HOW TO ADDRESS THE CHICKEN-EGG-PROBLEM OF ELECTRIC VEHICLES?*

Introducing an interaction market diffusion model for PEVs and charging infrastructure

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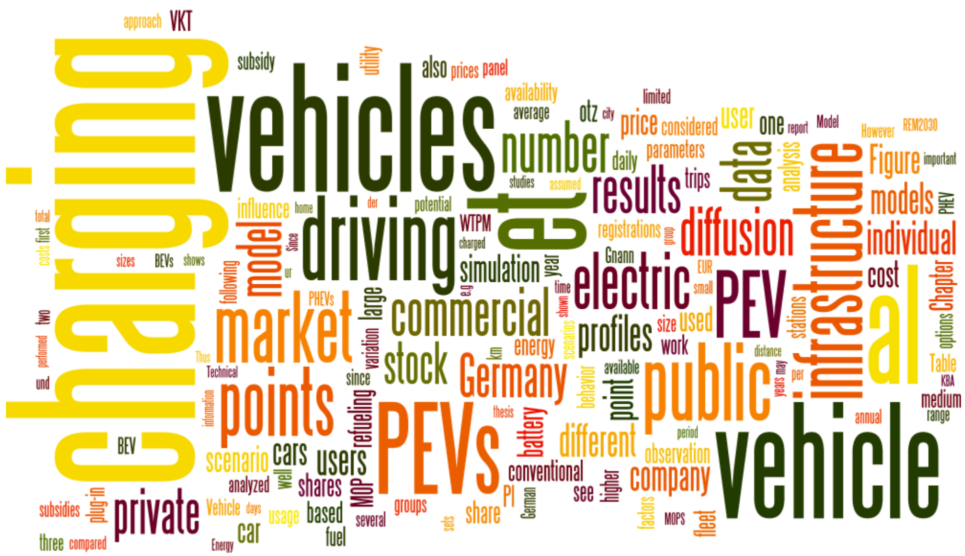

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*Slides from eceee Summer Study 2015:
Gnann, T., Plötz, P., and Wietschel, M.: How to address the chicken-egg-problem of electric vehicles? Introducing an interaction market diffusion model for EVs and charging infrastructure. Proceedings of the 2015 ECEEE summer study, Toulon/Hyères, France. ECEEE, 2015, S.873-884

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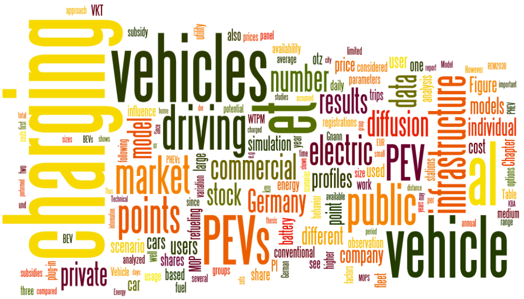
Agenda

1 Motivation

2 Data, Methods and Parameters

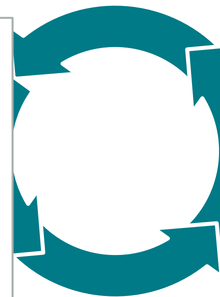
3 Central results

4 Summary, discussion and further research



Motivation: Is there a chicken-egg problem for plug-in electric vehicles?

- Potential PEV-users wish for charging infrastructure before purchase (Dütschke et al. 2012)
- Charging infrastructure may help to reduce range anxiety (Tate et al. 2008, Kurani et al. 1996, Kalhammer et al. 2007)



- Low usage of public charging points in PEV research projects (EV Project 2012, Bruce et al. 2012)
- Large deficit of current public charging points (Kley 2011)

- Users drive differently and have different purchase intentions (Plötz et al. 2013, Gnann et al. 2015a)

- Home charging possible for many users (Plötz et al. 2013) and sufficient for many potential PEV buyers (Kley 2011)

Models for co-diffusion of other alternative fuels available (Diesel, Gas, Hydrogen (Greene 1996, Sperling, Kurani 1987, Yeh 2007,…)), but transferability difficult due to PEV specialties

- Higher charging duration and lower ranges of PEVs (currently ca. 100-150 km)

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Motivation: A model is built based on requests

→**Request 1: Model the demand/desire for charging infrastructure**

→**Request 2: Consider the usage of public charging points**

→**Request 3: regard the varying driving**

→**Request 4: incorporate different charging facilities**

→**Request 5: charging time and frequency should be taken into account**

Development of an agent-based model grounded on driving profiles that covers the interaction at public charging points and copes with PEV and charging infrastructure specialties.

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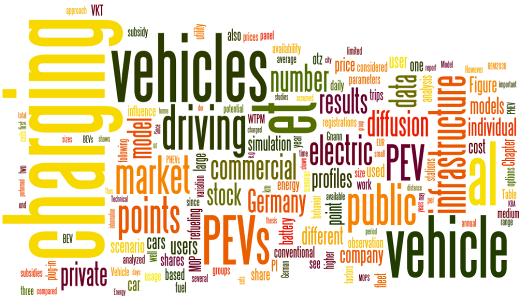

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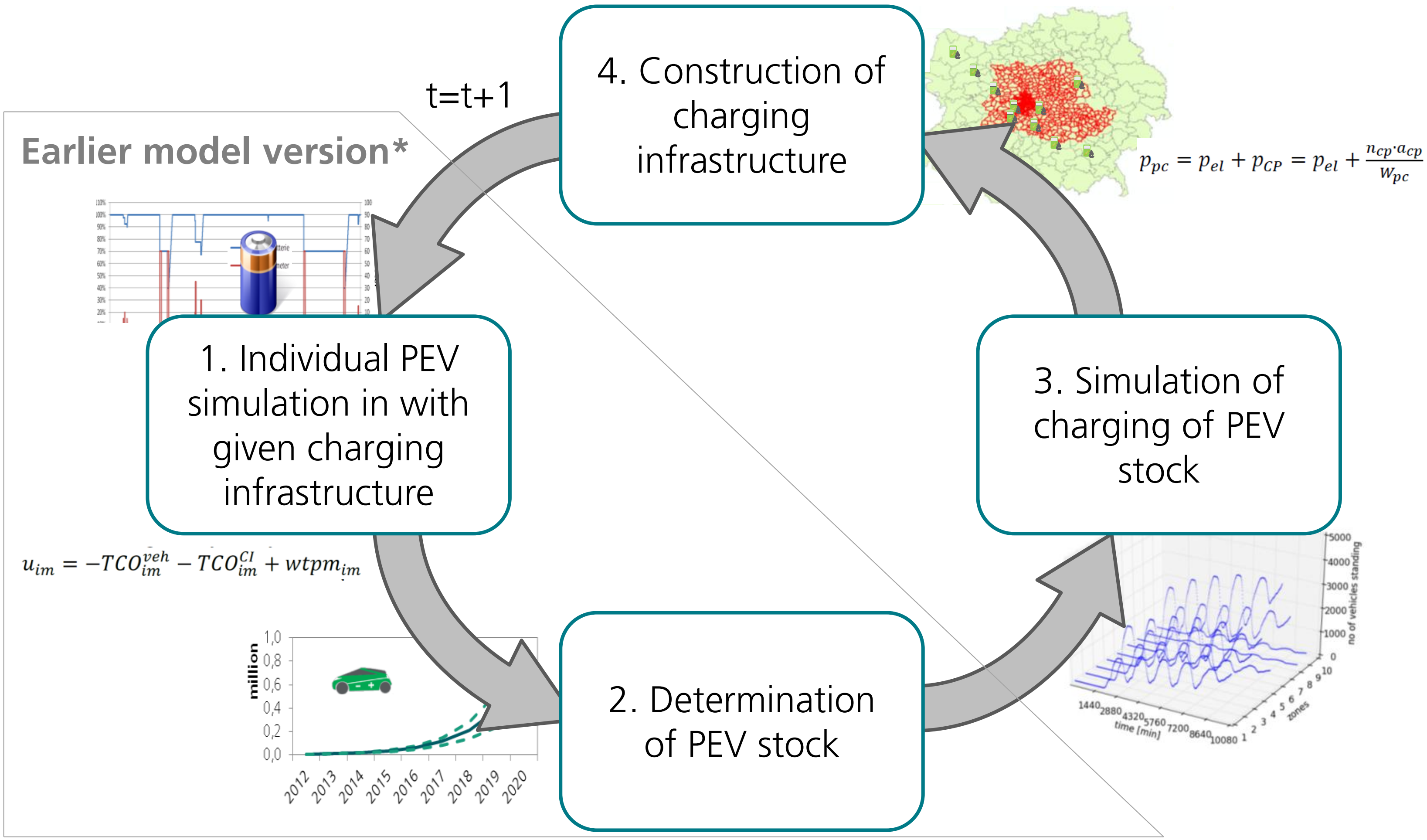
Method: The model uses a feedback loop for the PEV and public charging point stock.



*As presented in Plötz, Gnann, Wietschel, Ulrich: „How to foster EV market penetration?“ and published in (Plötz et al. 2014, Gnann et al. 2015b)

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Model ALADIN – **Al**ternative **A**utomobiles **D**iffusion and **In**frastructure

Model steps

Vehicle buyer agents

1. Individual PEV simulation

$$\mathrm{SOC}_i(\tau + \Delta\tau, t) = \begin{cases} \mathrm{SOC}(\tau,t) - d(\Delta\tau) \cdot c^e_{r,s}(t) & \text{for} \quad d(\Delta\tau) > 0 \\ \min\{\mathrm{SOC}(\tau,t) + \Delta\tau \cdot P_l(\tau,t), C_{r,s}(t)\} & \quad\quad d(\Delta\tau) = 0. \end{cases}$$

Results: electric driving share PHEV, BEV substitutability

2. Individual determination of the optimal vehicle

$$\max_m u_{im}(t) = -TCO^{veh}_{im}(t) - TCO^{CI}_{im}(t) + WTPM_{im}(t)$$

Results: (PEV-)registrations on drive trains and user groups

t:=t+1

CPO agent

4. Optimimal (de-) construction of public charging points

$$n_{cp}(t+1) := \frac{p_{pc}(t) - p_{el}(t)}{a_{cp}(t+1)} \cdot W_{pc}(t)$$

Results: public charging point stock

PEV agents

3. Calculation of PEV stock and joint PEV-stock simulation

$$W_{pc}(t) = \sum_i W_{i,l}(t) \text{ and } l = \text{public}$$

Results: Amount of public energy charged by location

Framework parameters

Parameters

- *Techn.*: battery sizes, consumptions
- *Economical*: car prices, residual values, O&M costs
- *Policies*: subsidies, taxes
- Energy- and battery prices

Charging Infrastructure

- Existing charging point stock
- Cost for charging infrastructure
- Initial cost for public charging

Vehicle market

- Registrations per user group
- Stock parameters
- Future PEV availability

Data on user behavior

Driving profiles

- All trips over at least one week: distance, dept. & arrival time & -place
- Owner information: sex, age, income, garage, city size

Favoring and limiting factors

- Willingness-to-pay-more by Rogers' adopter groups
- Limited infrastructure availability
- Limited Brands availability

Differentiation

- *3 groups of vehicle buyers agents:* private, commercial, company car
- *4 drive trains*: BEV, PHEV, gasoline, diesel
- *4 accessibility types for charging: domestic, commercial, work, public*

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Data: 1.3 million vehicle driving profiles of the region of Stuttgart are simulated as EV

- Mobility panel of 5,000 households for one week in the region of Stuttgart (see map)
- Transfer to all people in the region of Stuttgart based on socio-demographic data and trip matrices
- 2.7 Mio. inhabitants and 1.3 million vehicles (Hautzinger et al. 2013)

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Assumptions: Three scenarios are considered for simulation.

Charging power in different scenarios

Scenario name	Home* charging	Work charging	Public charging
Home-only	3.7 kW	-	-
Home-and-work	3.7 kW	3.7 kW	-
Home,work and public	3.7 kW	3.7 kW	3.7 kW

Public charging with subsidies until 2030

Charging infrastructure	unit	value 2015	value 2030
Annual cost for public charging point	€/yr	800	450
Annual subsidized price	€/yr	100	450

* Home charging means domestic charging for private vehicles and commercial charging for commercial fleet vehicles.

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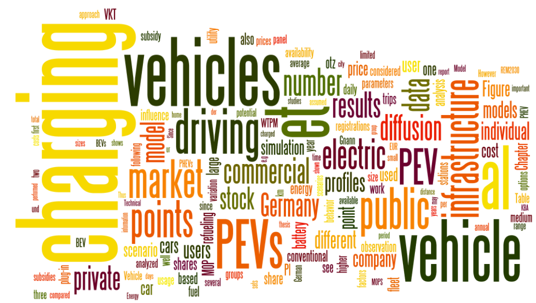
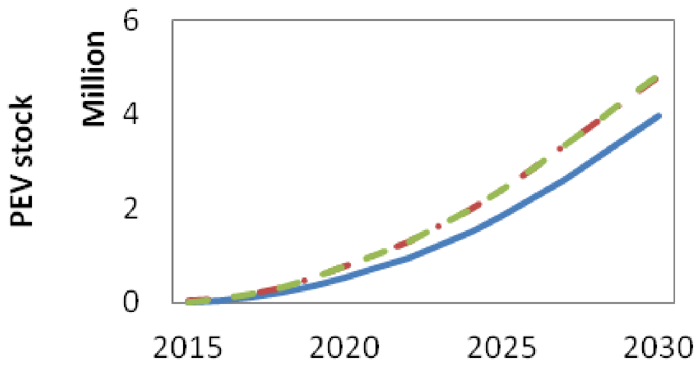
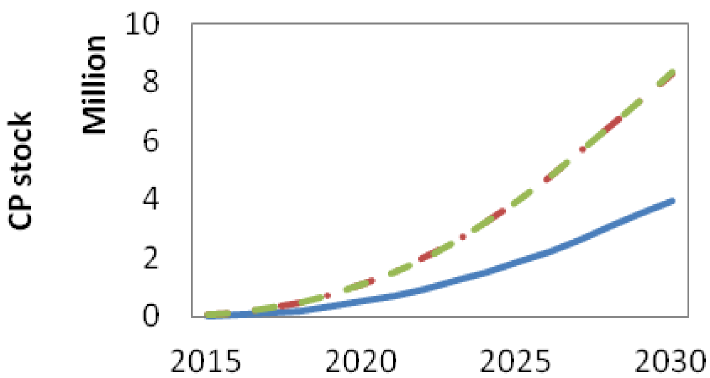


Results: The PEV diffusion with home charging can be increased with charging at work.

home charging — home and work charging — home, work and public charging



- Many PEVs with home-only charging
- Increase of PEV stock by 10-20% through work charging
- **No increase with public 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

Charging with 3.7 kW in all scenarios and 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)

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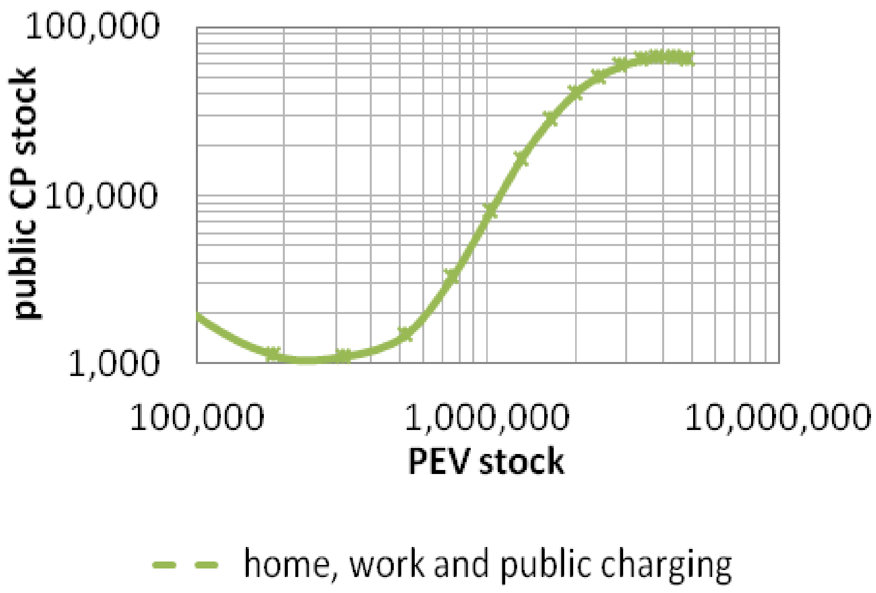
Results: Public charging points have no techno-economical influence on PEV diffusion



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

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

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

Charging with 3.7 kW at all locations.
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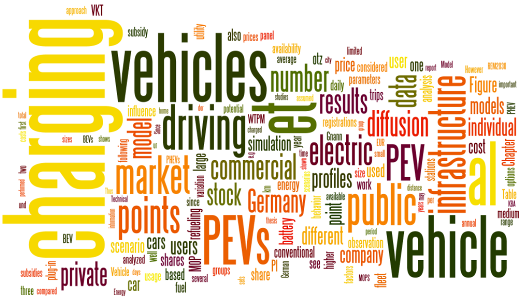

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Discussion & Conclusions: Home charging is most important for PEVs, then at work, then in public.

Discussion

- Techno-economical analysis of charging infrastructure, **psychological need** (value for the possibility) of public charging **not reflected**
- Data sets with **limited observation period**, yet additional calculations show no qualitative differences
- **Only slow charging** (AC) analyzed with this approach, yet approach not useful for fast charging

Conclusions

- **Charging at home** is **mandatory** for PEVs!
- Charging at work increases number of PEVs
- **Public slow charging without influence** from techno-economical point of view and **subsidies necessary**

- Differentiation of **different charging infrastructure** access **types** is **important**.
- Differering user behavior should be addressed.
- ABM is best solution for this complex system

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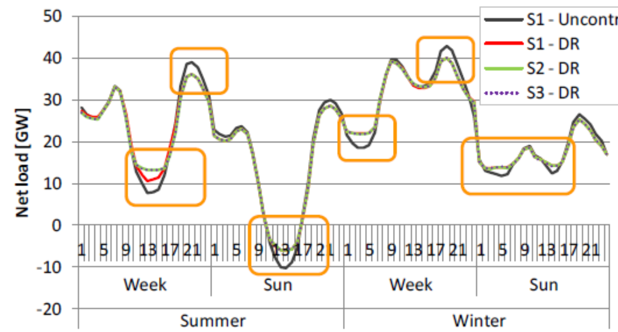
Further research

Currently working on…

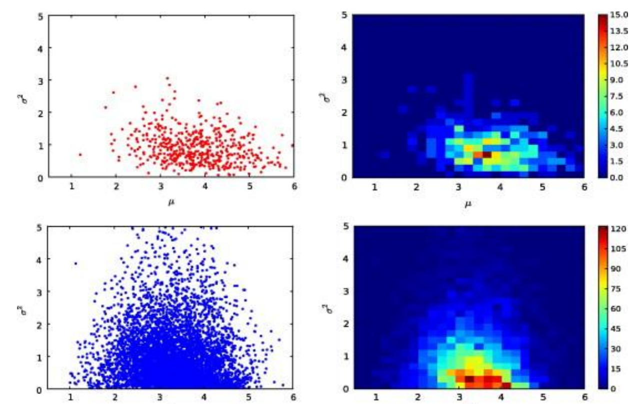
- …including the "psychological" cost for the "**option to charge**" based on a survey
- …analyzing the potential benefit of **load shifting**
- …how to **combine slow** ("opportunity") **with fast** ("interim") **public charging**

Preliminary result on load shifting potentials



Other works on PEVs with the model:

- Include assumptions for **fast charging**
- Look at the potentials for **first and second cars in households**
- Include **rental cars for long distance trips**
- More details on **PEVs as commercial passenger cars**



Regularity of driving of private vs. commercial passenger cars, taken from (Gnann et al. 2015a)

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Thank you for your attention!

Further questions?

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References:

Bruce, I.; Butcher, N.; and Fell, C. (**2012**). Lessons and Insights from Experience of Electric Vehicles in the Community. In Proceedings of Electric Vehicle Symposium 26 (EVS 26), Los Angeles, US.

Dütschke, E.; U. Schneider; A. Sauer; M. Wietschel; J. Hoffmann; und S. Domke: *Roadmap zur Kundenakzeptanz - Zentrale Ergebnisse der sozialwissenschaftlichen Begleitforschung in den Modellregionen*. Berlin: Fraunhofer ISI, Bundesministerium für Verkehr, Bau und Stadtentwicklung (BMVBS). **2011**

EV Project: Ecotality, und Idaho National Lab. **2012**. *The EV Project Q1 2012 Report*.

Gnann, T., Plötz, P., Funke, S., Wietschel, M.: (**2015a**). What is the market potential of electric vehicles as commercial passenger cars? A case study from Germany. Transportation Research D 37(0):171 – 187.

Gnann, T., Plötz, P., Kühn, A., and Wietschel, M. (**2015b**). Modelling market diffusion of electric vehicles with real world driving data: German market and policy options. Transportation Research Part A: Policy and Practice, 77(0):95 – 112

Greene, David L. "Survey evidence on the importance of fuel availability to the choice of alternative fuels and vehicles." *Energy studies review* 8 (**1996**): 215-231.

Hautzinger, H., Kagerbauer, M., Mallig, N., Pfeiffer, M., and Zumkeller, D.: Mikromodellierung für die Region Stuttgart - Schlussbericht. Technical report, INOVAPLAN GmbH, Institute for Transport Studies at the Karlsruhe Institute of Technology (KIT), Institut für angewandte Verkehrs- und Tourismusforschung e.V., Karlsruhe, Heilbronn **2013**

Kalhammer, F.R., Kopf, B.M., Swan, D.H., Roan, V.P. undWalsh, M.P.): Status and prospects for zero emissions vehicle technology. Report of the ARB independent expert panel 2007. State of California Air Resources Board. **2007**

Kley, F.: *Ladeinfrastrukturen für Elektrofahrzeuge - Analyse und Bewertung einer Aufbaustrategie auf Basis des Fahrverhaltens*. Karlsruhe: Fraunhofer Verlag. **2011**

Kurani, K.S., Turrentine, T. und Sperling, D.: Testing electric vehicle demand in 'hybrid households' using a reflexive survey. In: Transportation Research Part D: Transport and Environment, Bd. 1 (2), S. 131–150, doi:10.1016/S1361-9209(96)00007-7. **1996**

Pearre, N. S. et al.: Electric vehicles: How much range is required for a day's driving? *Transportation Research Part C*, 19 (6), pp. 1171–1184. **2011**

Plötz, P. , Gnann, T., Wietschel, M. und Kühn, A. "Markthochlaufszenarien für Elektrofahrzeuge - Langfassung. Studie im Auftrag der Acatech und der Nationalen Plattform Elektromobilität (AG7)," **2013**

Sperling, D., and Kurani, K. S. *Refueling and the vehicle purchase decision: the diesel car case*. No. CONF-870204-. Transportation Research Group, Departments of Environmental Studies and Civil Engineering, Univ. of California, Davis, **1987**

Tate, E.D., Harpster, M.O. und Savagian, P.J.: The electrification of the automobile: From conventional hybrid, to plug-in hybrids, to extended-range electric vehicles. In: 2008 SAE World Congress, Detroit, Michigan, 14-17 April 2008. General Motors Corporation, SAE 2008-01-0458, doi:10.4271/2008-01-0458. **2008**

Yeh, S., "An empirical analysis on the adoption of alternative fuel vehicles: The case of natural gas vehicles," *Energy Policy, vol. 35,* pp. 5865–5875, Nov. **2007**.