MODELLING MARKET DIFFUSION OF ALTERNATIVE FUEL VEHICLES

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Typology of energy models

Energy models

- **Top down (energy economics)**
  - Input output
  - General equilibrium
  - Macro-economic
- **Bottom up (energy systems)**
  - Optimization
  - Simulation

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Simulation

- **Simulation** is a method mainly to analyse dynamical systems
- In simulation studies, experiments are being performed on a model (instead of the real system) to learn about the real system
- As with all models: simplification and abstraction

- General mathematical form of a dynamical simulation model:

$$X_t = f_t\,(X_{t\text{-}1},\ \ldots,\ X_{t\text{-}n},\ Z_t\,,\ Z_{t\text{-}1}, \ldots,\ Z_{t\text{-}n},\ U\ )$$ – with time t

X : Variables calculated by the model (endogenous) – state of the system
Z: Variables outside the model, specified by user (exogenous)
U : stochastic term
t : time

[Küll et al, 1999]

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Discussion of simulation models

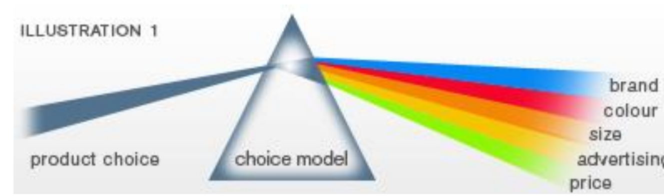
- **Reasons for using simulations**:
  - Study of real system is too difficult, too expensive or not possible
  - A simulation model is very easy for experiments: can be easily modified and results can be reproduced
  - The real system is not understood or too complex
- Compare with optimization models: no cost-optimal energy system is analysed but the "real energy world" is analysed in scenarios
  - Often with actual participants in energy world as "agents"
- Simulations and scenarios are particularly useful to study the effect of interventions or policies, varying energy prices or new technologies

Different methods & diffusion models are available to estimate market evolution.

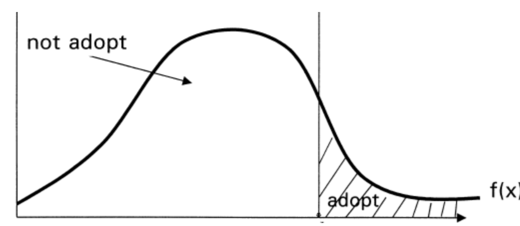
1. **Aggregated / epidemic models (top-down)**
   - Diffusion of technology highly aggregated
   - *Examples*: logistic, Bass, and Gompertz diffusion (cp. Geroski (2009): Models of technology diffusion)
   - Highly sensitive in early market phase

$$\frac{d}{dt}N(t) = rN\left(1 - \frac{N}{N_{\max}}\right)$$

2. **Discrete choice and logit models**
   - Very common in transport demand models
   - Utility maximisation interpretation established (cp. Train (2009): Discrete choice methods and simulation)
   - Difficult to apply to completely new products or technologies (participants never actually drove an EV)



3. **Probit / agent-based models (bottom-up)**
   - Acknowledge variety of users & properties change in time
   - Product characteristics distribution is required
   - Our model ALADIN is modified probit model



For a slightly similar yet independent classification see B.M. Al-Alawi & T.H. Bradley (2013): Review of hybrid, plug- in hybrid, and electric vehicle market modeling Studies. Renewable and Sustainable Energy Reviews 21, pp. 190–203. Distinction there: Diffusion rate, consumer choice, and agent based.

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

User-specific analysis

User behaviour

Driving profiles

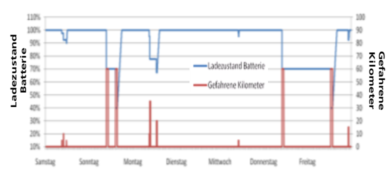
- All trips over at least one week: distance, duration, purpose, dep. & arrival time
- Owner information: gender, age, income, garage, city size
- Vehicle size, brand, age

EV user acceptance

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

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:

$$\max_p \left(-\text{TCO}_{ip} + \text{willingness-to-pay-more}_{ip} + -\text{limited choice}_{ip} - \text{home charging cost}_{ip} \right)$$

- Optimal vehicle choice for each user

Parameters

Vehicle dependent

- *Technical*: battery sizes, DoD, el./conv. consumption
- *Economical*: car prices, taxes, O&M costs, resale values
- *Policies*: subsidies, taxes,

Vehicle independent

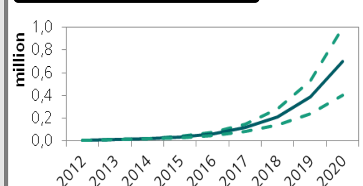
- Fuel/battery/electricity prices until 2020
- Costs for home charging
- Future EV availability

aggregated

Differentiation

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

Stock model



Projection of:

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

Car market

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

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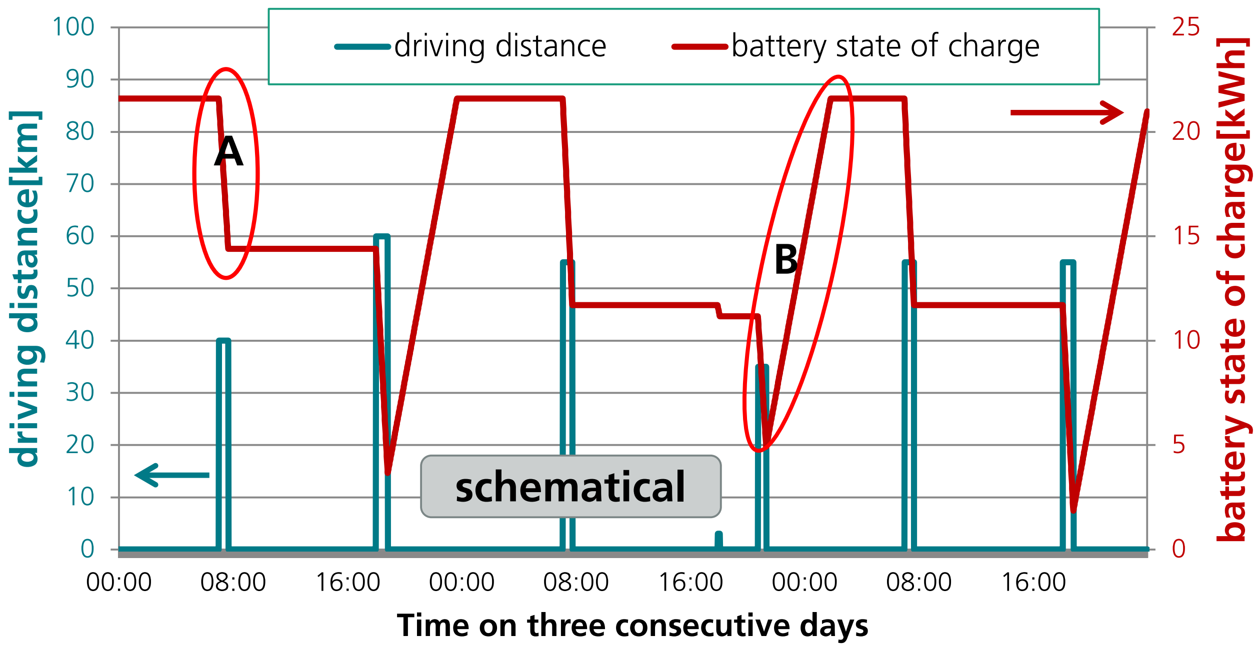
Battery simulation and technical potential for electric vehicles

Idea of calculation

- Battery discharged when vehicle in motion (A)
- Battery charged when vehicle stopped and charging infrastructure available (B)

Inputs

Driving profiles
- EV consumptions
- Battery sizes



Outputs

- BEV feasible: Yes/No
- Electric driving share PHEV/REEV

Variations/Options

- Infrastructure at more/other locations
- Different vehicle sizes and EV types

Assumptions for chart: 1) Charging strategy only at home 2) battery size 24 kWh, consumption 19 kWh/100 km

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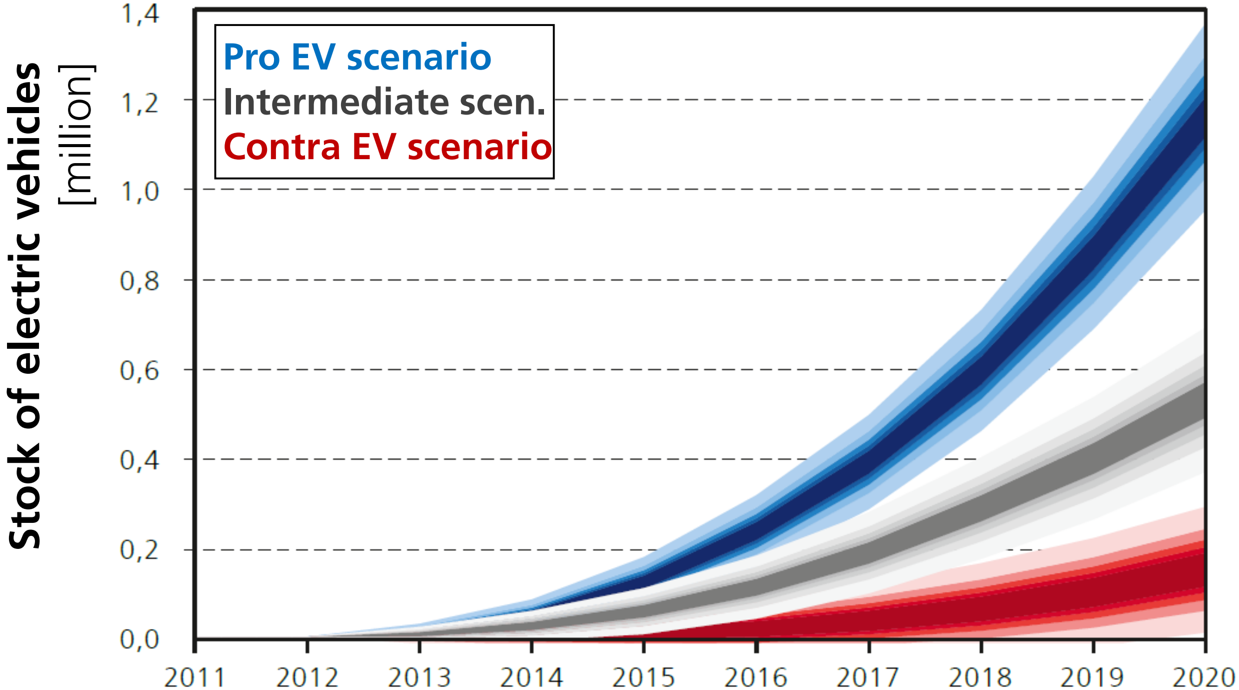
Market diffusion:
External conditions are highly important.

Stock evolution EVs in Germany incl. Cost for primary charging point, limited availability and willingness-to-pay-more in the three scenarios:



Shaded areas show the stock projection with confidence bands from the finite sample size with 10%, 30%, 50%, 70% and 90% confidence level.

Confidence bands are Clopper Pearson with gaussian error propagation.

2020 Scenario	Gasoline price *Euro/Liter*	Electricity private *Euro/kWh*	Electricity industry *Euro/kWh*	Battery price *Euro/kWh*
Pro	1,79	0,29	0,215	300
Intermed.	1,65	0,29	0,215	335
Contra	1,54	0,33	0,25	370

➢ **External conditions have high impact.**

Confidence bands quantify uncertainty only due to finite sample size. Uncertainties concerning future prices or high willingness to pay are not included. Source: Plötz et al (2013) – ALADIN (2013_04_26) – IP1IG1Sm/p/cOpt111).

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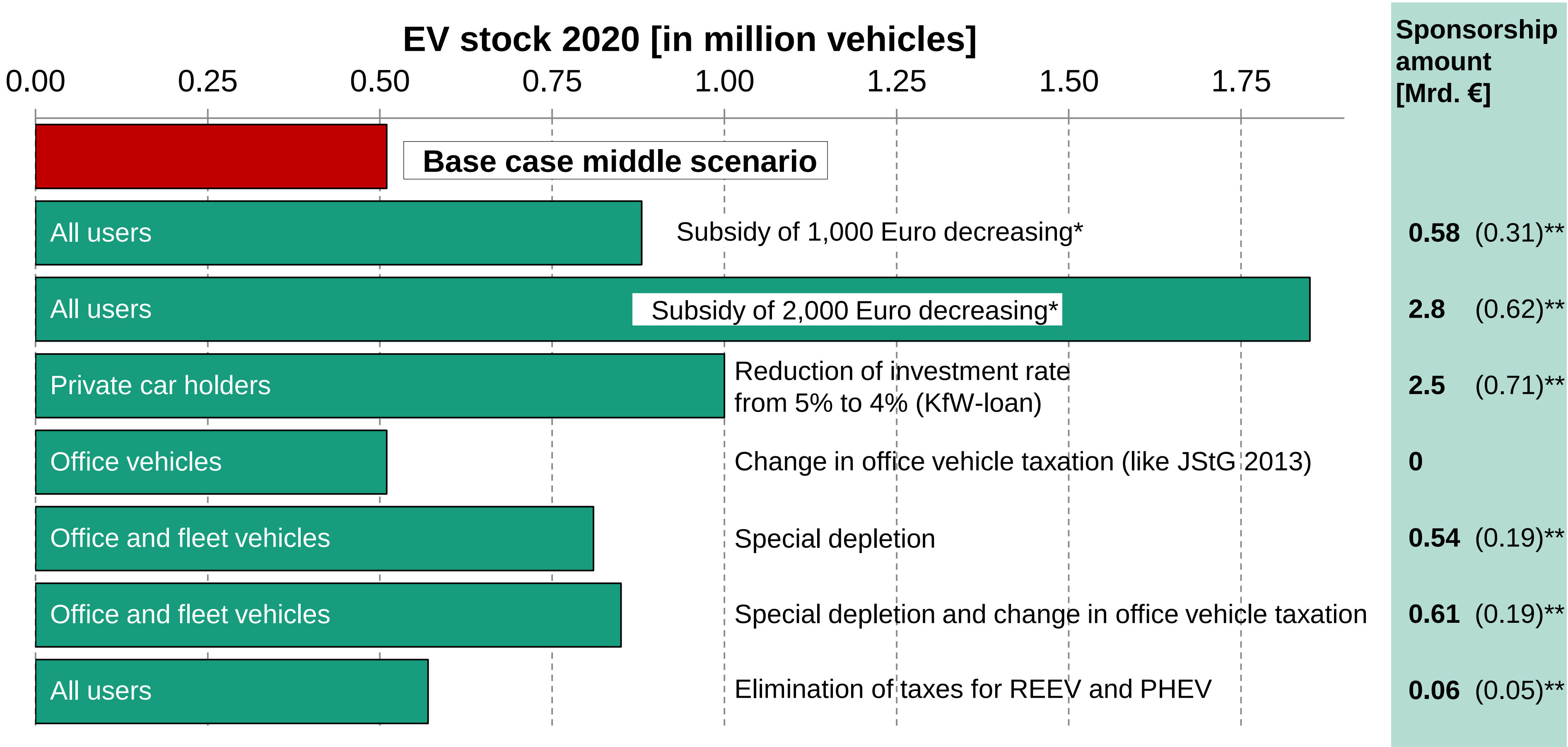
Market diffusion:
Policy actions can influence market diffusion



*Reduction of amount from 2013 by 100 (or 200 Euro) per year to 300 (or 600 Euro) in 2020 like the gross price reduction for office vehicles in JStG 2013

** windfall gain

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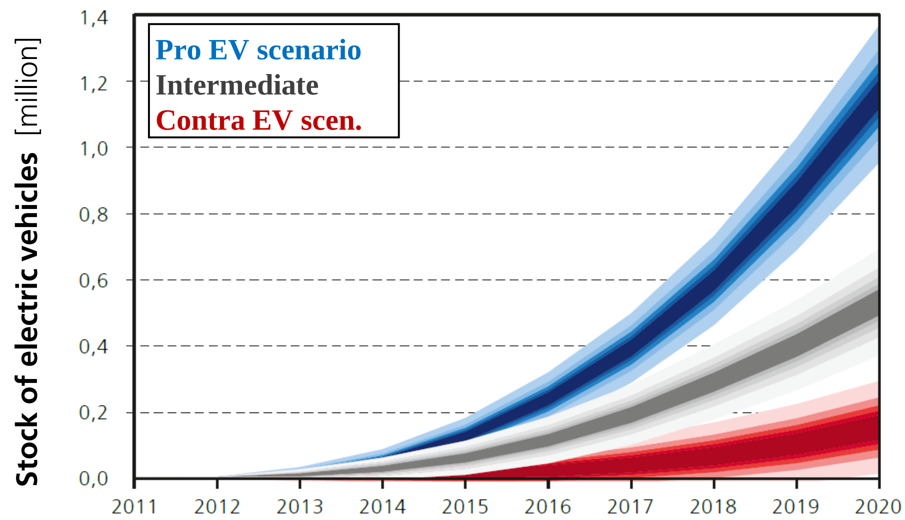
Possible conclusion: Market diffusion of EVs

Results on market diffusion:

1. Framework conditions count
The strong dependence on external parameters makes the market penetration of EVs highly uncertain.

2. The German federal goal is possible
Under favourable conditions such as high oil prices and low battery prices the German federal goal of one million EVs until 2020 is possible without financial incentives.

3. E-Mobility is on its way
Even with unfavourable framework conditions there will be a significant number of EVs in stock by 2020 (about 150,000 to 200,000).



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Discussion

- **“Modelling for insights – not for numbers!”** Hamming (1962), Geffrion (1976) & Huntington et al. (1982)
  - Simulations and Models help to understand complex systems – there are not accurate representations of the world
  - Ask for understanding and general conclusions
  - Try to understand the system and draw conclusion on that only
- **“All models are wrong but some are useful.”** – Statistician George Box
  - Ask for confidence intervals and error bars
  - Ask for highly robust findings
- **“Predictions are difficult – in particular about the future.** – Niels Bohr.
  - Ask for validation and reproduction of existing data
  - Many important aspects are unpredictable – prepare for it

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Thank you for your attention!

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