ATTRACTIVENESS OF ALTERNATIVE FUEL TRUCKS WITH REGARD TO CURRENT TAX AND INCENTIVE SCHEMES IN GERMANY: A TOTAL COST OF OWNERSHIP ANALYSIS

Fraunhofer Institute for Systems and Innovation Research ISI

Daniel Speth, Lena Kappler, Steffen Link, Marc Keller

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1. **Motivation**
2. Methodology and data
3. TCO
4. Conclusion, improvements and outlook

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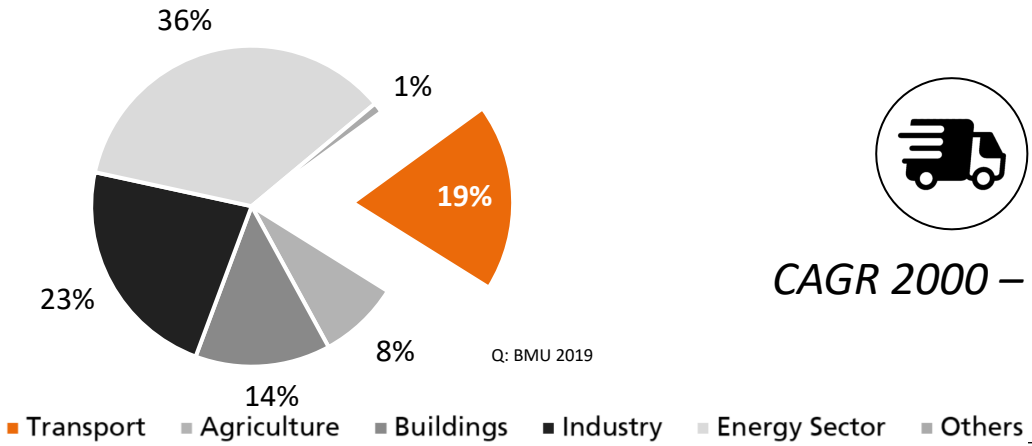
The global CO2 challenge is not just about electricity – spotlight on the transport sector in Germany

2018 CO2 Emission



Q: BMU 2019

Transport Performance

+2%

CAGR 2000 – 2015

Q: BMVI 2020

Technological Pathways

Direct use of electricity

e.g.

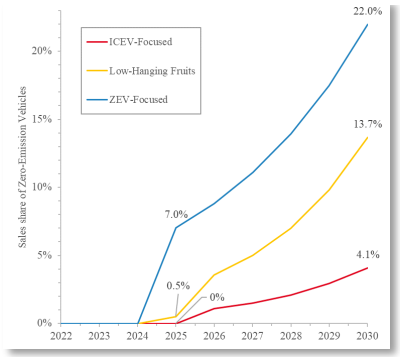
- *battery electric trucks (BET)*
- *plug-in hybrid trucks (PHET)*

Indirect use via synthetic energy carriers

e.g.

- *ICE trucks with synthetic fuels (DT)*
- *fuel cell electric trucks (FCET)*
- *hydrogen IC engine trucks (H2T)*
- *natural gas trucks (GT)*
- *plug-in hybrid trucks (PHET)*

Future Sales Shares of ZEV



Q:

Breed et al. (2021): CO2 fleet regulation and the future market diffusion of zero-emission trucks in Europe. https://doi.org/10.1016/j.enpol.2021.112640

Proposal for a Regulation of the European Parliament and of the Council on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU of the European Parliament and of the Council. Brussels

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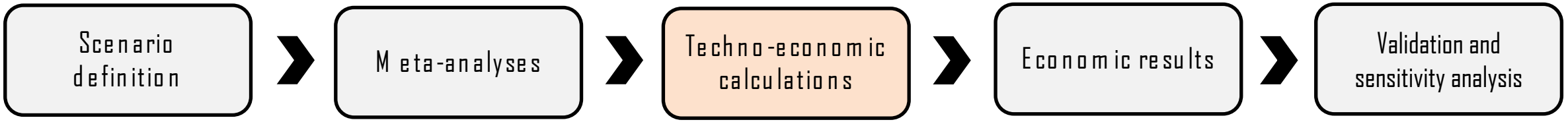
We used five main process steps and a modular approach for important parameters

Logical sequence



Modularity and Transferability

Based on Gnann et al. (2017), we accounted for market specific parameters – Most important:

Annual vehicle mileage

Energy prices

Toll

Taxes

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We compare six technologies in 2020, 2030 and 2050 via TCO with their net present value

TCO calculation

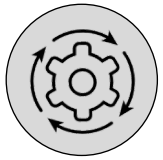
Full-cost accounting with present value

Main aspaects

Acqusition

Vehicle purchase price, residual value

Operating costs



Energy and fuel costs, insurance costs, maintainance and repair, toll, taxes

Formula

$$TCO = I_0 - S_0 - \frac{RV_T}{(1+i)^T} + \sum_{t=1}^{T} \frac{c_{fixed,t} + c_{var,t}}{(1+i)^t}$$

$$c_{\mathrm{fixed,t}} = c_{\mathrm{Ins}} + c_{\mathrm{Tax}}$$

$$c_{\mathrm{var,t}} = VKT * (c_{energy} + c_{\boldsymbol{O\&M}} + c_{Toll})$$

Scenarios

40t tractor-trailer with 100-1,000 km range

6 technologies:

- Diesel (synthetic/ biogenic fuels)
- BET
- FCET
- H2-ICE
- Natural Gas trucks
- PHET

3 timestamps:

- 2020
- 2030
- 2050

2 perspectives:

- company
- federal

Abbreviations and parameter description, see appendix

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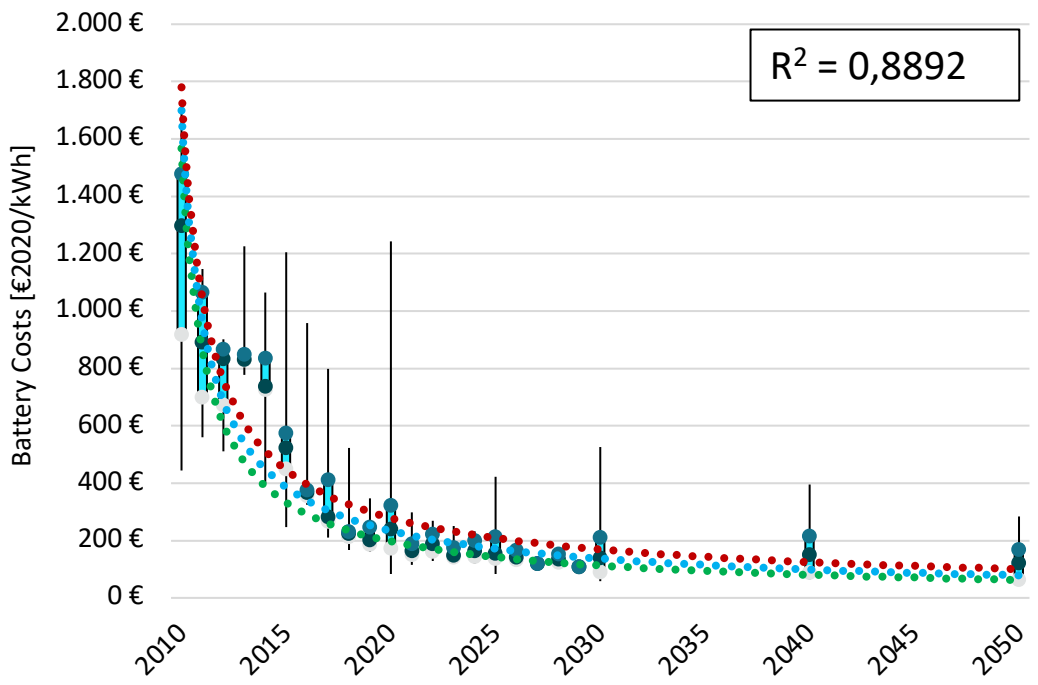
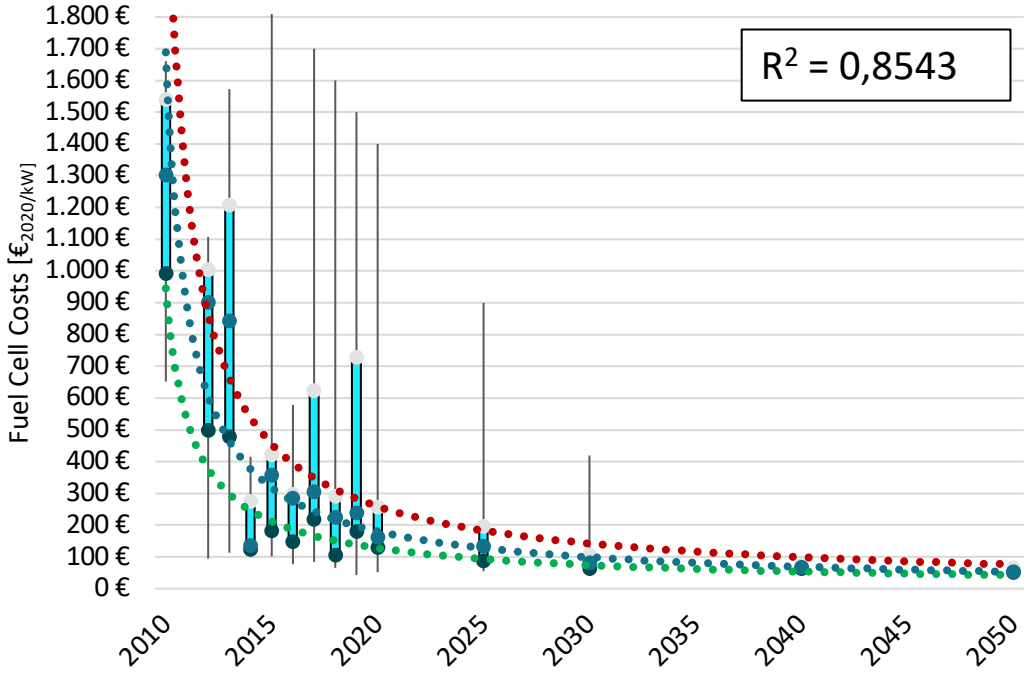
A meta-analysis for major components costs helped to derive meaningful cost projections

Battery Costs [€2020/kW]



		2020	2030	2050
Battery	€/kWh	235	139	80

Fuel Cell System Costs [€2020/kW]



		2020	2030	2050
PEM Fuel Cell	€/kW	181	99	53

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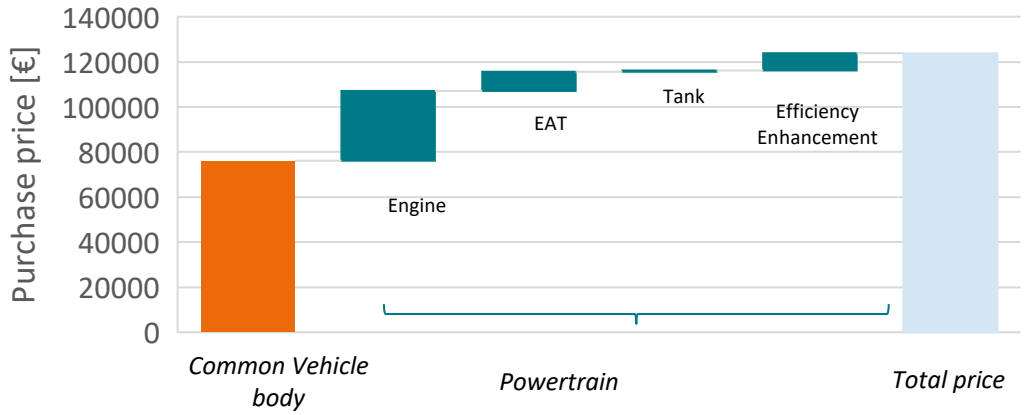
Component-based price modeling with common vehicle body

Bottom-up price modelling



		2020	2030	2050
DT	**€**	115,400	123,900	134,000
GT	**€**	137,200	140,600	143,900
PHET	**€**	178,500	164,700	144,800
H2T (1000 km)	**€**	252,900	208,200	164,000
FCET (1000 km)	**€**	310,000	231,300	164,100
BET (1000 km)	**€**	619,300	390,100	253,300

* without trailer; company perspective => in 2020 80% reduction on purchase price of BET, FCET and PHET (subsidy)

Assumptions & Variations

Main Assumptions

- vehicle purchase price without reduction as basis to calculate vehicle insurance
- toll exemption for ZEV in 2020
- energy price development follows [37]
- 6 years of service, 120,000 km/a, interest rate of 9.5 % for all drivetrains

Main variations for federal perspective

- not included: vehicle purchase price reductions, toll exemption, cap of hydrogen & electricity prices
- annual interest rate: 4%

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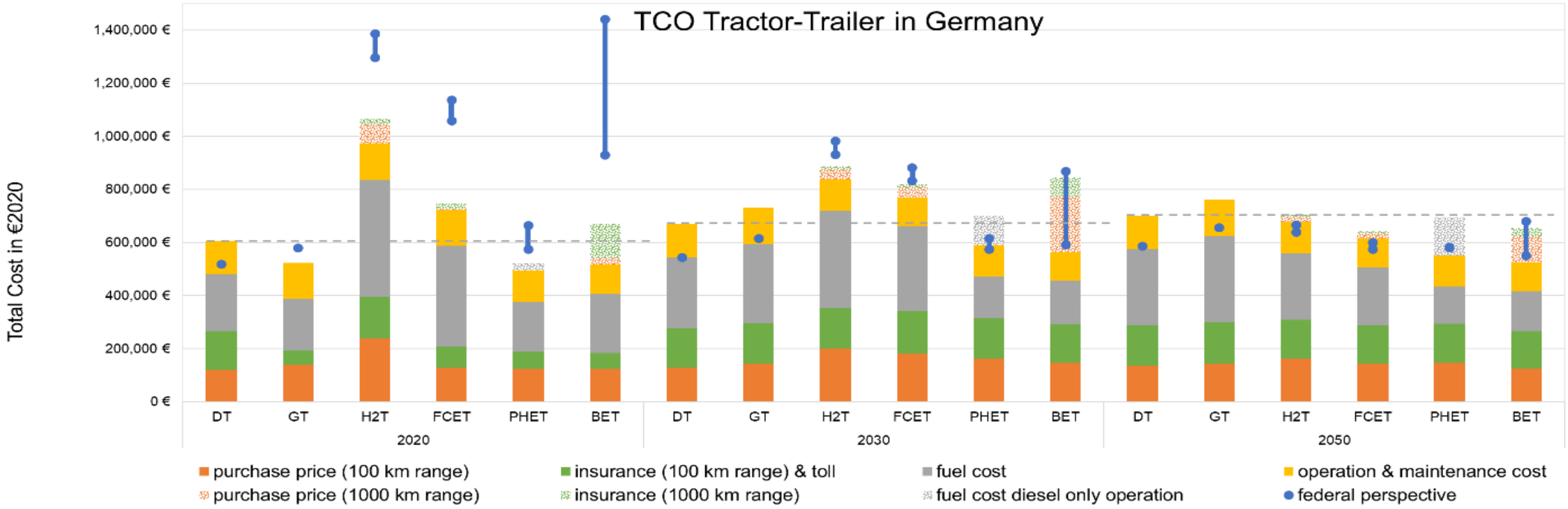
Total Cost of Ownership Comparison – operating costs dominate and will make ZEV attractive



In the medium term, BET is the cheapest alternative (depending on battery size);
In the long term all ZEV are cost-competitive compared to the DT

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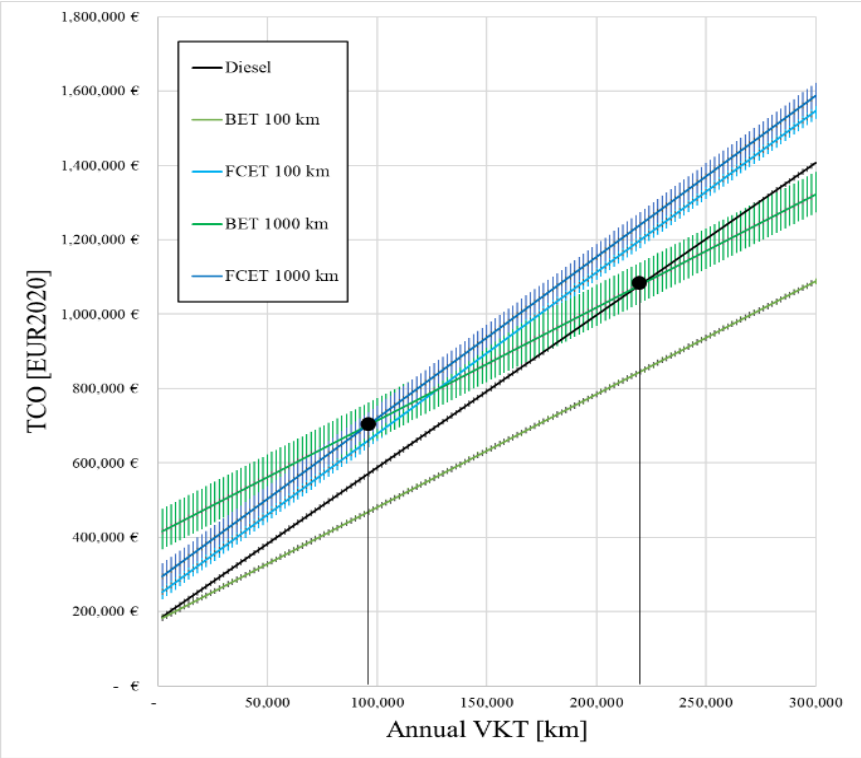
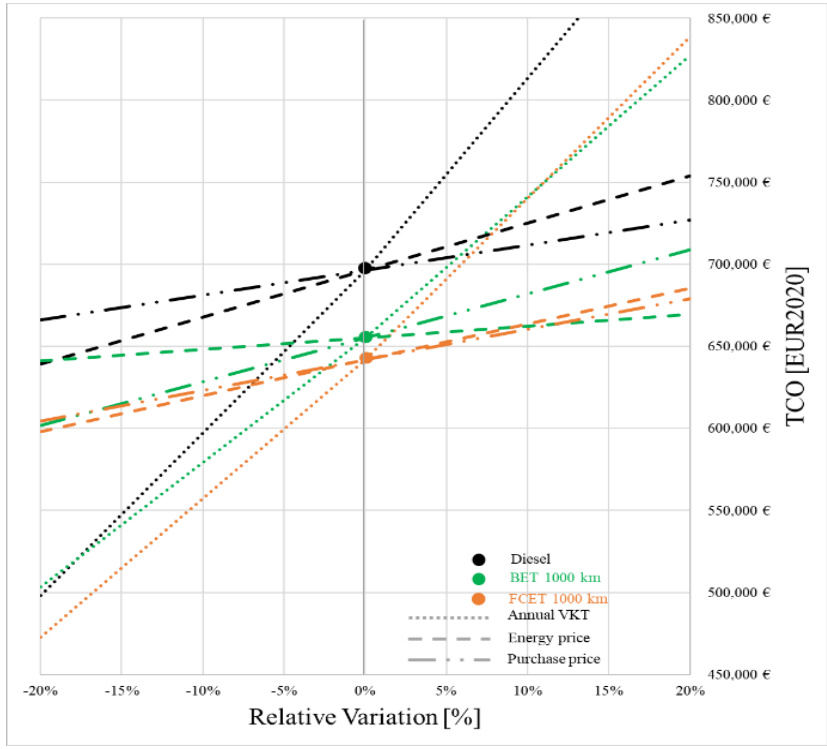
Sensitivities – We identify annual mileage as most important factor; 100 km BET most cost-effective at any annual mileage

TCO Comparison 2030 versus annual VKT



Parameter variation +-20% for 2050



Annual mileage and fuel prices have a high impact on the profitability of hydrogen vehicles compared to the vehicle purchase price. The 100 km BET is most cost-effective at any annual mileage.

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FCET, PHET and BET will become economically competitive from company and federal perspective

Conclusion

- BET is the cheapest alternative from a **company perspective** for long-haul transport
  - in 2030 nearly without subsidies
  - in 2050 all ZEV are cost-competitive to DT
  - dependent of battery size
- From a **federal perspective**
  - most ZEV aren‘t cost-competitive in 2030
  - FCET, PHET and BET are economically competitive in 2050

Discussion

- **Uncertainties**
  - parameters (due to long period of time)
  - costs for refueling and charging infrastructure
  - development of support policies
  - insurance price
- **Restrictions**
  - analysis focuses on an average vehicle, but sensitivities provide initial insights beyond
  - payload reductions due to lower heavier batteries not considered
  - environmental effects not considered

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Parameters

$$TCO = I_0 - S_0 - \frac{RV_T}{(1+i)^T} + \sum_{t=1}^{T} \frac{c_{fixed,t} + c_{var,t}}{(1+i)^t}$$

Here, I_0 stands for vehicle purchase price [€], S_0 for subsidies, RV for the residual value [€], T for service life [a]. Furthermore, ongoing costs are examined. These can be divided into fixed $c_{fixed,t}$ and variable costs $c_{var,t}$. In detail, both costs and their elements are listed in the following equations.

$$c_{fixed,t} = c_{Ins} + c_{Tax}$$

$$c_{var,t} = VKT * (c_{energy} + c_{O\&M} + c_{Toll})$$

Here, c_{Ins} stands for insurance costs [€] and c_{Tax} for vehicle taxes [€]. Both are charged annually and irrespective of vehicle use. Here, the annual mileage VKT [km] is used. Kilometre-dependent costs for energy c_{energy}, operation and maintenance including tires and ad-blue $c_{O\&M}$ and road toll c_{Toll}. Cost calculations from both perspectives, i.e. company versus federal, are differentiated by relevant taxes, subsidies S_0, and interest rate i,

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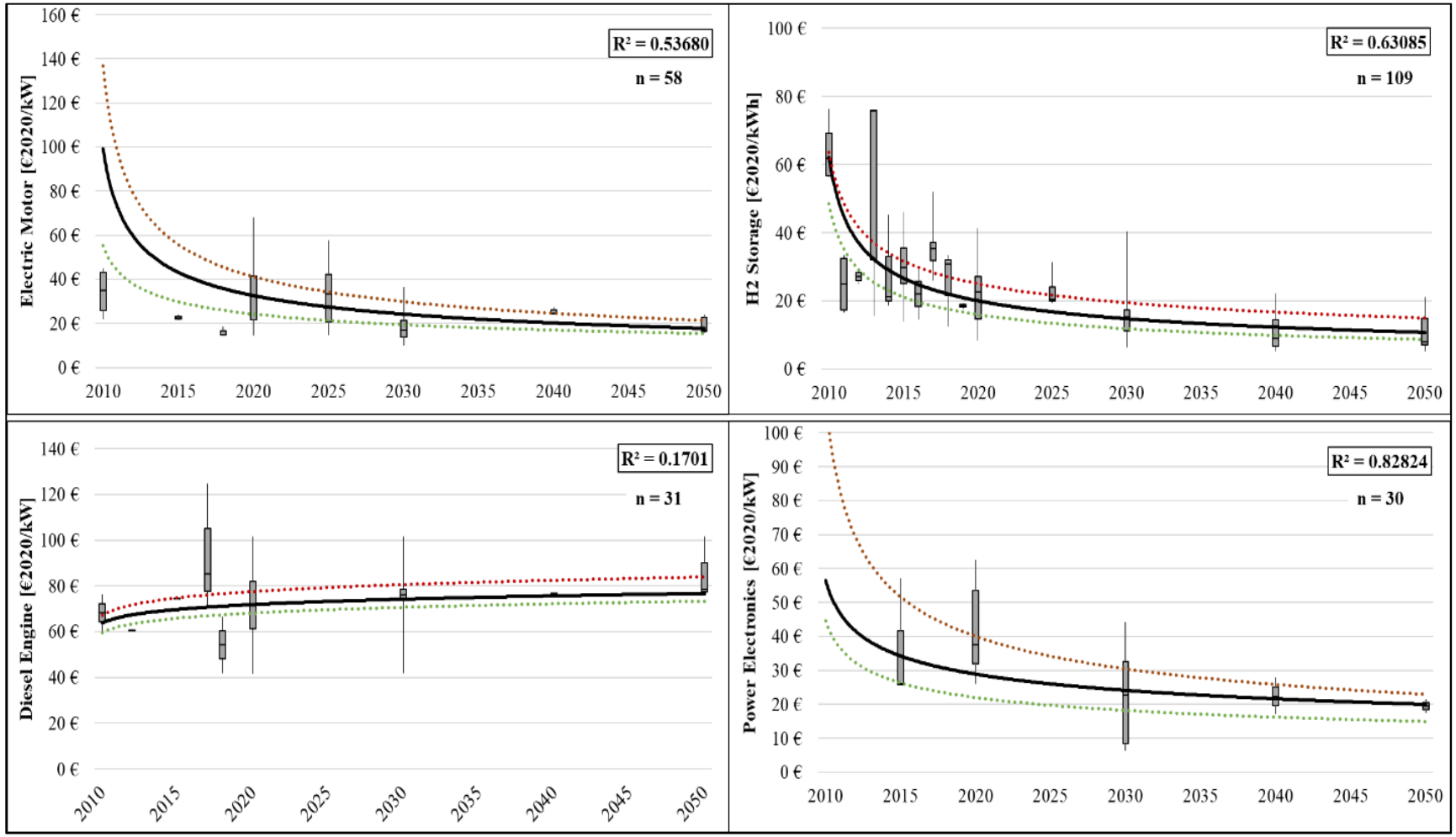
Other technology costs



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Technical vehicle parameters in 2020 (2030/2050)

Parameter	Unit	DT	GT	PHET	H2T	FCET	BET	Sources
Rated power	[kW]	330	330	300 con. 130 el.	330	330 (180 FC)	330	[26, 27]
Range conv.	[km]	1,000	1,000	1,000	100-1,000			
Range el.				65		100-1,000	100-1,000	
HV battery	[MWh]			0.080 (’20) 0.072 (’30) 0.065 (’50)		0.07	0.15-1.50 (’20) 0.14-1.37 (‘30’) 0.13-1.25 (’50)	Own assumption
H2 tank	[kg]				9-93 (’20) 8-77 (’30) 6-64 (’50)	8-80 (‘20) 7-86 (’30) 6-56 (’50)		Own assumption
Consumption	[kWh/ 100km]	318 (‘20) 265 (‘30) 221 (‘50)	349 (‘20) 298 (‘30) 248 (‘50)	318 (‘20) 265 (‘30) 221 (‘50)	311 (‘20) 259 (‘30) 214 (‘50)	269 (‘20) 226 (‘30) 187 (‘50)		Own calculation, based on [11, 17, 24, 25]
Consumption electric	[kWh/ 100km]			120 ('20) 110 ('30) 100 ('50)			120 ('20) 110 ('30) 100 ('50)	Own calculation, based on [11, 17, 24, 25]

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Other economics paramter

Parameter	Unit	DT	GT	PHET	H2T	FCET	BET	Sources
Vehicle insurance	[% VPP]	5.8	5.8	5.8	5.8	5.8	5.8	[30]
Toll charge	[EUR2020/km]	0.183 (’20)	0 (’20)	0 (’20)	0.171 (’20)	0 (’20)	0 (‘20’)	[31]
		0.183 (’30)	0.183 (’30)	0.169 (’30)	0.171 (’30)	0.169 (’30)	0.169 (’30)	
		0.183 (’50)	0.183 (’50)	0.169 (’50)	0.171 (’50)	0.169 (’50)	0.169 (’50)	
Toll share	[%]	92	92	92	92	92	92	[17]
Vehicle tax	[EUR2020/a]	929 (’20)	929 (’20)	929 (’20)	929 (’20)	373 (’20)	373 (’20)	[36]
		929 (’30)	929 (’30)	929 (’30)	929 (’30)	651 (’30)	651 (’30)	
		929 (’50)	929 (’50)	929 (’50)	929 (’50)	929 (’50)	929 (’50)	
O&M	[EUR2020/km]	0.17 (’20)	0.19 (’20)	0.16 (’20)	0.19 (’20)	0.18 (’20)	0.14 (’20)	based on [30, 32–34]
		0.17 (’30)	0.19 (’30)	0.16 (’30)	0.16 (’30)	0.14 (’30)	0.14 (’30)	
		0.17 (’50)	0.19 (’50)	0.16 (’50)	0.16 (’50)	0.14 (’50)	0.14 (’50)	
Service life	[a]	6	6	6	6	6	6	[32]
Annual mileage	[km]	120,000	120,000	120,000	120,000	120,000	120,000	[32]
Interest rate	[%]	9.5	9.5	9.5	9.5	9.5	9.5	[35]

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