Vehicle Cost Perspectives of Road Vehicles through 2050

NOVEMBER 19, 2021 | THOMAS GRUBE, STEFAN KRAUS, JULIAN REUL, JOCHEN LINßEN, DETLEF STOLTEN

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Paths to a Climate-Neutral Mobility

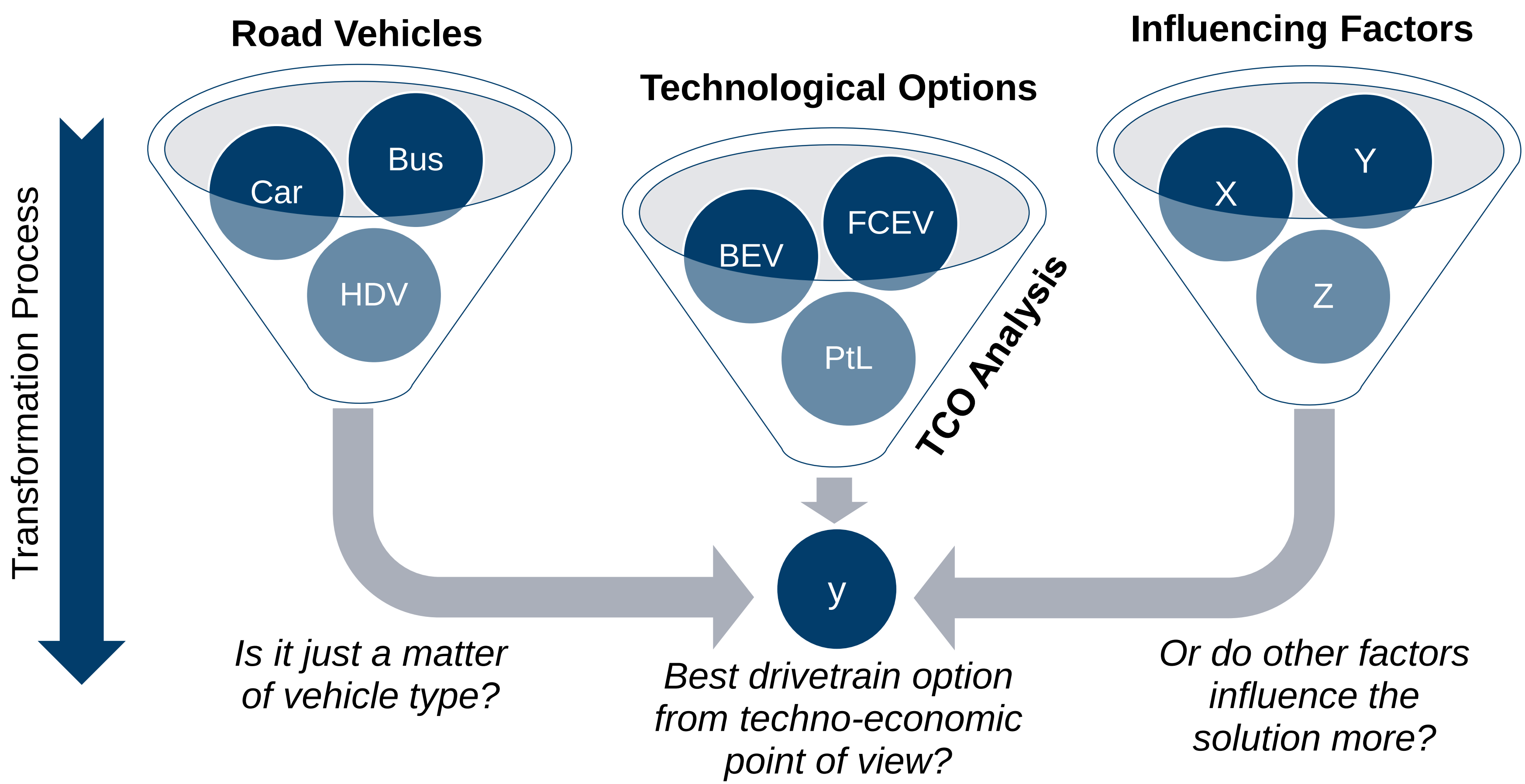
th.grube@fz-juelich.de

IEK-3: Techno-Economic Systems Analysis

JÜLICH Forschungszentrum

Motivation

Today: Fossil fuel based transport system



Future: Defossilized transport system

HDV: Heavy-Duty Vehicle
PtL: Power-to-Liquid
BEV: Battery Electric Vehicle
FCEV: Fuel Cell Electric Vehicle

Agenda

1 Motivation

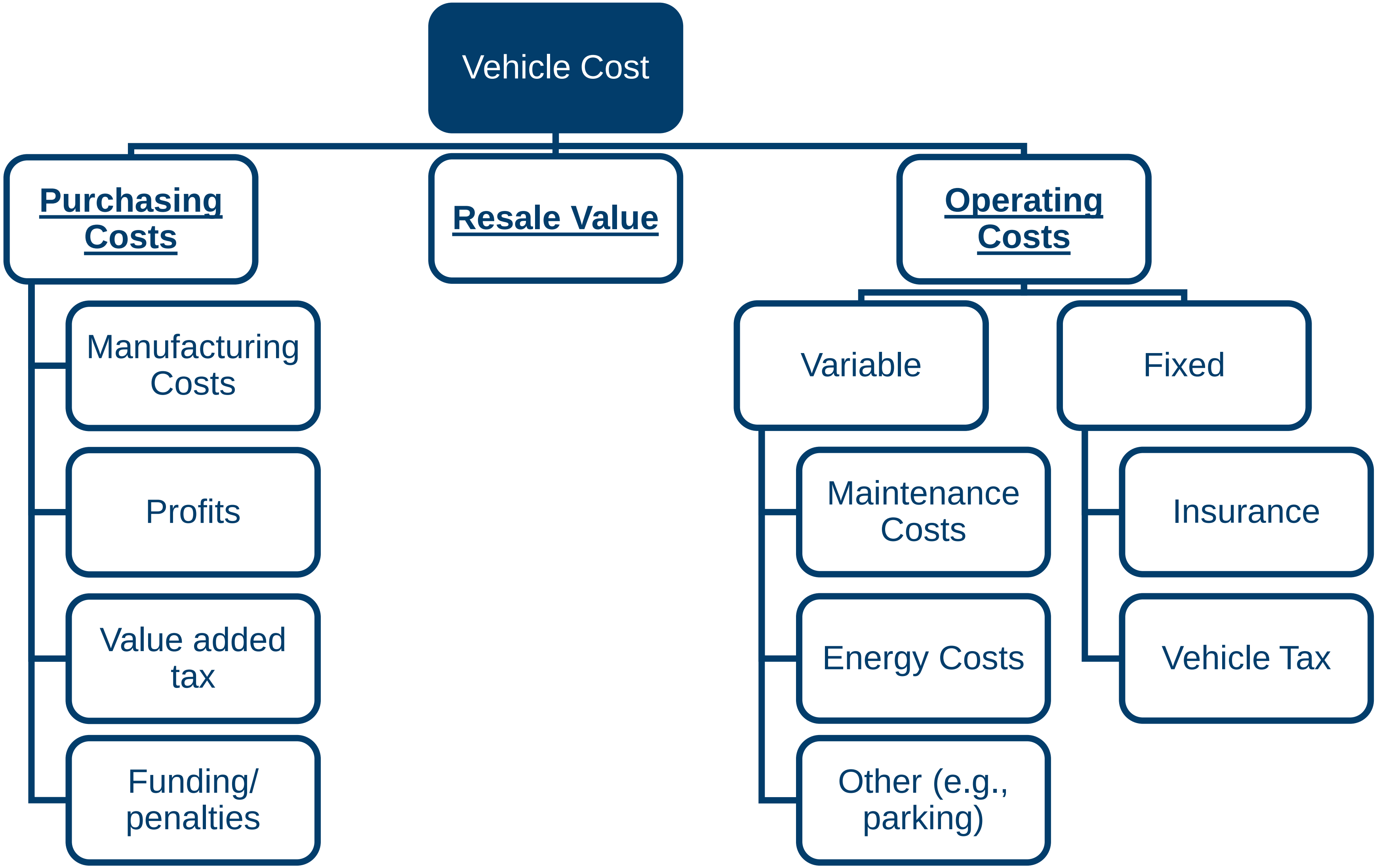
2 **Methodological Approach**

- Total Cost of Ownership
- CAPEX (Manufacturing Cost)
- OPEX (Maintenance & Fuel Cost)
- Investigated Vehicle Types

3 Results

4 Conclusion

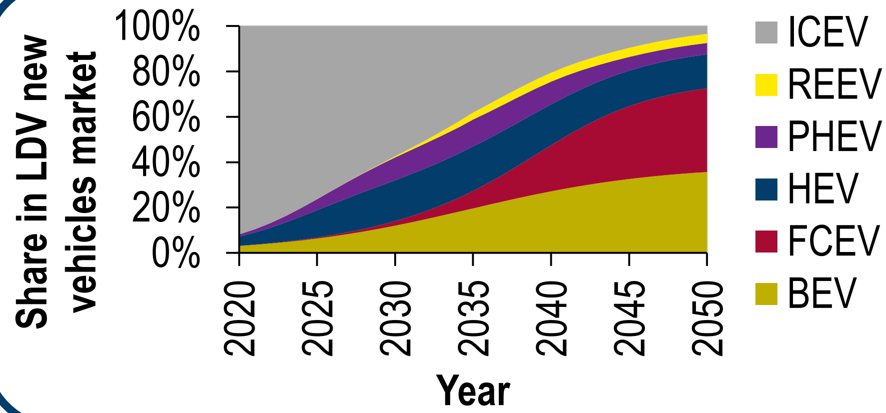
Total Cost of Ownership – A Tool for Evaluating Powertrain Alternatives.



[1] Redelbach, Entwicklung eines dynamischen nutzenbasierten Szenariomodells zur Simulation der zukünftigen Marktentwicklung für alternative PKW-Antriebskonzepte, 2016

Manufacturing Costs Calculated Bottom-Up via Learning Curve Approach.

World Market Scenario [1]



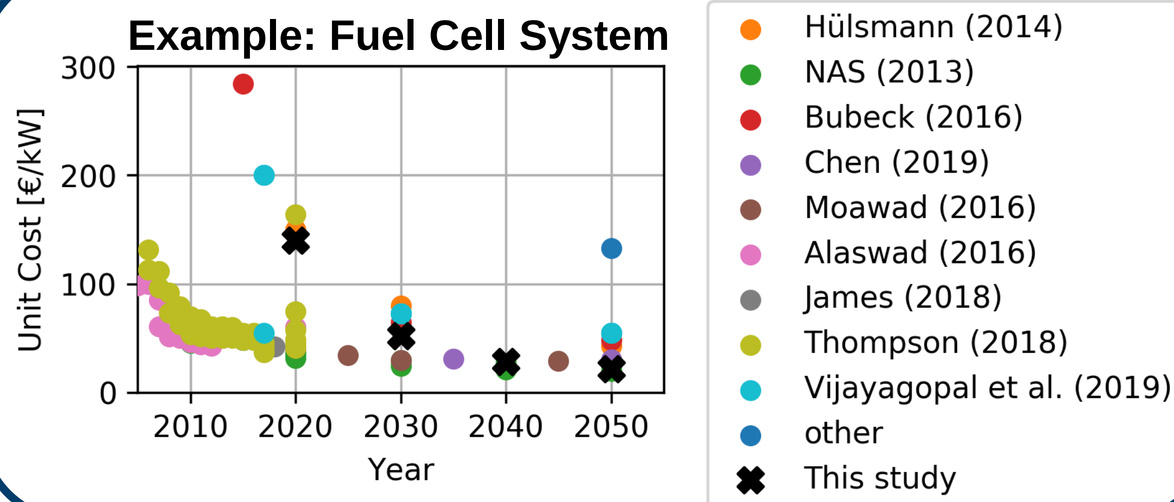
(1) $Cost_Q = Cost_0 * \left(\frac{Q}{Q_0}\right)^b = Cost_0 * Q^b$

(2) $b = \frac{\ln(1-LR)}{\ln(2)}$ [2]

Higher market shares lead to cost reductions

Assumed learning rates for batteries and fuel cells: 15%

Component based cost reduction



Cost reduction leads to increasing market shares

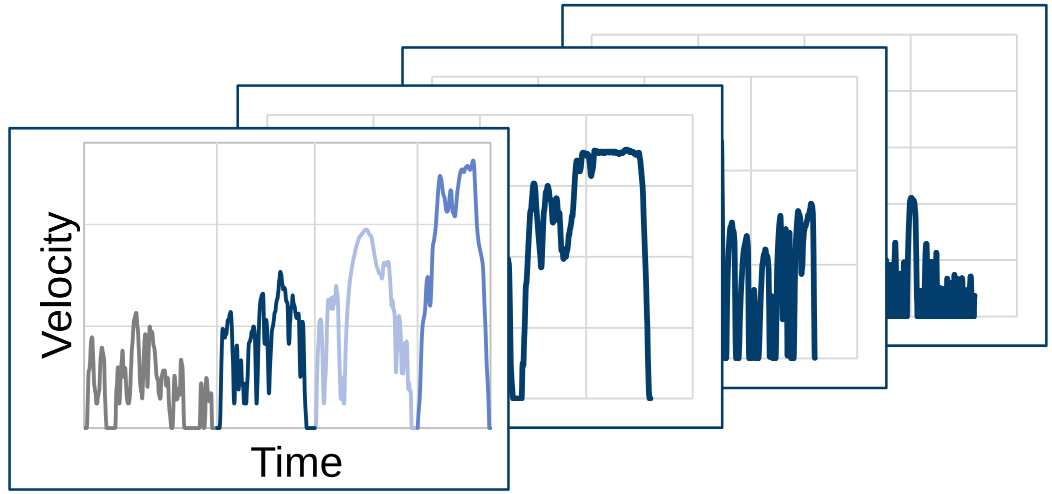
LDV: Light-duty vehicle
HDV: Heavy-duty vehicle
ICEV: Internal combustion engine vehicle
HEV: Hybrid electric vehicle
PHEV: Plug-in hybrid electric vehicle
REEV: Range-extender electric vehicle
BEV: Battery electric vehicle
FCEV: Fuel cell electric vehicle
Q: Production Quantity LR: Learning Rate

[1] Grube et al., Passenger Car Cost Development through 2050 (unpublished), 2021
[2] Junginger et al., "Technological Learning in the Transition to a Low-Carbon Energy System", 2019

From Usage Profiles to Fuel Costs. Various Factors to be Considered.

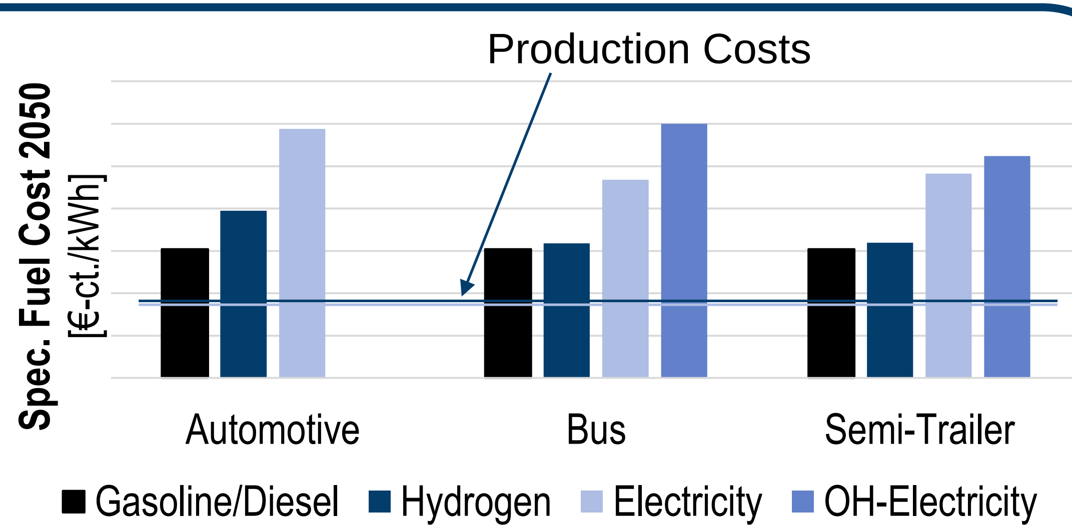
Fuel Demand

- **Driving cycle** chosen based on usage profile
- Vehicle mass calculated **bottom-up**
- **Drivetrain efficiency** and **aerodynamic** performance development over time considered



Specific Fuel Costs

- Specific fuel costs include **production and infrastructure**
- **Infrastructure costs** are vehicle type dependent
- Gasoline/Diesel infrastructure costs neglected
- **Hydrogen infrastructure** cheaper than electric at high market penetration levels



The Properties of the Investigated Vehicle Types – From Small to Large.

	Vehicle Type	Segment / Length / Weight	BEV Driving Range (O-BEV)	Yearly Mileage
Passenger Cars	*City Car*	A, B	200 km	10,000 km/a
	Long Distance Car	C, D, E	500-850 km	30,000 km/a
	SUV Trailer Use	J	300-600 km	15,000 km/a
Buses	*City Bus*	18 m	225 km (100 km)	60,000 km/a
	Rural Bus	12 m	400 km (200 km)	90,000 km/a
	Coach	-	500 km (250 km)	70,000 km/a
Freight Modes	*Urban Cargo*	<7.5 t	230 km	35,000 km/a
	Garbage Vehicle	<26 t	300 km	30,000 km/a
	Long-Haul Semi	<40 t	600 km (200 km)	114,000 km/a

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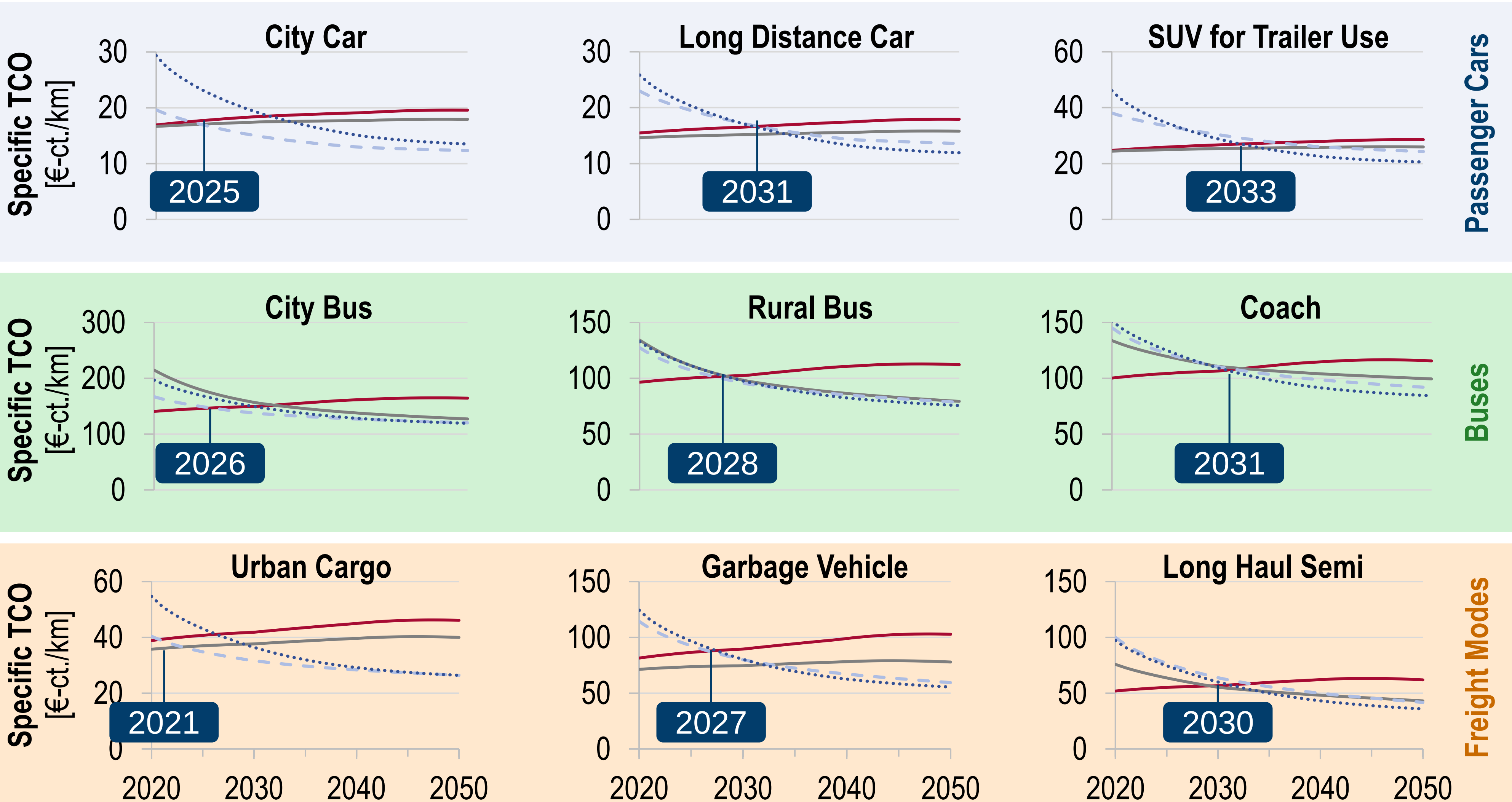
3 **Results**

- ➢ Vehicle Type Analysis
  - *Passenger Cars*
  - *Buses*
  - *Commercial Vehicles*
- ➢ Key Factor Analysis
  - *Driving Range*
  - *Mileage*
  - *Fuel Costs*

4 Conclusion

Electrified Vehicles Become Cheapest Option in All Cases Studied.

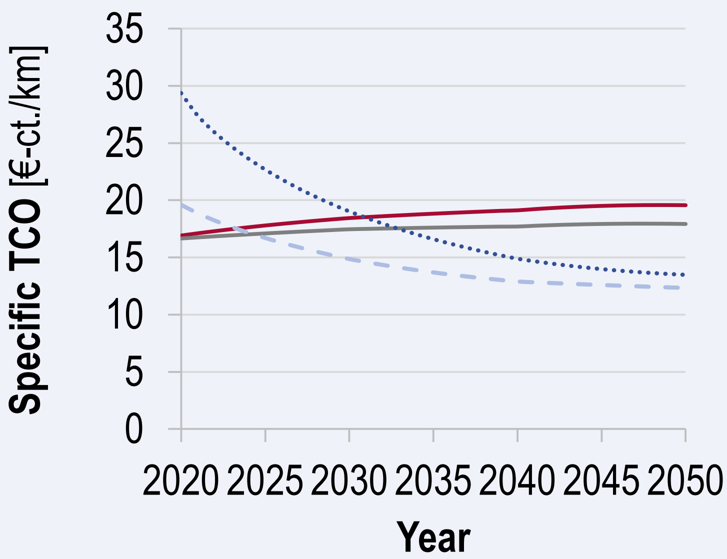


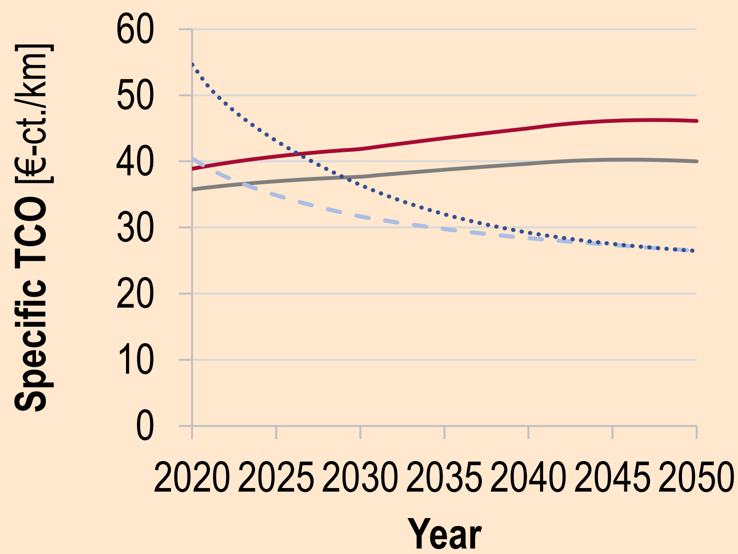
20xx Year of cost parity BEVs or FCEVs with ICEVs

ICEV — HEV / O-BEV — BEV — FCEV

ICEV: Internal combustion engine vehicle
O-BEV: Overhead-battery electric vehicle
FCEV: Fuel cell electric vehicle
HEV: Hybrid electric vehicle
BEV: Battery electric vehicle
TCO: Total cost of ownership

For Urban Vehicles, the Future is Battery-Electric from a TCO perspective.





- **Smaller batteries** are sufficient for short distances
- Stop-and-go traffic leads to **increased benefits of electrification**

➢ **For short-distance urban passenger & freight transport BEVs the cheapest option before 2025**

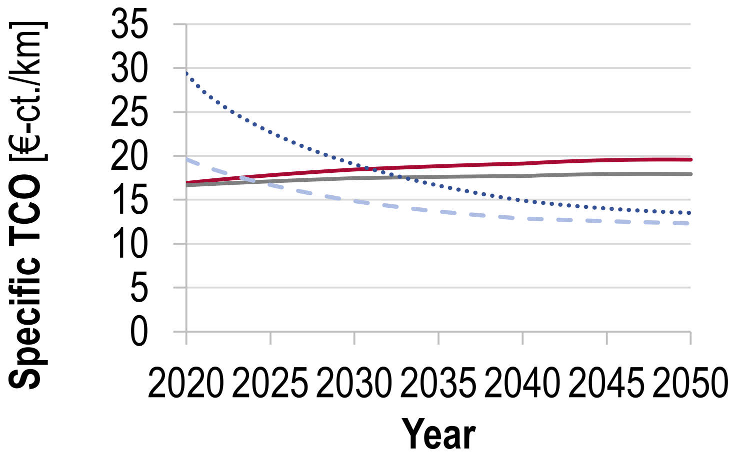
ICEV: Internal combustion engine vehicle
BEV: Battery electric vehicle
TCO: Total cost of ownership

HEV: Hybrid electric vehicle
FCEV: Fuel cell electric vehicle

ICEV HEV BEV FCEV

Different Usage Profiles lead to different TCO-Ratios for Passenger Cars.

City Car



- **Small battery capacity** due to small driving ranges
- **Battery electric** cheapest already before **2025**

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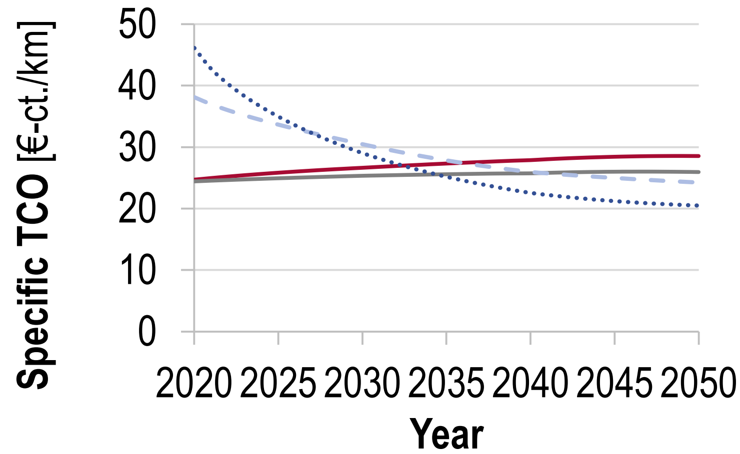
SUV for Trailer Use



- **High battery capacity** due to trailer operation
- **Fuel cell vehicle** cheapest after **2035**

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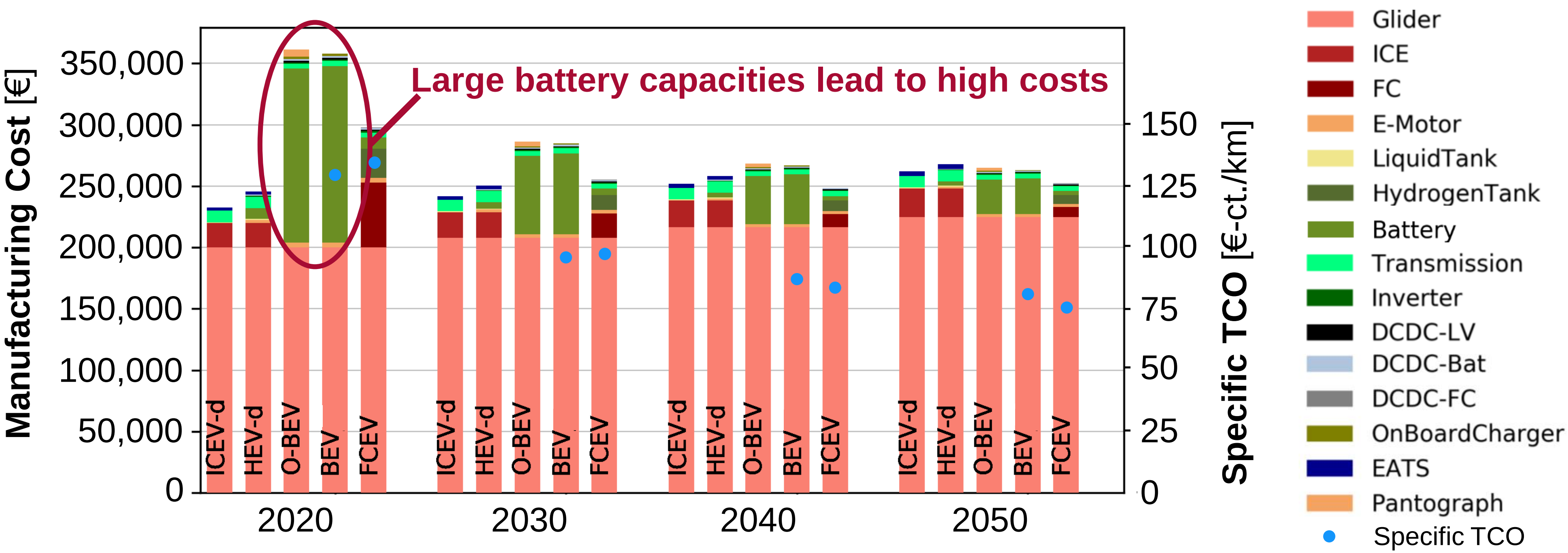
ICEV HEV
BEV FCEV

Rural Buses Highlight the Disadvantages of BEVs.



0°C at design point → We consider **cold winter day** as design point for battery capacity

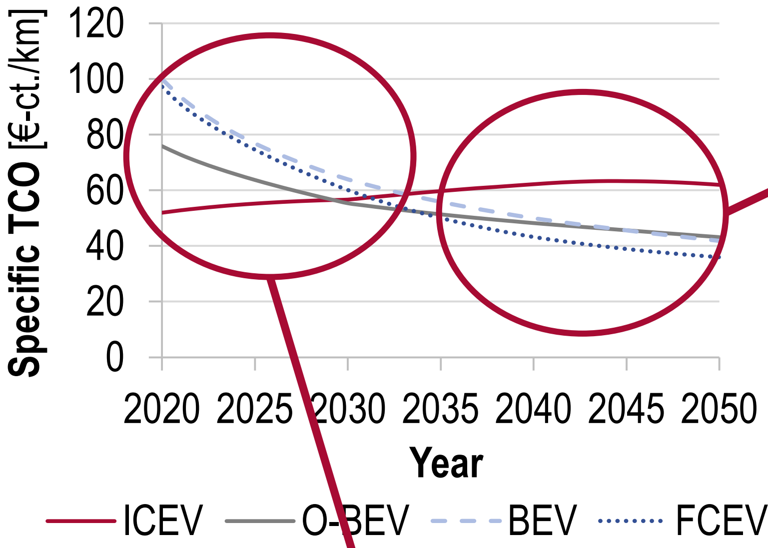
100% Occupancy → **Mass of passengers** also to be taken into account

A few trips a year determine battery scaling

ICEV-d: Internal combustion engine vehicle (Diesel)
HEV-d: Hybrid electric vehicle (Diesel)
O-BEV: Overhead-battery electric vehicle
BEV: Battery electric vehicle (large battery)
FCEV: Fuel cell electric vehicle
EATS: Exhaust aftertreatment system

Cheaper Infrastructure is one Key to Success of Fuel Cell Semis.

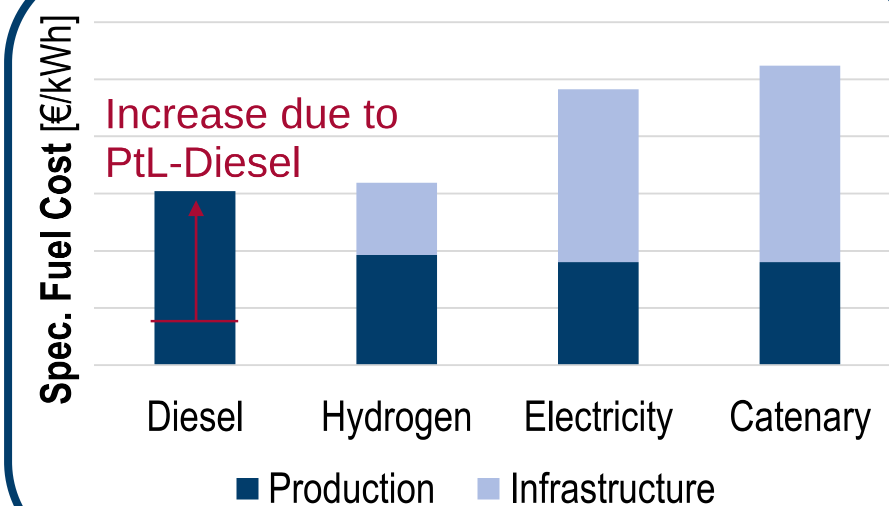
Specific TCO Semis



Costs for FCEVs decrease more than for overhead and battery-electric

Firstly, overhead vehicles the cheapest electrified alternative

Specific Fuel Cost Semis 2050



ICEV: Internal combustion engine vehicle
FCEV: Fuel cell electric vehicle
O-BEV: Overhead-battery electric vehicle
TCO: Total cost of ownership
BEV: Battery electric vehicle
PtL: Power to Liquid

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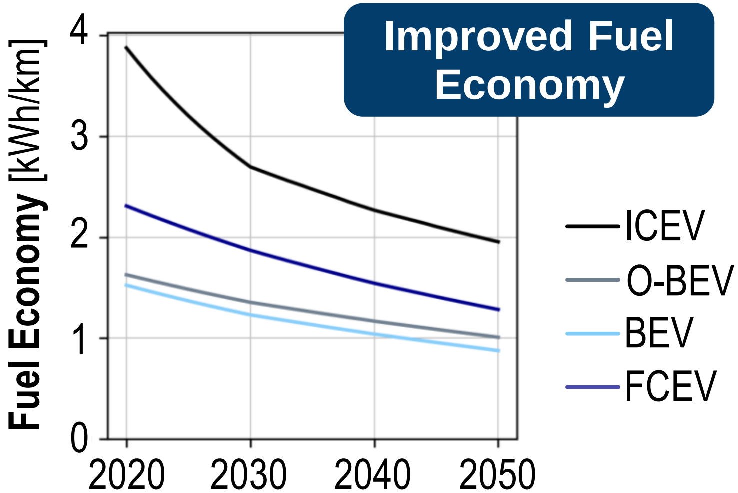
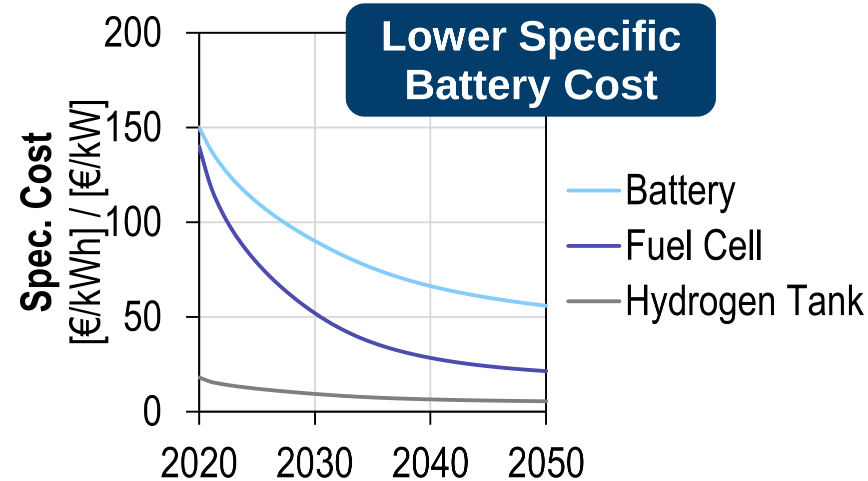
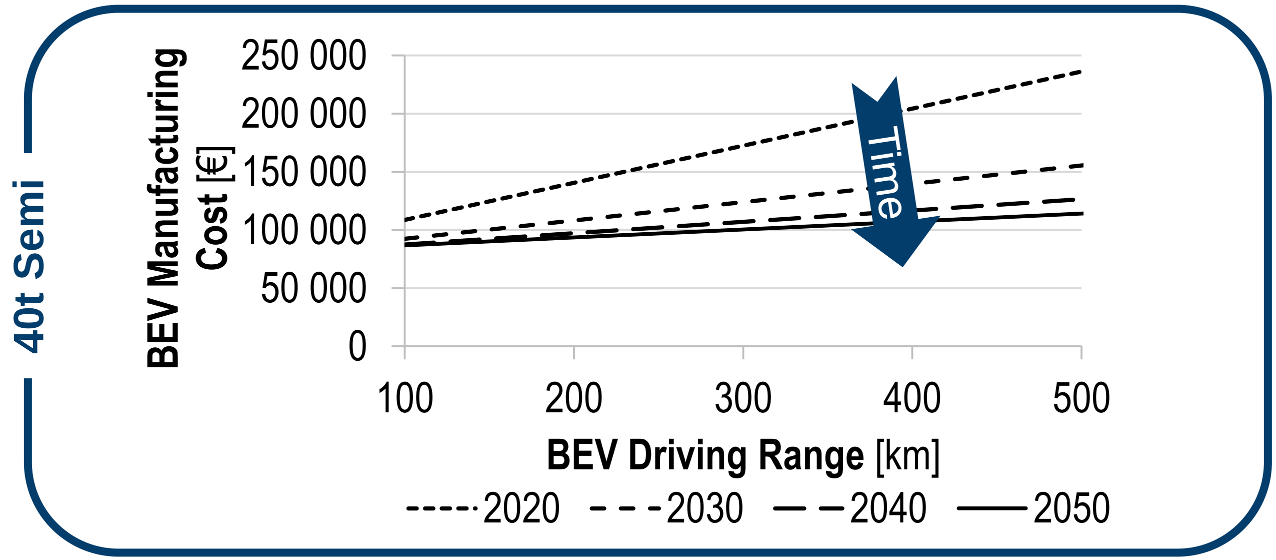
  - *Driving Range*
  - *Mileage*
  - *Fuel Costs*

4 Conclusion

The Influence of Driving Ranges Decreases over time.







ICEV: Internal combustion engine vehicle
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O-BEV: Overhead-battery electric vehicle
TCO: Total cost of ownership
BEV: Battery electric vehicle

High Mileage is not the BEV's Problem. It is the Rarely Used High Ranges.

Higher mileages advantageous for BEV

Difference in TCO between BEVs and FCEVs

Medium Car 2030

Yearly Mileage [km/a]

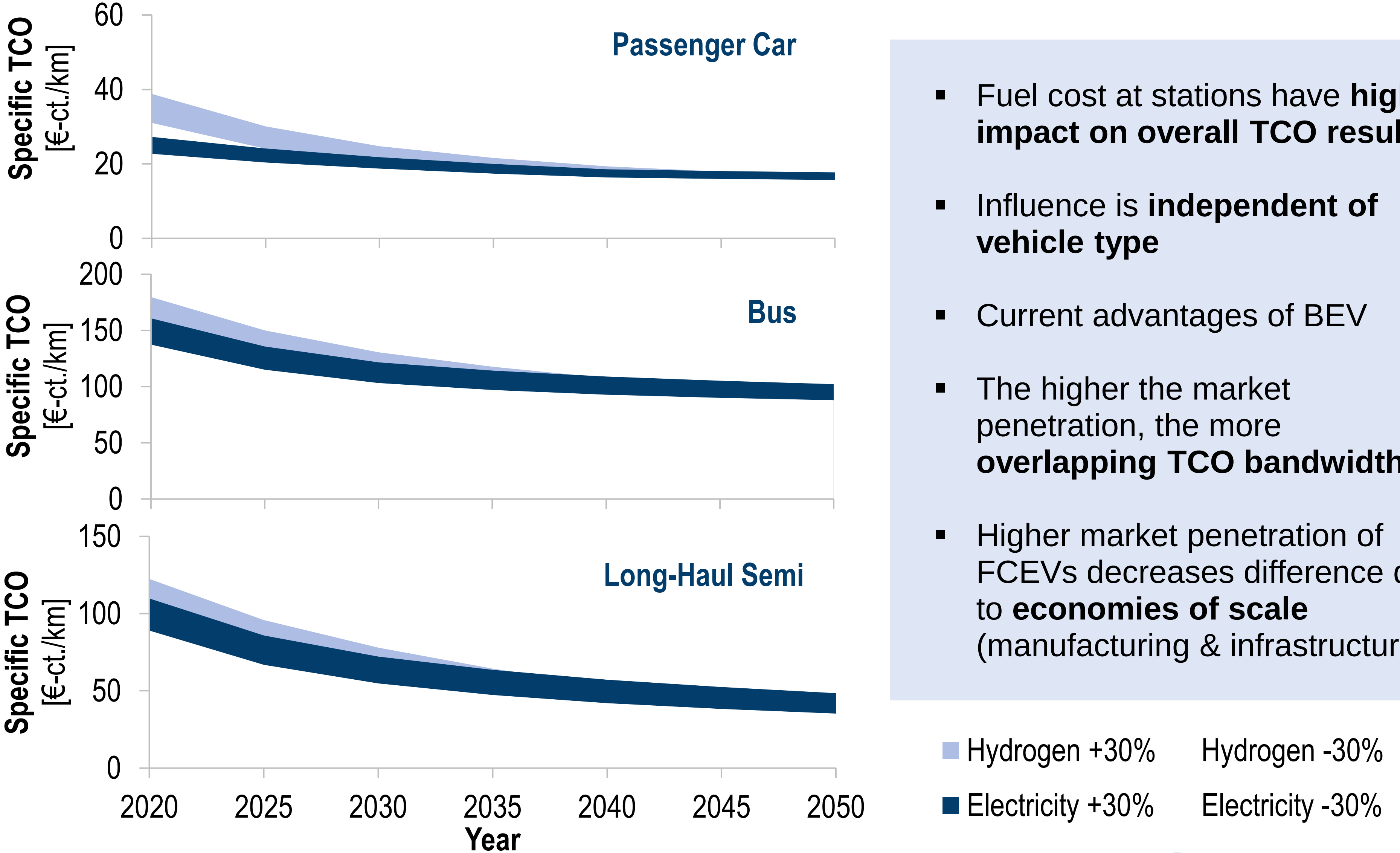
Range [km]	5000	7500	10000	12500	15000	17500	20000	30000	40000
100	-37%	-39%	-40%	-40%	-41%	-42%	-42%	-44%	-45%
200	-25%	-27%	-29%	-30%	-31%	-31%	-32%	-34%	-35%
300	-15%	-17%	-19%	-20%	-21%	-22%	-23%	-25%	-27%
400	-6%	-8%	-10%	-11%	-13%	-14%	-14%	-17%	-19%
500	2%	0%	-2%	-3%	-5%	-6%	-7%	-10%	-11%
600	10%	7%	5%	4%	2%	1%	0%	-3%	-5%
700	16%	14%	12%	10%	9%	8%	7%	4%	2%
800	22%	20%	18%	16%	15%	14%	13%	10%	8%
900	28%	25%	23%	22%	20%	19%	18%	15%	13%
1000	33%	30%	29%	27%	25%	24%	23%	20%	18%

Higher driving ranges advantageous for FCEVs

TCO parity dependent on driving range and yearly mileage

BEV: Battery electric vehicle FCEV: Fuel cell electric vehicle TCO: Total cost of ownership

BEV and FCEV: High Market Penetration Beneficial for FCEV Performance.



- Fuel cost at stations have **high impact on overall TCO result**
- Influence is **independent of vehicle type**
- Current advantages of BEV
- The higher the market penetration, the more **overlapping TCO bandwidth**
- Higher market penetration of FCEVs decreases difference due to **economies of scale** (manufacturing & infrastructure)

BEV: Battery electric vehicle FCEV: Fuel cell electric vehicle TCO: Total cost of ownership

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Conclusion

I. ***The best drivetrain from a techno-economic point of view depends not on the type of vehicle but on the usage profile.***

II. ***High mileage is not the BEV's problem. It is the rarely used high ranges.***

III. ***Higher market penetration helpful for FCEV performance due to lower manufacturing and infrastructure costs.***

Thank you for your attention!