HOW DOES CHARGING INFRASTRUCTURE INFLUENCE THE MARKET DIFFUSION OF PLUG-IN ELECTRIC VEHICLES?

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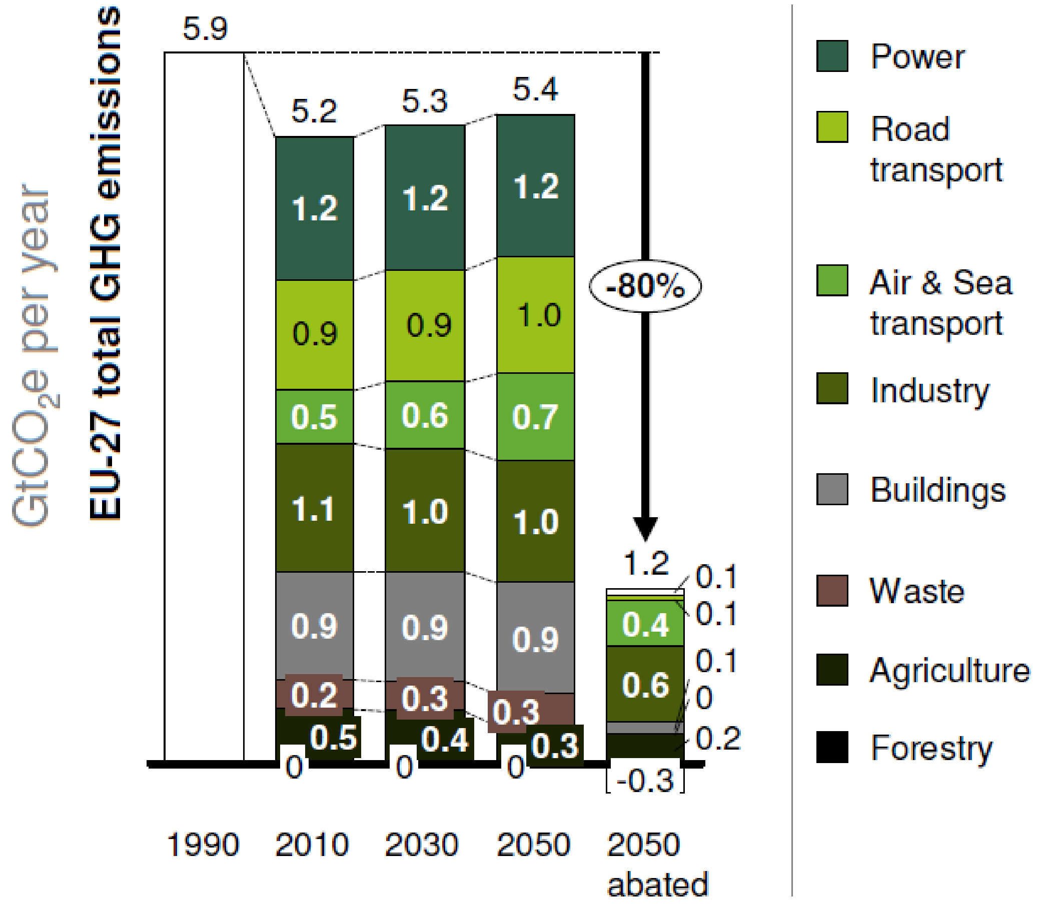
Erfurt, Lecture Series "International Case Studies In Transportation", November, 11th, 2019

Source: http://www.klimaexpo.nrw/mitmachen/projekte-vorreiter/vorreitergefunden/vorreitermobilitaet/

AGENDA

1. **Introduction**
2. Status quo
3. A look into the future
4. Discussion, conclusions and outlook

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%
- 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

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Different propulsion technologies are available as plug-in electric vehicles.

There are different electric vehicle and hybrid vehicle concepts:

- Only electric propulsion: BEV – *Battery electric vehicle.*
- Hybrids: *plug-in-hybrid electric vehicle (PHEV)* and *range extended electric vehicle (REEV).*

Key parameters

		Plug-in electric vehicles		
Property	**Combustion engine vehicle**	**Plug-in hybrid vehicle (PHEV)**	**Range extender vehicle (REEV)**	**Battery electric vehicle (BEV)**
Range	> 700 km	30 + 600 km	80 + 600 km	150 - 300 km
Refuelling frequency	Every 2 weeks	Every day+ When needed	Every day + When needed	Every third day or 30% every day
Refuelling duration	3 minutes	3 minutes + 2 hours	3 minutes + 4 hours	1/2 - 8 hours
Electrification	Combustion engine			Electric motor

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...and what's the upside of plug-in electric vehicles?

Source: https://www.amazon.de/Postkarte-61016-Elektroautos-Inkognito-K%C3%BCnstler/dp/B06XDMKHK5

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There are several types of charging infrastructure for plug-in electric vehicles.

Charging Infrastructure		Characteristics	# charging points
Private Connection	Regular / daily recharge	▪ Garage / parking close to house ▪ 3.7 – 11 (22) kW ▪ regular sockets, wallboxes, three-phase connections ▪ often without meter	1
Semi-public Connection	At work Shopping / leisure	▪ restricted access to group of users (employees, customers, ...) ▪ 3.7 – 22 kW ▪ regular sockets, wallboxes, three-phase connections ▪ metering possible	1-2
Public Charging Point	Slow charging (< 22kW)	▪ open to the public ▪ (3.7) – 22 kW ▪ AC charging stations with meters	2-4
	Fast charging (>22 kW)	▪ open to the public ▪ 22 - 350 kW ▪ DC charging stations with meters	2-4

What is the amount of charging infrastructure needed for each PEV type and user group?

Aim of this talk

Charging Infrastructure		Private vehicles BEV	Private vehicles PHEV / REEV	Commercial vehicles BEV	Commercial vehicles PHEV / REEV
Private Connection	Regular / daily recharge	?	?	?	?
Semi-public Connection	At work	?	?	?	?
	Shopping / leisure	?	?	?	?
Public Charging Point	Slow charging (< 22kW)	?	?	?	?
	Fast charging (>22 kW)	?	?	?	?

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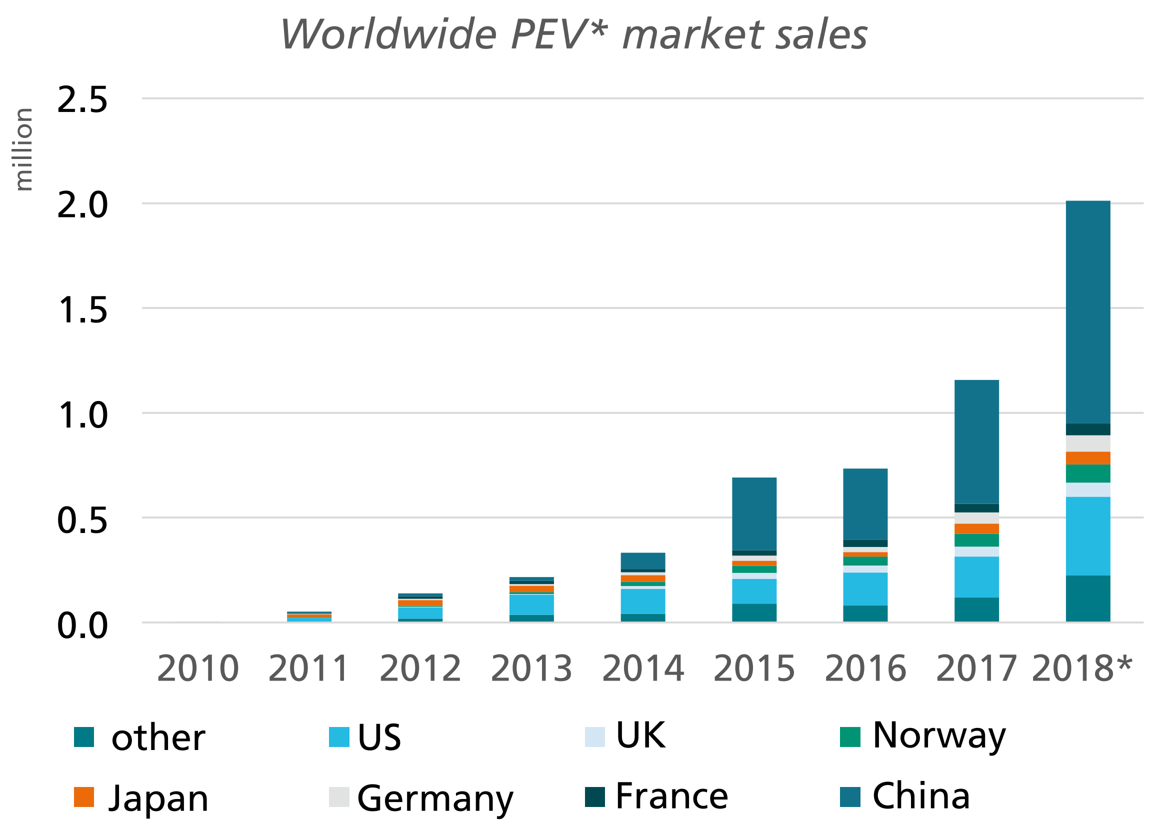
Plug-in electric vehicles show a large increase in sales, but also have a growing market potential.



- worldwide PEV market sales share 2018: 2.4%
- Norway, The Netherlands and Sweden with market shares above 3%
- Yet, large car markets with higher number of PEVs:
  - China 2018: 1.1 mn. PEVs (~3%)
  - US 2018: 375,000 PEVs

*PEV: Plug-in electric vehicles = Battery electric vehicles (BEV) + Plug-in Hybrid electric vehicles (PHEV)
Source: Marklines 2018, real values until 10/2018, prognoses afterwards

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Early adopters of PEV mainly charge at home, yet public fast charging is needed for user acceptance.

Empirical data on charging behavior of PEV early adopters[1)]:

- **charging occurs mainly at home** (50-80% of charging events)
- **some charging at work** (15-25% of charging events)
- **rare** charging events at **public slow** chargers and only on **exceptional** events at **fast chargers** (ca. 5% of charging events)

Source: https://blog.elektro-plus.com/2018/e-mobilitaet-so-laden-sie-ihr-elektroauto-schnell-und-sicher

- Surveys show[1)]:
  - The **access to a charger at home has the largest influence** on the vehicle buying decision
- Simulations on coverage of trips show:
  - **Low power** options (3,7 KW) **at home** are **sufficient**
- Analyses of driving profiles of German drivers show[3)]:
  - Average number of trips (with private cars) above 100km: 10 times per year
- But, data collections also show:
  - **Public charging is necessary for a general willingness to buy a PEV**[1)]
  - A wish for more charging infrastructure is often stated in surveys[2)]
  - Existing public charging infrastructure increases the electric driving share[1)]

1) Hardman, S. et al. (2018): A review of consumer preferences of and interactions with electric vehicle charging infrastructure. In Transport Research Part D. (2018), 508 -523.

2) Gnann, T.et al. (2017): Öffentliche Ladeinfrastruktur für Elektrofahrzeuge. Ergebnisse der Profilregion Mobilitätssysteme Karlsruhe. Fraunhofer-ISI: Karlsruhe

3) Funke, S.Á. (2018) Techno-ökonomische Gesamtbewertung heterogener Maßnahmen zur Verlängerung der Tagesreichweite von batterieelektrischen Fahrzeugen. Dissertation, Universität Kassel. http://nbn-resolving.de/urn:nbn:de:hebis:34-2018041155288

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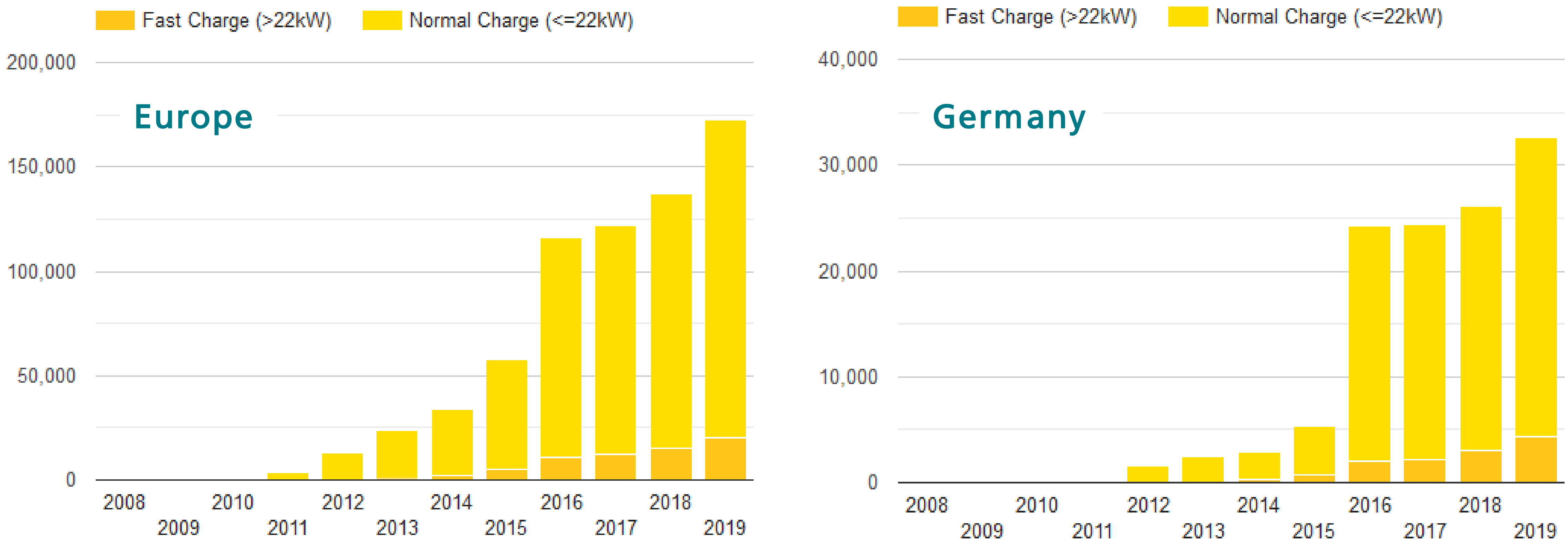
There are numerous public charging points available in Europe and Germany.



- Large amounts of public (fast) charging points have been constructed in the last years.

Source: https://www.eafo.eu/ last accessed: Nov, 6th, 2019

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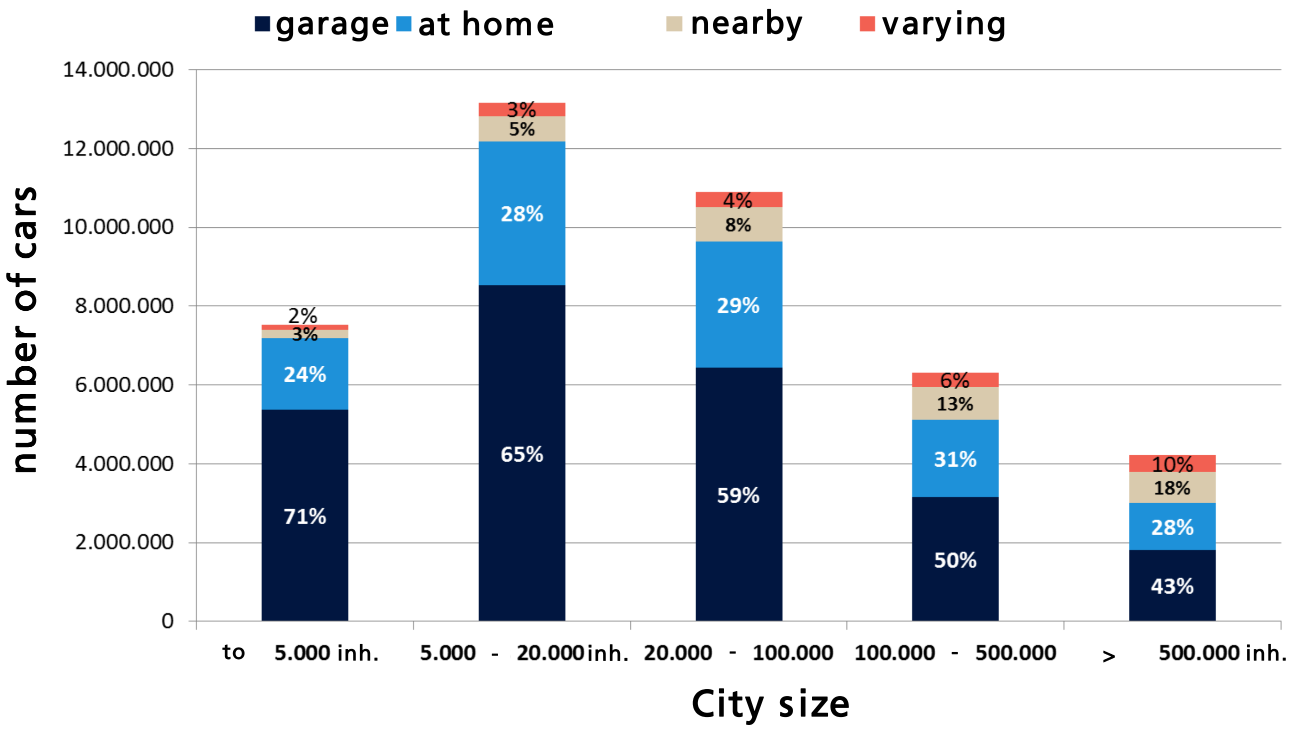
Most people could charge at home easily.

Where do you park at night?



- **ca. 60%** of all car users park in a garage
- **Few people searching for parking:** only 11% do not park at home
- Installation of charging would be cheap and easy in a garage

Source: own calculations based on "Mobilität in Deutschland 2008"

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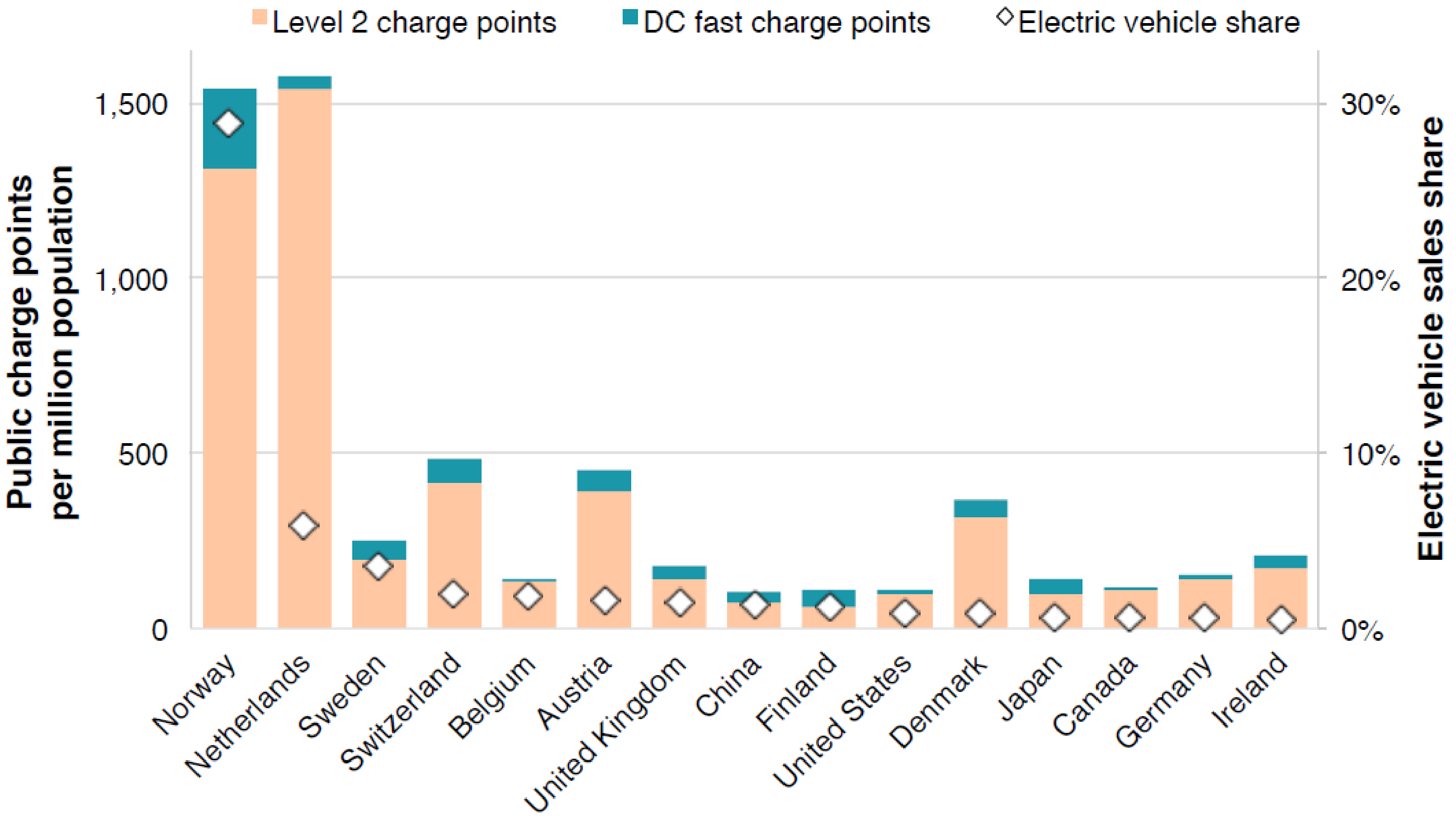
What are current policies and funding programs for charging infrastructure in Germany?

- EU Alternative Fuels Directive (**AFID**; Directive 2014/94/EU) requires **National Public Action Plans** that contain targets for public refueling infrastructure
  - **Target for Germany in 2020: 36,000 slow chargers; 7,000 fast chargers**
  - Footnote: The annex to the initial directive contained minimum targets from the EU with 150,000 charging points for Germany.[1]
- Subsidies through BMVI for up to 15,000 charging points (100mn. for slow, 200mn. for fast charging; 30-50% of initial cost + up to 5,000/50,000€ for installation)
- Several programs on a state and local level for public charging infrastructure setup

- Current discussion in **German Climate Conservation Program**:
  - **One million charging points in 2030** (not clearly defined if in public or also other premises)
  - Footnote 2: Initial statements talked about one million charging stations

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013SC0006&from=EN

Public charging infrastructure can increase vehicle sales, but is it really the key?



Abbildungsquelle: Hall, D. Lutsey, N. (2017): Global Assessment of Charging Infrastructure Deployment. EVS30 Symposium Stuttgart

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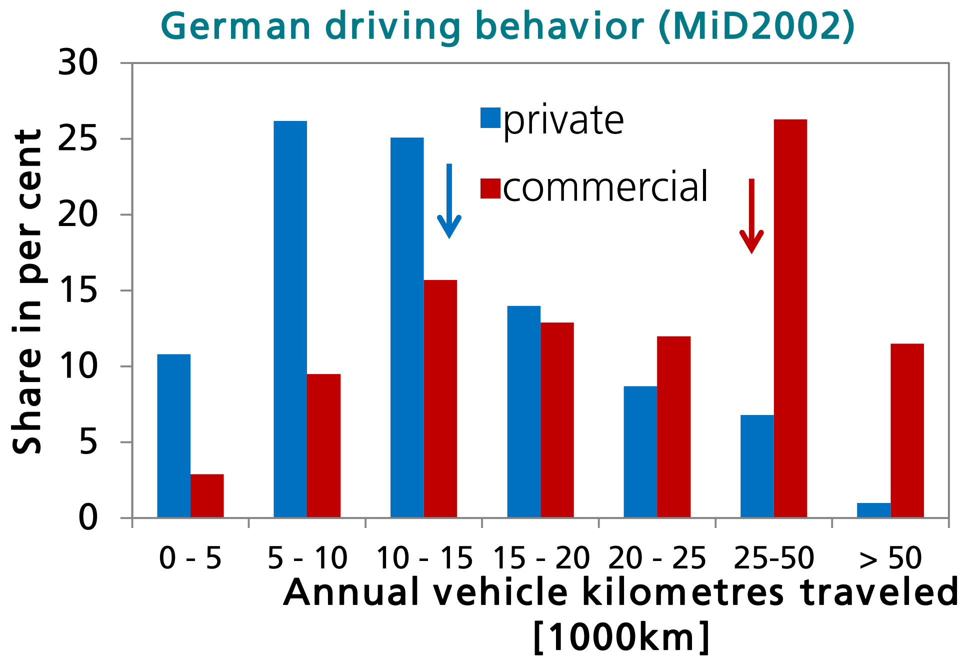
Driving differs significantly between different individuals and user groups.

- **Annual vehicle kilometers travelled vary strongly between user groups**
- Variety of usage not reducible to simple influence factors (e.g. vehicle size, city size or industrial branches)
- Average values (↓) cannot reproduce this heterogeneity
- **Limited electrical range** of BEVs important in buying decision
- **Electric driving shares** of PHEVs and REEVs important for realistic TCOs



Source: Own analysis based on MiD (2002).

We use driving profiles of private and commercial users.

- **Long observation periods** are crucial for EV characteristics
  - Limited range of BEVs, electric driving share of PHEVs/REEVs
  - Usage varies largely between users and days (esp. weekday vs. weekend)

attribute	Private and company cars German Mobility Panel (MOP)* 1994 – 2011	Fleet vehicles Fraunhofer ISI REM 2030-Data
Data collection design	Questionnaire	GPS-tracking
Observation period	**7 days**	**average 18.7 days**
Data set size	6,339 vehicles ~190,000 single trips Socio-demographic data	604 vehicles 80,899 trips company information

- Other sources (MiD or KiD 2002/2008) have larger samples but only one day observation
- Similar data is available for other countries

* MOP considers people and their movements, a mapping to vehicles can only be done in unambiguous cases, see Kley (2011): Ladeinfrastrukturen für Elektrofahrzeuge, Dissertation, KIT.

ALADIN – Alternative Automobiles Diffusion and Infrastructure – model overview

ALADIN
ALternative Automobiles Diffusion and INfrastructure

User-specific analysis

aggregated

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

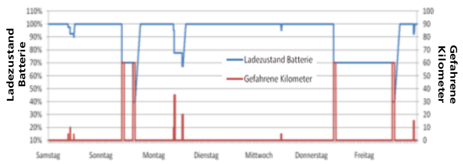
- Willingness-to-pay-more by adopter status (innov., early adopter, majority, laggards)
- Limited charging infrastruc.
- Limited vehicle choice EVs

Differentiation

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

Model steps

Individual EV simulation



For each user i:

- Feasibility BEV
- Electric driving share PHEV / REEV

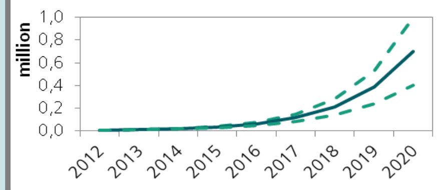
Individual utility maximisation

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

Stock model



Projection of:

- Vehicle stock
- Primary charging points stock
- Sales in user group

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 PEV availability

Car market

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

Source: Plötz, P; Gnann, T.; Wietschel, M. (2014): Modelling market diffusion of electric vehicles with real world driving data — Part I: Model structure and validation Elsevier, Ecological Economics Vol 107, Nov 2014, pages 411-421.

www.aladin-model.eu

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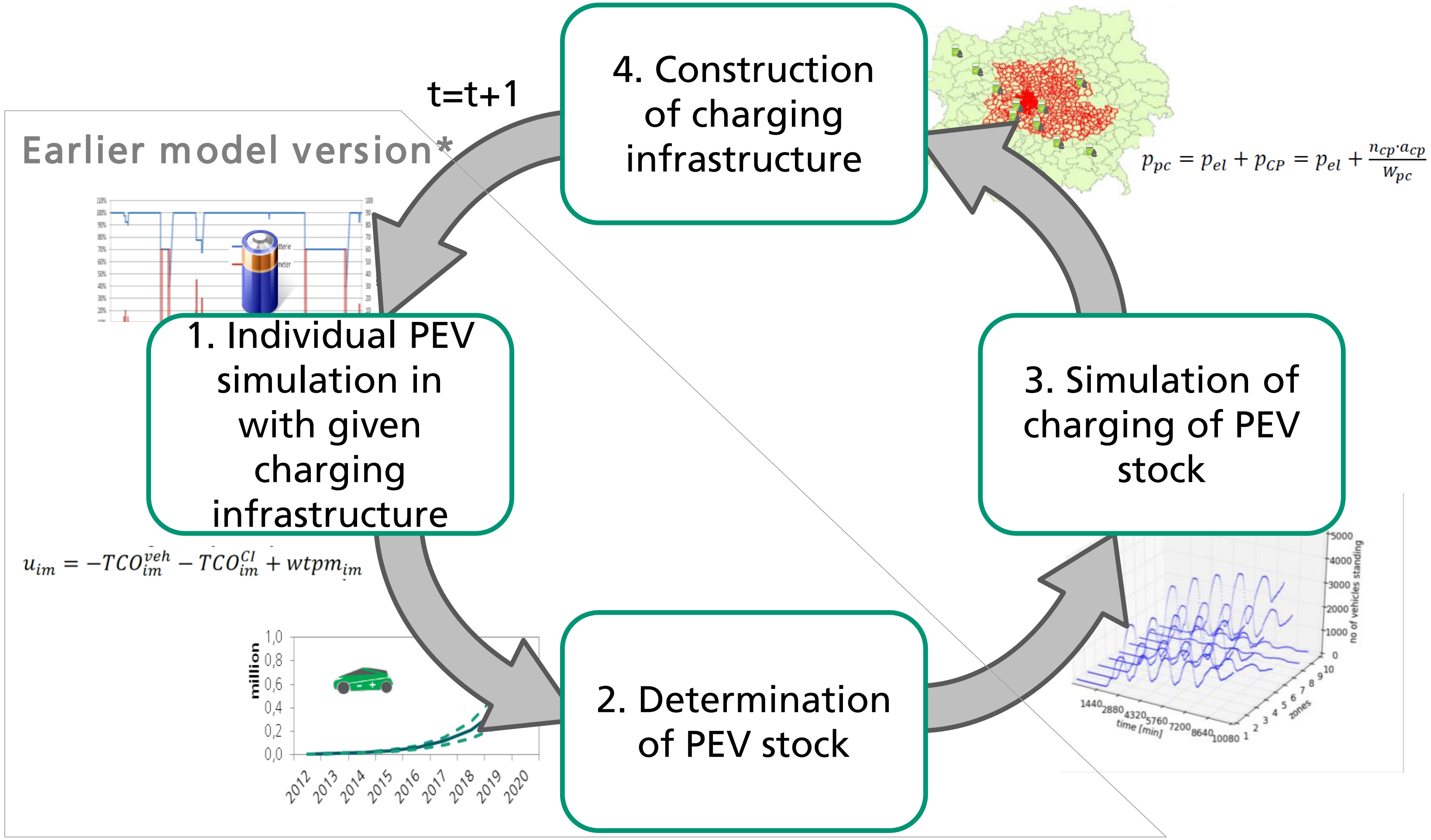
ALADIN – **Al**ternative **A**utomobiles **D**iffusion and **In**frastructure – model extension for public slow charging.

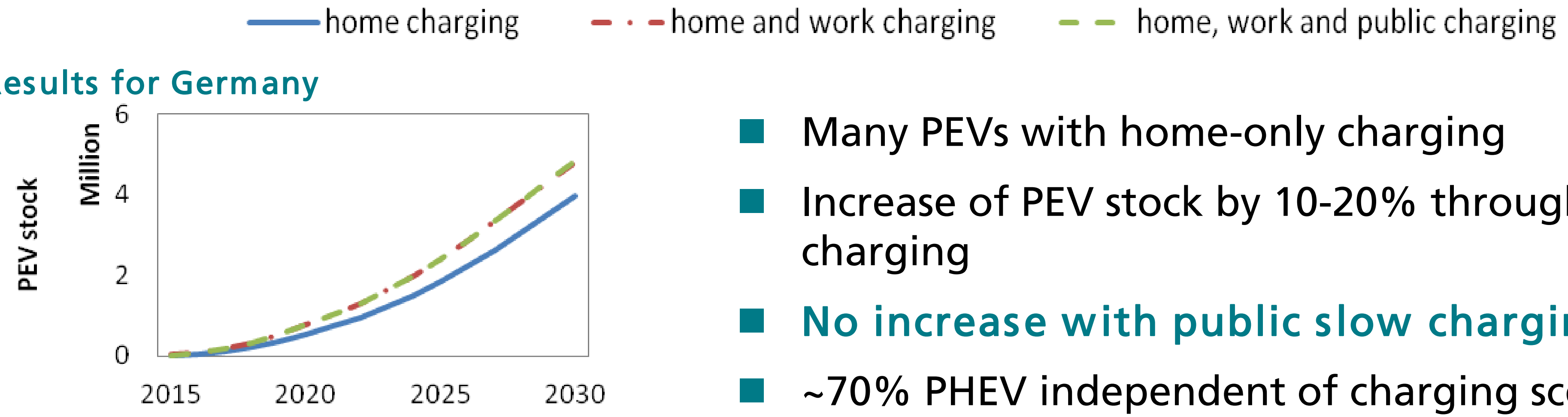


Gnann, T. (2015): Market diffusion of plug-in electric vehicles and their charging infrastructure. Dissertation. Stuttgart: Fraunhofer-Verlag.

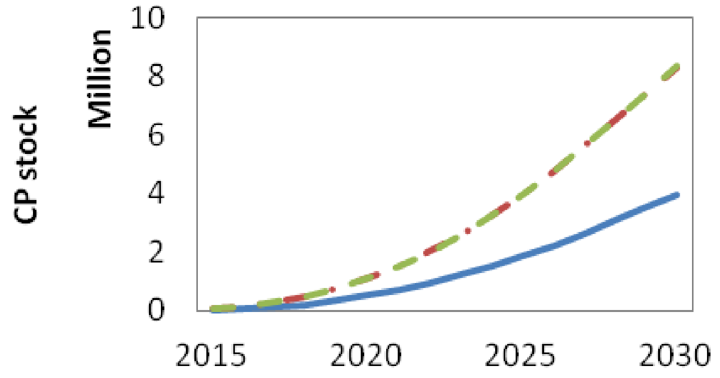
www.aladin-model.eu

PEV diffusion with home charging can be increased with charging at work.

Results for Germany



Results for Germany



- Many PEVs with home-only charging
- Increase of PEV stock by 10-20% through work charging
- **No increase with public slow charging**
- ~70% PHEV independent of charging scenario (but depending on costs assumptions)

- CP stock equal to number of PEVs in home only charging (precondition)
- CP stock doubles with work charging (precondition)
- Small increase of CP stock for public charging points

Source: Gnann, T.; Plötz, P.; Wietschel M. (2019): [Can public slow charging accelerate plug-in electric vehicle sales? A simulation of charging infrastructure usage and its impact on plug-in electric vehicle sales for Germany](). International Journal of Sustainable Transportation 13 (7), pp. 528-542.

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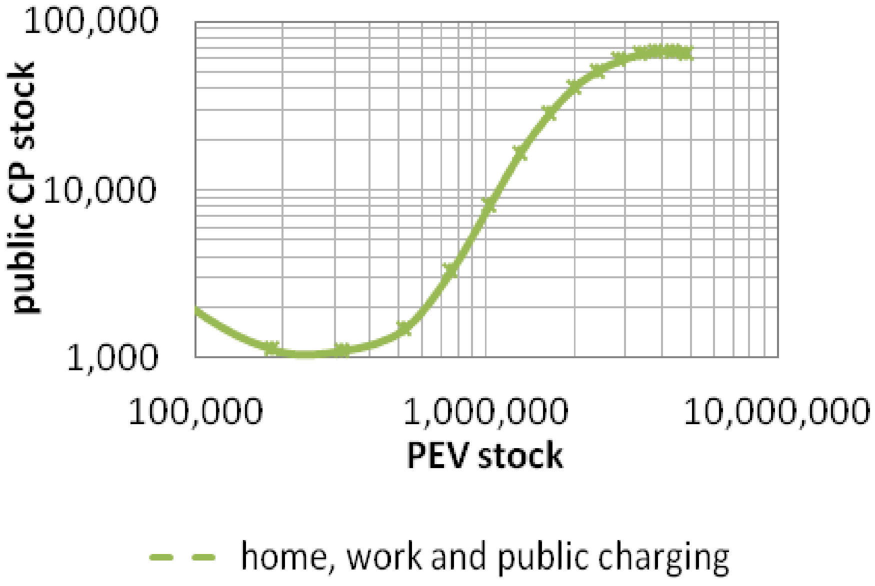
Public slow charging points have no techno-economical influence on PEV diffusion.



- PEV stock independent of public charging point stock
- Number of PEVs has large influence on number of public CPs
- **Public slow charging points only with subsidies**

$$p_{pc} = p_{el} + p_{CP} = p_{el} + \frac{n_{cp} \cdot a_{cp}}{W_{pc}}$$

- Tipping point (saturation) when decrease of subsidy is equivalent to increase of energy charged in public ($\Delta a_{cp} = \Delta W_{cp}$)

Charging with 3.7 kW at all locations.

Annual cost for public charging point: 800€/a (2015), 450€/a (2030)
Annual subsidized price: 100€/a (2015), 450€/a (2030)

Initial public charging price: 0.40€/a (2015)

Source: Gnann, T.; Plötz, P.; Wietschel M. (2019): Can public slow charging accelerate plug-in electric vehicle sales? A simulation of charging infrastructure usage and its impact on plug-in electric vehicle sales for Germany. International Journal of Sustainable Transportation 13 (7), pp. 528-542.

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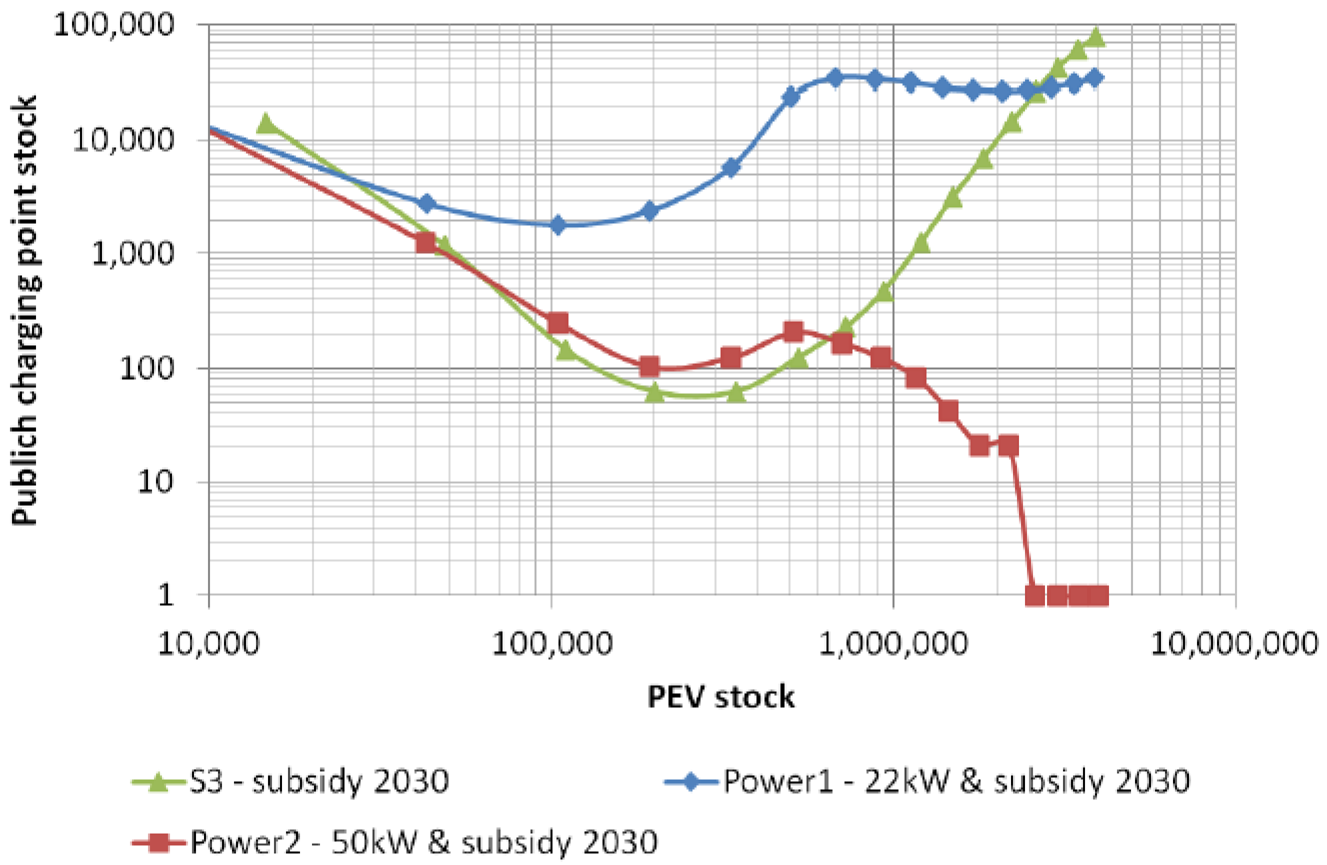
Results for PEV also remain stable if higher charging power is considered.



Source: Gnann, T.; Plötz, P.; Wietschel M. (2019): Can public slow charging accelerate plug-in electric vehicle sales? A simulation of charging infrastructure usage and its impact on plug-in electric vehicle sales for Germany. International Journal of Sustainable Transportation 13 (7), pp. 528-542.

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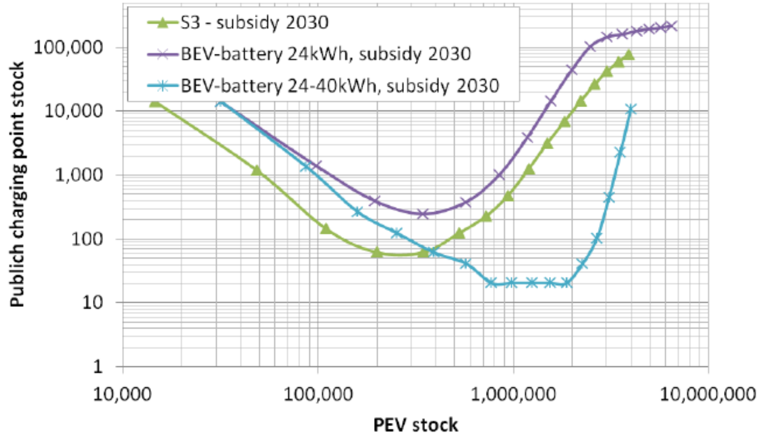
Different battery sizes change the number of PEVs and public charging infrastructure.



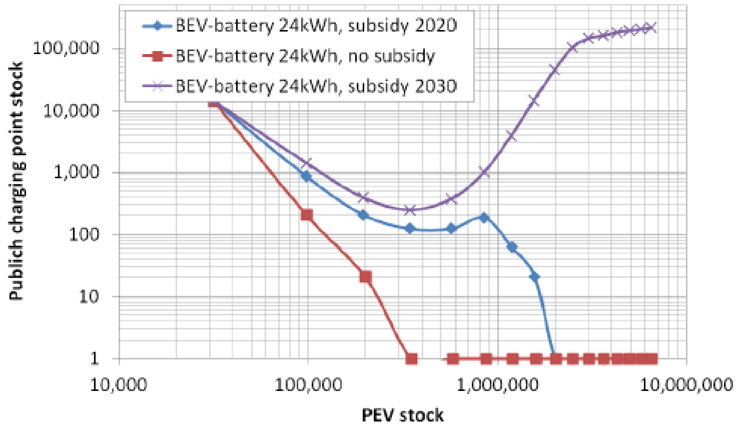


Table 2: Considered battery sizes and resulting ranges.

Parameter	unit	2015	2020	2025	2030
BEV gross battery capacity[a]	kWh	27	40	40	40
BEV range	km	121	189	200	212
PHEV gross battery capacity[a]	kWh	10	10	10	10
PHEV electric range	km	42	45	48	50

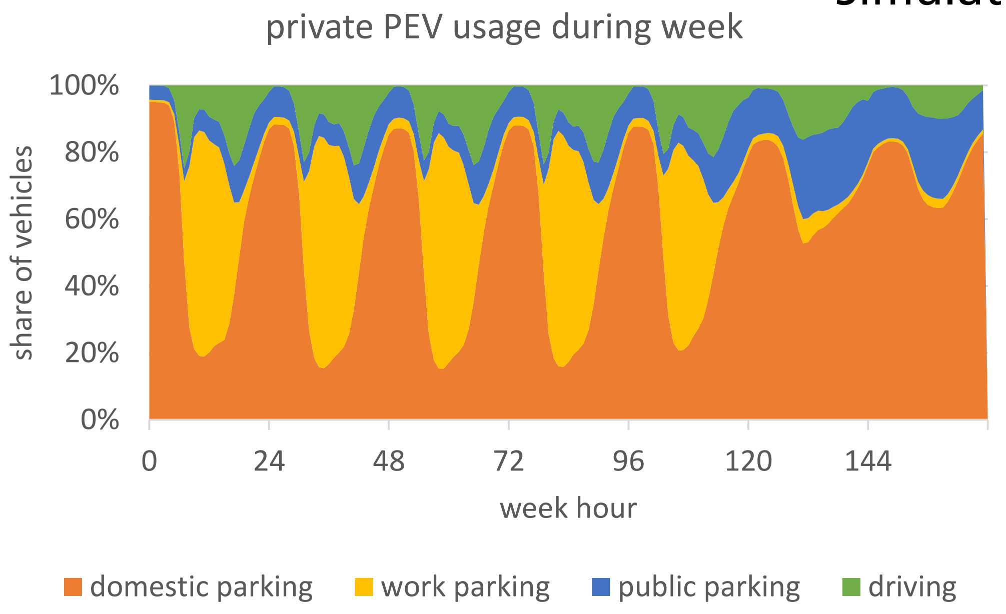
a:[27, 38–40]

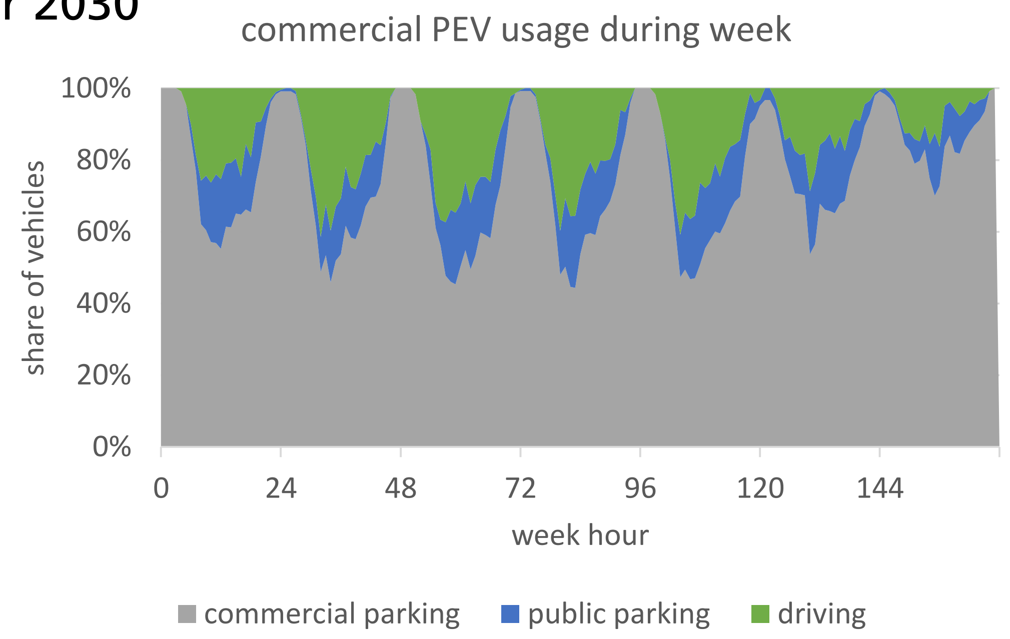
BUT: The number of public slow charging stations does not influence the number of PEVs.

Source: Gnann, T.; Plötz, P.; Wietschel M. (2019): Can public slow charging accelerate plug-in electric vehicle sales? A simulation of charging infrastructure usage and its impact on plug-in electric vehicle sales for Germany. International Journal of Sustainable Transportation 13 (7), pp. 528-542.

Private and commercial plug-in electric vehicles are parked more than 60% at domestic or commercial sites.

Simulations for 2030





- private PEVs are driving in 10% of the time
- ~60% are parked at domestic, 20% at work and 10% in public places

- commercial PEVs drive 15% of the time
- they are parked 75% at commercial sites and 10% in public

Source: own calculation based on results from
Gnann, T.; Plötz, P.; Wietschel M. (2019): Can public slow charging accelerate plug-in electric vehicle sales? A simulation of charging infrastructure usage and its impact on plug-in electric vehicle sales for Germany. International Journal of Sustainable Transportation 13 (7), pp. 528-542.

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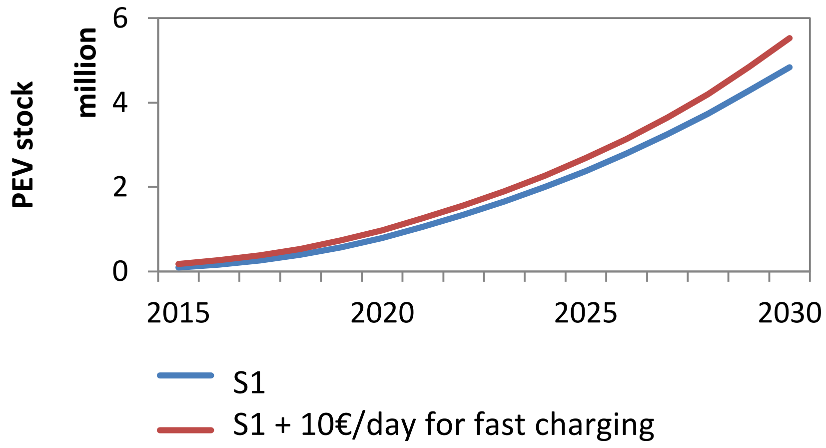
Public fast charging can influence the market diffusion of plug-in electric vehicles.

Assumptions

- On days with long distances (>driving range), BEVs can fast charge
- One charging event covers 150km (Plötz 2014)
- 20 kWh per charge + public charging price of 50€ct/kWh (electricity + charging station payoff)
  →**10 €/day for fast charging**
- Simulation of PEV market diffusion with 10 €/day for BEVs on days with long-distance trips

Results



- PEV stock 2030: 4,8 → 5,5 mill. **PEV (+15%)**
- On average 30 trips p.a. exceeding the range
  → 1,78 bn. € from 2015 to 2030.
- For 115.000€* per fast charger, about 7.500 fast charging stations could be paid off
- This would result in ca. 50 charging events/(day*charging station) or 18 charging events (day*charging point)

Sources:

Plötz (2014): *How to estimate the probability of rare long-distance trips*. Fraunhofer ISI Working Paper.

Gnann, T. (2015): Market diffusion of plug-in electric vehicles and their charging infrastructure. Dissertation. Stuttgart: Fraunhofer-Verlag.

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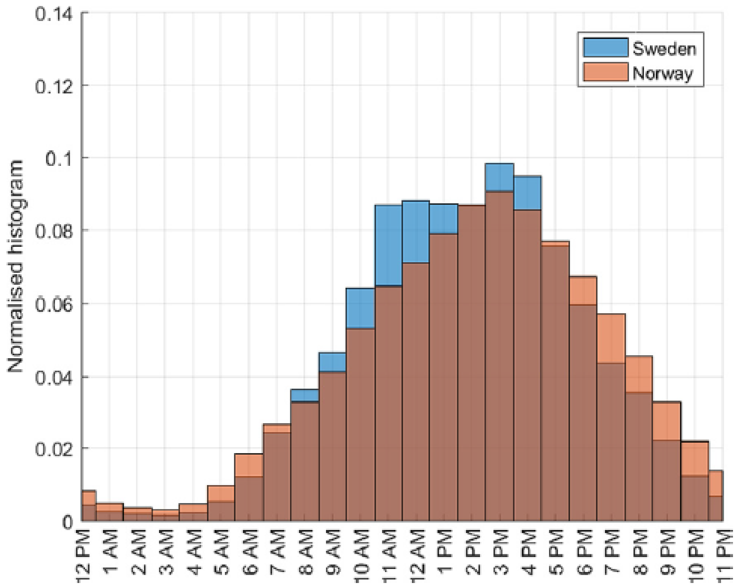
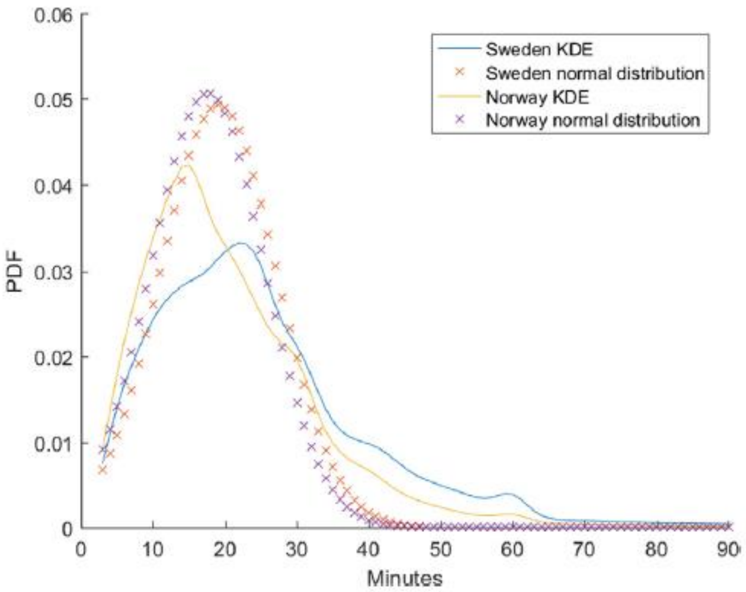
Fast charging needs will be similar to other alternative fuel or conventional vehicles.

- Charging behavior in Sweden and Norway very similar to refueling behavior with regard to timing during the day
- ~20 min charging time on average





- Ratio of BEVs to public fast charging points can be similar to other alternative fuels in the future (close to one fast charging point per 1000 vehicles for high power rates of 150 kW).

Results and figures from: Gnann, T.; Funke, S.; Jakobsson, N.; Plötz, P.; Sprei, F.; Bennehag, A. (2018): Fast charging infrastructure for electric vehicles: Today's situation and future needs. Transportation Research Part D 62 (2018) 314-329.

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Summary: There is no need for an extensive construction of charging infrastructure.

Charging Infrastructure		Private vehicles		Commercial vehicles	
		BEV	PHEV / REEV	BEV	PHEV / REEV
Private Connection	Regular / daily recharge	Required, but available/easy to install in many households & companies in Germany → no subsidies needed except for intelligent chargers			
Semi-public Connection	At work	Would accelerate market diffusion → could be subsidized		Does not apply	
	Shopping / leisure	No public action required (apart from standardization) → private investments			
Public Charging Point	Slow charging (< 22kW)	Only required for some users for overnight charging, necessary from a psychological point of view, but not from a techno-economical one → could be replaced by fast charging			
	Fast charging (>22 kW)	private investments ongoing	Not required	private investments ongoing	Not required

* Joint Venture Ionity

Results based on: Wietschel, M.; Gnann, T.; Plötz, P.; Funke, F.: Wie sieht ein bedarfsgerechter Ladeinfrastrukturaufbau für Elektrofahrzeuge in Deutschland aus? . Energiewirtschaftliche Tagesfragen. 65 (2015), Nr.12, S.78-82

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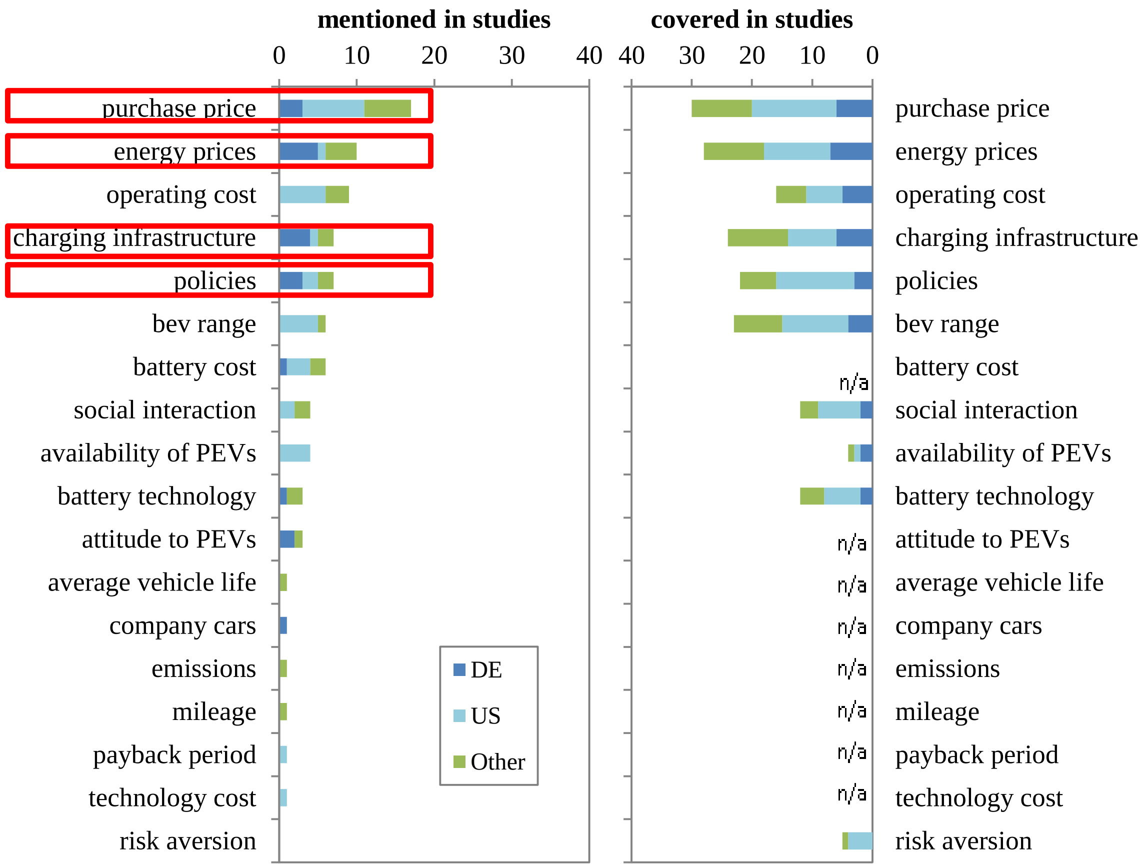
Discussion (1/2): The market diffusion of PEV does not only depend on charging infrastructure.



Main findings:

- A lot of factors are stated to be important after the analysis (16 different factors in 40 models)
- factors with "n/a" were not investigated by us
- Some country-specific differences:
  - For the US vehicle cost seems to be most important
  - For Germany, energy prices and other factors tend to be more important
- **charging infrastructure** mentioned as **one out of many important drivers** on market diffusion results

Source: Gnann, T.; Stephens, T. S.; Lin, Z.; Plötz, P.; Liu, C.; Brokate, J. (2018): What drives the market for plug-in electric vehicles? - A review of international PEV market diffusion models. Renewable and Sustainable Energy Reviews 93C (2018) pp. 158-164.c

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Discussion (2/2): Are these findings transferable to other countries?

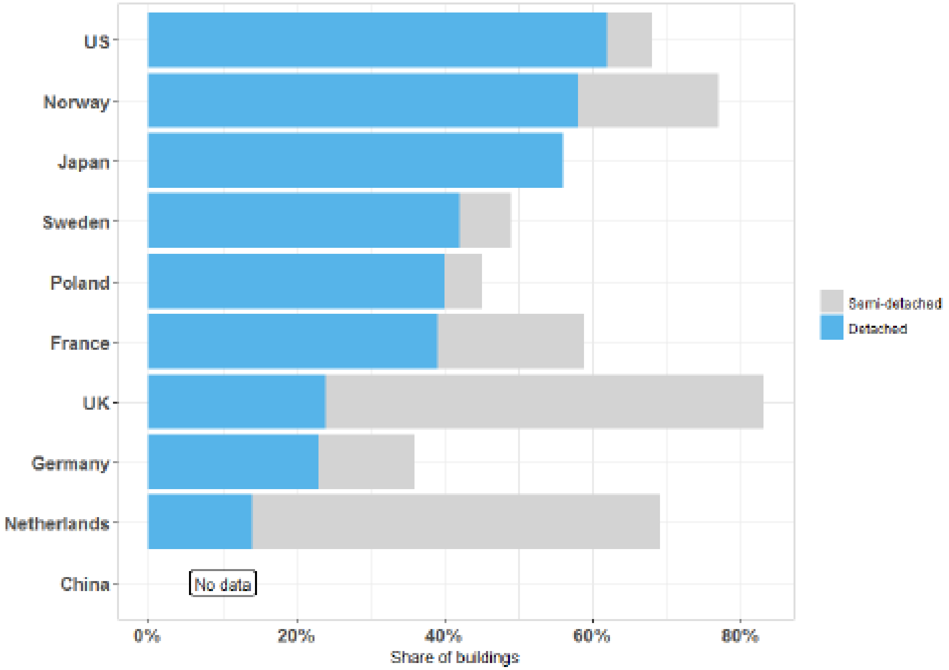

Figure 2. Share of detached and semi-detached houses for different countries (share of buildings). Data sources: US Census Bureau 2017, Eurostat 2016, Statistic Japan 2013.

Findings from an international literature review of charging infrastructure requirements [Funke et al. 2019]:

1. The availability of charging infrastructure supports PEV diffusion.
2. Broad availability of home charging infrastructure is sufficient for the early market diffusion of PEV.
3. Public slow charging infrastructure is only needed as a substitute for home charging.
4. DC high power charging infrastructure is mainly needed for BEV long-distance trips.

Source: Funke, S.; Sprei, F.; Gnann, T.; Plötz, P. (2019): How much charging infrastructure do electric vehicles need? A review of the evidence and international comparison; Accepted for publication in Transportation Research D. https://doi.org/10.1016/j.trd.2019.10.024

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Concluding remarks and policy recommendations

- There are **already a lot of charging points**, also in public.
- Some good ideas in the charging infrastructure master plan of BMVI make more sense, like: open parkings with charging infrastructure of shops to private users overnight.
- Apart from that, **other policy options would accelerate vehicle sales** even **more**:
  - Information on and interoperability of existing public charging points.
  - Direct subsidies to car buyers [Münzel et al. 2019]
  - Real car bans in cities and sales [Plötz et al. 2019]

→ **Much more public slow charging infrastructure is not really necessary** in our point of view and we assume these charging stations **will only rarely be used** in future. [Wietschel et al. 2015]

Münzel, C.; Plötz, P.; Sprei, F.; Gnann, T. (2019): How large is the effect of financial incentives on electric vehicle sales? – A global review and European analysis. Energy Economics. In press.

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What's next?

Some facts about heavy-duty trucks:

- large increase in transport volume and thus CO_2 emissions (currently one sixth in Germany)
- one 40t truck emits about 50 times more CO_2 than a passenger car per year
- high utilization of trucks and hardly any time to recharge at a charging station

One promising solution...

Source: Siemens AG

Thank you for your attention!

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Acknowledgements for their contributions to: Prof. Dr. Martin Wietschel, Dr. Patrick Plötz, Dr. Simon Funke, and Dr. Uta Burghard.

Large parts of this research were analyzed in the framework of the Profilregion Mobilitätssysteme Karlsruhe, which is funded by the Ministry of Economic Affairs, Labour and Housing in Baden-Württemberg and as a national High Performance Center by the Fraunhofer-Gesellschaft.

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