issues?
- Tong [2017] calculate higher costs both for DB and FCEB
- High BEB TCO in Roland Berger [2018] (financed by FCHJU) attributable to additional knowledge of the FCEB community?

→ More in-depth study-comparison is required to harmonize the study-inherent different frame conditions of the studies (mileage, energy costs,…)

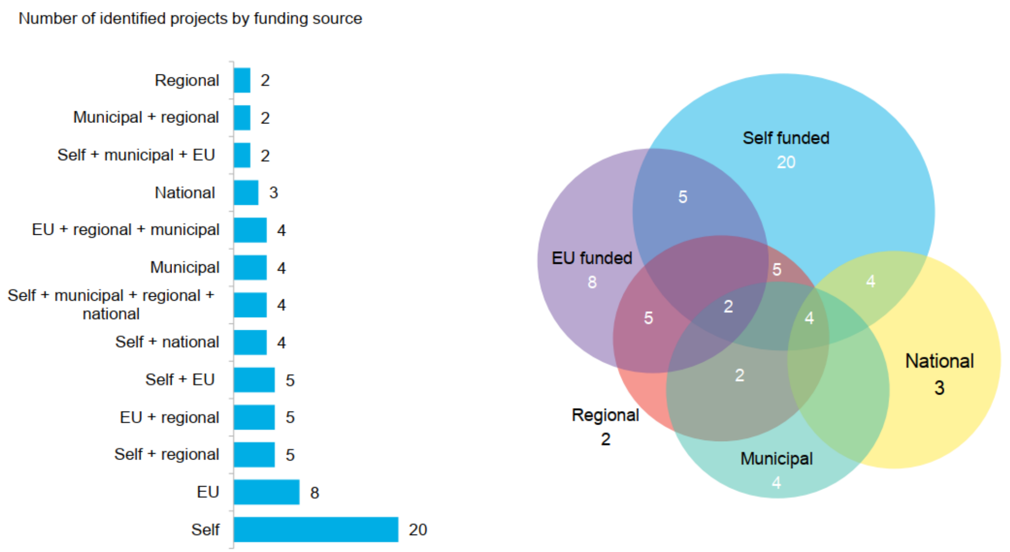


(without driver and external costs; 1 € = 1.14 US$)

Subsidies / Public Funding

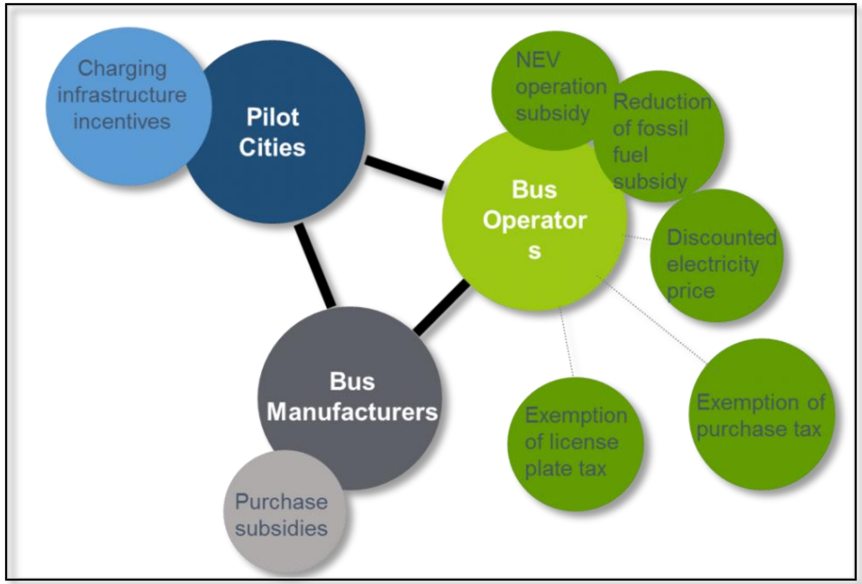
- Subsidies can close the (current) TCO gap – it is a mix of funding sources
- National and supranational funding (usually CAPEX) is often a prerequisite for economic viability
- Current German national funding scheme (80 % of BEB CAPEX markup against DB) caused a run on (limited) funds
- Joint procurement will lower BEB prices through scale effects
- China shifts from CAPEX to OPEX subsidies and the cut of diesel fuel subsidies

Figure 7: Electric bus funding sources for selected European e-bus projects



BNEF [2018]

Chinese bus subsidy strategies



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Generalized economic aspects

- The analyzed BEB TCO studies come to quite different results
- **In practice, the case individual BEB TCO will depend on a variety of frame conditions:**
  - Line network structure (line lengths, daily mileage, elevation profile)
  - Type and number of required recharging infrastructure
  - Climatic conditions
  - Energy costs (diesel, electricity, sectoral coupling incentives)
  - Labor costs (reserves in case of service interruptions)
  - Bus CAPEX and level of subsidy (or taxation/penalty respectively)
  - Bus lifetime and annual mileage
  - Interest level (what if the central banks increase interests)
  - Risk allowances

→every case is different – and linked to country, operational and site specific conditions

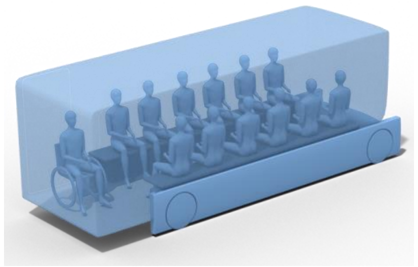
Technology development
The future bus

- How will future e-bus technologies shape the next generation BEB?

Battery	• cost decrease • increased cycle stability and energy density
Drivetrain	• gearless PMSM free up space for passengers
Lightweight construction	• lightweight structures can open up mass reserves for larger capacity batteries
Automation	• no drivers cabin required freeing up space for passengers • smaller, flexible units • mobility-as-a-service
Modular design	• Modular passenger/freight capsules

CNH Industrial Design, Iveco , L'École de design Nantes Atlantique

Postauto: Autonomous Shuttle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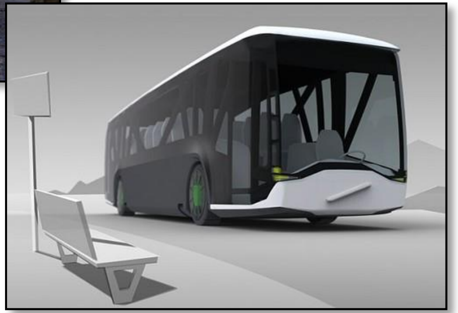
http://psipunk.com/safety-bus/


Mercedes Benz

proEME - Decision Support Model for Busses

- TCO web tool and mock-up for trucks has been developed as an outcome of the ICVUE project
- Now, DLR develops within the ProEME project a **DSM** (decision support model) for trucks and a tool is planned also **for busses**
- We will be happy to cooperate with interested parties

contact: oezcan.deniz@dlr.de

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Thank you for your attention

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