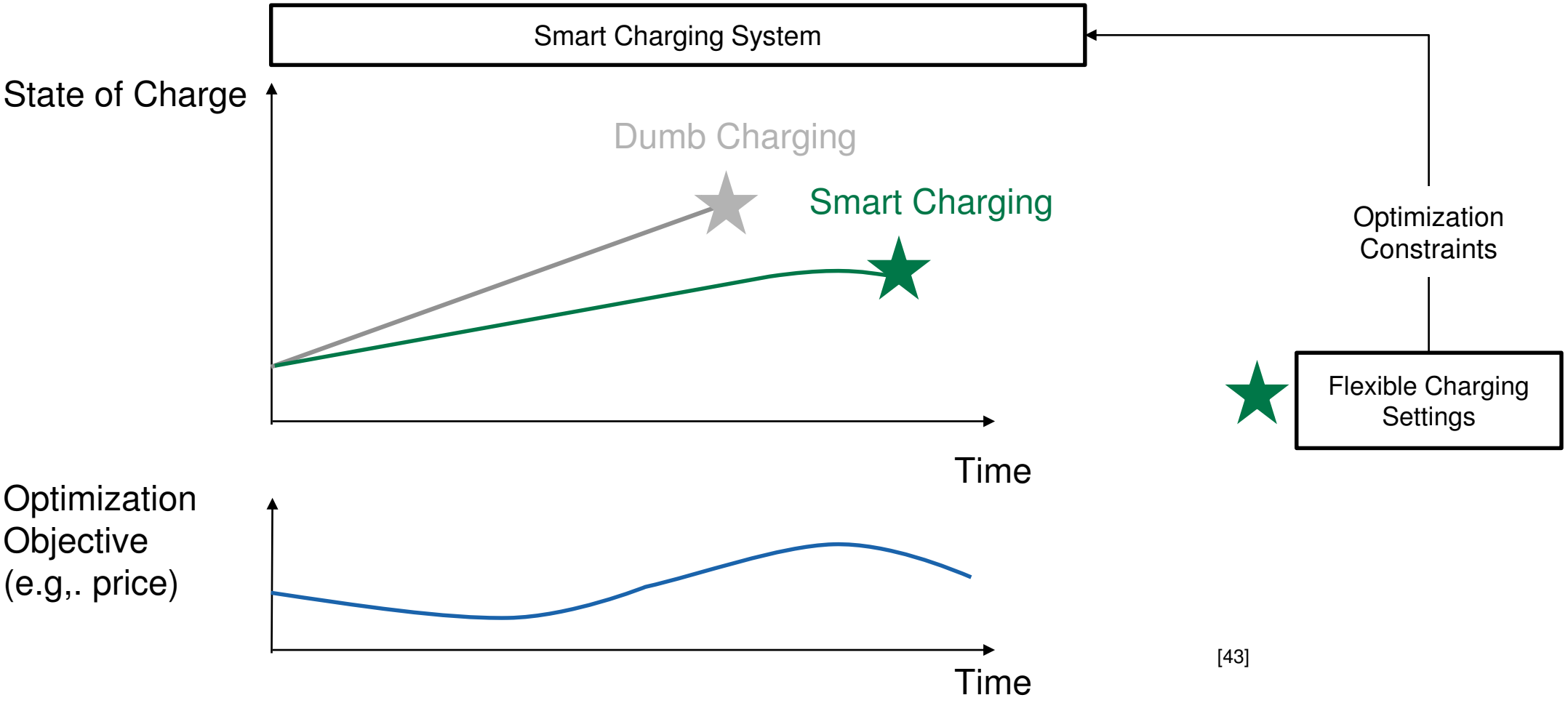
Quo vadis smart charging?

A literature review and expert survey on technical potentials and user acceptance of smart charging systems

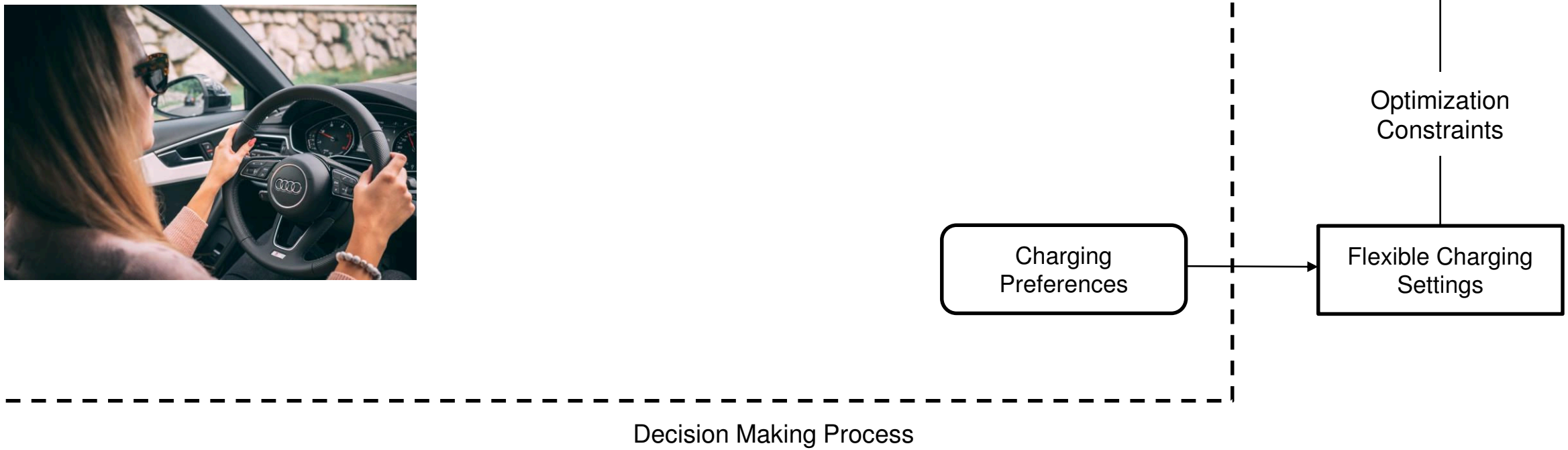
Julian Huber[1], Elisabeth Schaule[2], Dominik Jung[2], Christof Weinhardt[2]

[1]FZI Forschungszentrum Informatik, Germany, julian.huber@fzi.de

[2]Karlsruhe Institute of Technology, Germany


Smart Charging System
State of Charge
Dumb Charging
Smart Charging
Time
Optimization Constraints
Flexible Charging Settings
Optimization Objective (e.g,. price)
Time

[43]


Smart Charging System
Optimization Constraints
Charging Preferences
Flexible Charging Settings
Decision Making Process

Motivation

German Driver

- likes driving
- is somehow concerend about the environment and charging costs

German Utiltiy

- likes grid stability
- dislikes digging

Photos by Andraz Lazic and Jamar Pennyon Unsplash

Smart Charging

- systems use flexibility within the charging process to achieve different optimization objectives

Research Questions

RQ 1.2

- What **incentives** motivate BEV **drivers** to use smart charging systems?

RQ 1.1

- What are **objectives** of charging system **operators** present in academic literature?

Photos by Andraz Lazic and Jamar Pennyon Unsplash

RQ 2

- Do the most promising objectives of smart charging system operators **fit** the BEV drivers motivation to use smart charging systems?

Literature Review

- Yilmaz & Krein 2013 [11]
  - technical environment (battery charger topologies, charging power levels, and charging infrastructure)
- Garcia-Villalobos et al. 2014 [12]
  - main **objectives**, solvers and tools, software, and strategy
  - decentralized and centralized concepts
- Mwasilu et al. 2014 [13]
  - focus on renewable energy sources integration
- Benjamin, Jonn Axsen & Kempton 2017 [5]
  - Main objectives if smart charging systems:
    - financial
    - technical
    - socio-environmental

Literature Review

RQ 1.1

- What are **objectives** of charging system **operators** present in academic literature?

Objectives	Concept Indicators Keywords	Source
Financial		
Socio-environmental		
Technical		

Table 2: Objectives for smart charging

Literature Review

RQ 1.1

- What are **objectives** of charging system **operators** present in academic literature?

Objectives	Concept Indicators Keywords	Source
Battery degradation	*'lifetime', 'life time', 'degregation', 'aging'*	[20]
Cost advantage	*'market', 'day ahead', 'cost'*	[27]
Socio-environmental		
Technical		

Table 2: Objectives for smart charging

Literature Review

RQ 1.1

- What are **objectives** of charging system **operators** present in academic literature?

Objectives	Concept Indicators Keywords	Source
Battery degradation	*'lifetime', 'life time', 'degregation', 'aging'*	[20]
Cost advantage	*'market', 'day ahead', 'cost'*	[27]
Social aspects	*'social', 'fairness'*	[28]
Integration of RES (renewable energy sources)	*'PV', 'pv', 'wind', 'RES'*	[7]
Technical		

Table 2: Objectives for smart charging

Literature Review

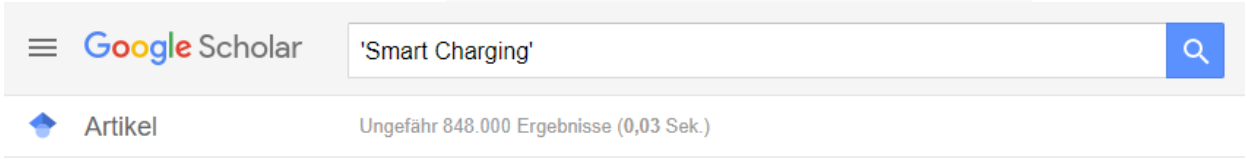
RQ 1.1

- What are **objectives** of charging system **operators** present in academic literature?

Objectives	Concept Indicators Keywords	Source
Battery degradation	*'lifetime', 'life time', 'degregation', 'aging'*	[20]
Cost advantage	*'market', 'day ahead', 'cost'*	[27]
Social aspects	*'social', 'fairness'*	[28]
Integration of RES (renewable energy sources)	*'PV', 'pv', 'wind', 'RES'*	[7]
Congestion management	*'load curve', 'flattening', 'peak', 'congestion'*	[7]
Ancillary services	*'frequency', 'voltage', 'power quality', 'losses'*	[7]

Table 2: Objectives for smart charging

Literature Review



Richard H Schallenberg. Prospects for the electric vehicle: a historical perspective. IEEE Transactions on Education, 23(3):137–143, 1980.

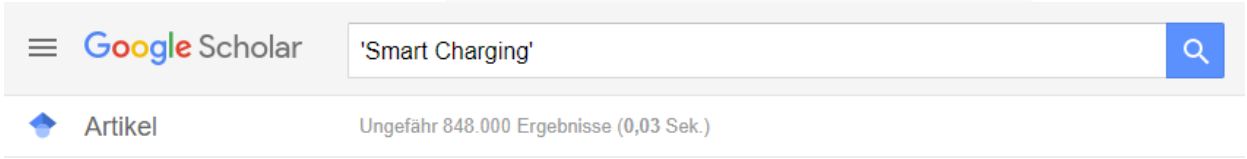
RQ 1.1

- What are **objectives** of charging system **operators** present in academic literature?

Objectives	Concept Indicators Keywords	Source
Battery degradation	*'lifetime', 'life time', 'degregation', 'aging'*	[20]
Cost advantage	*'market', 'day ahead', 'cost'*	[27]
Social aspects	*'social', 'fairness'*	[28]
Integration of RES (renewable energy sources)	*'PV', 'pv', 'wind', 'RES'*	[7]
Congestion management	*'load curve', 'flattening', 'peak', 'congestion'*	[7]
Ancillary services	*'frequency', 'voltage', 'power quality', 'losses'*	[7]

Table 2: Objectives for smart charging

Literature Review



RQ 1.1

- What are **objectives** of charging system **operators** present in academic literature?

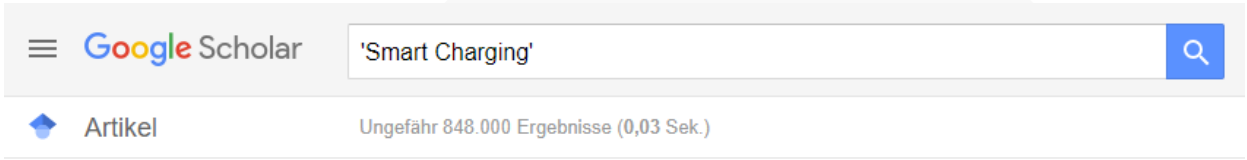
Objectives	Concept Indicators Keywords	Source
Battery degradation	*'lifetime', 'life time', 'degregation', 'aging'*	[20]
Cost advantage	*'market', 'day ahead', 'cost'*	[27]
Social aspects	*'social', 'fairness'*	[28]
Integration of RES (renewable energy sources)	*'PV', 'pv', 'wind', 'RES'*	[7]
Congestion management	*'load curve', 'flattening', 'peak', 'congestion'*	[7]
Ancillary services	*'frequency', 'voltage', 'power quality', 'losses'*	[7]

Table 2: Objectives for smart charging

	Search Term *vehicle ∧ charging ∧*		
	objective	*incentive*	*acceptance*
ACM Digital Library	17	6	10
IEEE Explore	422	75	69
ScienceDirect	319	120	98

Table 1: Matches for the search term in different data bases

Literature Review



RQ 1.1

- What are **objectives** of charging system **operators** present in academic literature?

Objectives	Concept Indicators Keywords	Source
Battery degradation	*'lifetime', 'life time', 'degregation', 'aging'*	[20]
Cost advantage	*'market', 'day ahead', 'cost'*	[27]
Social aspects	*'social', 'fairness'*	[28]
Integration of RES (renewable energy sources)	*'PV', 'pv', 'wind', 'RES'*	[7]
Congestion management	*'load curve', 'flattening', 'peak', 'congestion'*	[7]
Ancillary services	*'frequency', 'voltage', 'power quality', 'losses'*	[7]

Table 2: Objectives for smart charging

	Perspective			Objective					
Source	System Operator	Aggregator	End User	Battery	Cost	Social	RES	Congestion	Ancillary
[22]					●				●
[29]									●
[30]	●		●					●	
...									
Sum	112	76	89	125	634	74	293	225	309

Table 3: Results of the literature review

Literature Review

RQ 1.1

- What are **objectives** of charging system **operators** present in academic literature?

- Cost reduction
- Most papers consider a integrated charging station operator that …

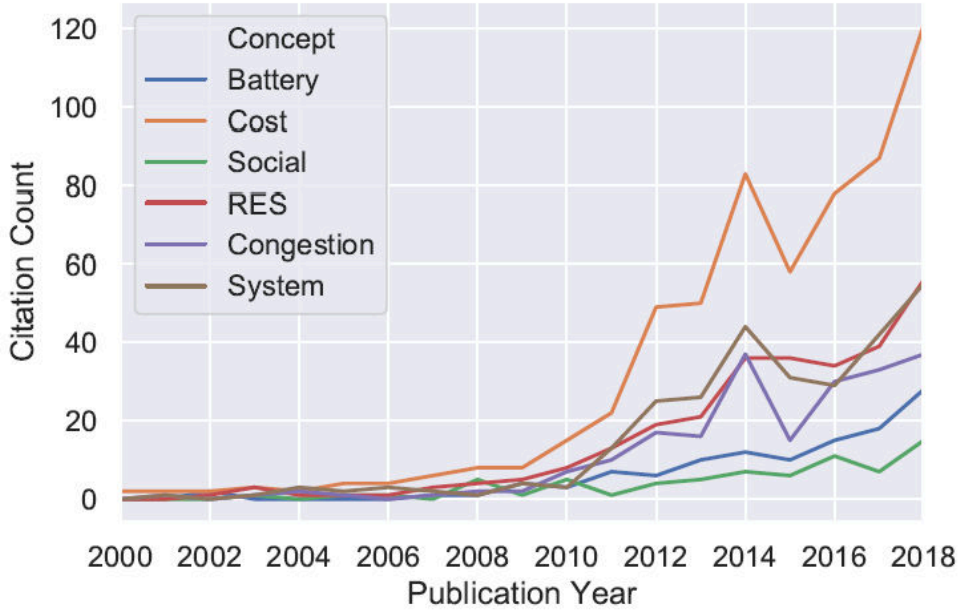


Figure 2: Occurrence of keywords in literature over time

Literature Review

RQ 1.2

- What **incentives** motivate BEV **drivers** to use smart charging systems?

- Cost reduction
- Renewable Integration

Objective	Incentive	Source
Battery degradation	Battery degradation	[20, 31]
Cost advantage	Cost advantage	[27, 31, 39]
Social aspects	Social aspects	[28]
Integration of RES	Integration of RES	[7]
	Environmental protection	[28]
	Health impact	[38]
	Climate impact	[40, 3]
Congestion management and ancillary services	Grid impact	[7]

Table 4: Mapping of smart charging objectives with possible incentives

Smart Charging System Operators Primary Objectives

		Technical		Financial		Socio-Environmental	
Constraints	Congestion Management	Ancillary Services	Battery Degregation	Energy Cost	RES Integration	Social Aspects	
Input and Tariff Selection	Grid Impact						
Mobility Needs							

BEV Drivers‘ Primary Objective

Results

What framings can convince BEV drivers to use smart charging?

- Statements on smart charging

Incentive	Example Statement
Battery degradation	*Flexible charging can help protect the battery.*
Cost advantage	*Flexible charging allows the user to benefit from lower electricity prices.*
Social aspects	*The power grid is shared with other users and benefits from the fact that they are flexible when charging BEVs.*
Integration of RES	*If users provide charging flexibility, the BEV can be charged with more solar and wind power.*

- Expert Survey
  - 16 domain experts
  - Scale 1: Technical accuracy [1-5]
  - Scale 2: Persuasiveness [1-5]

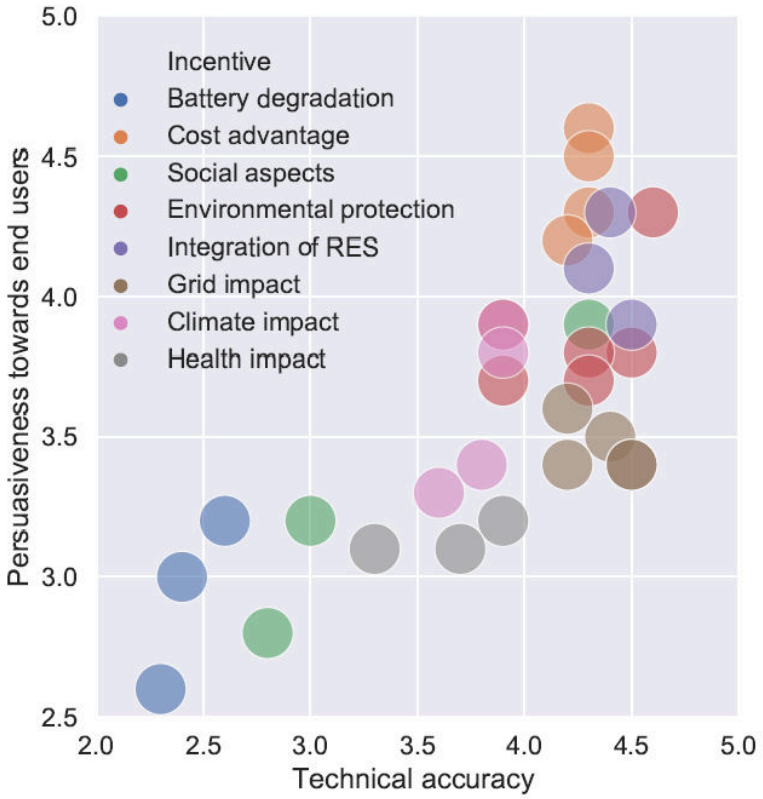


Figure 3: Statements evaluated on their technical accuracy (x-axis) and persuasiveness towards end users (y-axis)

Conclusion and Outlook

RQ 1.2

- What **incentives** motivate BEV **drivers** to use smart charging systems?

RQ 1.1

- What are **objectives** of charging system **operators** present in academic literature?

Photos by Andraz Lazic and Jamar Pennyon Unsplash

RQ 2

- Do the most promising objectives of smart charging system operators **fit** the BEV drivers motivation to use smart charging systems?

Conclusion and Outlook

BEV Drivers

- can be motivated by cost savings and renewable integration

Charging station operators

- have to consider multiple objectives
- financial outcome

Photos by Andraz Lazic and Jamar Pennyon Unsplash

Successful Smart Charging Systems

- consider both sides
- price discounts & renewable integration

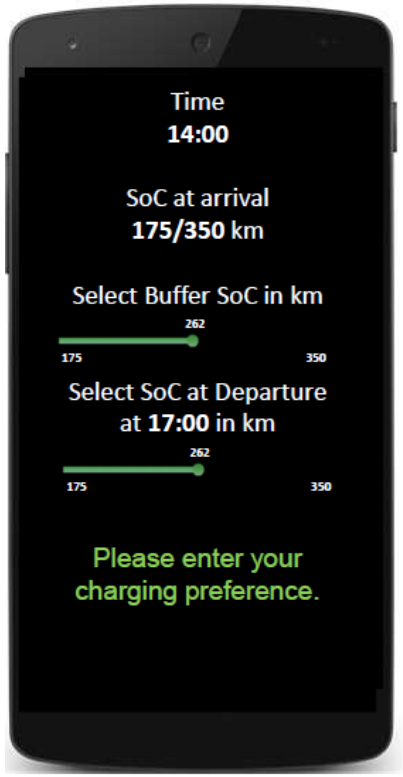
Digital Nudging in Smart Charging Systems

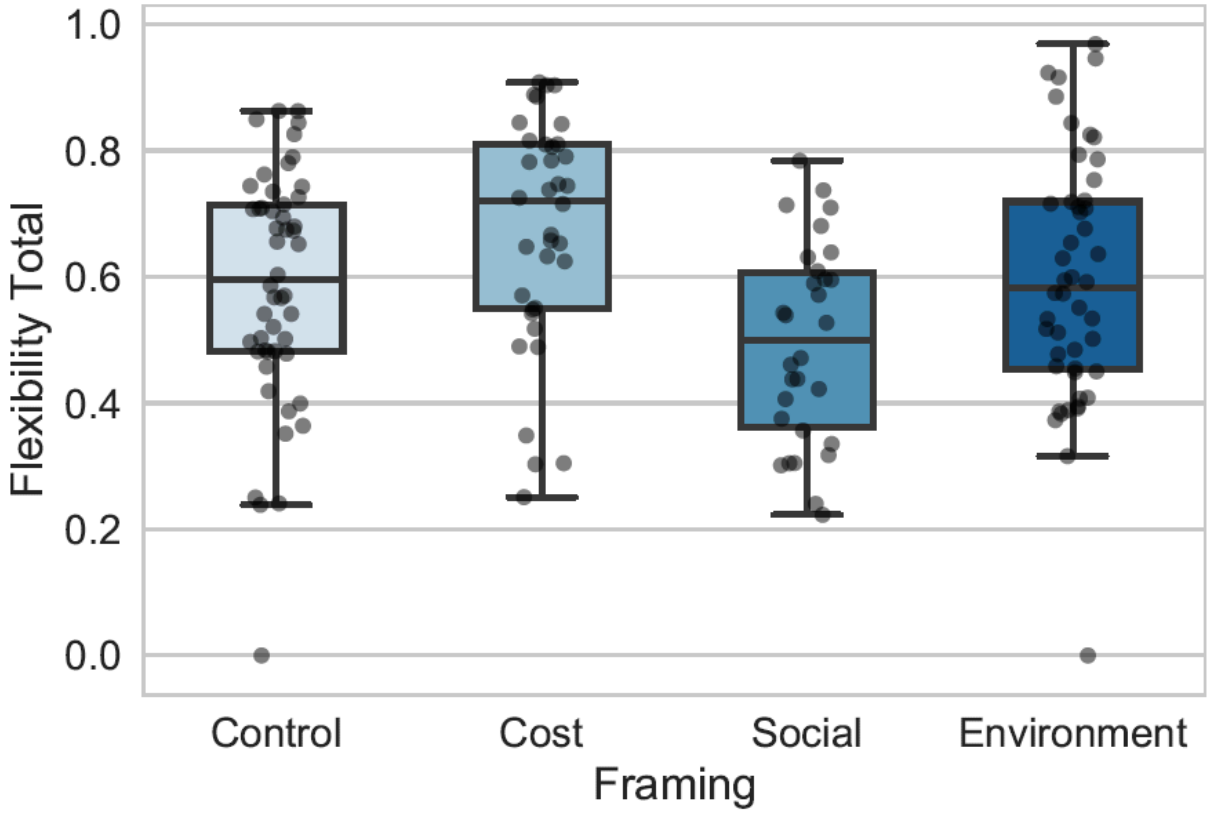
- use interface desing to make BEV users more flexible
- framing messages can nudge users towards higher flexibility [8, 43]

Outlook

Online Experiment with BEV drivers

- Scenario based online experiment
- Hypothetical charging situations
- Different framing messages
- No incentives






VIELEN
DANK

Contact

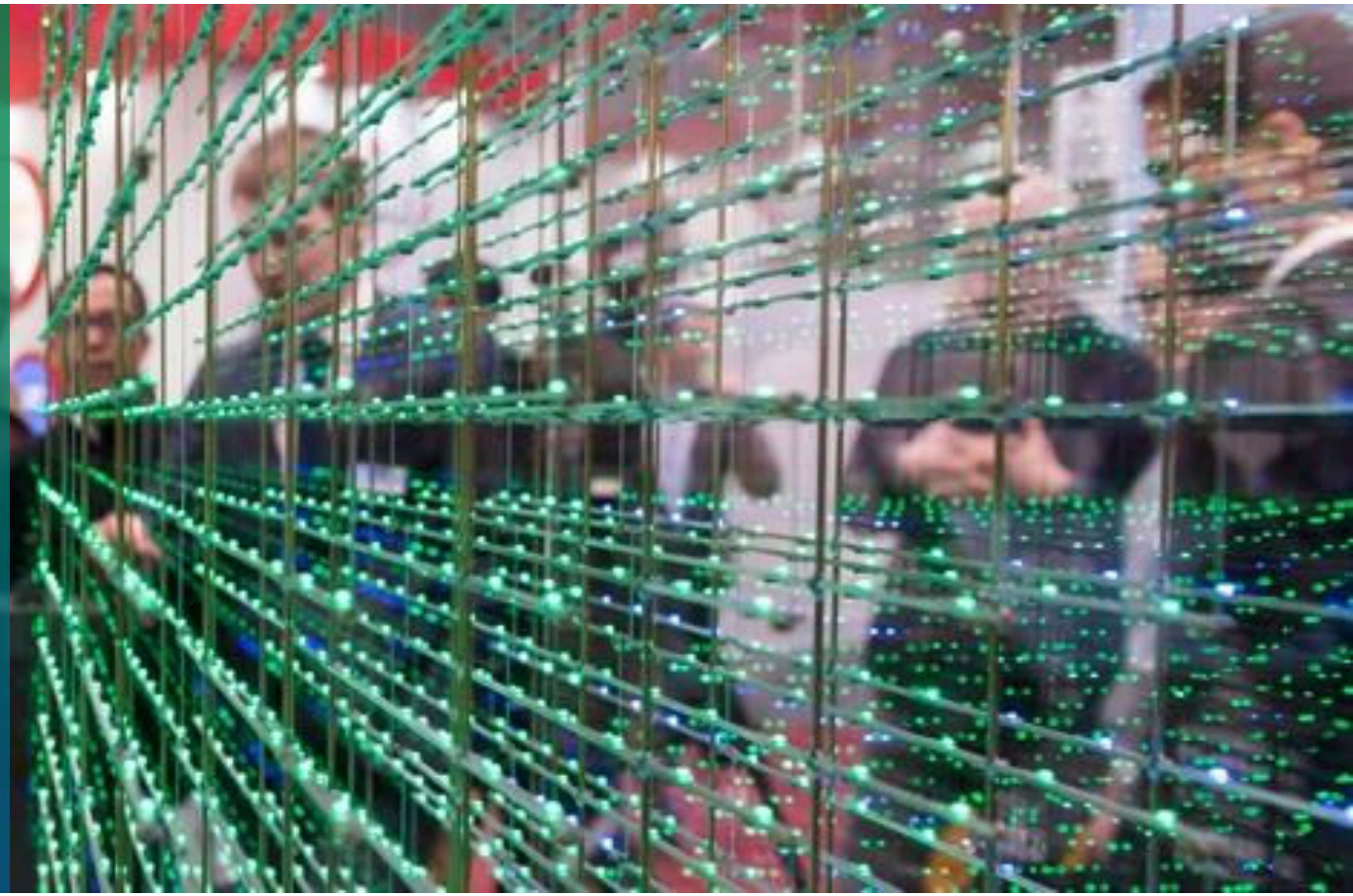
FZI Forschungszentrum Informatik

Julian Huber

Research Scientist

Haid-und-Neu-Str. 10-14
76131 Karlsruhe

Tel: +49 721 9654 - 817
E-Mail: julian.huber@fzi.de
Web: www.fzi.de



References

- [3] Julian Huber and C. Weinhardt. Waiting for the sun - can temporal flexibility in bev charging avoid carbon emissions? Energy Informatics, 1(1):49, Oct 2018.
- [5] Benjamin K Sovacool, Jonn Axsen, and Willett Kempton. The future promise of vehicle-to-grid (v2g) integration: a sociotechnical review and research agenda. Annual Review of Environment and Resources, 42:377–406, 2017.
- [8] Julian Huber, E. Schaule, and Dominik Jung. How to increase charging flexibility? developing and testing framing nudges for bev drivers. In 31st Conference on Environmental Informatics
- (EnviroInfo 2018), Garching, 5.-7. September 2018. LRZ, Garching, 2018.
- [11] Murat Yilmaz and Philip T Krein. Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles. IEEE Transactions on Power Electronics, 28(5):2151–2169, 2013.
- [12] J Garc´ıa-Villalobos, I Zamora, JI San Mart´ın, FJ Asensio, and V Aperribay. Plug-in electric vehicles in electric distribution networks: A review of smart charging approaches. Renewable and Sustainable Energy Reviews, 38:717–731, 2014.
- [13] Francis Mwasilu, Jackson John Justo, Eun-Kyung Kim, Ton Duc Do, and Jin-Woo Jung. Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration. Renewable and sustainable energy reviews, 34:501–516, 2014.
- [43] Julian Huber, E. Schaule, D. Jung, C. Weinhardt. Goal Framingin Smart Charging-Increasing BEV users' charging flexibility with Digital Nudges. In Proceedings of European Conference on Information Systems (ECIS) (2019)]