FCN | Institute for Future Energy Consumer Needs and Behavior

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Präferenzen, Zahlungsbereitschaften und Heterogenität der Fahrzeugkäufer für alternative Fahrzeugantriebe in Deutschland

Source: http://www.expertmarket.co.uk/sites/default/files/filemanager/Car%20Green

Prof. Dr. Reinhard Madlener, André Hackbarth

Institute for Future Energy Consumer Needs and Behavior (FCN)
School of Business and Economics / E.ON Energy Research Center
RWTH Aachen University

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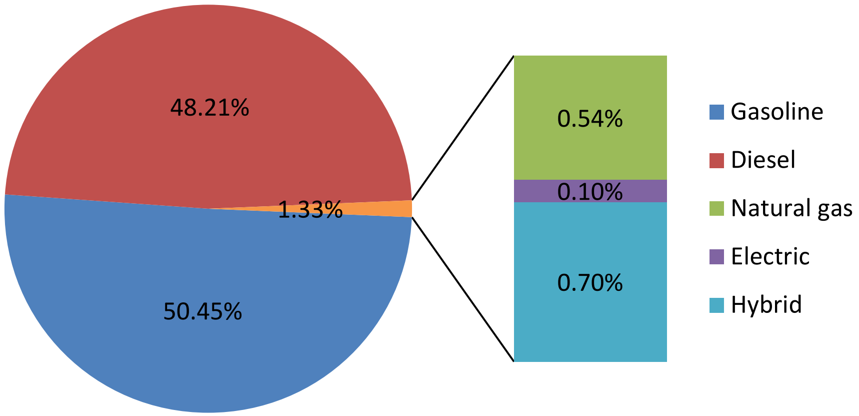
Research motivation

- Despite much policy action **alternative fuel vehicles (AFVs) have not significantly penetrated the German market** yet
  - **AFVs account for only** about 1.5% of the overall German vehicle stock and **1.3% of the new vehicle registrations in 2012** (KBA, 2013)



- Thus, especially the **electric mobility goal seems to be unreachable**
  - **Only about 12,000 electric vehicles were registered in Germany in 2013**, mainly by commercial users (KBA, 2014)
  - **Market share of electric vehicles about 30 times larger in Norway** and **10-15 times larger in Japan and the Netherlands** (IEA, 2013)

Research questions

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1. Why are **German car buyers so reluctant to adopt AFVs**, and what can to be done to **increase consumer demand**?
2. Does the **acceptance of alternative fuels**, compared to gasoline and diesel, **vary for distinct consumer groups**?
3. How do the **most important vehicle characteristics** (e.g. driving range, fuel availability, refueling/recharging time, CO_2 emissions) **influence the purchase decision,** and do they **have to meet some minimum requirements**?
4. How much are German vehicle buyers **willing to pay for an improve-ment** of these essential vehicle characteristics?

→ Answers are useful for both policy-makers and car manufacturers who want to **increase adoption rates of AFVs** in the future by **tailoring** their **products, marketing activities, and incentive schemes to heterogeneous consumer preferences**

Literature review

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- Rich body of **discrete choice literature on the demand for AFVs**
  - Ewing & Sarigöllü (2000), Brownstone et al. (2000), Batley et al. (2004), Potoglou & Kanaroglou (2007), Hidrue et al. (2011), Mabit & Fosgerau (2011), Lebeau et al. (2012), Daziano (2013), Ito et al. (2013), Tanaka et al. (2013)

- Studies on Germany:
  - **Eggers & Eggers (2011):** predict AFV adoption and diffusion process, various scenarios
  - **Achtnicht et al. (2012)** examine influence of fuel availability on vehicle choice (standard logit model)
  - **Achtnicht (2012)** analyze relevance of CO_2 emissions in vehicle choice decisions (mixed / random parameters logit model)
  - **Ziegler (2012)** examine influence of individual characteristics on vehicle choice (flexible multinomial probit models)
  - **Daziano & Achtnicht (2012)** analyze impact of fuel station network density on market shares of electric and H_2 vehicles (flexible multinomial probit model / Bayesian approach)
  - **Hackbarth & Madlener (2013a)** study preferences for AFVs, also considering driving range, recharging time, governmental incentives, and policy measure combinations (mixed logit / error component model)

Data

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- Data collected in a **Germany-wide, web-based survey** among new car buyers (purchase within ±1 year) conducted in **Jul-Aug 2011**
- **Survey** gathered information on respondents' existing and planned car **ownership**, **driving habits**, **familiarity with AFVs**, **environmental awareness**, **technophilia**, and **socio-economic characteristics**
- Core of the survey was a **discrete choice experiment**
  - **7 different vehicle/fuel types**: conventional (gasoline, diesel) vehicle (CV), NatGasV, HybridEV, Plug-inHybridEV, BatteryEV, BiofuelV, and FuelCellEV
  - Vehicles additionally described by up to **8 attributes**: (1) purchase price, (2) fuel cost, (3) CO_2 emissions, (4) driving range, (5) fuel availability, (6) refueling time, (7) battery recharging time, and (8) incentives
  - Every **choice set** consisted of **4 out of the 7 vehicle alternatives**
  - **711 respondents** completed the survey, facing **15 choice sets each**

    → **10,665 observations**

Our contribution (Hackbarth & Madlener 2013b)

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- **We expand on these German studies by**
  - Applying a **latent class model (LCM) (multinomial logit, MNL)** to evaluate German car buyers' vehicle choices, which allows for a **segmentation of the population into distinct consumer groups** and a specification of the **size of these consumer segments**
  - Calculating car buyers' **willingness to pay (WTP) and compensating variation (CV)** for the **different drive technologies** and the **improvement of vehicle characteristics**, taking **consumer heterogeneity** into account
  - Considering the effect of **decreasing marginal utilities** in our model, and assessing this non-linear functional form of the WTP for **driving range, fuel availability, recharging time and CO_2 emissions**

Exemplary choice card

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Please choose the vehicle that you would most likely purchase.

Fuel type	Plug-in hybrid	Hybrid	Electric	Gasoline
Purchase price	31,250 Euro	25,000 Euro	18,750 Euro	25,000 Euro
Fuel cost per 100 km	5 Euro	25 Euro	15 Euro	25 Euro
CO_2 emissions [% of average car]	0%	75%	100%	50%
Cruising range	1000 km	700 km	100 km	400 km
Fuel availability [% of stations]	60%	60%	20%	100%
Refueling time	10 min	10 min		5 min
Charging time	6 hours		10 minutes	
Incentives			No vehicle taxes	
	○	○	○	○

Main results – Multinomial logit model

- **Almost all parameters** are **highly significant** and **impact vehicle choice in the expected direction**
- **CFVs** are **highly preferred to all AFVs**

Main results – Latent class model

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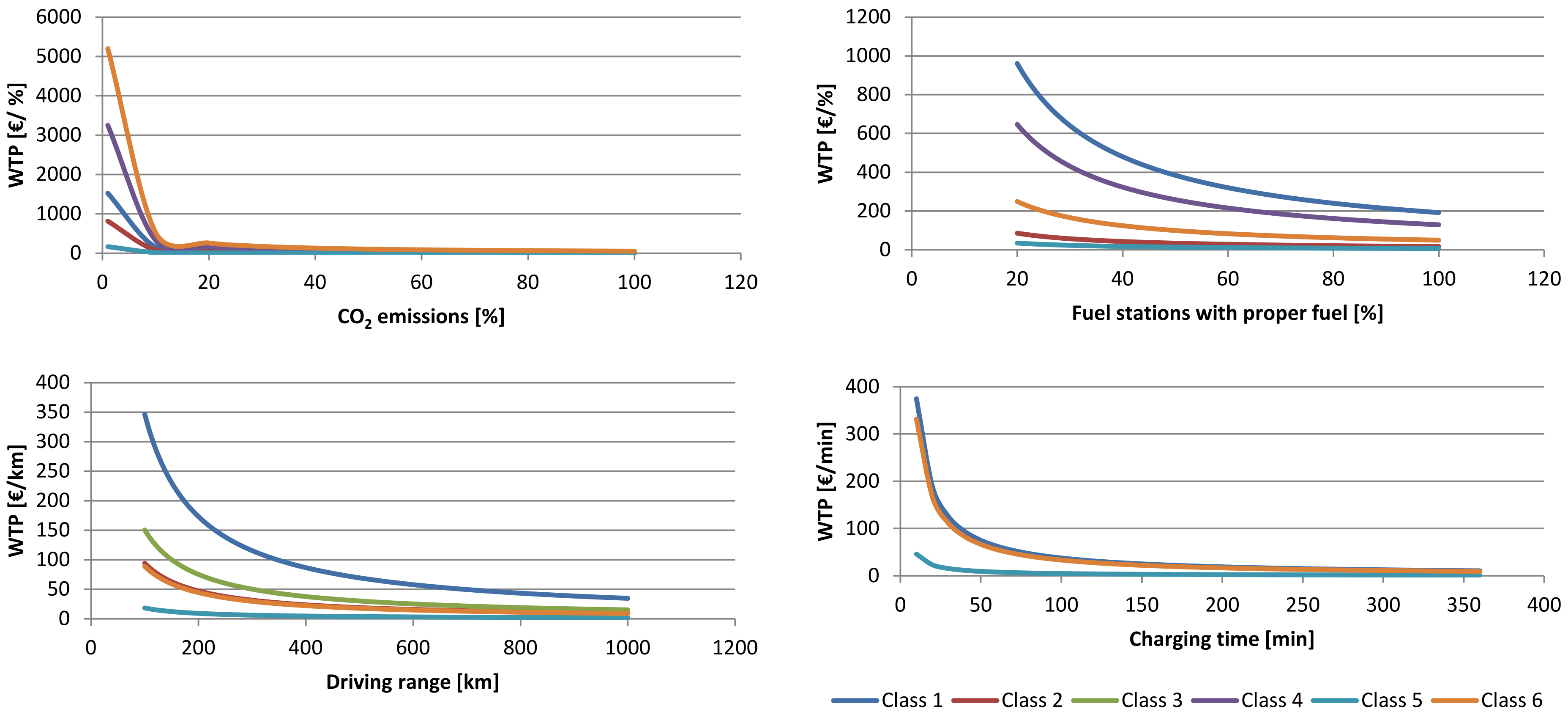
- **Considerable taste heterogeneity exists in the population**, since
  - Coefficients vary substantially between the **six different adopter groups**
  - No. and structure of attributes significantly influencing vehicle choice differ across classes (only **purchase price, fuel cost, and driving range** enter the utility functions significantly in all segments)
- **Individuals** sharing many socio-demographic characteristics **behave quite differently** (i.e. attributes that are important in one class are irrelevant in another class)
- **Purchase price and fuel cost** are relatively unimportant for individuals preferring AFVs
- **Incentives** do have a large impact on vehicle choice
- **AFVs are disliked in the population on average**, but **two segments exist who favor at least some AFVs** (PHEVs, BEVs, BVs, and FCEVs in class 6; PHEVs in class 4)

Main results – Willingness-to-Pay (1)

- **WTP expressed as additional purchase price th**at individuals are willing to spend for marginal changes in different attributes' levels



Main results – Willingness-to-Pay (2)

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- **German car buyers** are **willing to pay significant amounts** for the improvement of vehicle attributes
- Improvement of **driving range, fuel availability, recharging time, and CO_2 emissions abatement** show **diminishing marginal returns**
- The **distinct consumer groups** identified **put different importance on these vehicle features**
- **Consumers exhibit minimum requirements to be met,** so that they are actually willing to pay money for improvements of vehicle attributes
  - WTP for fast-charging increases sharply when the recharging process undercuts the 30-minute mark
  - WTP functions for driving range and fuel availability have long tails with low WTP
  - WTP for CO_2 emissions reduction by 1% accelerates when emissions drop below 10-15% of emissions of an average car today

Summary and conclusions (1)

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- **Population of German car buyers** can be classified by **6 distinct groups** that vary in taste concerning vehicle characteristics
- **Two consumer groups** exist that are **open-minded towards AFVs**
  - **20.6% of respondents** (particularly elderly and technophile buyers of larger cars) **prefer PHEVs** over all other propulsion technologies
  - **Especially younger, less educated, and highly environmentally aware consumers with high annual mileage** (15% of the population) **are more likely to choose new vehicle technologies** (PHEVs, BEVs, BVs, and FCEVs) than vehicles that mainly rely on fossil fuels

  → **Specifically tailored marketing strategies should aim at these two consumer groups** in order to effectively increase the adoption rates of AFVs
- **German car buyers** are **willing to pay significant amounts** for the improvement of vehicle attributes, but they **have minimum requirements** to be met for a positive WTP

Summary and conclusions (2)

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- The **acceleration of the diffusion of AFVs** in general and BEVs in particular can be **fostered cost-effectively** through
  - **Monetary and non-monetary governmental incentives**
  - **Extension of the fuel availability or the fast-charging infrastructure**, which is especially important in the light of limited BEV driving range
- **Installation of a comprehensive fast-charging infrastructure** could be **accomplished cost-effectively by private investors**, since individuals would accept considerable markups on the electricity price
- **Heterogeneity of car buyers is challenge and opportunity** for policy-makers and car manufacturers to accelerate the adoption of AFVs with individually customized incentive / marketing programs
- **Future research: Should focus on revealed preferences** (our study is based on a DCE, i.e. results suffer from the drawbacks of this approach – e.g. stated preferences, hypothetical questions)

Thanks for your attention! – Any questions?

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Contact: **Prof. Dr. rer.soc.oec. Reinhard Madlener**

Tel. 0241-80 49 820, -822

RMadlener@eonerc.rwth-aachen.de

www.eonerc.rwth-aachen.de/FCN

Hackbarth A., Madlener R. (2013a). Consumer Preferences for Alternative Fuel Vehicles: A Discrete Choice Analysis, Transportation Research Part D – Transport and Environment, 25: 5-17.

Working Papers published so far (more in the pipeline):

Hackbarth A., Madlener R. (2013b). Willingness-to-Pay for Alternative Fuel Vehicle Characteristics: A Stated Choice Study for Germany, FCN Working Paper No. 20/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

→ Free Download from: **SSRN, RePEc, FCN Website**

Achtnicht et al. (2012)

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Table 6: Simulation scenarios and results

	Scenario 1			Scenario 2			Scenario 3		
	Netw.	Prob.	SD	Netw.	Prob.	SD	Netw.	Prob.	SD
Gasoline	100	24.3	9.4	100	22.8	9.1	100	17.3	7.8
Diesel	100	28.1	9.9	100	26.2	9.2	100	19.6	7.0
Hybrid	100	22.9	3.6	100	21.3	3.2	100	15.9	2.2
LPG/CNG	50	13.4	3.6	50	12.4	3.2	100	14.2	3.1
Biofuel	10	4.0	0.7	33	5.9	0.9	100	10.0	1.1
Hydrogen	10	5.1	1.1	33	7.8	1.5	100	14.1	2.1
Electric	10	2.2	0.8	33	3.7	1.2	100	8.9	2.5

Note: For the simulation, standard cars were used that are identical in all respects except for fuel type and fuel availability. The used values for purchase price (€20,700), engine power (127 hp), fuel costs (€11.67), and CO_2 emissions (128 g) are approximate mean values from the sample data.

Table 7: The marginal WTP (in thousands of €) for greater fuel availability

	High upper price bound				Low upper price bound			
	Diesel cars		Electric cars		Diesel cars		Electric cars	
Netw.	WTP	Std.Err	WTP	Std.Err	WTP	Std.Err	WTP	Std.Err
10	0.629***	0.171	0.824***	0.147	0.227***	0.064	0.297***	0.058
20	0.576***	0.152	0.771***	0.130	0.208***	0.057	0.278***	0.052
30	0.522***	0.134	0.717***	0.114	0.188***	0.051	0.259***	0.046
40	0.469***	0.117	0.664***	0.101	0.169***	0.045	0.239***	0.041
50	0.416***	0.102	0.611***	0.090	0.150***	0.039	0.220***	0.037
60	0.362***	0.088	0.557***	0.083	0.131***	0.034	0.201***	0.034
70	0.309***	0.077	0.504***	0.080	0.111***	0.029	0.182***	0.033
80	0.255***	0.071	0.450***	0.083	0.092***	0.027	0.162***	0.033
90	0.202***	0.070	0.397***	0.090	0.073***	0.026	0.143***	0.035

Asterisks denote statistical significance at the *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ level.

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Back-up slide: Motivation (2)

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- The **road transport sector** has increasingly been the **focus of energy efficiency and GHG mitigation legislation in the EU** in past decades
  - In **Germany**, for instance, it is **the largest consumer of final energy,** responsible for **17% of the total GHG emissions** (UBA, 2013)

- Consequently, **reduction of GHG emissions in the road transport sector** is a **major objective of the EU** and German administration
  - **EU defined legally binding CO_2 emission abatement targets** for newly registered vehicles: **fleet average emission limit** set to **130 g CO_2/km in 2015** and **95 g CO_2/km in 2021**, but **super-credits for cars with CO_2 emissions below 50 g CO_2/km** are granted (EC, 2014)
  - German goal to get **one million electric vehicles on the road by 2020** and become a **lead market for electric mobility** (Bundesregierung, 2009)
  - Tax reductions, minimum quotas and research grants for **other alternative fuels in Germany (**BImSchG, 2011; BMVBS, BMWi, BMBF, 2006)

Back-up slide: Methodology

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- Empirical analysis of the stated preference vehicle choice data is based on a **Latent Class Model (LCM) approach** (Swait, 1994, 2007; Boxall and Adamowicz, 2002; Greene and Hensher, 2003; Hess et al., 2011)
- **Main assumption in the LCM framework** is the **existence of *S* unknown segments in the population**
  - Individuals within each group are characterized by unique and homogeneous utility functions or tastes, while preferences can differ between classes
- **LCM consists of two separate probabilistic models**, which are estimated simultaneously:
  - **A choice model**, which **explains individuals' choice among the alternatives** available in the different choice occasions, **conditional on their membership to a specific segment**
  - **A class membership model**, which **allocates the decision-makers to the *S* segments,** based on their socio-demographic characteristics

Back-up slide: Data

- **Vehicle attributes and their levels** in the choice experiment

Variable	Alternative (Fuel type)	No. of levels	Levels
Purchase price	All	3	75%, 100%, 125% of stated reference value (in €)
Fuel cost per 100 km	All	3	€5, €15, €25
CO_2 emissions	CV, NGV, HEV	3	50%, 75%, 100% of average vehicle
	PHEV, BEV, BV, FCEV	3	0%, 50%, 100% of average vehicle
Driving range	CV, NGV, HEV, PHEV, BV, FCEV	3	400 km, 700 km, 1,000 km
	BEV	3	100 km, 400 km, 700 km
Fuel availability	CV, HEV	2	60%, 100% of all stations
	NGV, PHEV, BEV, BV, FCEV	3	20%, 60%, 100% of all stations
Refueling time	CV, NGV, HEV, PHEV, BV, FCEV	2	5 min, 10 min
Battery recharging time	PHEV, BEV	3	10 min, 1 h, 6 h
Policy incentives	PHEV, BEV, BV, FCEV	3	None, No vehicle tax, Free parking and bus lane access

Back-up slide: Methodology (1)

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- Definition of **variables used in the models**

Variables	Definition
NGV	1 if fuel type is natural gas, 0 otherwise
HEV	1 if fuel type is hybrid electric, 0 otherwise
PHEV	1 if fuel type is plug-in hybrid electric, 0 otherwise
BEV	1 if fuel type is battery electric, 0 otherwise
BV	1 if fuel type is biofuel, 0 otherwise
FCEV	1 if fuel type is hydrogen (fuel cell), 0 otherwise
Purchase price	Purchase price in thousands of €
Fuel cost	Fuel cost in € per 100 km
CO_2 emissions	Natural logarithm of the fraction of CO_2 emissions of a comparable average current vehicle of the respondents' favorite car segment in percent
Driving range	Natural logarithm of driving range on a full tank/battery in km
Fuel availability	Natural logarithm of the percentage of filling/recharging stations with proper fuel
Refueling time	Refueling time in minutes
Battery recharging time	Natural logarithm of battery recharging time in minutes
Incentive 1	1 if incentive (no vehicle tax) is granted, 0 otherwise
Incentive 2	1 if incentive (free parking, bus lane usage) is granted, 0 otherwise
Vehicle segment	Respondents' favorite vehicle segment ordered by purchase price
Technophilia	Respondents' score on a 5-level Likert scale capturing enthusiasm for new technologies
Environmental awareness	Respondents' score on the environmental consciousness scale by Preisendörfer (1999)
Age	Age of the respondent in years
Daily mileage	Daily mileage of respondents in 5 categories
Educational level	Educational level of respondent in 6 categories
Additional vehicle	1 if vehicle is an additional one, 0 otherwise

Back-up slide: Methodology (2)

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- Definition of **base scenario** used in **CV calculations**

	Purchase price (€)	Fuel cost (€)	CO_2 emissions (%)	Driving range (km)	Fuel availability (%)	Refueling time (min)	Battery recharging time (min)	Incentive 1	Incentive 2
CFV	21,800	9.0	100	1000	100	5			
NGV	23,900	6.5	84	1000	50.9	5			
HEV	26,700	7.5	77	1000	100	5			
PHEV	30,200	5.5	31	750	43.3	5	240	0	0
BEV	36,800	4.0	0	175	14.1		480	0	1
BV	22,900	9.0	23	750	2.3	5		0	0
FCEV	33,800	7.5	0	750	0.2	5		0	0

- **Choice probabilities** in base scenario

	MNL	LCM					
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
CFV	0.315	0.405	0.211	0.497	0.224	0.463	0.113
NGV	0.213	0.170	0.282	0.250	0.034	0.265	0.123
HEV	0.198	0.336	0.201	0.111	0.234	0.111	0.123
PHEV	0.118	0.069	0.134	0.018	0.426	0.034	0.137
BEV	0.043	0.005	0.032	0.013	0.029	0.002	0.258
BV	0.080	0.013	0.099	0.059	0.038	0.122	0.133
FCEV	0.033	0.002	0.040	0.050	0.015	0.004	0.114

Back-up slide: Methodology (3)

Choice model

- The **utility alternative *j* provides person *n* in choice situation *t*** is assumed to be

$$U_{njt} = \beta_s' x_{njt} + \varepsilon_{njt}$$

  where x_{njt} is a vector of the vehicle alternatives' attributes (e.g. purchase price, driving range), β_s' is a class-specific vector of parameters, and ε_{njt} is a random term, distributed independent and identically extreme value

- Assuming that the class membership of each decision-maker is given and independence of the *t* consecutive choice situations, the **joint probability of the observed sequence of choices of decision-maker *n* in class *s*** is

$$P_{nj|s} = \prod_{t=1}^{T} \left[\frac{\exp(\beta_s' x_{njt})}{\sum_{j=1}^{J} \exp(\beta_s' x_{njt})} \right]$$

Back-up slide: Methodology (4)

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- **Class membership model**
  - The **probability that decision-maker *n* belongs to class *s*** is (again assuming iid extreme value error terms)

$$H_{ns} = \frac{\exp(\theta_s' z_n)}{\sum_{s=1}^{S} \exp(\theta_s' z_n)}$$

with observable socio-demographic or attitudinal characteristics of the decision-maker z_n, and the class-specific parameter vector θ_s'. To attain model identification, one of the *s* parameter vectors has to be normalized to 0

- The **unconditional choice probability that decision-maker *n* selects a sequence of alternatives** $j = (j_1, \ldots, j_T)$ is then is given by

$$P_{nj} = \sum_{s=1}^{S} \frac{\exp(\theta_s' z_n)}{\sum_{s=1}^{S} \exp(\theta_s' z_n)} \prod_{t=1}^{T} \left[\frac{\exp(\beta_s' x_{njt})}{\sum_{j=1}^{J} \exp(\beta_s' x_{njt})} \right]$$

Back-up slide: Methodology (5)

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- The **number of classes has to be specified by the analyst *a priori***, since the true number of classes is unknown to the analyst
- **Decision criteria can guide the selection of *S***, such as the Akaike Information Criterion (AIC) or the Bayesian Information Criterion (BIC)
- We decided for an **LCM with 6 classes as best model**, since
  - BIC is slightly preferred over other selection criteria, as it strives for parametrically parsimonious models
  - LCM with seven classes led to a very small segment (selection probability <1%), while leaving all other classes almost unchanged

Classes	1 (MNL)	2	3	4	5	6	7
LL	-12874.32	-12,322.87	-11,879.30	-11,579.14	-11344.08	-11,190.55	-11,121.43
BIC	25,887.8	24,998.2	24,324.4	23,937.4	23,680.6	23,586.8	23,661.9
AIC	25,778.6	24,721.7	23,880.6	23,326.3	22,902.2	22,641.1	22,548.9
$\rho^2(0)$	0.380	0.406	0.428	0.442	0.453	0.461	0.464
$\rho^2(c)$	0.091	0.130	0.162	0.183	0.199	0.210	0.215
Parameters	15	38	61	84	107	130	153

Main results – MNL/LCM (1)

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	MNL	LCM					
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Class-specific parameters							
NGV	-0.2648***	-0.3914**	0.0371	-0.6511***	-1.7498***	-0.0508	0.1276
HEV	-0.2949***	-0.0742	0.0199	-1.3858***	0.0782	-0.2390	0.1252
PHEV	-0.0910	0.2003	0.0423	-2.5097***	1.0260***	0.2947	0.5931***
BEV	-0.2155**	0.1535	-0.4887	-2.4808***	-1.2298***	-0.0637	1.0618***
BV	-0.4069***	-0.2273*	-0.0413	-1.7913***	-0.8525***	-0.2626*	0.4066***
FCEV	-0.4227***	-0.1260	-0.2533	-1.5091***	-1.1995***	-0.5335***	0.3467**
Purchase price	-0.0519***	-0.0399***	-0.0786***	-0.0282***	-0.0192**	-0.2665***	-0.0165***
Fuel costs	-0.0480***	-0.0446***	-0.1988***	-0.0224***	-0.0291***	-0.0681***	-0.0142***
CO_2 emissions (logarithmic)	-0.0489***	-0.0608***	-0.0640***	0.0186	-0.0625**	-0.0444**	-0.0855***
Driving range (logarithmic)	0.4939***	1.3803***	0.7395***	0.4240***	0.1871	0.4845***	0.1458**
Fuel availability (logarithmic)	0.2203***	0.7661***	0.1352**	0.0428	0.2485***	0.1872***	0.0820**
Refueling time	-0.0043	-0.0016	-0.0213	-0.0241*	-0.0008	0.0091	-0.0018
Recharging time (logarithmic)	-0.0651***	-0.1493***	-0.0519	-0.0847	-0.0246	-0.1221***	-0.0546**
Incentive 1	0.2104***	0.2692***	0.2494*	0.4884***	0.0020	0.2788***	0.2914***
Incentive 2	0.1458***	0.1768*	0.2214*	0.3992***	0.1360	0.0755	0.2207***
Class assignment parameters							
Constant		-1.6810	-4.5600**	-2.0268	-8.3148***	-3.1742*	0
Vehicle segment		0.6100***	0.3800**	0.6202***	0.5161**	0.4004**	0
Technophilia		-0.5853**	0.6170**	-0.1224	0.6255*	-0.2102	0
Environmental awareness		-0.1334***	-0.0703*	-0.1177***	-0.0061	-0.0783*	0
Age		0.0696***	0.0659***	0.0800***	0.0897***	0.1028***	0
Daily mileage		-0.3003	-0.4943*	-0.7443**	-0.6615	-0.7515**	0
Educational level		0.4987**	0.2257	0.1883	0.2599	0.3479*	0
Additional vehicle		0.3531	0.3411	0.6457	0.3430	1.3071*	0
Class probabilities		0.174	0.196	0.084	0.206	0.190	0.150

Back-up slides: Main results – LCM (1)

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- **Summary of the LCM results (I)**
  - **Segment 6** (base group with which other groups are compared)
    - Only consumer group which favors all kinds of AFVs, and at the same time considers CO_2 emissions as being very important
    - Individuals are younger, more environmentally aware, slightly less educated buyers of smaller/cheaper cars, with high daily mileage and moderate technical interest
  - **Segment 1**
    - Individuals are very concerned with the vehicles' mobility and put the highest weight of all segments on driving range, recharging time, and fuel availability
    - Individuals are older, planning to buy a larger (more expensive) vehicle, are less environmentally aware and interested in new technologies, and have a higher educational level
  - **Segment 2**
    - Purchase price and fuel cost are the most decisive factors in vehicle choice for individuals in this group
    - Individuals are older, planning to buy a larger (more expensive) vehicle, are less environmentally aware and more interested in new technologies, and have a lower daily mileage

Back-up slides: Main results – LCM (2)

- **Summary of the LCM results (II)**
  - **Segment 3**
    - Consumers in this group base their vehicle choice mainly on fuel types and governmental incentives, leaving all other attributes aside
    - Individuals are older, planning to buy a larger (more expensive) vehicle, are less environmentally aware, and have a lower daily mileage
  - **Segment 4**
    - Car buyers in this group have a strong preference for PHEVs (in contrast to individuals in segment 3), while also disliking all other AFVs and mainly basing their decision on ASCs
    - Individuals are older, planning to buy a larger (more expensive) vehicle, and are more interested in new technologies
  - **Segment 5**
    - Purchase price and fuel cost are the most decisive factors in vehicle choice for individuals in this group
    - Individuals are older, planning to buy a larger (more expensive) vehicle, are less environmentally aware and more likely to look for an additional car, have a lower daily mileage, and a higher educational level

Back-up slides: Main results – WTP (3)

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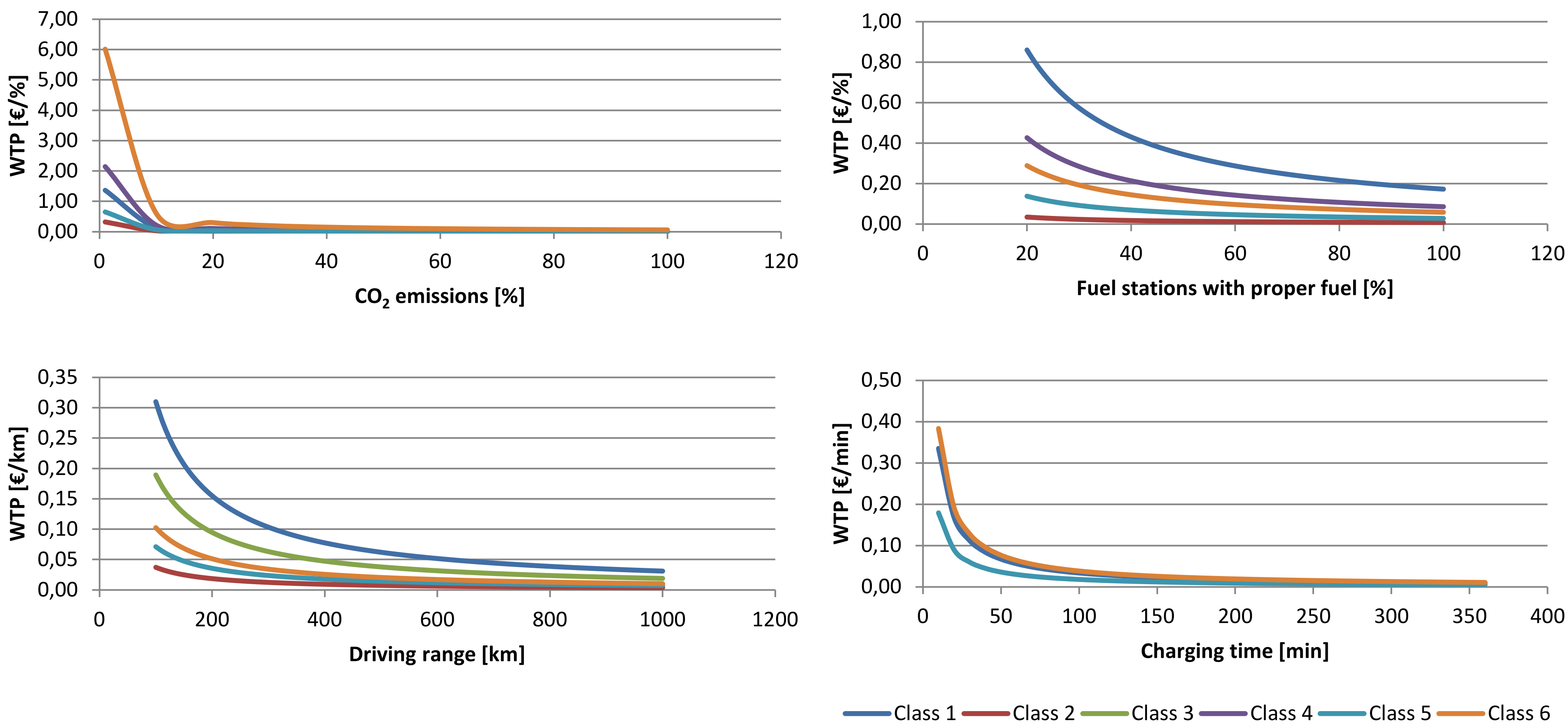
- **WTP expressed as additional fuel cost per 100 km** that individuals are willing to spend for marginal changes in different attributes' levels



Back-up slides: Main results – CV (1)

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- **More revealing than the WTP is an economic welfare measure which accounts for uncertainty** in the choice process and potentially highly dissimilar selection probabilities of different vehicle options → CV
- **Compensating variation (CV)**
  - The **CV indicates the change in income** or a comparable monetary measure (purchase price or fuel cost) **needed to compensate changes in utility after the change in a vehicle attribute's level** occurred, leaving individuals equally well off in the initial situation as under the new conditions
  - The **CV for a representative individual *n*** is calculated as a comparison of the (class-specific) indirect utility functions before (V_{nj}^0) and after (V_{nj}^1) the attribute change, scaled by the (class-specific) marginal utility of money (β_c)

$$CV = -\frac{1}{\beta_c}\left[\ln\left(\sum_{j=1}^{J} e^{V_{nj}^1}\right) - \ln\left(\sum_{j=1}^{J} e^{V_{nj}^0}\right)\right]$$

with *J* indicating the number of choice alternatives (Small and Rosen, 1981; Louviere et al., 2000; Train, 2003; Lancsar and Savage, 2004)

Back-up slides: Main results – CV (2)

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- **CV** for changes in vehicle attributes **in € of purchase price surcharge**

	MNL	LCM					
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Fuel cost reduction							
BV (€9/100 km → €6.5/100 km)	197.03	37.29	787.81	120.08	149.26	83.85	290.95
FCEV (€7.5/100 km → €6.5/100 km)	31.22	2.06	112.34	40.51	23.21	1.08	99.25
Incentive 1 (No vehicle tax)							
PHEV	524.66	532.38	473.04	402.06	45.01†	40.49	2751.67
BV	360.06	97.64	352.61	1291.02	4.02†	144.00	2665.59
FCEV	148.13	13.96	144.49	1108.94	1.60†	4.94	2301.12
Incentive 2 (Free parking and bus lane access)							
PHEV	353.08	334.56	414.86	313.66	3131.18†	9.92†	2020.11
BEV	129.90	21.98	99.53	232.00	219.39†	0.72†	3752.55
BV	241.97	61.16	309.06	1009.92	287.20†	35.65†	1956.54
FCEV	99.37	8.74	126.52	867.00	114.21†	1.21†	1687.68
CO_2 emissions abatement							
CFV (100% → 50%)	208.38	433.79	121.45	-227.09†	512.84	53.86	416.54
NGV (84% → 50%)	105.03	136.04	120.67	-85.52†	58.85	23.06	338.17
HEV (77% → 50%)	81.35	223.31	71.47	-31.70†	331.72	8.02	280.55
Driving range increase							
BEV (175 km → 350 km)	336.14	181.70	267.11	161.72	208.68†	3.64	1644.37
BEV (175 km → 750 km)	854.49	723.54	756.48	402.63	470.45†	9.34	3596.26
Fuel availability increase							
NGV (50.9% → 60%)	150.71	565.34	80.49	62.57†	74.52	30.92	101.44
PHEV (43.3% → 60%)	168.48	489.76	76.49	9.02†	1838.33	7.96	225.19
BEV (14.1% → 60%)	309.72	230.17	86.90	30.30†	649.86	2.84	1945.99
BV (2.3% → 60%)	1566.43	3308.50	680.98	311.19†	2413.15	365.68	2421.33
FCEV (0.2% → 60%)	1533.46	3299.62	582.73	490.83†	2398.58	29.21	4000.49
NGV (50.9% → 100%)	646.76	2730.67	338.72	259.01†	325.59	131.49	424.23
PHEV (43.3% → 100%)	454.51	1518.95	202.25	23.40†	4887.15	21.41	588.41
BEV (14.1% → 100%)	443.24	393.36	121.67	41.44†	938.28	4.04	2673.31
BV (2.3% → 100%)	1912.98	4876.05	813.26	363.71†	2984.72	441.42	2852.53
FCEV (0.2% → 100%)	1777.37	4756.35	658.27	540.54†	2815.68	33.66	4442.26
Battery recharging time reduction							
PHEV (4 h → 1 h)	213.37	397.42	126.40†	79.95†	761.88†	23.28	650.07
BEV (8 h → 1 h)	120.09	41.38	45.90†	91.29†	79.04†	2.64	1854.64
PHEV (4 h → 5 min)	640.37	1327.25	373.41†	248.41†	2164.66†	75.73	1925.37
BEV (8 h → 5 min)	285.41	110.86	107.41†	223.30†	178.77†	6.81	4278.42

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- **CV** for changes in vehicle attributes **in €/100 km of fuel cost increase**

	MNL	LCM					
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Purchase price reduction							
BEV (€36,800 → €30,000)	0.376	0.032	0.111	0.126	0.139	0.182	2.114
FCEV (€33,800 → €30,000)	0.149	0.007	0.070	0.254	0.039	0.105	0.515
NGV (€23,900 → €21,800)	0.503	0.330	0.249	0.677	0.048	2.657	0.303
HEV (€26,700 → €21,800)	1.160	1.573	0.454	0.732	0.783	3.824	0.722
PHEV (€30,200 → €21,800)	1.296	0.612	0.593	0.216	2.469	3.654	1.412
BEV (€36,800 → €21,800)	1.029	0.083	0.347	0.314	0.331	1.795	4.900
BV (€22,900 → €21,800)	0.098	0.013	0.045	0.083	0.028	0.596	0.170
FCEV (€33,800 → €21,800)	0.583	0.025	0.309	0.899	0.134	1.347	1.728
Incentive 1 (No vehicle tax) implementation							
PHEV	0.566	0.476	0.187	0.506	0.030†	0.158	3.182
BV	0.389	0.087	0.139	1.626	0.003†	0.563	3.082
FCEV	0.160	0.012	0.057	1.397	0.001†	0.019	2.661
Incentive 2 (Free parking and bus lane access) implementation							
PHEV	0.381	0.299	0.164	0.395	2.064†	0.039†	2.336
BEV	0.140	0.020	0.039	0.292	0.145†	0.003†	4.339
BV	0.261	0.055	0.122	1.272	0.189†	0.139†	2.262
FCEV	0.107	0.008	0.050	1.092	0.075†	0.005†	1.952
CO_2 emissions abatement							
CFV (100% → 50%)	0.225	0.388	0.048	-0.286†	0.338	0.211	0.482
NGV (84% → 50%)	0.113	0.122	0.048	-0.108†	0.039	0.090	0.391
HEV (77% → 50%)	0.088	0.200	0.028	-0.040†	0.219	0.031	0.324
Driving range increase							
BEV (175 km → 350 km)	0.363	0.163	0.106	0.204	0.138†	0.014	1.901
BEV (175 km → 750 km)	0.922	0.648	0.299	0.507	0.310†	0.037	4.159
Fuel availability increase							
NGV (50.9% → 60%)	0.163	0.506	0.032	0.079†	0.049	0.121	0.117
PHEV (43.3% → 60%)	0.182	0.438	0.030	0.011†	1.212	0.031	0.260
BEV (14.1% → 60%)	0.334	0.206	0.034	0.038†	0.428	0.011	2.250
BV (2.3% → 60%)	1.690	2.961	0.269	0.392†	1.591	1.430	2.800
FCEV (0.2% → 60%)	1.655	2.953	0.230	0.618†	1.581	0.114	4.626
NGV (50.9% → 100%)	0.698	2.444	0.134	0.326†	0.215	0.514	0.491
PHEV (43.3% → 100%)	0.490	1.359	0.080	0.029†	3.222	0.084	0.680
BEV (14.1% → 100%)	0.478	0.352	0.048	0.052†	0.619	0.016	3,091
BV (2.3% → 100%)	2.064	4.364	0.322	0.458†	1.968	1.726	3.299
FCEV (0.2% → 100%)	1.918	4.257	0.260	0.681†	1.856	0.132	5.137
Battery recharging time reduction							
PHEV (4 h → 1 h)	0.230	0.356	0.050†	0.101†	0.502†	0.091	0.752
BEV (8 h → 1 h)	0.130	0.037	0.018†	0.115†	0.052†	0.010	2.145
PHEV (4 h → 5 min)	0.691	1.188	0.148†	0.313†	1.427†	0.296	2.226
BEV (8 h → 5 min)	0.308	0.099	0.042†	0.281†	0.118†	0.027	4.947

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Back-up slides: Main results – CV (4)

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Summary CV results (I)

- **CV values vary considerably between consumer groups** and are dependent on the improved attribute and the vehicle alternative
- While **individuals in segment 6** had the highest WTP for incentives and CO_2 emissions only, they show **the highest CV values for most of the vehicle attribute improvements**
- **Consumers are willing to forfeit**
  - up to ca. €790 for reduction in fuel costs to €6.5/100 km (BVs, class 2)
  - up to €4.90/100 km for purchase price reduction of €15,000 (BEVs, class 6)
  - more than €2750 or €3.18/100 km for vehicle tax exemption (PHEVs, class 6)
  - more than €3750 or €4.34/100 km for permission to use bus lanes and park free of charge (BEVs, class 6)
  - ca. €513 (class 4) or €0.48/100 km (class 6) for halving CO_2 emissions (CFVs)
  - ca. €3600 or €4.16/100 km for expanding BEV driving range to 750 km (class 6)
  - almost €4890 (PHEVs, class 4) or €5.14/100 km (FCEVs, class 6) for increasing fuel station density to 100%
  - ca. €4280 or €4.95/100 km for shortening recharging time to 5 min (BEVs, class 6)

Back-up slides: Main results – CV (5)

- **Summary CV results (II)**
  - The single **vehicle attributes show differences in their potential to increase the acceptance of AFVs** and the **possibility of a cost-effective provision**
    - Especially **non-monetary governmental incentives could increase AFVs' choice probability very cost-effectively**, at least in segment 6
    - **Vehicle tax exemptions and fuel cost reductions** (demanded payback period of max. 2 years) **are not valued sufficiently high** for cost-effective provision, although they could push demand for AFVs
    - **Governmental purchase price subsidies** have the potential to strongly **increase the choice probability of AFVs**, as car buyers seem to perceive upfront costs more negatively than operational expenses, even though they could not be provided cost-effectively
    - **CO_2 mitigation measures** for all vehicles that mainly run on fossil fuels are **not appreciated much**
    - **German car buyers** (even the BEV-affine ones) are **not willing to pay sufficient amounts of money for the increase in battery capacity**

Back-up slides: Main results – CV (6)

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- **Summary CV results (III)**
  - **German car buyers** (especially in segment 6) are **not unwilling to pay considerable amounts for a spatially fully extended network of refueling and fast-charging stations** for their FCEVs, PHEVs and/or BEVs
    - They would **accept an increase in fuel price by more than ⅔ for FCEVs**
    - They would not only **accept more than a tripling of current operating costs of BEVs**, but also much higher operating costs than comparable CFVs
    - Financially attractive **(cost-efficient) provision of electric mobility might be achievable for private investors**, e.g. electric utilities