RANGE LIMITS OF ELECTRIC VEHICLES: INVEST IN CHARGING INFRASTRUCTURE OR BUY LARGER BATTERIES: A TECHNO-ECONOMIC COMPARISON

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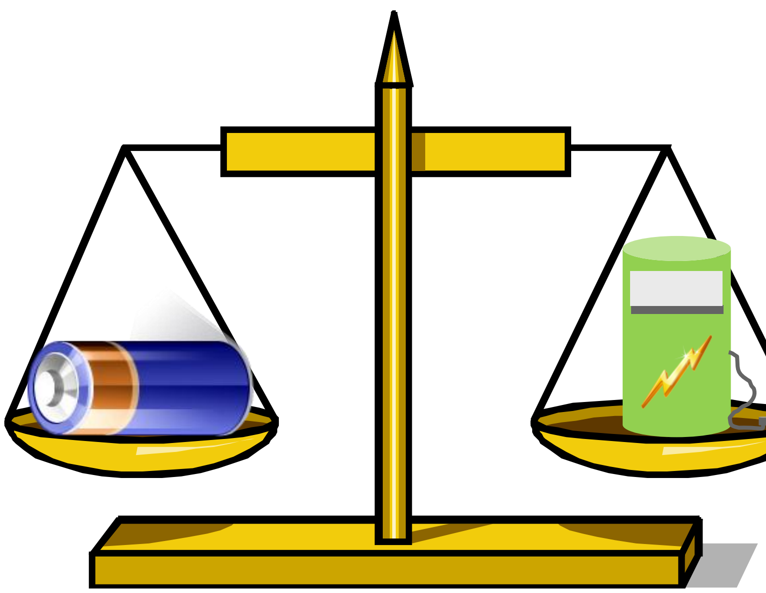

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Besides all positive effects, electric vehicles clearly lack of driving range.

- Positive effects of EVs, like lower primary energy consumption, reduce CO2 and noise emissions, diminish dependence on fossil fuels
- Range anxiety of users as problem of BEVs, which may be reduced by: e.g.
  - Using a PHEV
    - but no independence on carbon fuels
    - behavioural change
  - Larger batteries
  - Charging Infrastructure
    - Development of charging infrastructure considered in many countries [European Expert Group (2011)]
    - How much infrastructure is actually needed?

→ We compare the effects of the last two options to determine whether an investment in infrastructure or in additional battery capacity is cheaper.

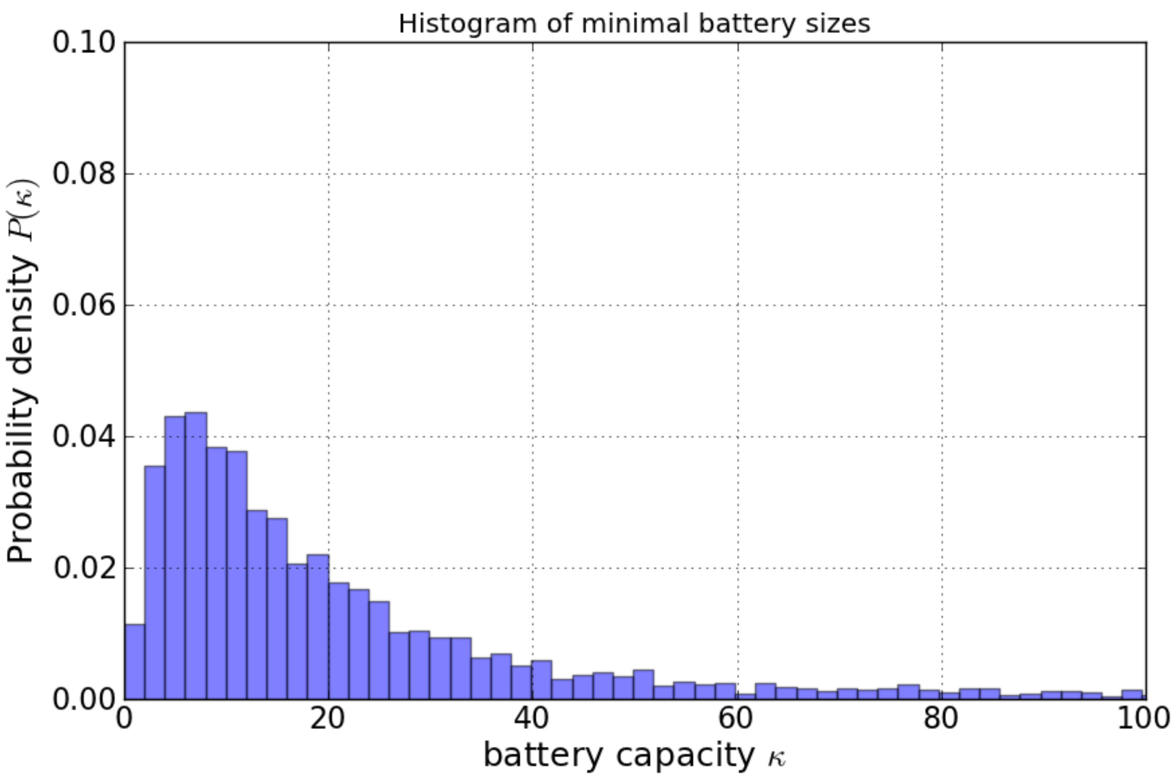
In a simulation of battery profiles we determine the minimal battery capacity necessary per driver.

- Driving behaviour from German Mobility Panel [MOP (2008)]
  - German movement profiles for one week
  - 1994-2008: 12,812 households
  - Allocation to cars where possible reduces sample to 6,629 car-specific driving profiles

- Simulation of battery profiles with main assumptions:
  - Uncontrolled charging whenever possible
  - All cars medium-sized with consumption 0.194 kWh/km [Helms and Hanusch (2011)]
  - in different infrastructure scenarios (table below) [Kley (2011)]

power rates [kW]	private	semipublic	public
home-only (IS_a)	3.7	-	-
home-and-semipublic (IS_b)	3.7	11.1	-
everywhere (IS_a)	3.7	11.1	11.1

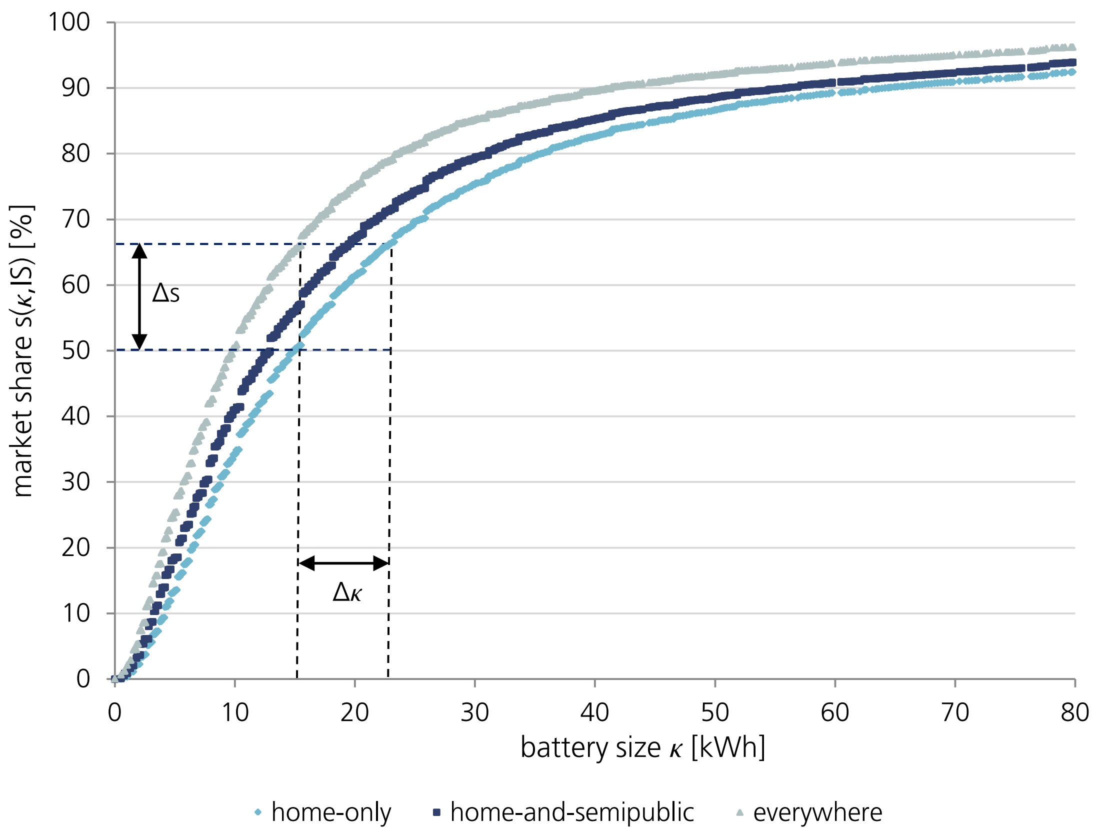
A lot of users could do all their driving with BEVs with small batteries (< 20 kWh).



- Home-only charging scenario for simulation
- Every user with minimal battery capacity
- 50% of users would only need a net capacity of 15kWh
- Only very few users needed large battery capacities (> 40 kWh)

→ Easier to observe in cumulative distribution function

We compare investments via additional market shares of infrastructure and battery capacity.



- Results of previous slide as cumulative distribution function
- Different infrastructure scenarios

→ Additional users (market shares) Δs with additional infrastructure or battery capacity

- Main assumptions:
  - All drivers use same battery capacity
  - One additional charging option per additional driver

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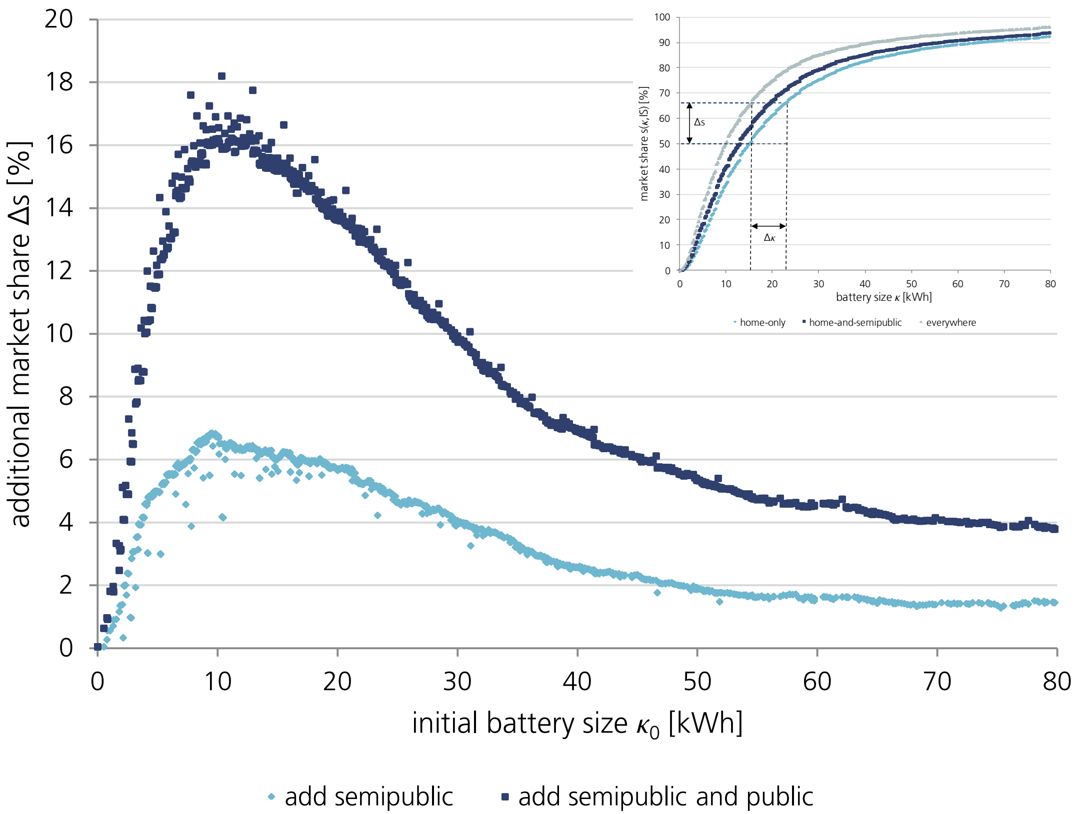
Additional market shares through infrastructure development reach 17 percent.



- Increasing infrastructure availability adds more potential users (Δs)

$$\Delta s = s_1(IS_1, \kappa_1) - s_0(IS_0, \kappa_0)$$

- Additional users depend on initial battery size κ_0
- Maximum values at 10kWh
  - with an additional 7% of users if there was also semipublic charging infrastructure
  - Or 17% if there was infrastructure everywhere

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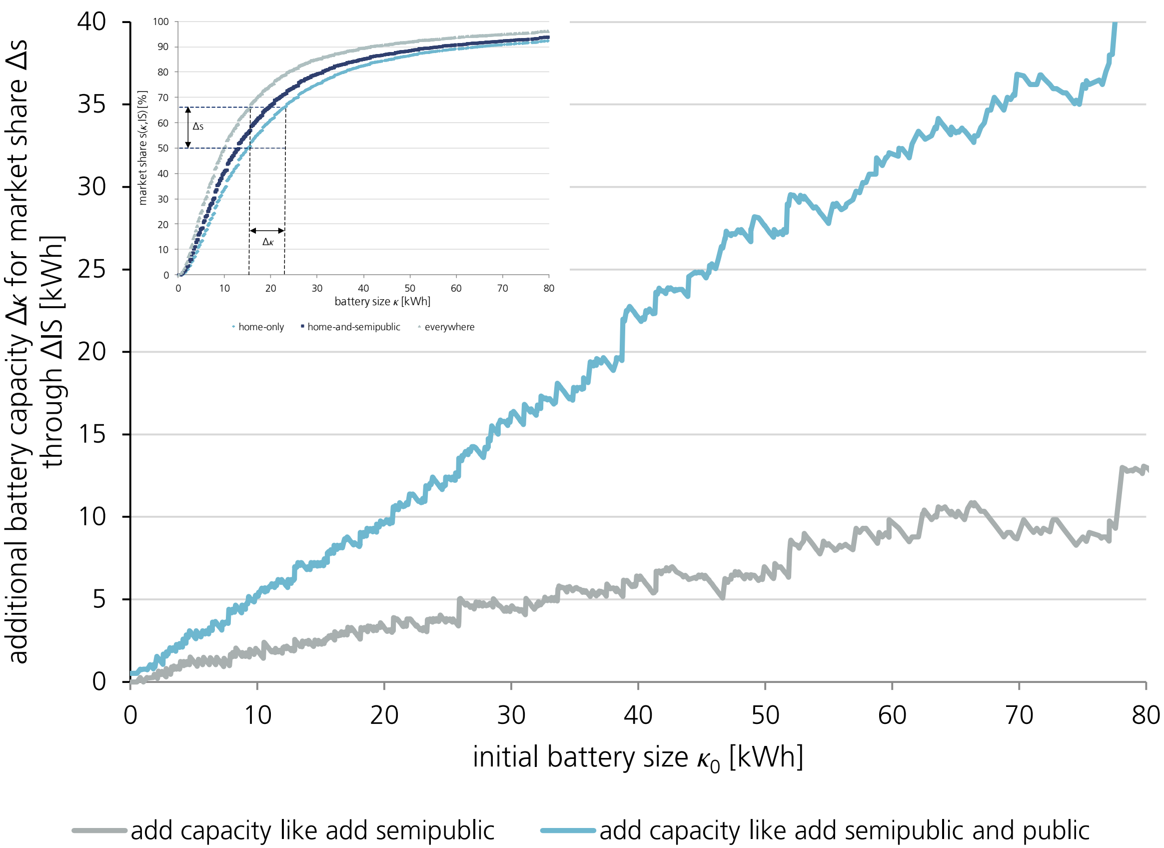
Additional battery capacity for same additional market shares is growing with initial battery size.



- Shown is battery capacity for same increase of market share as with additional infrastructure $s_1(IS_1, \kappa_0) \stackrel{!}{=} s_1(IS_0, \kappa_1)$
- Additional battery capacity growing constantly with initial battery size κ_0
- For initial battery capacity of 10kWh, we needed 2kWh additionally to reach the same increase as with additional semipublic charging options

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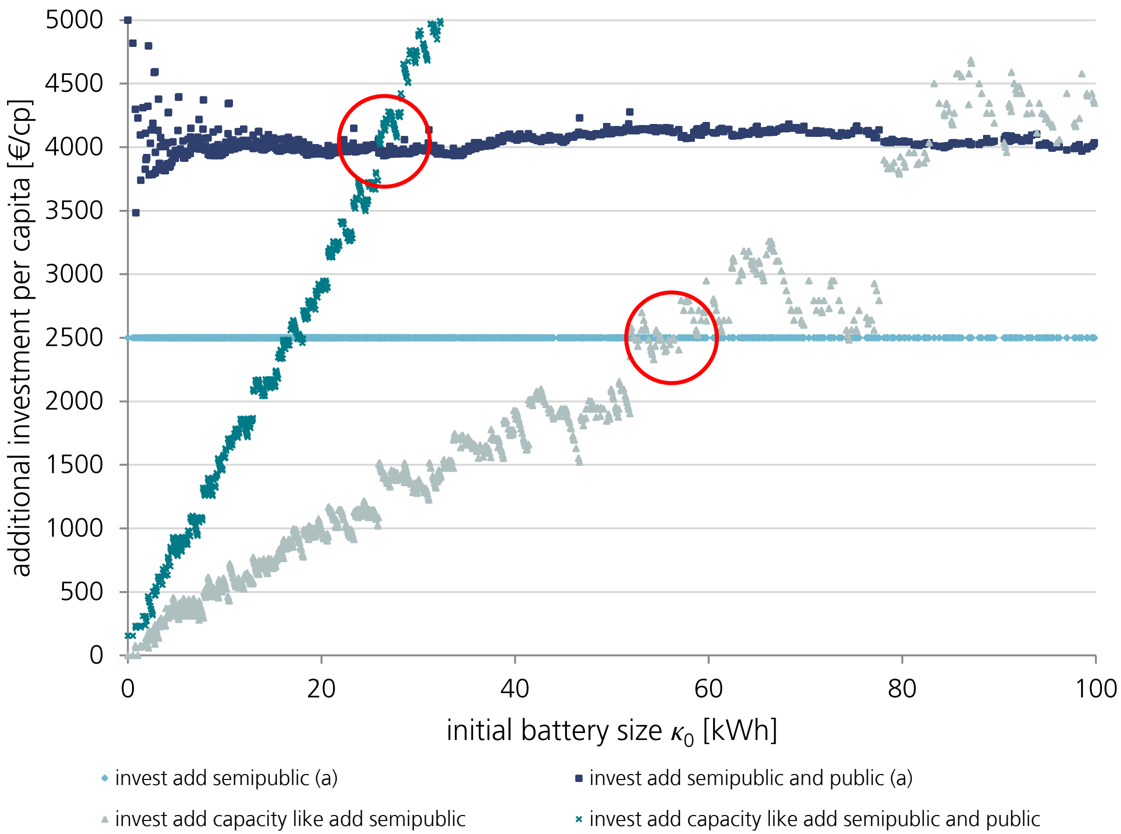
If only additional users paid infrastructure (a), it would be cheaper to invest in battery size.



- Investments per capita under the assumption that every additional user needs one charging point (semipublic or public)
- Investments borne by **additional** users (case a)
- Intersection of additional semipublic charging options compared to increasing battery capacity at around κ_0=50kWh
- For semipublic and public charging options at κ_0=25kWh

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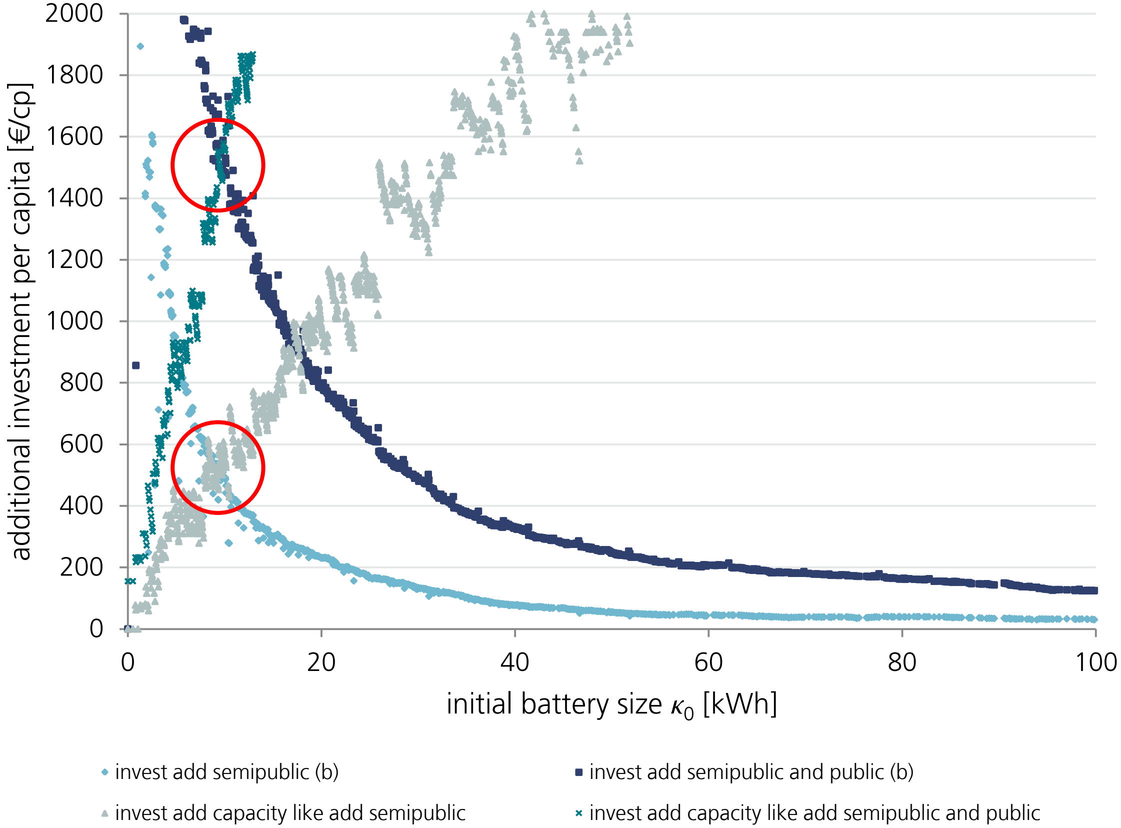
If all BEV-users paid for infrastructure (b), it would be less expensive than investing in battery size.



- Investments per capita under the assumption that every additional user needs one charging point (semipublic or public)
- Investments borne by **all** users (case b)
- Intersection of additional semipublic charging options compared to increasing battery capacity at around κ_0=10kWh
- For semipublic and public charging options at κ_0=10kWh

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An example shows the difference of the two cases.

	In the battery profile simulation with a battery capacity of 20 kWh	Electric vehicles and charging infrastructure in 2020 [NPE 2011]
vehicles	▪ 60 % of all drivers in MOP could drive BEV with private infrastructure ▪ 66 % could manage all their ways with private-and-semipublic charging infrastructure	▪ 1 million EVs in 2020 ▪ 45 % are BEVs → 450,000
infrastructure	→ Additional 6 % needed semipublic charging points	▪ 450,000 * 6/66 = 40,900 semipublic charging points ▪ Total investment for semipublic charging points: 102.3 million Euro ▪ Additional BEV-users bear investment (a): 2500 Euro/capita ▪ All BEV-users bear investment (b): 227.3 Euro/capita
battery	▪ Same market share with battery capacity of κ =23 kWh → $\Delta\kappa$ =3 kWh	▪ Investment for additional battery capacity: 900 Euro/capita

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Under the given assumptions we can find three main conclusions.

1. If charging infrastructure is borne by only those users who needed the infrastructure, it would always be cheaper to invest in additional battery capacity. This could be the case if companies added a supplement to the electricity price at charging facilities.

2. If all BEV-users carried the cost (e.g. via a special BEV-tax), one charging point per additional user would be less expensive than an investment in additional battery size.

3. It is important to determine who invests in charging infrastructure.

We expect the first case to be more likely and there may also be different battery sizes available to users. Thus, an economic justification for charging infrastructure seems difficult with the results presented here.

Please read our paper for further information.

Thank you for your attention.

References:

European Expert Group (2011): „Infrastructure for Future Transport Fuels - Report of the European Expert Group on Future Transport Fuels“, Dez. 2011.

Helms, H. und Hanusch, J. (2010): Energieverbrauch von Elektrofahrzeugen. ifeu - Institut für Energie- und Umweltforschung Heidelberg GmbH, Heidelberg, Mar. 2010.

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Mobilitätspanel Deutschland (2008). Project management by the Institute for Transport Studies of the Karlsruhe University. Data available at http://mobilitaetspanel.ifv.uni-karlsruhe.de/de/index.html, 1994–2008

Nationale Plattform Elektromobilität (NPE) (2011): Zweiter Bericht der Nationalen Plattform Elektromobilität. Gemeinsame Geschäftsstelle Elektromobilität der Bundesregierung, Berlin, May 2011.

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Equations for battery profile simulation and investment comparison

- Calculation of battery state of charge:

$$\mathrm{SOC}(t+1) = \begin{cases} \mathrm{SOC}(t) - d_{\Delta t} \cdot c_{size} & \text{for } d_{\Delta t} > 0 \\ \min\{\mathrm{SOC}(t) + \Delta t \cdot P_{loc_t}, C\} & \text{for } d_{\Delta t} = 0 \end{cases}$$

- Calculation of additional market shares:

$$\Delta s = s_1(IS_1, \kappa_1) - s_0(IS_0, \kappa_0)$$

- Equilibrium where additional market share through infrastructure is equal to additional market share through additional battery capacity:

$$s_1(IS_1, \kappa_0) - s_0(IS_0, \kappa_0) \stackrel{!}{=} s_1(IS_0, \kappa_1) - s_0(IS_0, \kappa_0)$$

$$s_1(IS_1, \kappa_0) \stackrel{!}{=} s_1(IS_0, \kappa_1)$$

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Sensitivities for case (b) where all users bear the cost

TABLE II

SENSITIVITIES OF $I_r = I_{IS}^{tot} / I_{batt}^{tot}$ FOR ADDITIONAL SEMIPUBLIC CHARGING INFRASTRUCTURE AS WELL AS ADDITIONAL SEMIPUBLIC AND PUBLIC CHARGING INFRASTRUCTURE FOR BATTERY SIZE κ_0=20 KWH

I_r semip. [€/cp]	public [€/cp]	change	battery price [€/kWh] 180 -40%	240 -20%	300 0%	360 +20%	420 +40%
1500	-	-40%	0.234	0.176	0.140	0.117	0.100
2000	-	-20%	0.313	0.234	0.188	0.156	0.134
2500	-	0%	0.391	0.293	0.234	0.195	0.167
3000	-	+20%	0.469	0.352	0.281	0.234	0.201
3500	-	+40%	0.547	0.410	0.328	0.273	0.234
1500	3000	-40%	0.271	0.203	0.162	0.135	0.116
2000	4000	-20%	0.361	0.271	0.217	0.180	0.155
2500	5000	0%	0.451	0.338	0.271	0.226	0.193
3000	6000	+20%	0.541	0.406	0.325	0.271	0.232
3500	7000	+40%	0.632	0.474	0.379	0.316	0.271

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Parameters used in calculations

- Electric consumption per car:
  - 0.194 kWh/km
- Battery price:
  - 300 Euro/kWh
- Investment for semipublic charging point:
  - 2500 Euro/kWh
- Investment for public charging point:
  - 5000 Euro/kWh

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