EVS35
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Fraunhofer

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» What is the right battery size for an electric truck with respect to its charging infrastructure?

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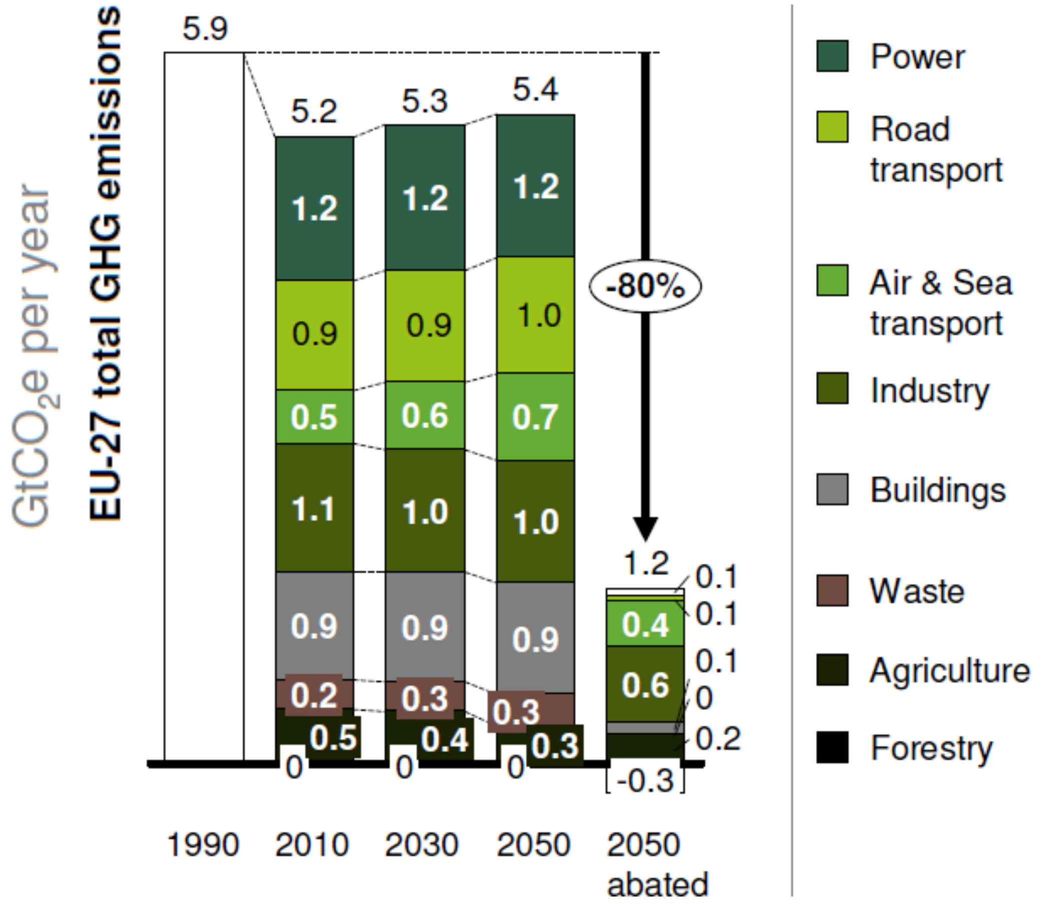
To achieve Europe‘s climate targets, a drastic reduction in transport CO_2 emissions is needed



- The EU‘s long term goal is to reduce GHG emissions by 80% until 2050
- **Germany** wants to be **carbon neutral in 2045**
- Power production and road transport have to become almost CO_2 free
- This is **impossible with** efficiency gains in **combustion engines**
- New technologies and concepts are clearly needed.
- **Electric vehicles powered by renewable energies** can contribute significantly

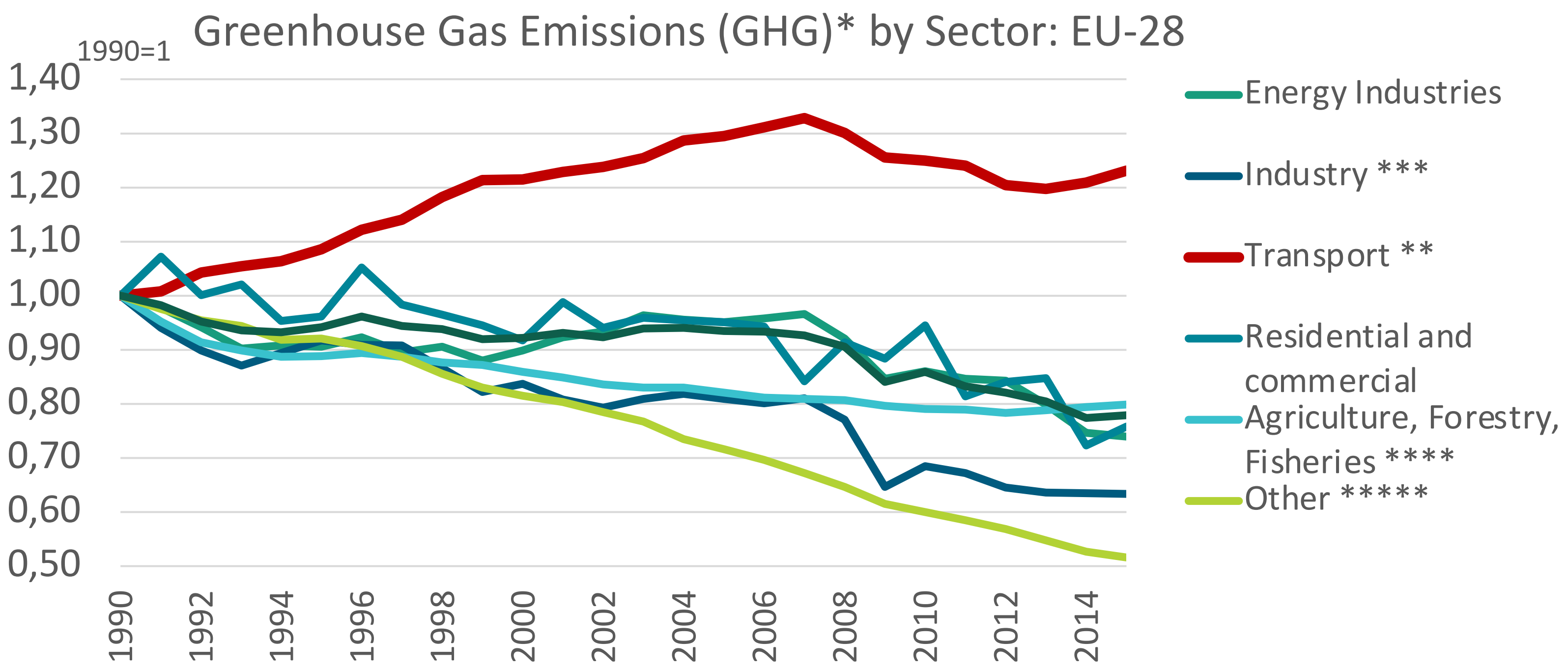
Source: www.roadmap2050.eu

Energy consumption and GHG emissions in transport have been growing though.

Transport is the only GHG sector with growing emissions!

All efficiency increase has been overturned by increased activity (usage)

Both passenger and freight transport are expected to grow further.



Research questions:

How can the different transport modes change to alternative fuels in 2050?

How much renewable eletricity do we need?

Source: European Environment Agency (EEA), June 2017

* Excluding LULUCF (Land Use, Land – Use Change and Forestry) emissions and international maritime, including international aviation and indirect CO2

** Excluding international maritime (international traffic departing from the EU), including international aviation

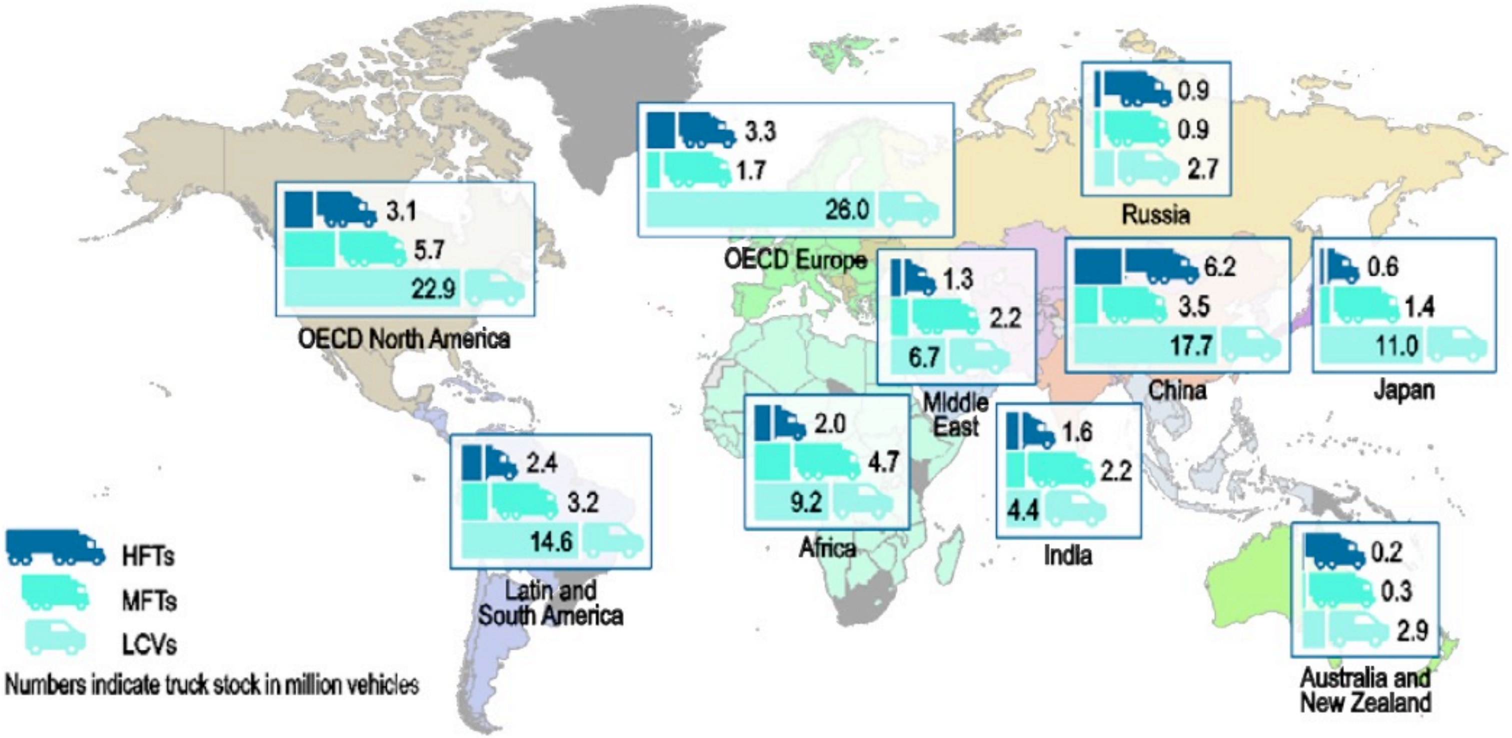
*** Emissions from Manufacturing and Construction, Industrial Processes and Product Use

**** Emissions from Fuel Combustion and other Emissions from Agriculture

***** Emissions from Fuel Combustion in Other (Not elsewhere specified), Fugitive Emissions from Fuels, Waste, Indirect CO2 and Other

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

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

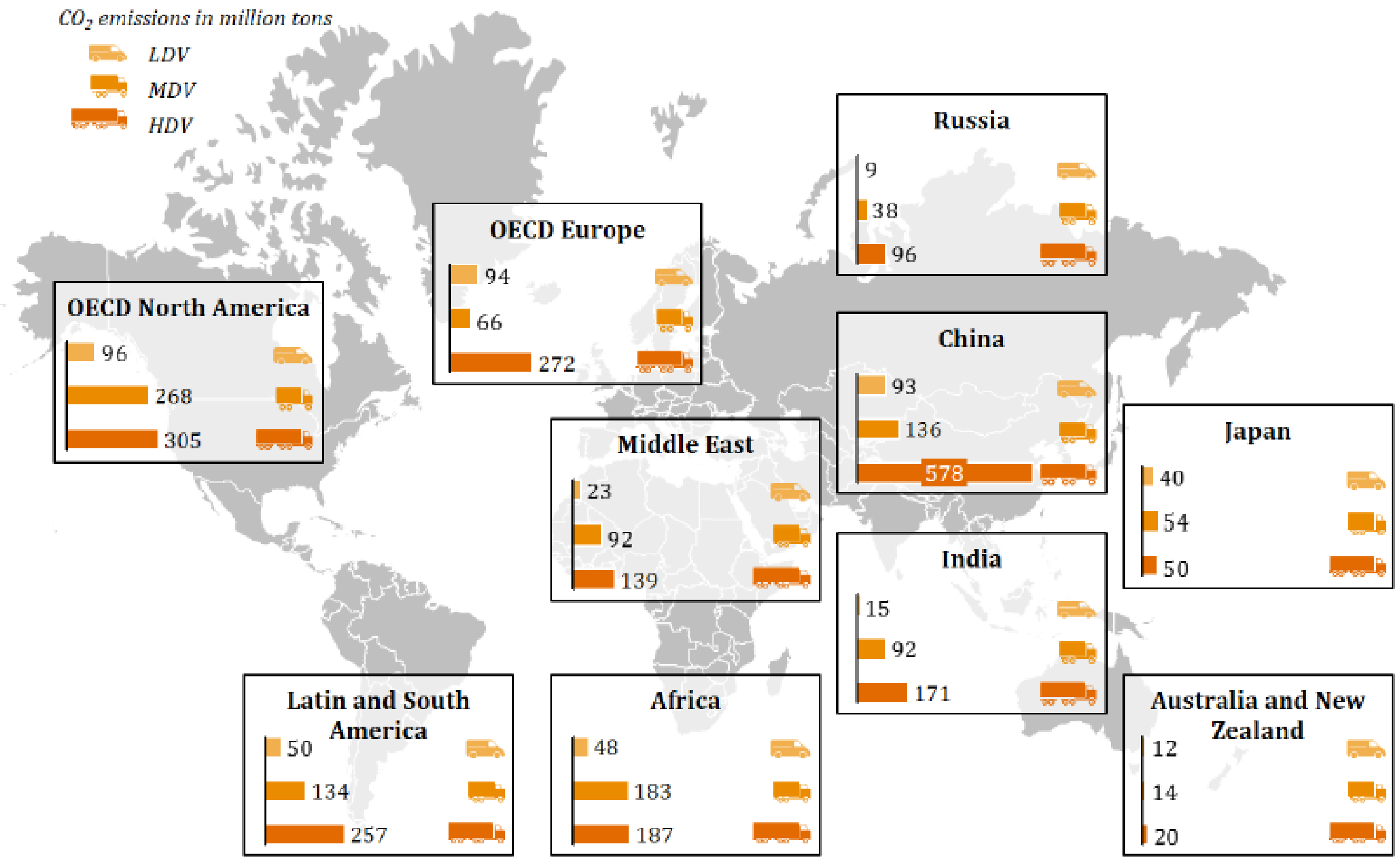


Figure source: Kluschke et al. (2019): Decarbonization of heavy-duty vehicles: A literature review of alternative fuels and powertrains, Energy Reports, DOI: 10.1016/j.egyr.2019.07.017.

Electric trucks offer a large GHG reduction potential while their market potential depends on the battery size and infrastructure.

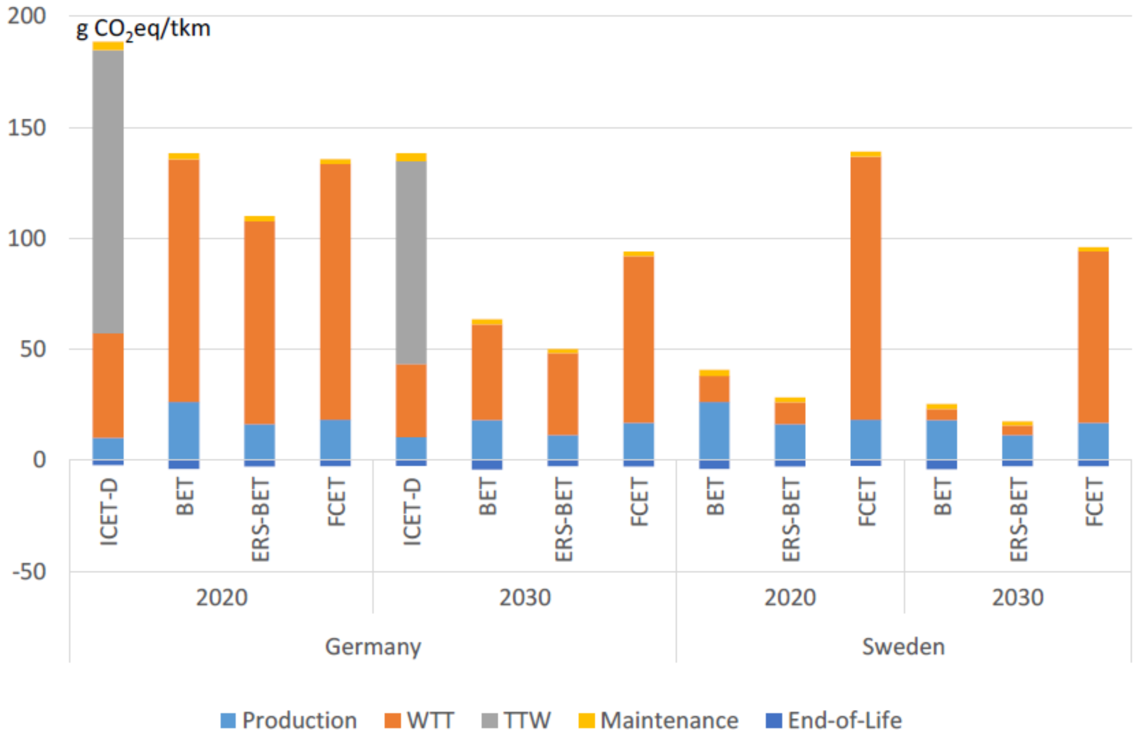


Figure 1: Lifetime impacts by powertrain type[2] for Artic Lorry 40t GVW in Germany and Sweden 2020 and 2030. Life-time mileage 800.000 km, BEV battery capacity of 990 kWh (2020) and 1450 kWh (2030), Hydrogen mostly steam reforming (100 % in 2020 and 90 % in 2030). Source: Results Viewer from (Hill et al. 2020).
Abbreviations: *WTT = Well-to-tank, TTW = Tank-to-wheel, ICET-D = Internal combustion engine truck with diesel, BET = Battery Electric Truck, ERS-BET= Electric road system battery electric truck; FCET = fuel cell electric truck, tkm = ton kilometre.*

- Battery electric trucks (BET) powered at high power charging stations (HPC) or electric road systems (ERS) offer the largest GHG reduction potential
- Range and market share depends on infrastructure and battery size

→ What is the right battery size for an electric truck wrt charging infrastructure?

We perform a monte carlo simulation with 1,000 random combinations for infrastructure and battery size in 2030 and 2050.

Method: Monte carlo simulation with 1,000 calculations for market potential in 2030 and 2050 with the model ALADIN (www.aladin-model.eu).

Assumptions:

- Daily mileage := annual VKT divided by 260 working days
- Mileage on highways is based on [4] as $s_h = 1 - exp(-\frac{dVKT}{L_0})$ with L_0 = 127.3 km
- HPC charging infrastructure rolled out based on utility with maximum coverage of 2,258 charging stations [8] with 100 km maximum distance between charging stations and **20% BEV charging in public**.
- BET can charge overnight in a depot and starts his daily trips with a full battery. The **battery range charged at the highway** is calculated as $\boldsymbol{r_{HPC} \coloneqq \kappa \cdot \frac{n_{HPC}}{2{,}258}}$ with n_{HPC} being the number of HPCs and κ the battery capacity.
- The **infrastructure for CET** is constructed based on truck usage. For individual user, this results in an individual utility $\boldsymbol{u_{BAB}(x)=1-\Phi(\Phi_{-1}(1-x)-\sigma^2)}$ with σ = 1.19 and x is the share of highway-km traveled

parameter	Value range 2030	Value range 2050
battery capacity of BET	[100, 500]	[100; 1000] -
battery capacity of CET	[100, 500]	[100; 1000]
HPC infrastructure density [number of HPCs]	[0;677]	[0; 2258]
overhead line infrastructure [total construction in km]	10	[500; 4,500]

Energy carrier price	2030	2050
Gasoline price	0.233	0.293
Diesel prices	0.197	0.261
Hydrigen price	0.285	0.235
LNG price	0.212	0.304
Electricity price industrial	0.101	0.085
Battery price BET	100	80
Battery price PHET	110	88
Fuel cell price	80	55

We use the model ALADIN (**Al**ternative **A**utomobiles **D**iffusion and **In**frastructure) to determine market shares.

ALADIN
ALternative Automobiles Diffusion and INfrastructure

User-specific analysis

User behaviour

Driving profiles

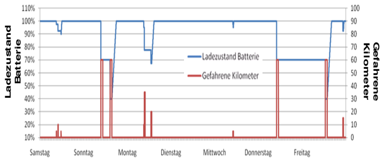
- All trips over at least one week: distance, duration, purpose, dep. & arrival time
- Owner information: gender, age, income, garage, city size
- Vehicle size, brand, age

EV user acceptance

- Willingness-to-pay-more by adopter status (innov., early adopter, majority, laggards)
- Limited charging infrastruc.
- Limited vehicle choice EVs

Model steps

Individual EV simulation



For each user i:
- Feasibility BEV
- Electric driving share PHEV / REEV

Individual utility maximisation

For each user i and propulsion technology p:

$$\max_p \left(-\mathrm{TCO}_{ip} + \text{willingness-to-pay-more}_{ip} + -\text{limited choice}_{ip} - \text{home charging cost}_{ip} \right)$$

- Optimal vehicle choice for each user

Parameters

Vehicle dependent

- *Technical*: battery sizes, DoD, el./conv. consumption
- *Economical*: car prices, taxes, O&M costs, resale values
- *Policies*: subsidies, taxes,

Vehicle independent

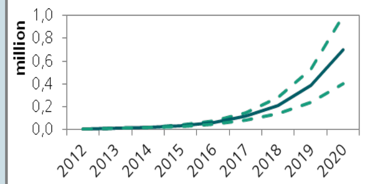
- Fuel/battery/electricity prices until 2020
- Costs for home charging
- Future EV availability

aggregated

Differentiation

- *3 user groups:* private, commercial, company car
- *4 vehicle sizes*: S, M, L, LCV
- *6 technologies*: BEV, PHEV, gasoline, diesel, FCEV, NGV

Stock model

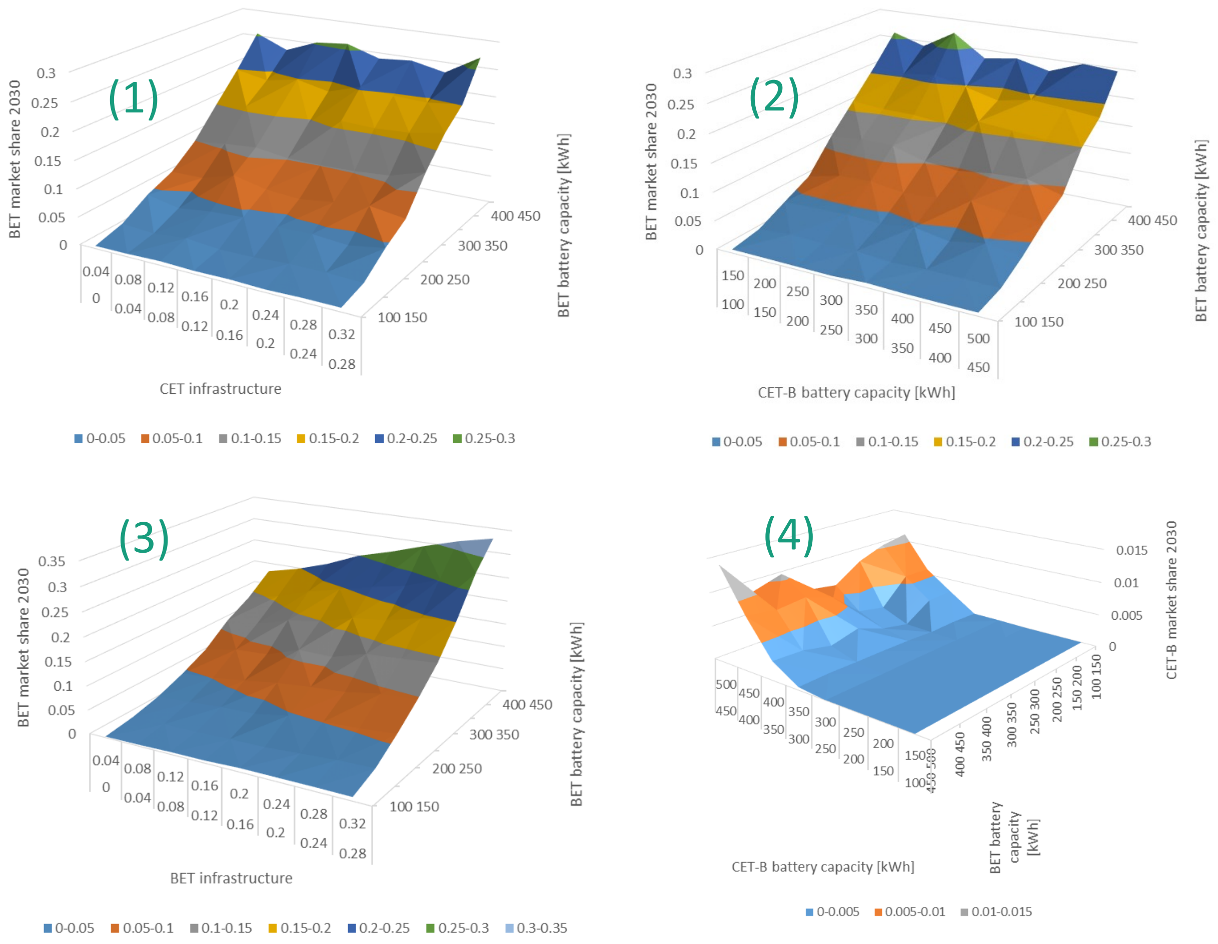


Projection of:
- Vehicle stock
- Primary charging points stock
- Sales in user group

Car market

- Registrations in user group and vehicle size class
- Stock & sales parameters
- Future availability of EVs

In 2030, we do not find an optimal battery capacity for electric trucks.



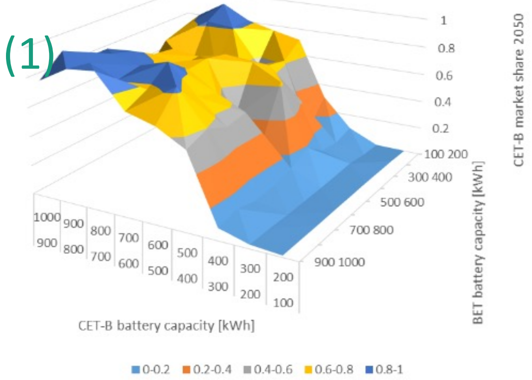
- market share of BET increases with battery capacity not influenced by CET infrastructure (1) or CET-B battery capacity (2)
- market shares of BETs can be further increased with more HPCs (3)
- market shares of CET-B can be increased with battery capacity - also independent of BET battery capacity (4)
- additional infrastructure for CET-B without show a strong effect (not shown)

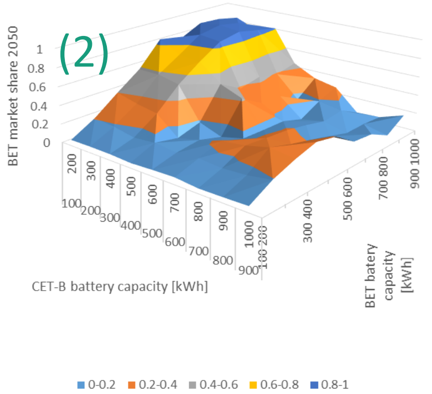
→ **In 2030**, adding **battery capacity is the main factor** to increase market shares

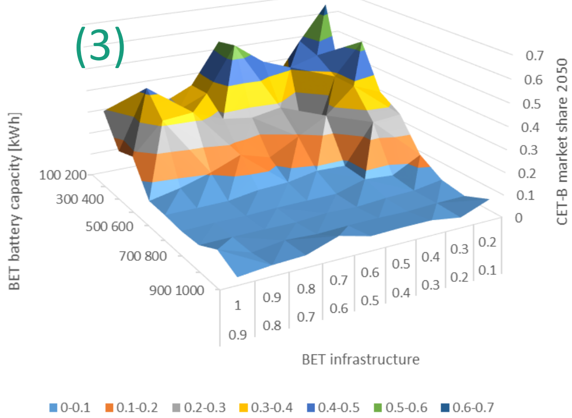
→ Pure **infrastructure increase is not sufficient** for both technologies

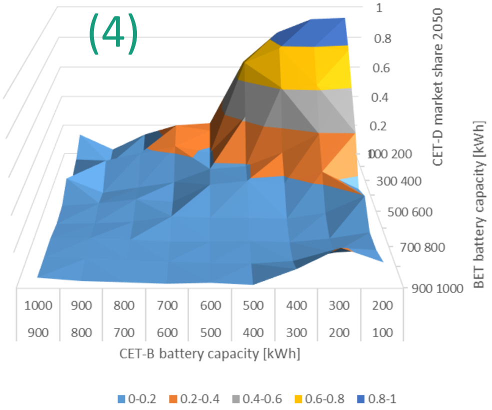
In 2050, both technologies compete for market shares.

- Market share of CET-B increases with battery size up to 700 kWh independent of the BET battery size (1) (see 2030)
- Market shares of BET decreases when CET-B batteries are large or the battery capacity of BETs is low (2)
- Market share of CET-B also dependent on BET battery capacity and infrastructure setup (3).
- If battery capacities for BET and CET-B are low, CET-D gain the highest market shares (4).
- Increasing the infrastructure for CET does not show clear effects on market shares (not shown)

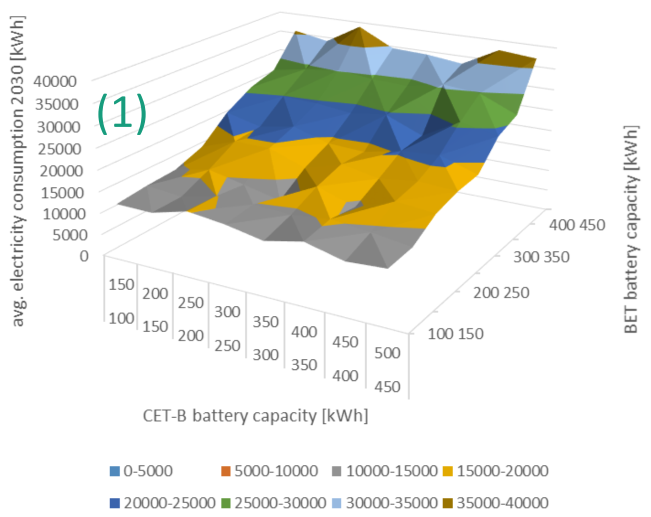


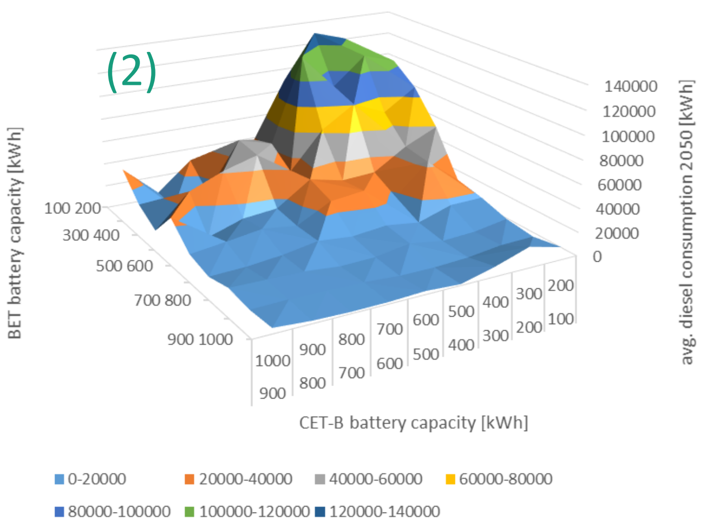






Battery capacity of both technologies affect the energy consumption in 2050.





- In **2030**, we can **increase** the **electricity consumption** by **increasing BET battery size**
- Increasing CET-B battery capacity has hardly any effect in 2030 (1)
- In **2050**, the **diesel consumption is highest when BET and CET-B battery capacities are low** (2) (see also (4) on previous slide)

Summary

First results on the dependence of battery capacity and infrastructure setup on market shares of battery electric and catenary electric trucks in 2030 and 2050 with monte-carlo-simulation:

(1) Market share for **BET and CET-B mainly depend on their battery capacity in 2030** and are only affecting each other in 2050

(2) Additional **infrastructure** seems to only have a **limited effect on market shares** for BET and hardly any on CET-B

(3) By **increasing battery capacities**, the **use of electricity can be increased**; otherwise diesel remains the dominating fuel in this setup.

Further analyses will also comprise the investments for battery capacities and infrastructure.

THANK YOU FOR YOUR ATTENTION

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