Behaviour-driven electric vehicle charging decisions and its implications on demand response flexibility for the integration of renewable energies in Germany

4NEMO summerschool, IFO institute Munich

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2019/07/31

BEniVer
Begleitforschung Energiewende im Verkehr

EVer Energie und Verkehr

DLR

ENavi KOPERNIKUS PROJEKTE
Die Zukunft unserer Energie

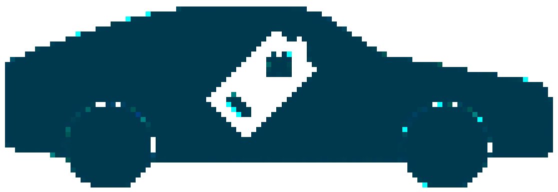
Agenda

Introduction

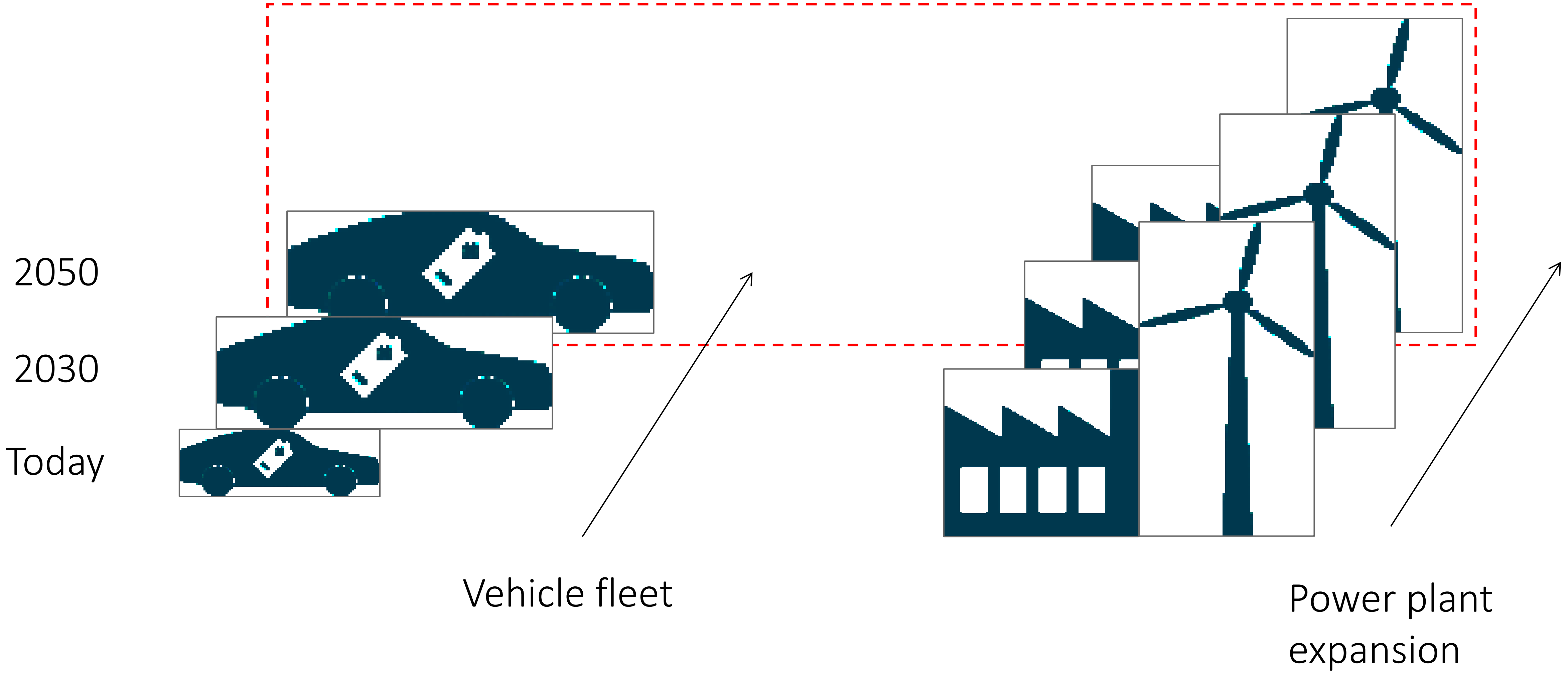
Models and model coupling

Preliminary results

Introduction

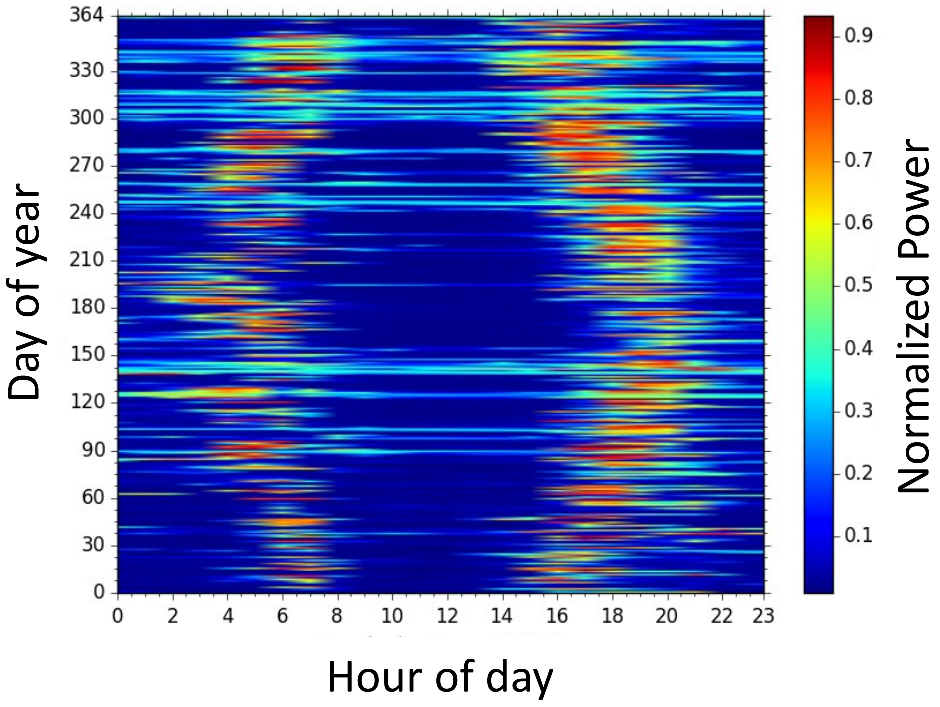


Introduction

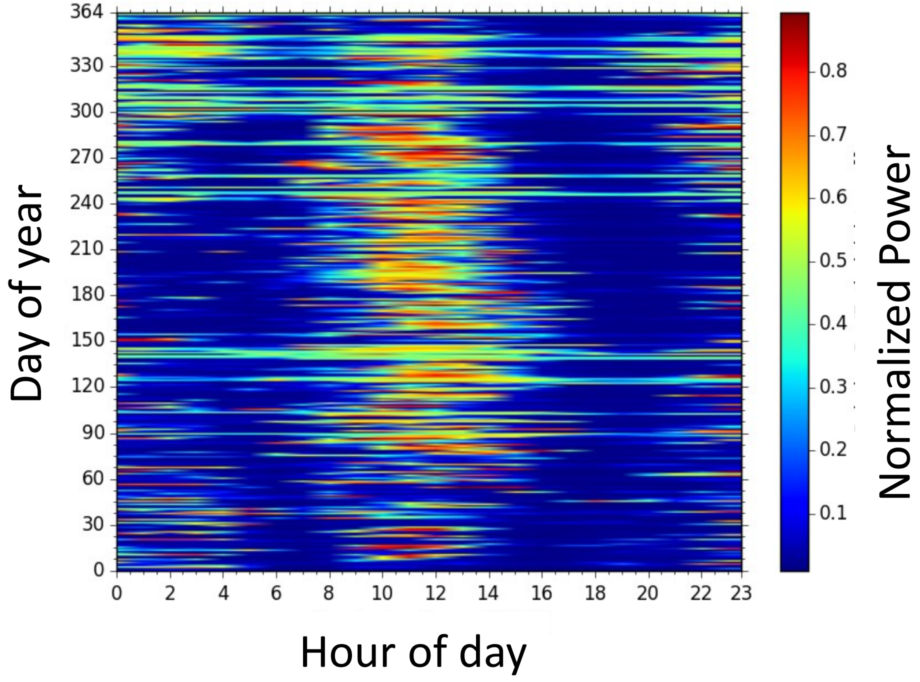


Introduction – What flexibility demand does the German energy system have (over time)?

Lithium ion battery discharge
High residual load



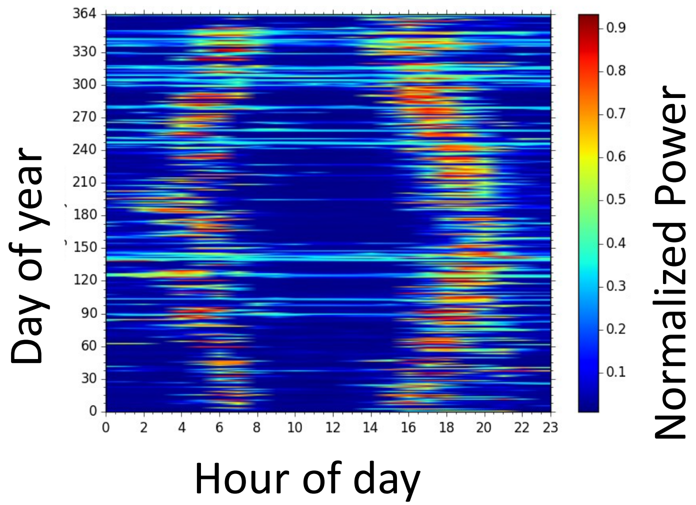
Lithium ion battery charge
Low residual load

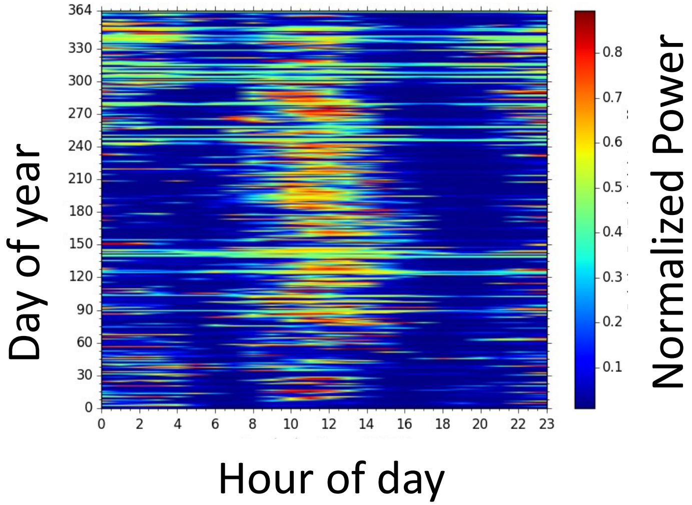


Cebulla et al. (2017)

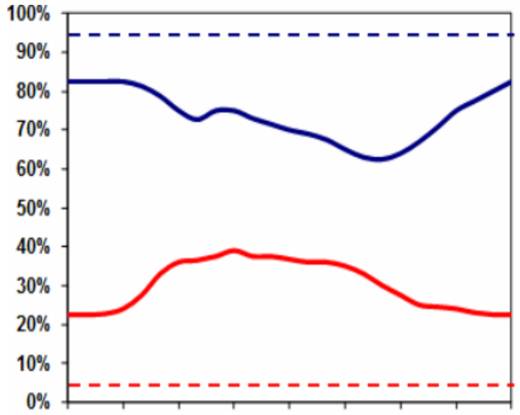
Introduction – Electric vehicle fleet as balancing option for the power system's short-term flexibility demand

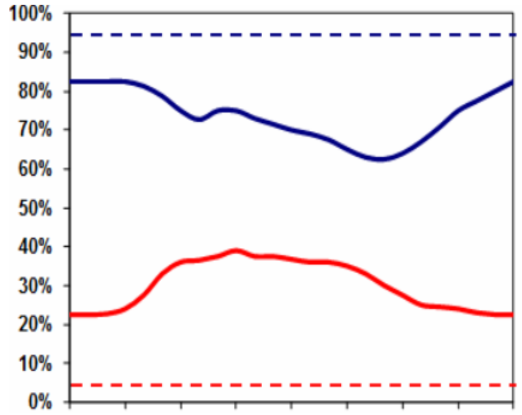
Cebulla et al. (2017)





Luca de Tena (2014)





Motivation – findings from literature (power sector)

- - 9.2% reduction in grid capacities (Luca de Tena & Pregger, 2018)
- - 0.9% - +2.69% in total capacity expansion in time horizon 2020-2050 (Taljegard et al. 2019)
- - 9.28 % - +10.31% new interconnectors in time horizon 2020-2050 (Taljegard et al. 2019)

Technology capacity

- - 6 TWh system losses (Luca de Tena & Pregger, 2018)
- - 1.6-1.8 TWh system losses (Gnann et al., 2018)
- - 19.05 % reduced wind power curtailment in 2030 (Taljegard et al. 2019), total curtailed wind power in base: 2%

Curtailment

Reduced peak power

- - 4.5 GW (Luca de Tena & Pregger, 2018)
- -2.2-+0.76 GW (Gnann et al., 2018)
- -3-9 GW (21-59 %) reduced investments in peaking capacity in time horizon 2020-2050 (Taljegard et al. 2019),

System costs

- 850 bn. € system cost savings (Luca de Tena & Pregger, 2018)
- 0-12 % increased system cost from operation in 2030 (Taljegard et al. 2019)
- 5-12 % increased system cost from investment modeling (Taljegard et al. 2019)

Research Questions

1. What structural effects do behaviour-driven charge decisions for future electric vehicle fleets in future cost-optimal power systems with high shares of photovoltaic and wind power plants?

2. How do hourly power prices affect charge decisions? How do these changes affect load shifting potential of future electric vehicle fleets?

Agenda

Introduction and motivation

Models and model Coupling

Preliminary results

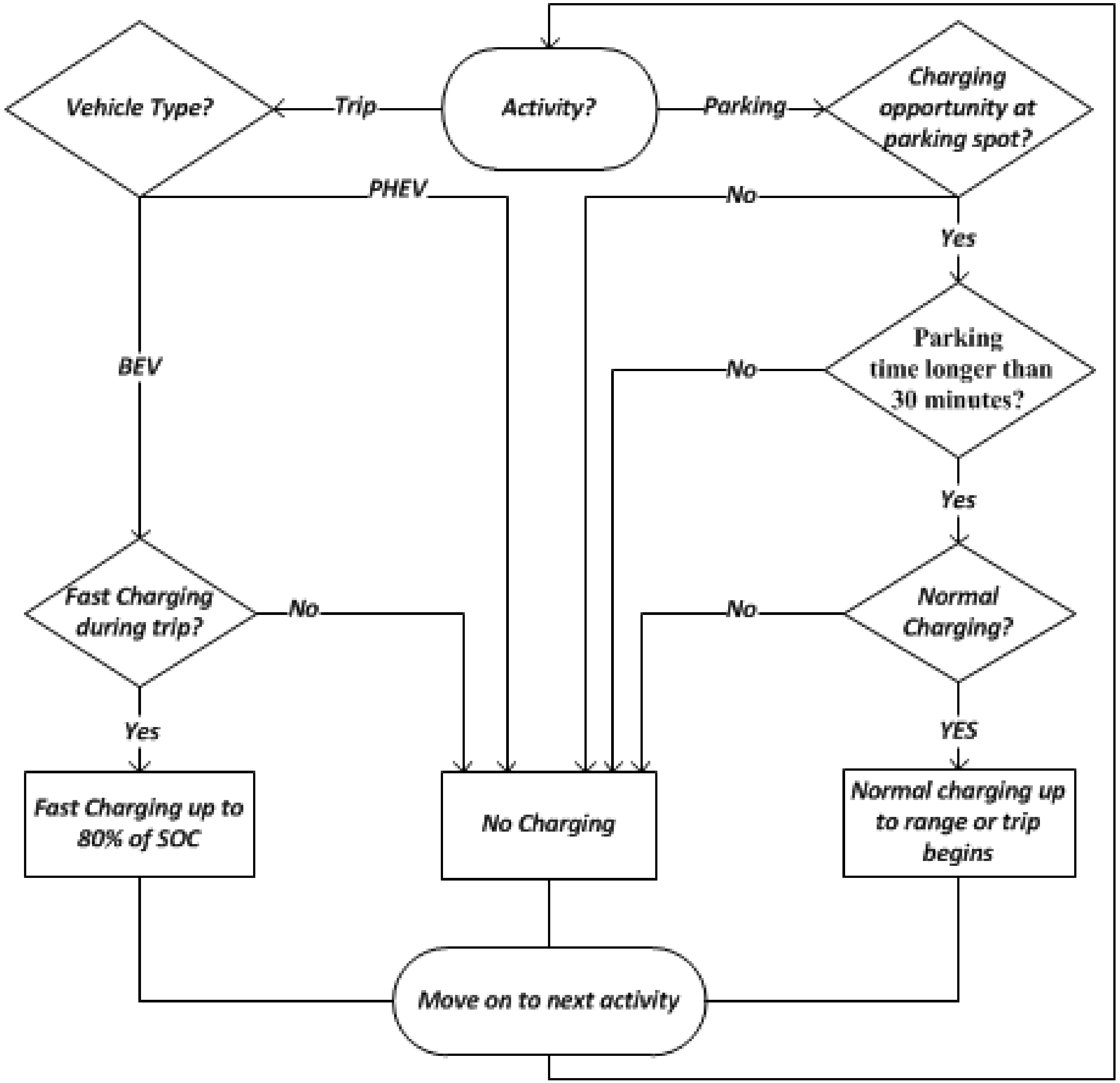
Model description - CURRENT

$$U_{i,n} = \beta\_LOC_i + \beta\_PRICE * p_i + \varepsilon_{i,n}$$

U: Utility
i: activity
n: electric vehicle
Beta_LOC: preference for location
Beta_PRICE: preference for price
p_i: price
Epsilon: stochastic term

$$U_{nonchoice,n|i} = SoC_{nonchoice,n|i} + \varepsilon_{nonchoice,n}$$

$$P_{i,n} = \frac{e^{V_{i,n}}}{\sum_{j=1}^{J} e^{V_{j,n}} + \gamma_{i,n} * \left(e^{V_{nonchoice,n|i}} + \alpha\right)}$$



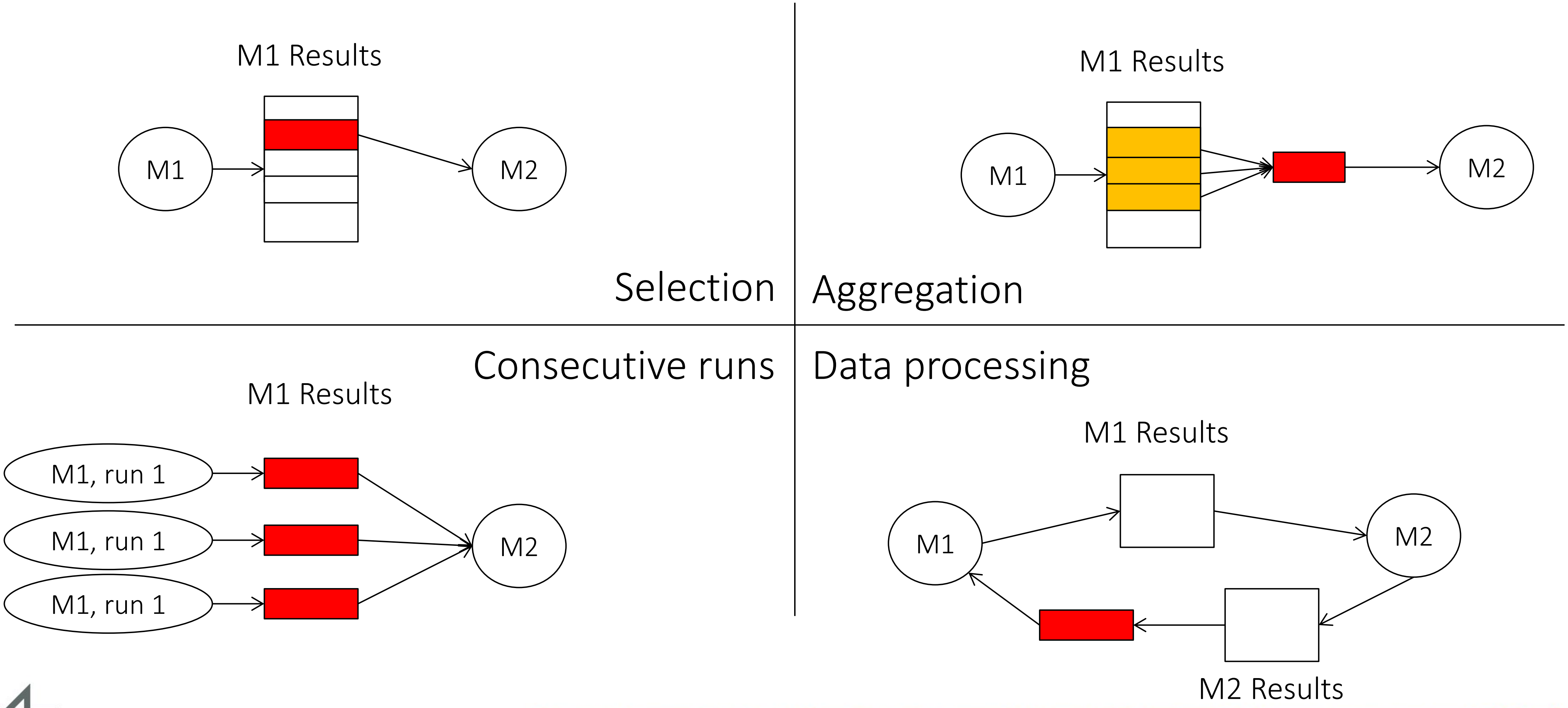
Steck et al. (2019)

Systematics of model coupling

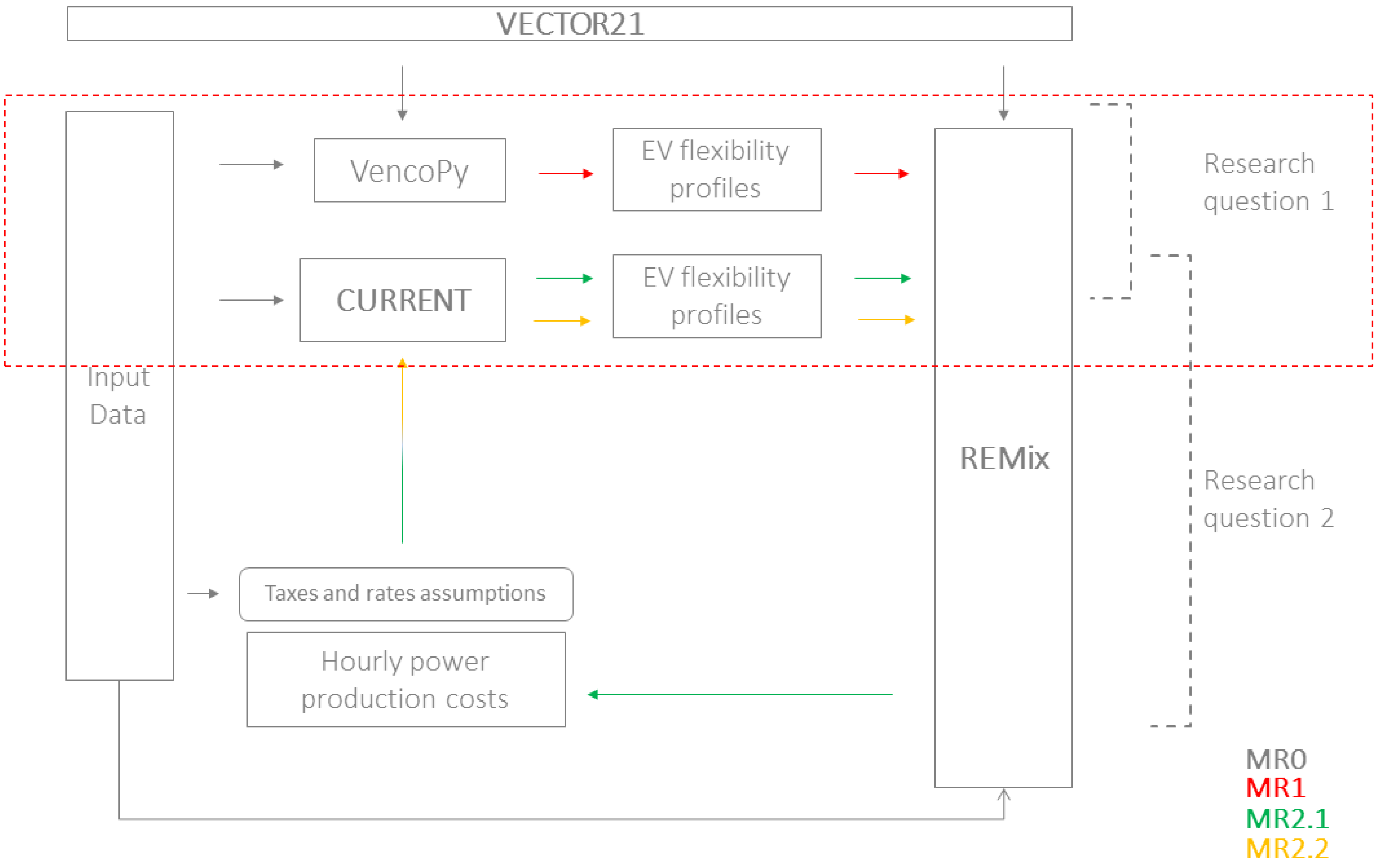
Degree of integra-tion

Exemplary Aim	Degree of integration	Data harmonization	Scope harmonization	Methodological harmonization
Comparison	**Harmonization**	Central assumptions	Optional	No
Model chain	**Model linking**	For relevant dimensions	Optional	No
Feedback effects	**Model coupling**	Yes	Yes	No
Model refinement	**Model integration**	Selection	Yes	Yes

Methods of model coupling without a strict harmonization of scope

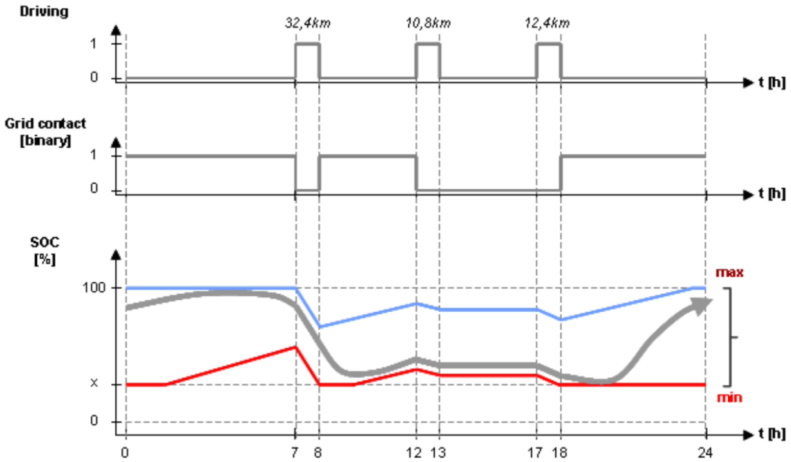


Methodological framework and depiction of model runs

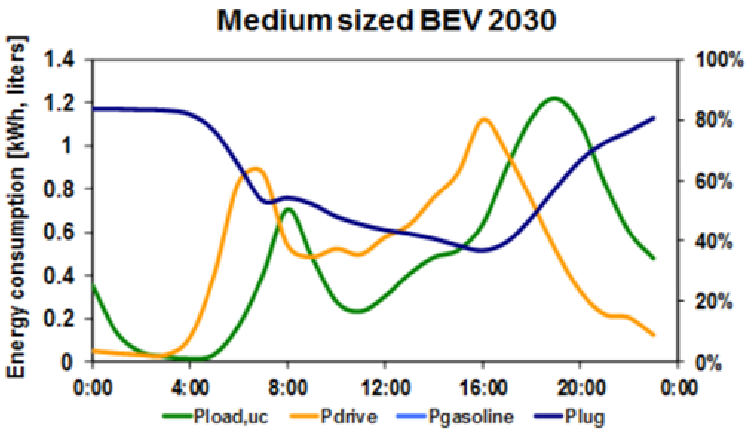


Input – load shifting profiles

Power system view



Source: DLR/IFHT/ISE, 2012



Car owners' view

- Data: Mobility demand survey of 25k German households, 60k persons and 35k cars for one day each
- Aggregated to ~18k hourly drive profiles as well as hourly boolean connection profiles

- Resulting profiles for each technology:
  1. SOC max
  2. SOC min
  3. Electric demand
  4. Charge availability
  5. Uncontrolled charging

Input – load shifting profiles

Power system view

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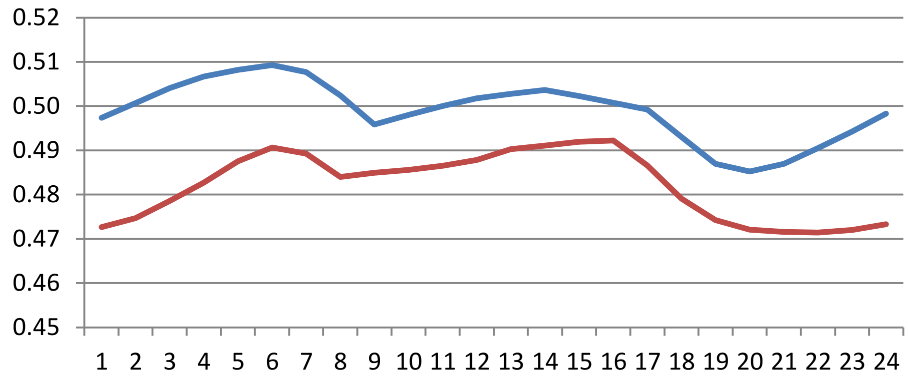

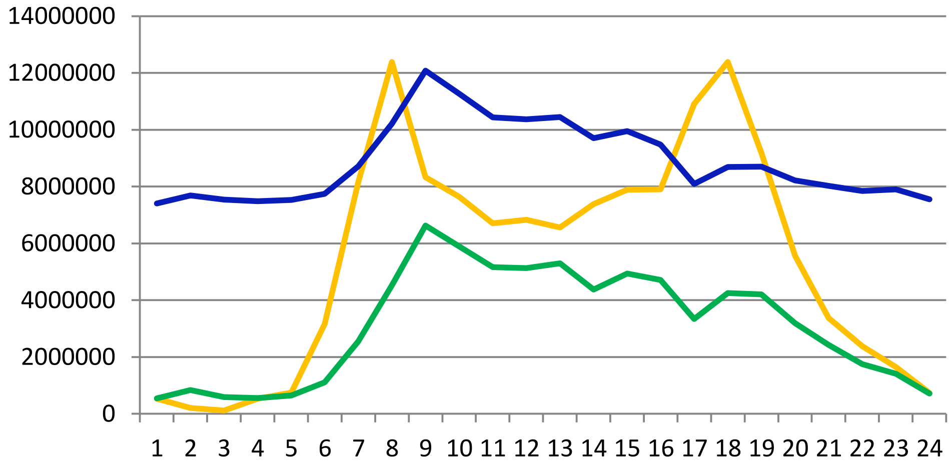

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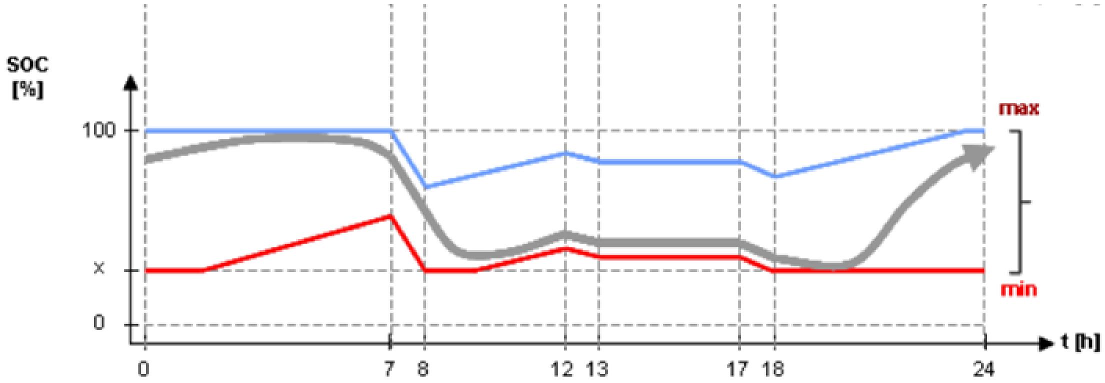

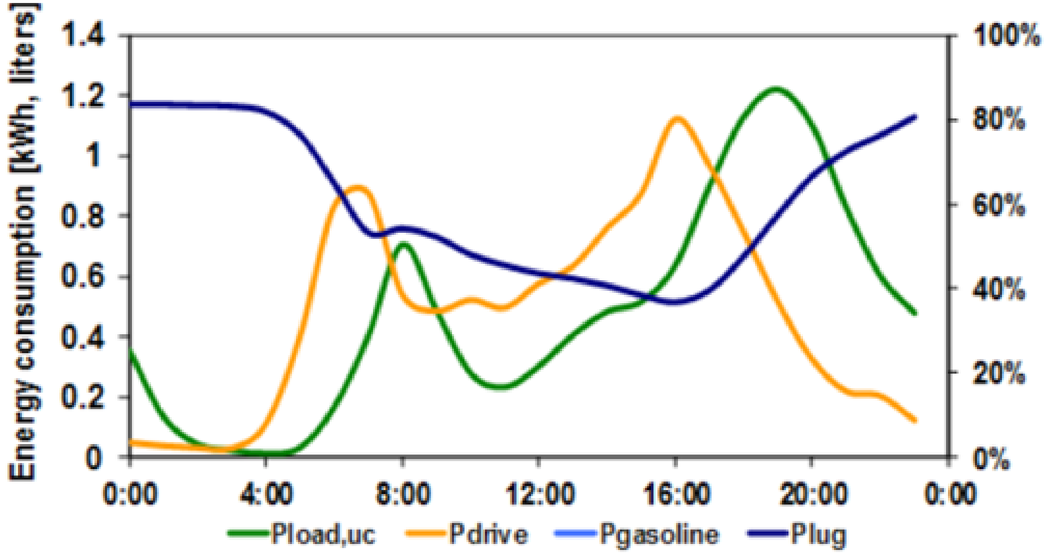

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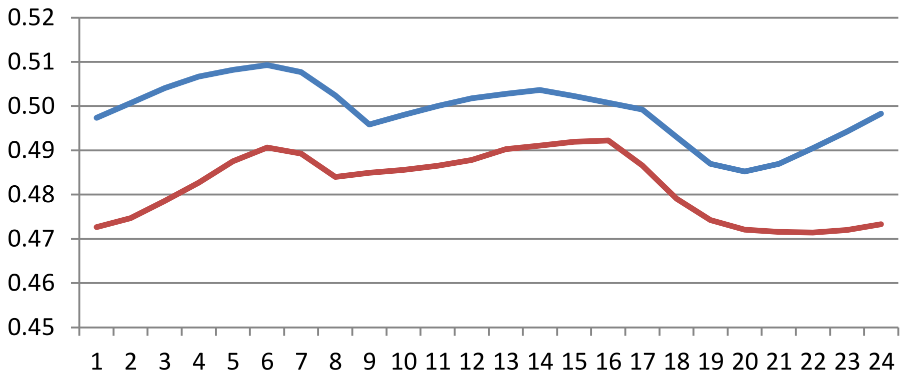
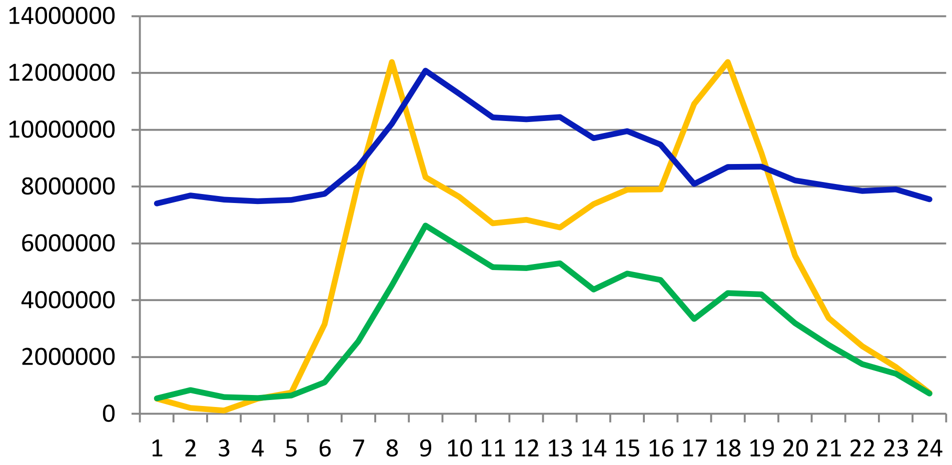
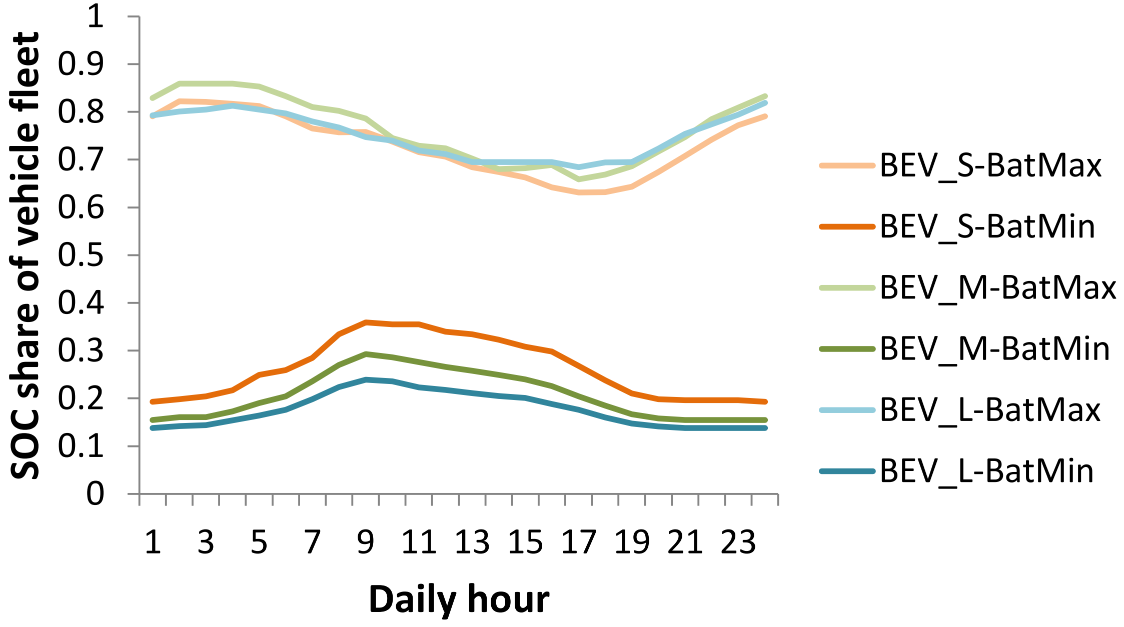




Input – load shifting from EV fleet

Model run (MR)	Demand for electric driving in TWh/a	Hourly load shifting potential in Germany in GWh		
		Average	Max	Min
MR0	0	0	0	0
MR1	100	749	935	592
MR2.1				
MR2.2				
Taljegard et al. (2019)	110 (S2), 210 (S6)	1300 (S2), 2300 (S6)		



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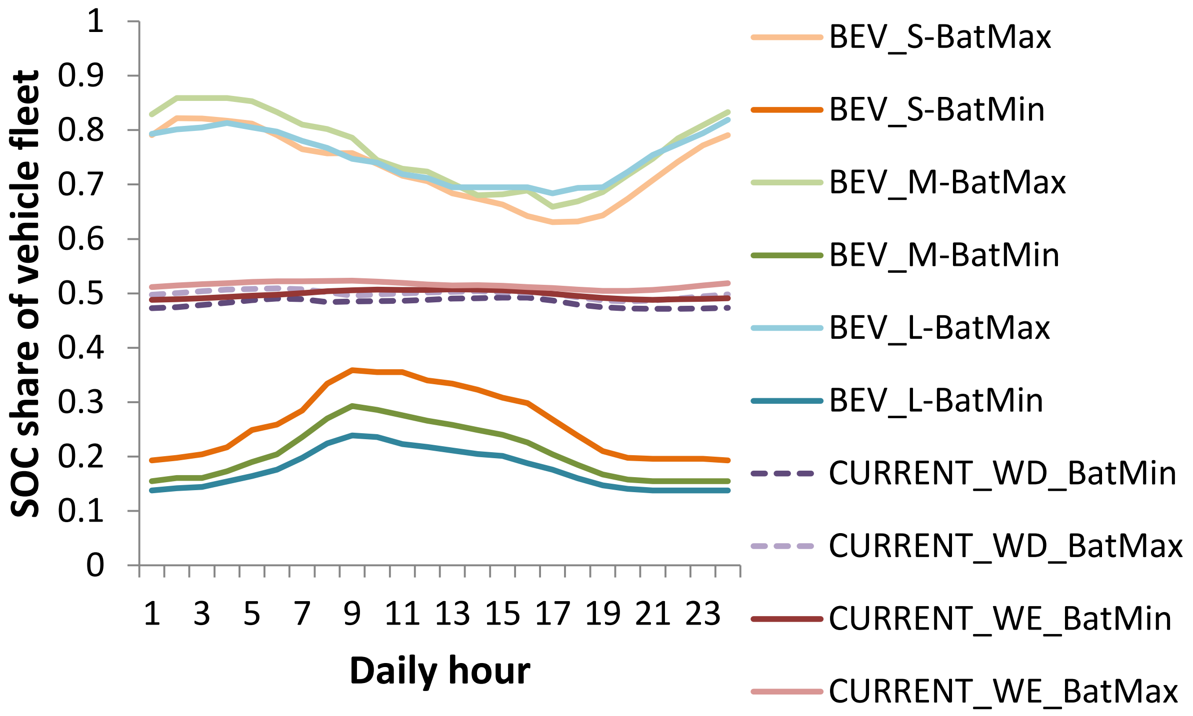


DLR

Agenda

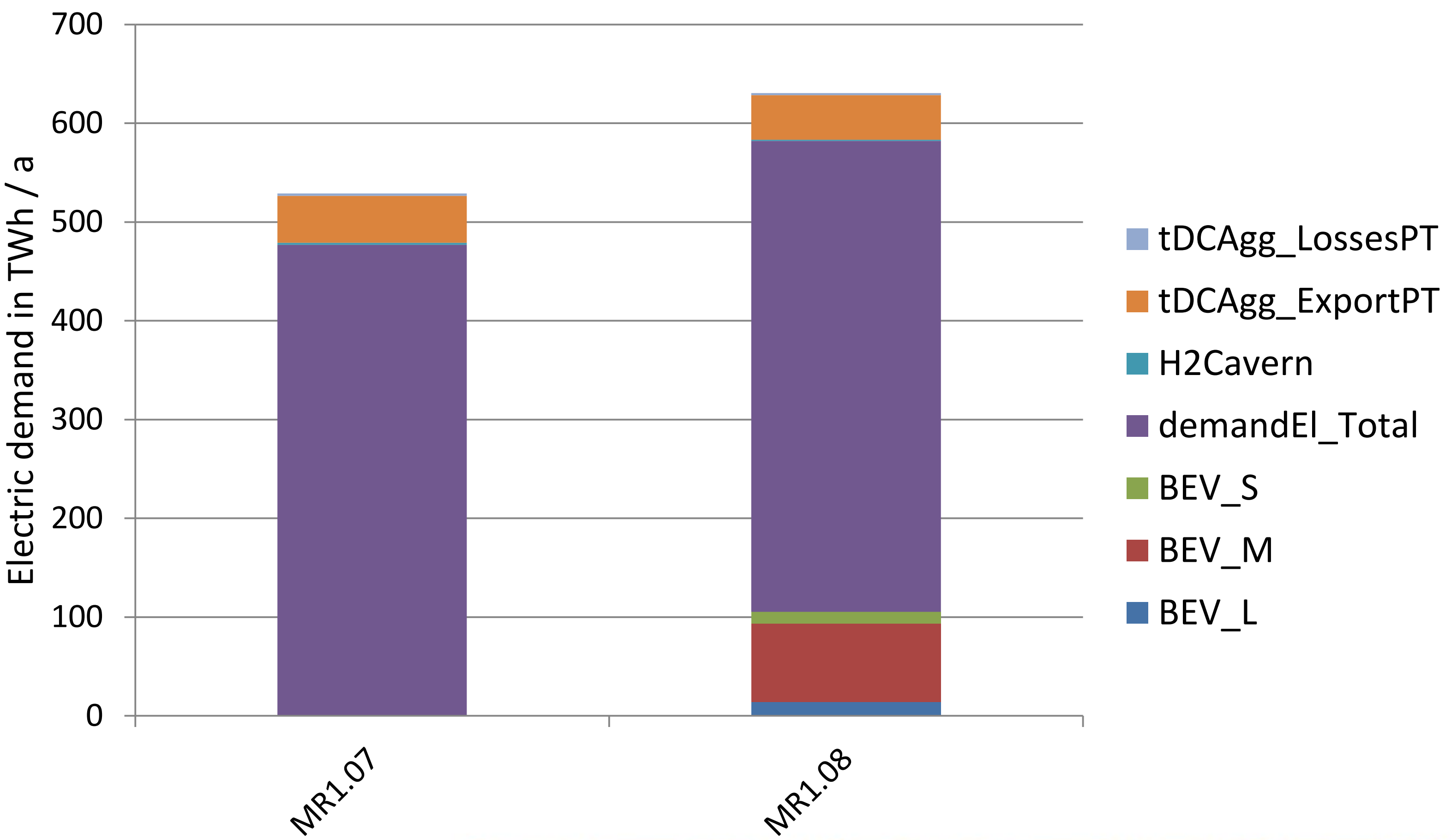
Introduction and motivation

Model Coupling

Preliminary results

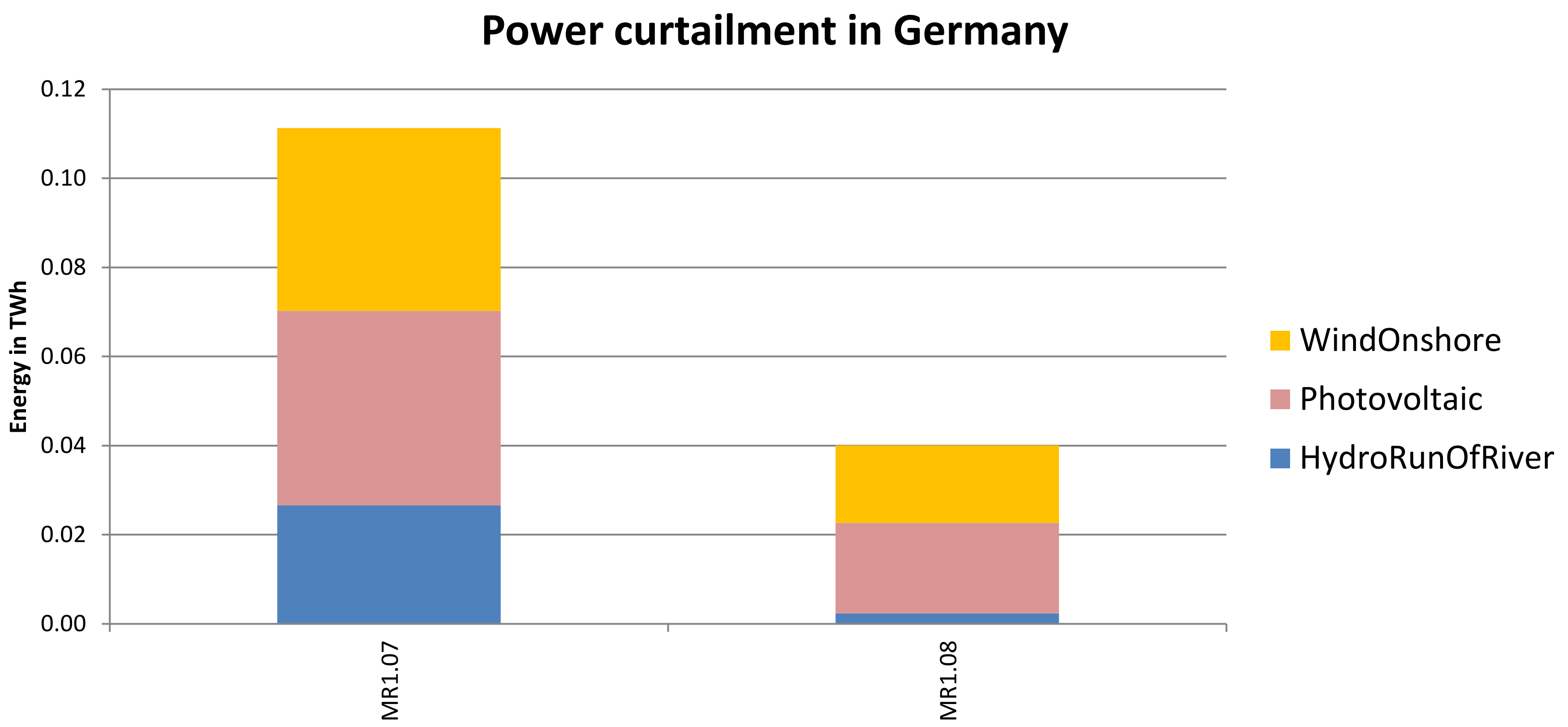
Preliminary results – MR0 vs. MR1

Power demand



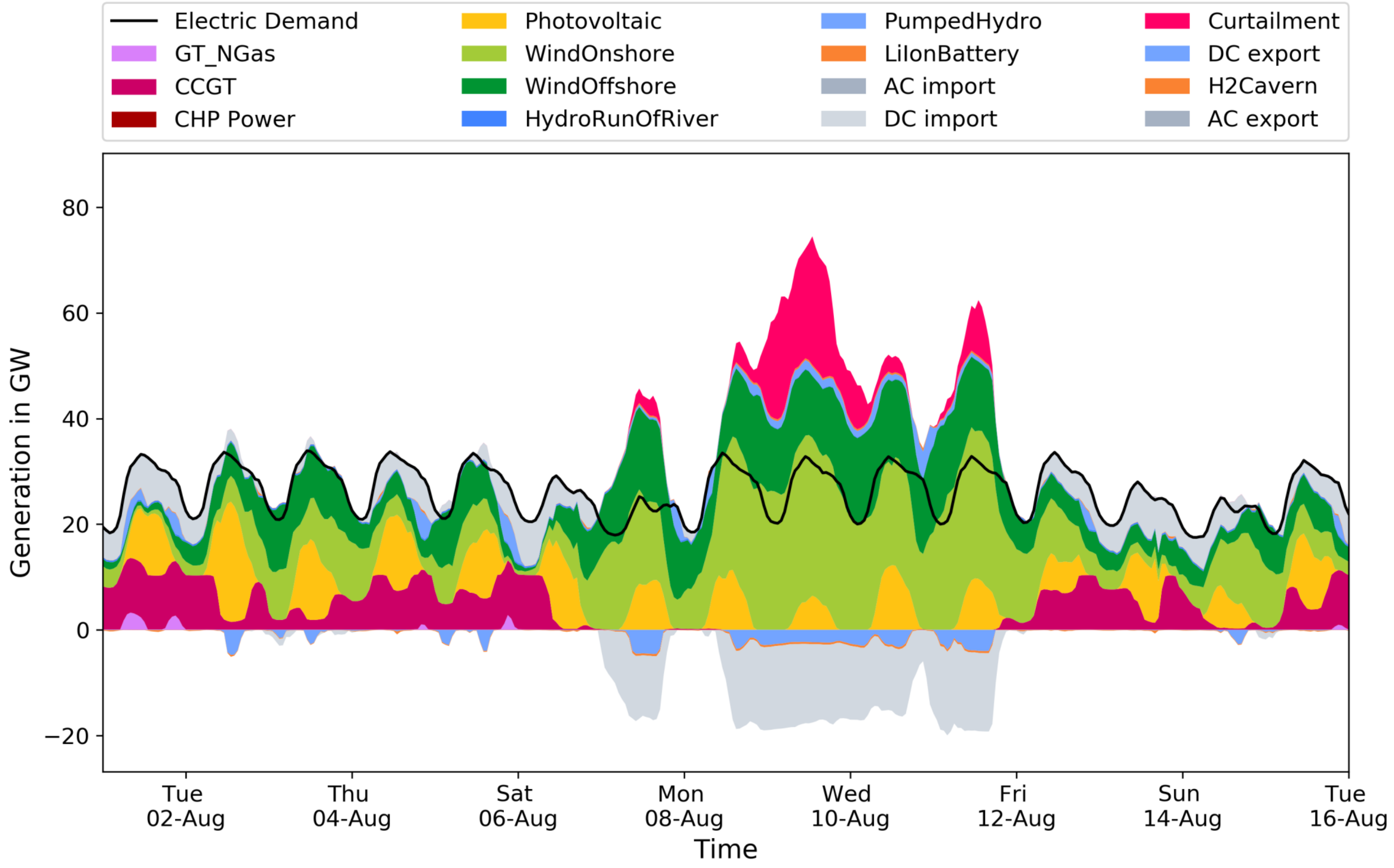
Preliminary results – MR0 vs. MR1

Curtailment



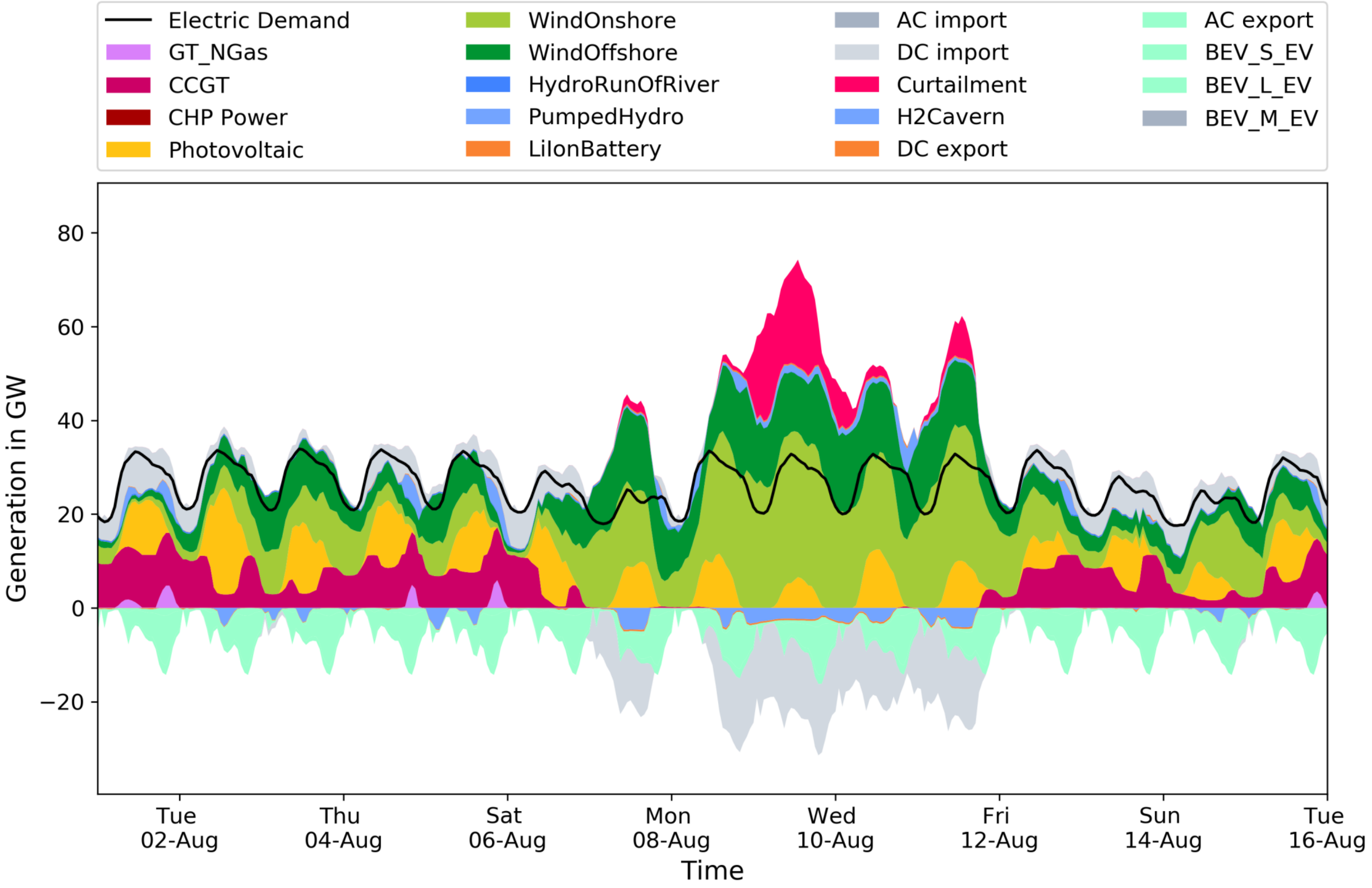
Preliminary results – MR0 vs. MR1

Dispatch



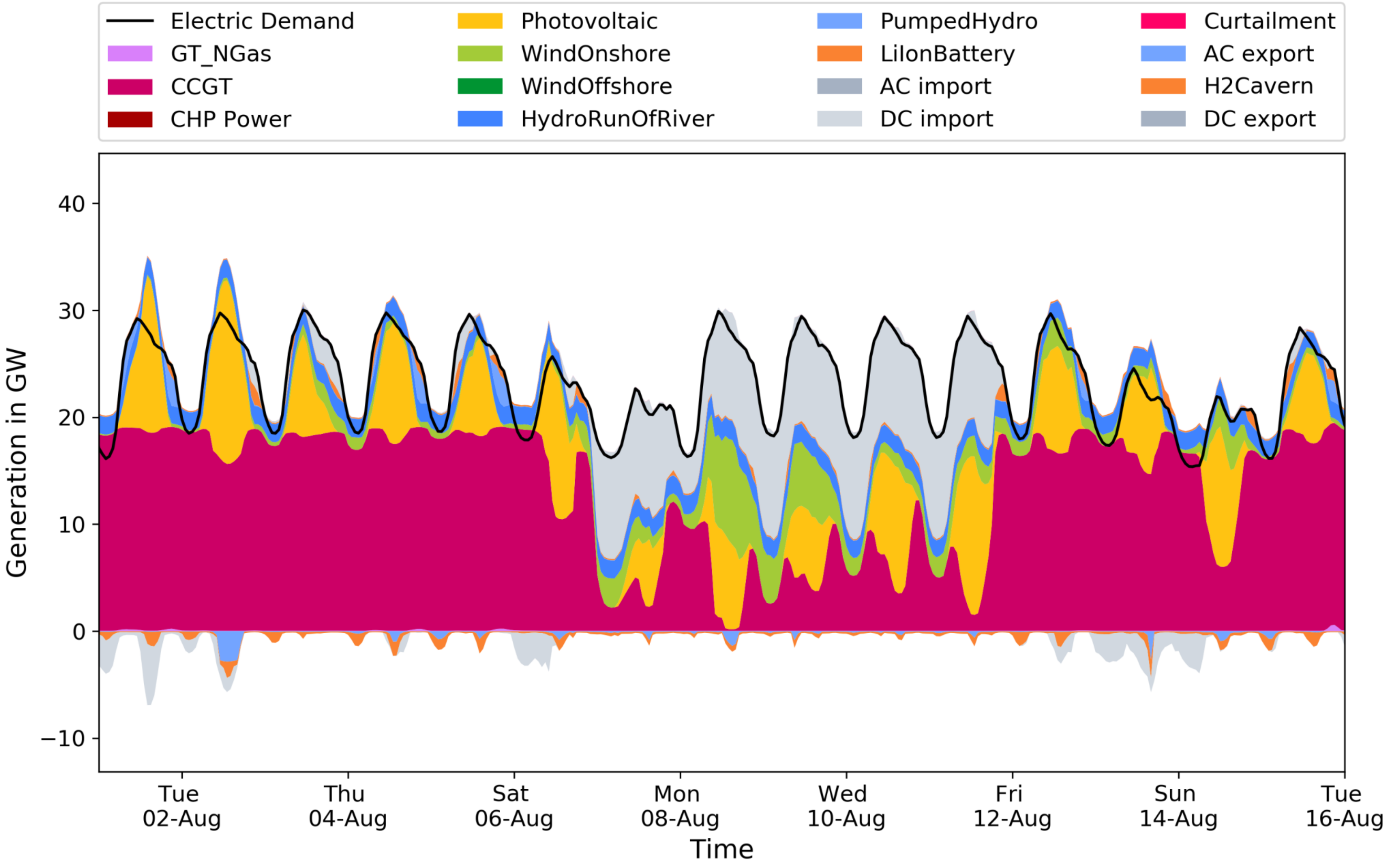
Preliminary results – MR0 vs. MR1

Dispatch



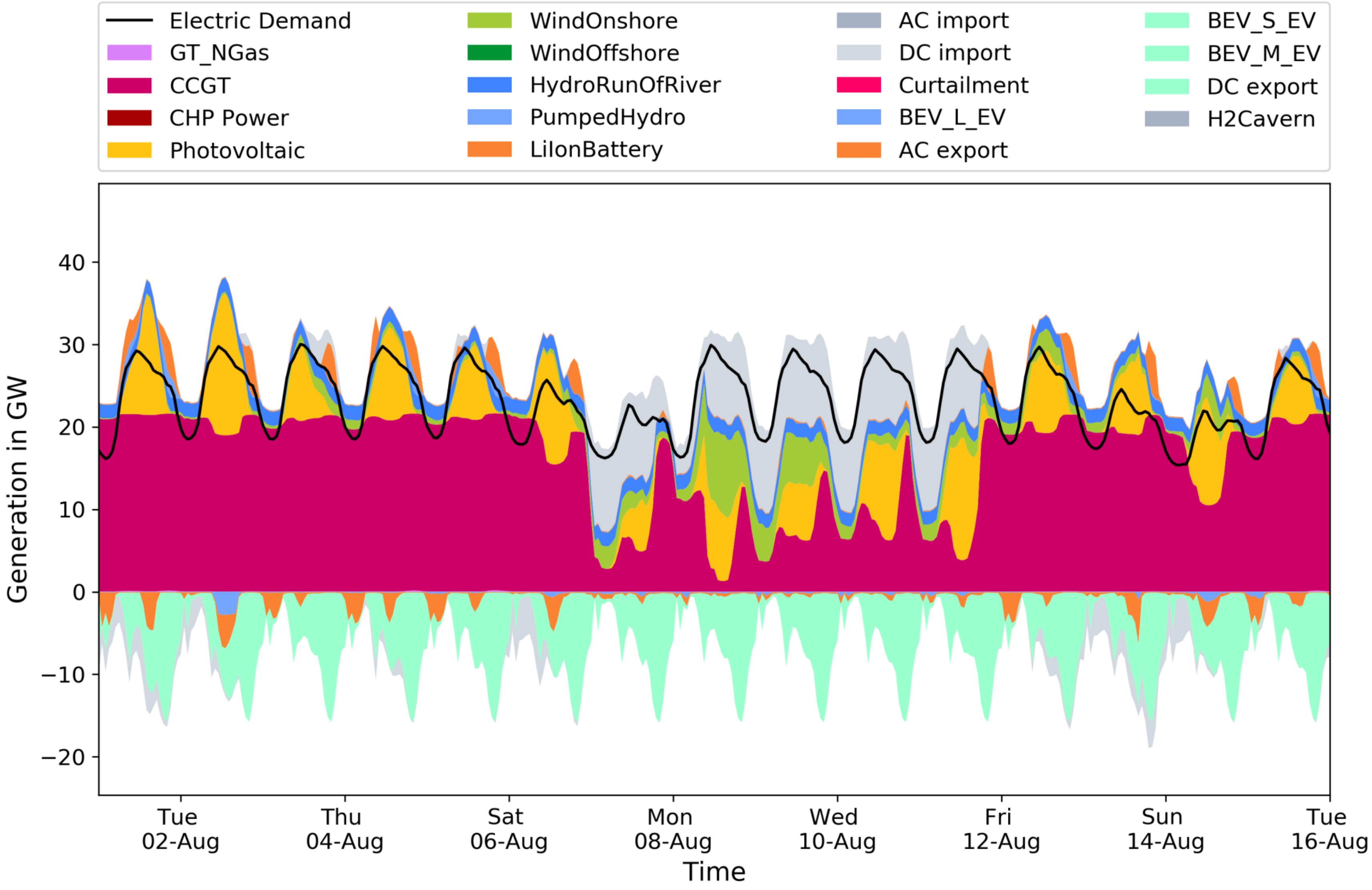
Preliminary results – MR0 vs. MR1

Dispatch



Preliminary results – MR0 vs. MR1

Dispatch



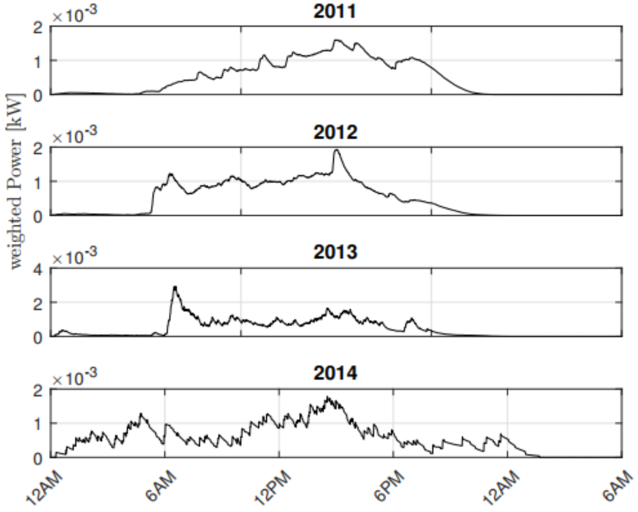
Further work and weaknesses of the analysis

Next steps

- REMix-Model Run 2 with CURRENT-Output
- Setting up feedback loop for power prices
- Result depiction
- Sensitivity analyses for different weather and load years (currently 2011)

Further improvements

- Validation of charging decisions modelling
- Change in charging behaviour
- Assumptions on taxes and rates



Schaeuble et al. (2017)

Background Literature

Cebulla, F., Naegler, T. & Pohl, M. (2017). Electrical energy storage in highly renewable European energy systems: Capacity requirements, spatial distribution, and storage dispatch. Journal of Energy Storage 14, 211-223. doi: https://doi.org/10.1016/j.est.2017.10.004

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Luca de Tena, D. & Pregger, T. (2018). Impact of electric vehicles on a future renewable energy-based power system in Europe with a focus on Germany. Int J Energy Res. 42, 2670–2685. doi: 10.1002/er.4056

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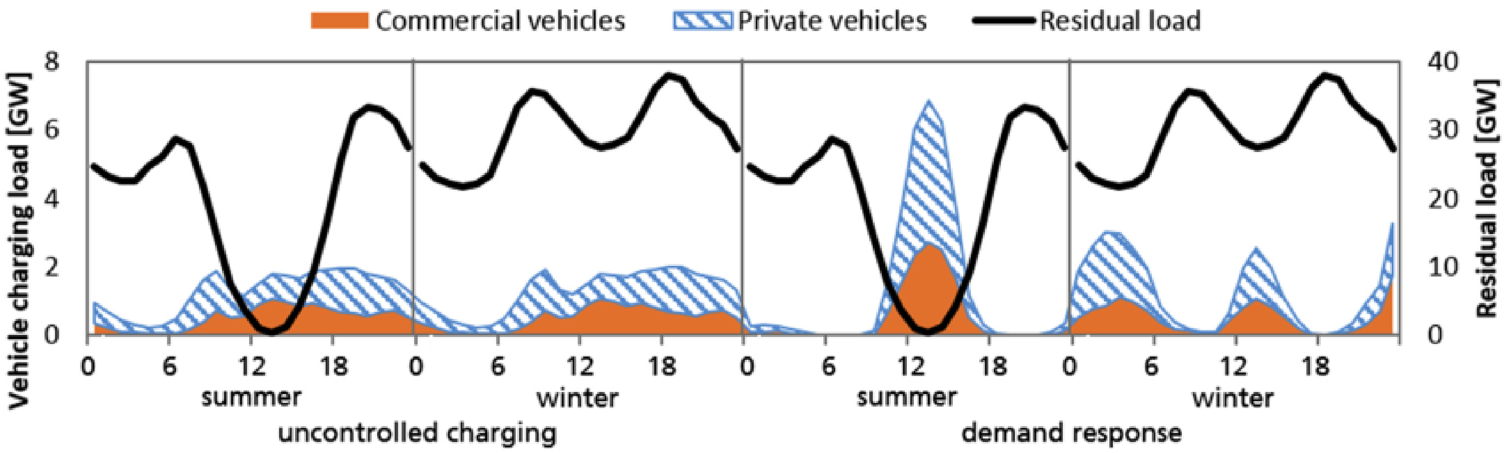
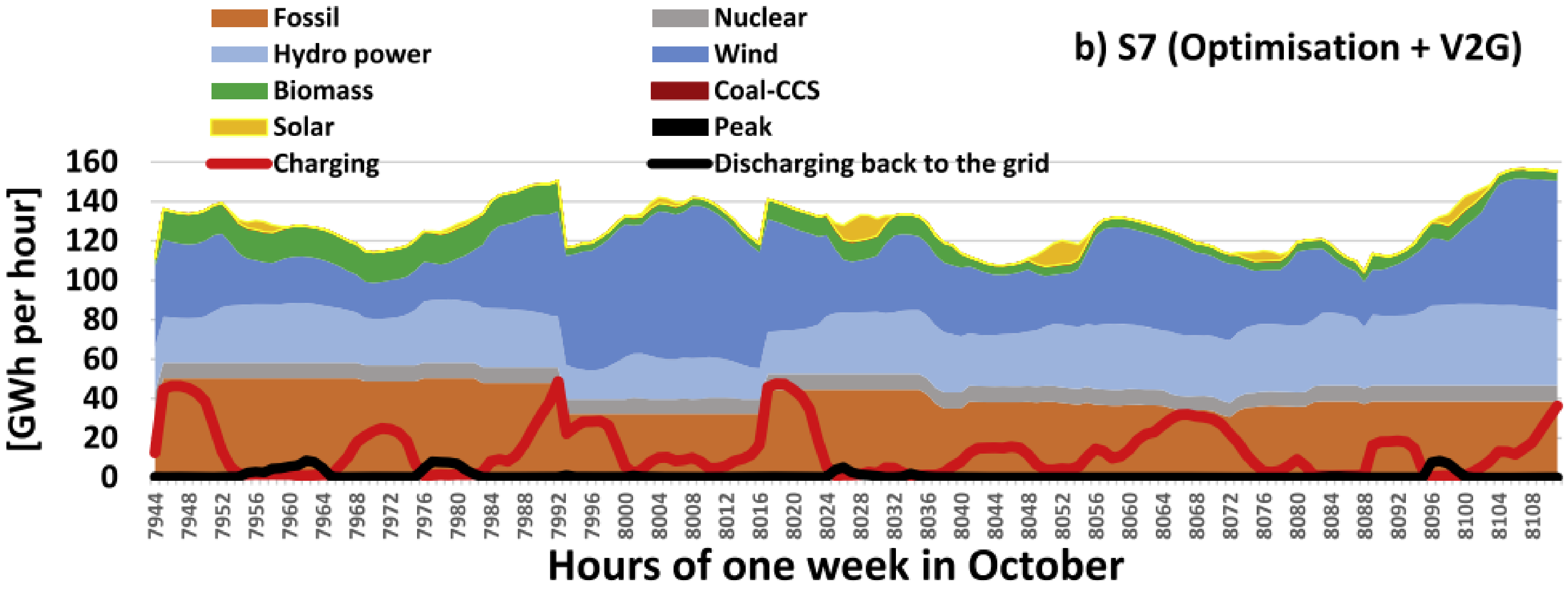
Taljegard, M., Göransson, L., Odenberger, M. & Johnsson, F. (2019). Impacts of electric vehicles on the electricity generation portfolio – A Scandinavian-German case study. In: Applied Energy 235. Elsevier. DOI: https://doi.org/10.1016/j.apenergy.2018.10.133

Back-up slides

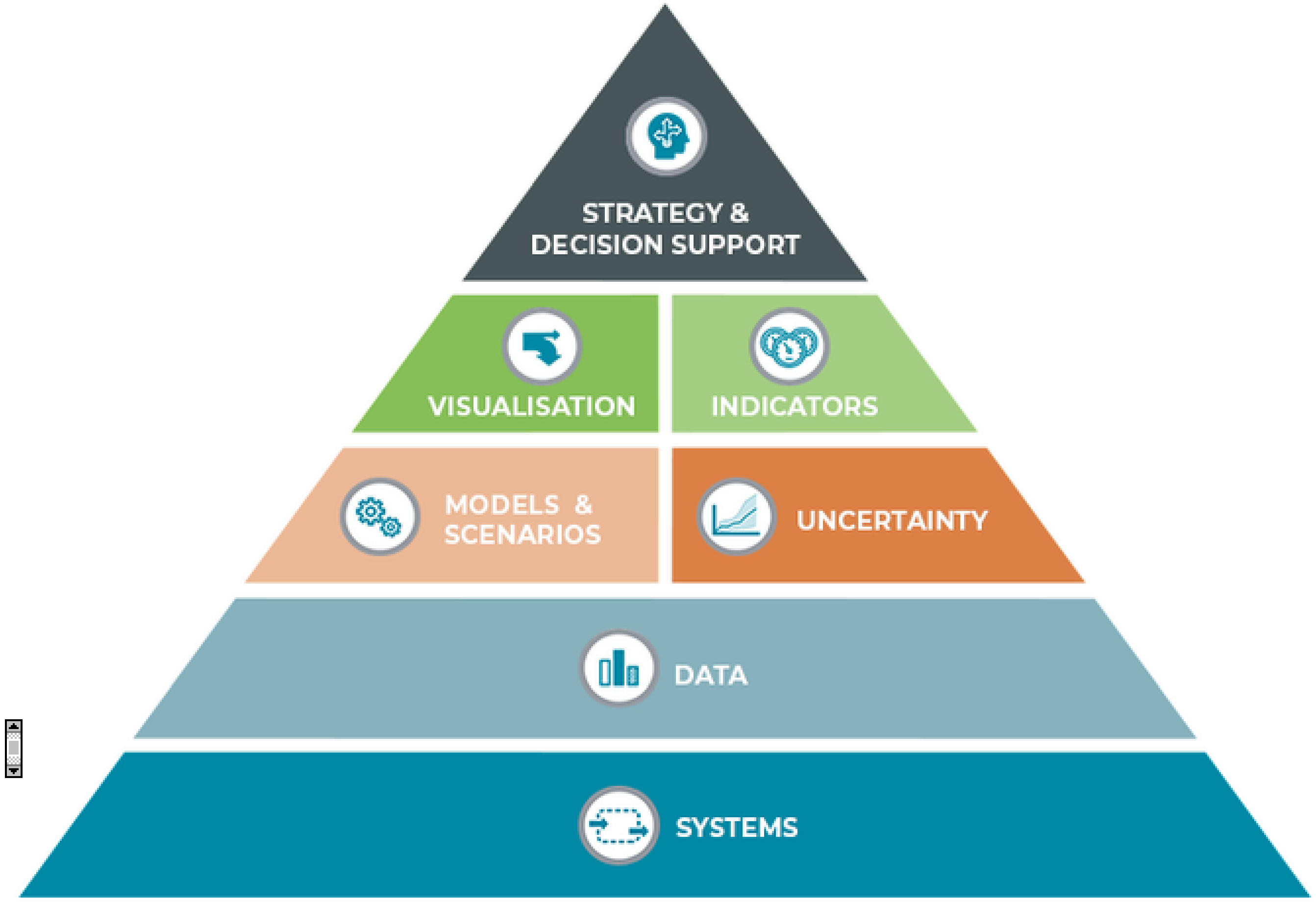
Motivation – findings from literature (power sector)

Other



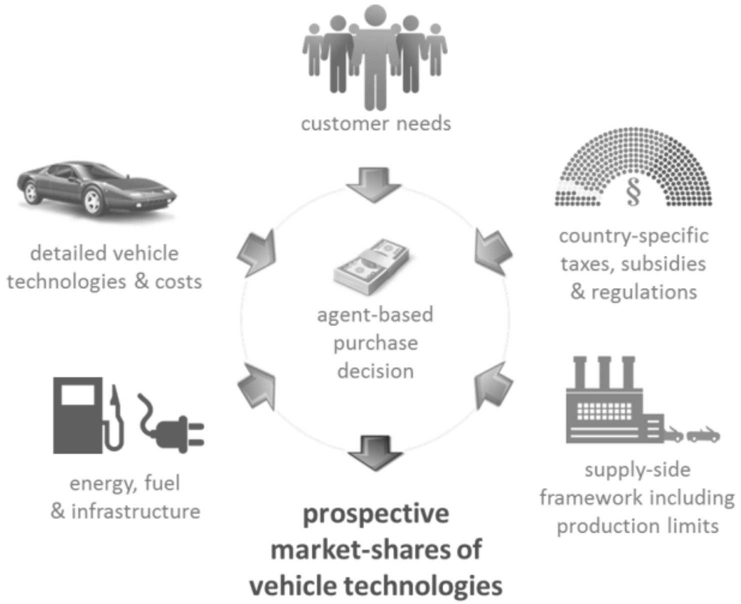


Introduction



MinFuture (2019)

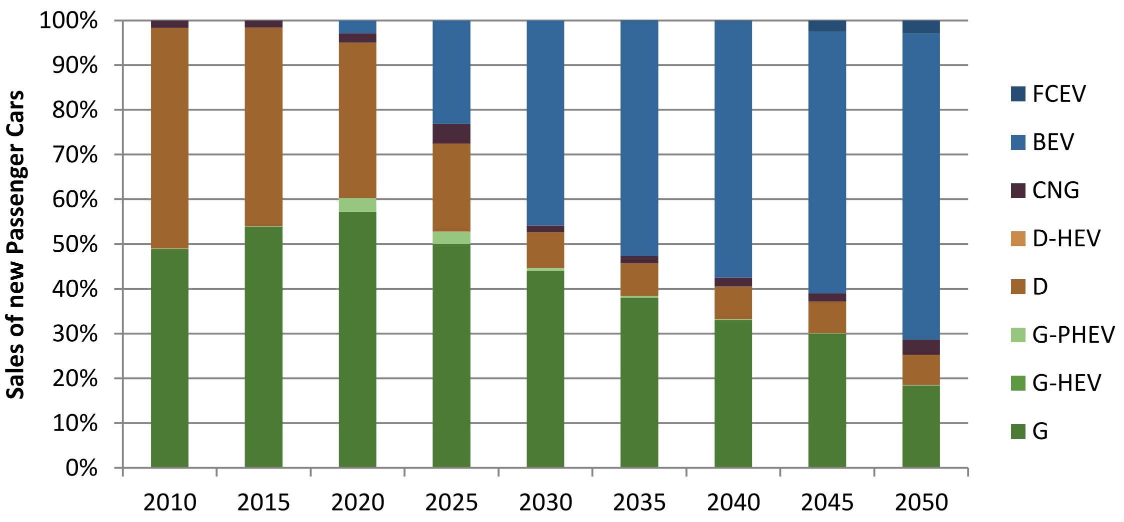
Model 1 – VECTOR21



No of agents	92,135
Infrastructure availability	100% from 2040 onwards
CO2 emission cap in 2050	5 kg/100km

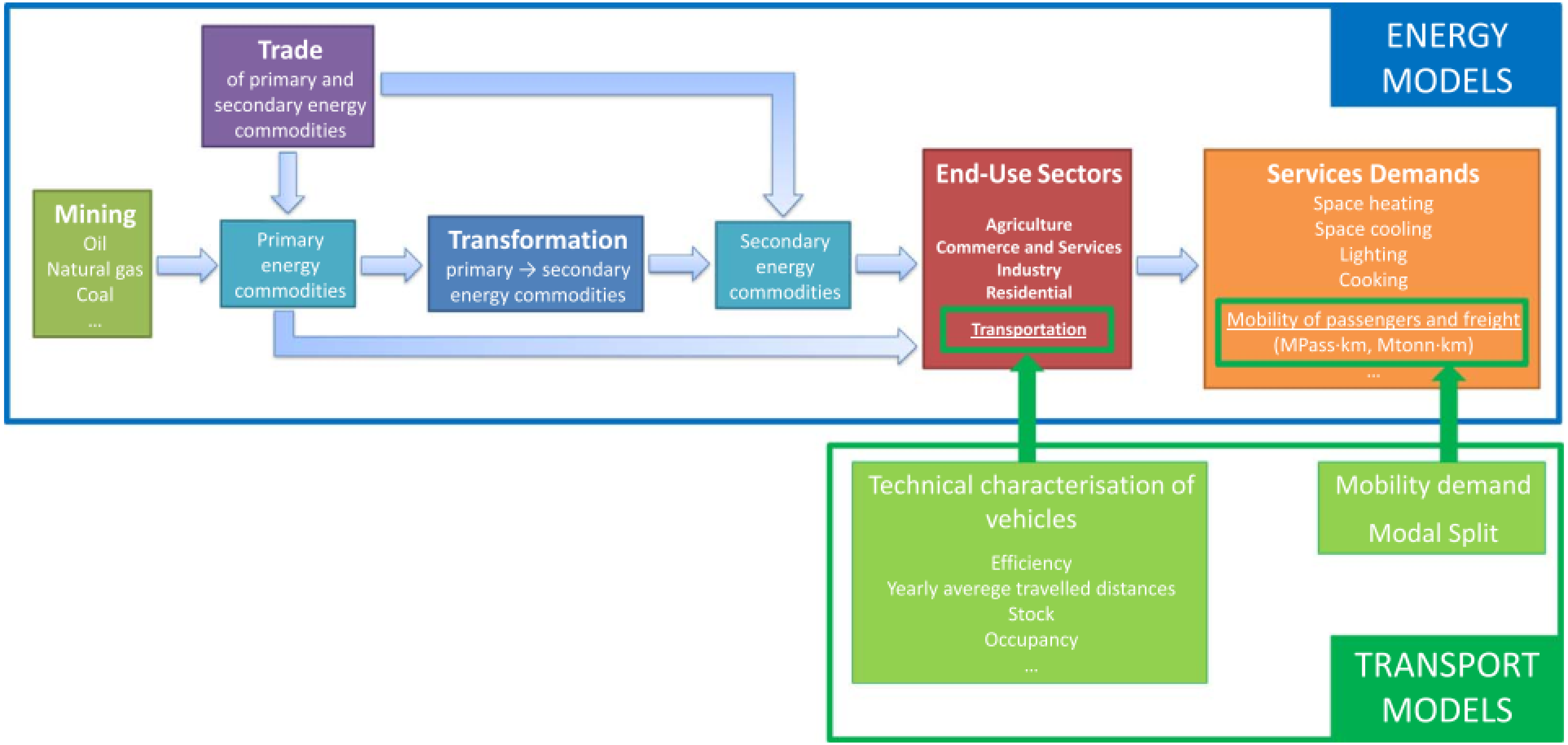
Relevant cost of ownership

$$RCO = I \cdot (1+r)^n + \sum_{t=1}^{n} \left(A(t) \cdot (1+r)^{n-t}\right) - R$$

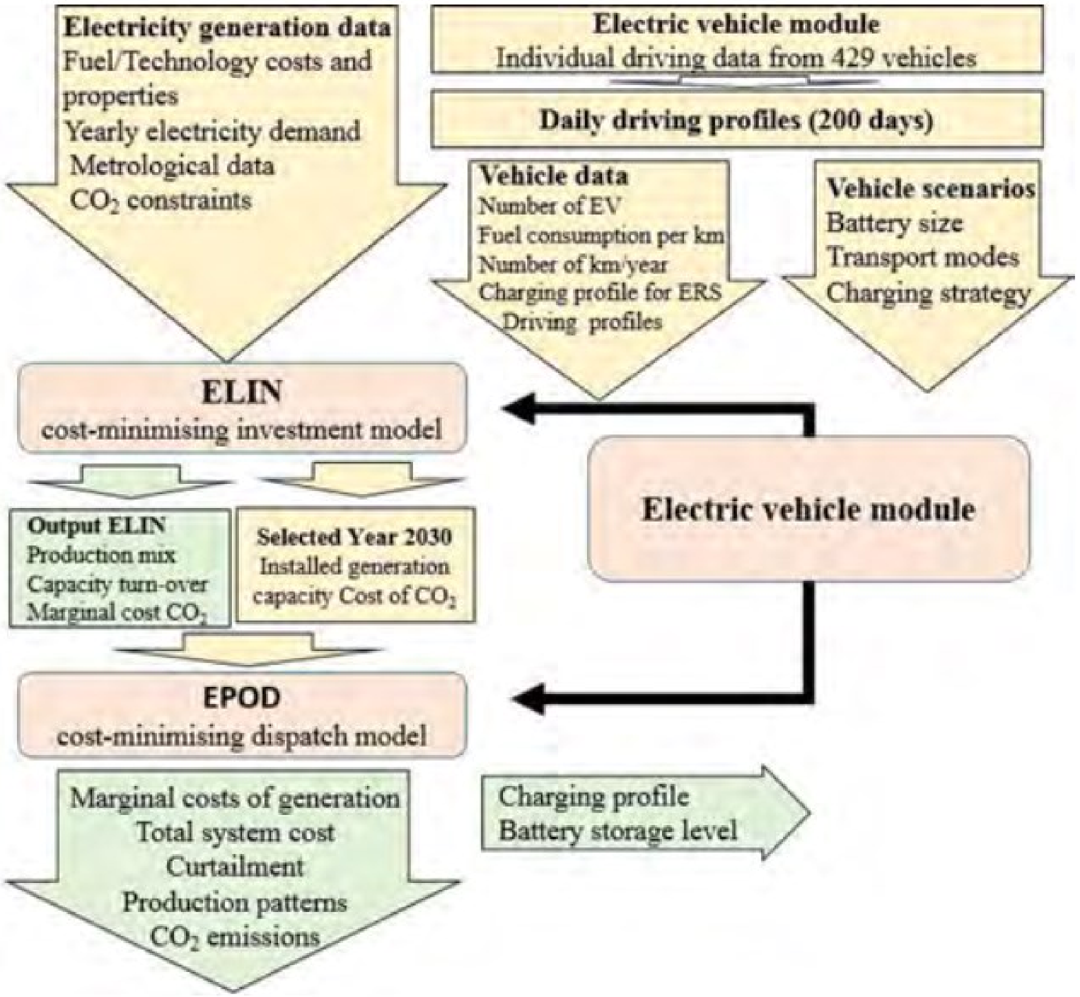


Kugler et al. (2017)

Model coupling – Gerboni et al. (2017)



Model coupling – Taljegard et al. (2019)



Method – User-behaviour implications for power systems

Aggregation
(weighted and scaled)

Disaggregation
(weighted and scaled)

CURRENT

Individual driving and charging profiles

- Fix charging profile
- Driving profile
- Charg.-Infr .avail.
- Flexibility profile

REMix Electric Cars

1 „Fleet battery“
≙
Battery capacity of all EVs in one technology class

Optimized charge profile

Plausibilisation

Individual optimized charging profiles

Unidirectional model communication

Model description - REMix

Technology data

Climate and weather data

Energy statistics / scenario data

Population / land occupation

Input

Energy Data Analysis Tool *REMix-EnDAT*

- Renewable Energies Potential
- Power demand
- Heat demand
- Demand flexibility
- Fuel demand

Technology and scenario input

Hourly demand and RE feed-in

Energy System Optimization Model REMix-*OptiMo*

Temporal and spatial cost minimization in high resolution

DLR

Power

Heat

Gas, SynGas, SynFuel

Electrolysis, methanation, liquid fuels, storage, transport

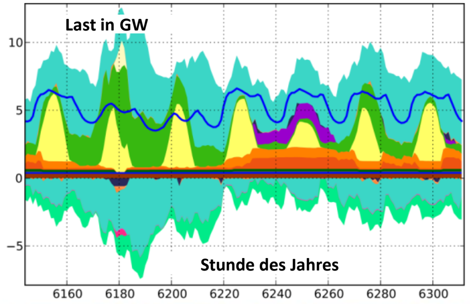
Transport

EV: Battery and Fuel Cell

Output

Results: Strategies for generation, transmission and storage

- Expansion of power plants, storages, grids and sector coupling
- Hourly dispatch of all facilities
- Supply cost
- CO_2-emissions

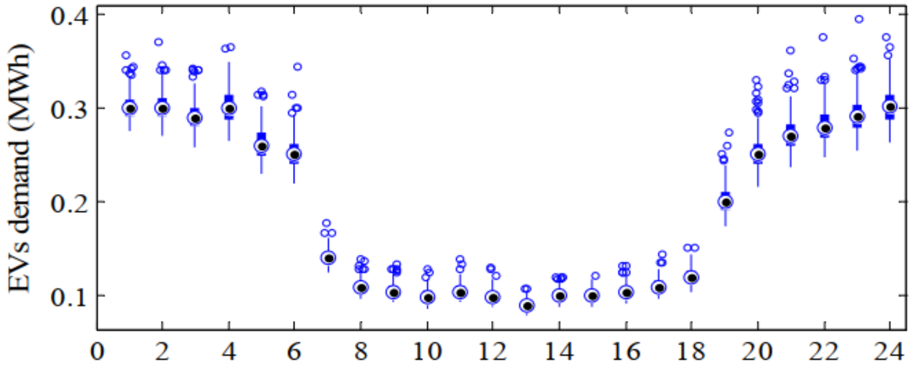


Based on Gils et al.. (2017)

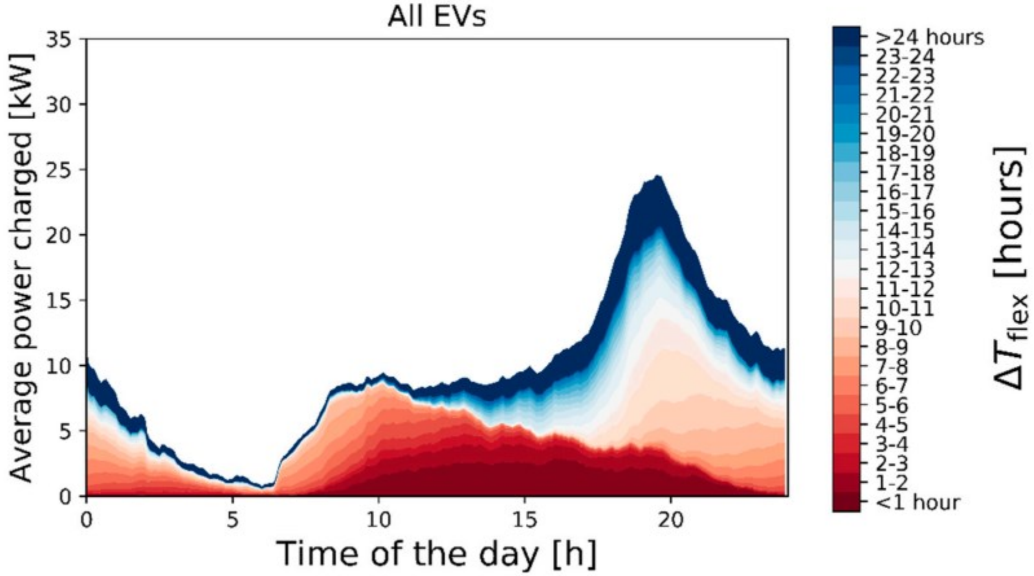
DLR

Data and daily charging behaviour

Rashidizadeh-Kermani et al. (2018)



Gerritsma et al. (2019)



- Analysis of an electricity aggregator
- ARIMA-simulation varying stochastic parameters ~200 scenarios
- Nordpool market data, 100 Evs, 16 kWh battery size

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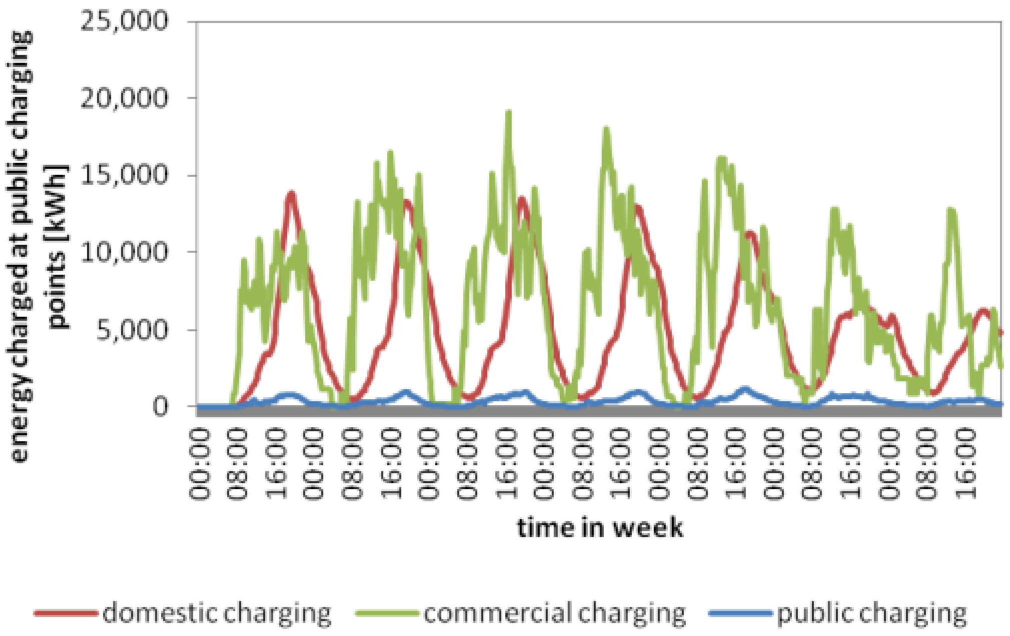
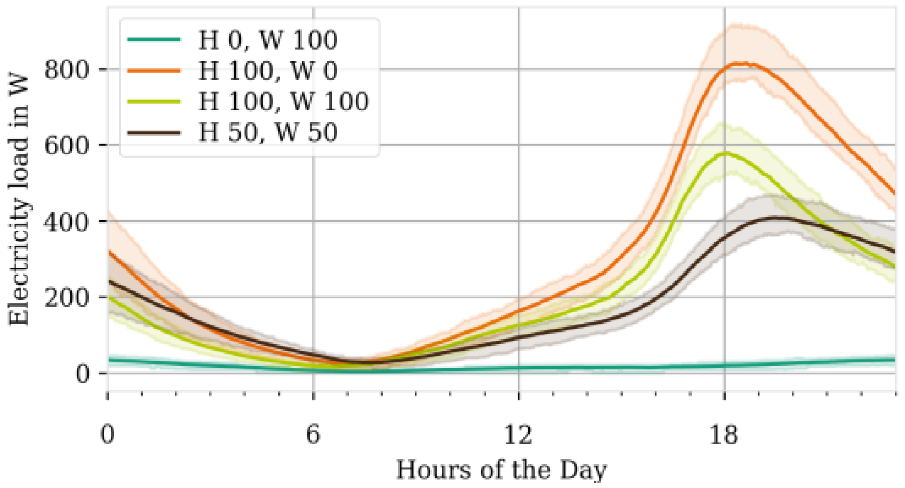
Data and daily charging behaviour – different effects (Gerhardt et al. (2018))



- Infrastructure availability

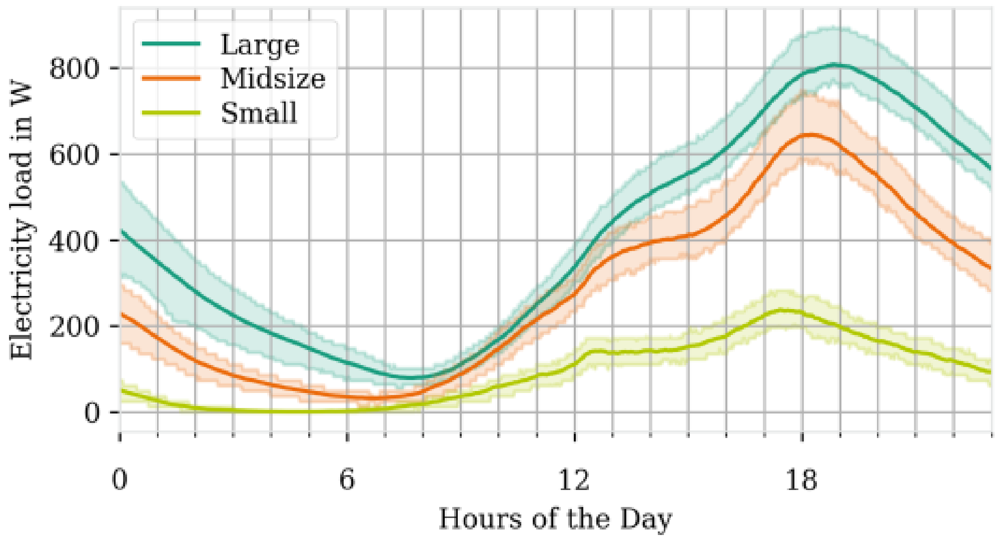
Data and daily charging behaviour – different effects (Fischer et al. (2018))

Charge location (thresholds)

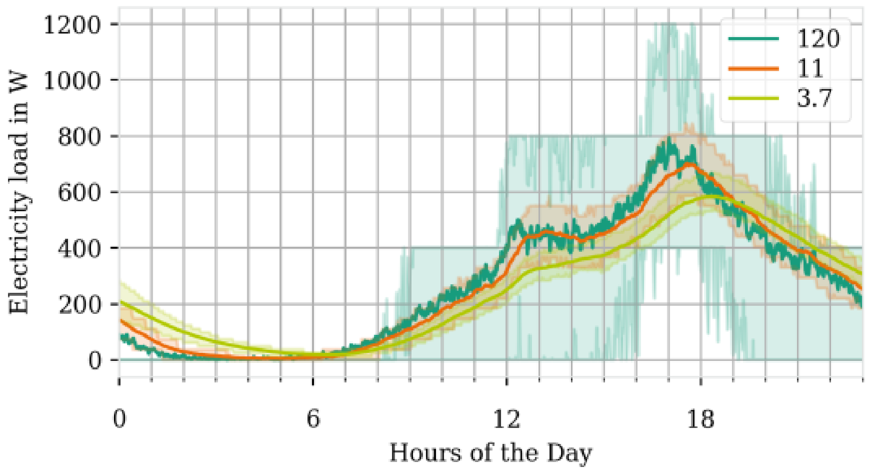


- Statistical simulation of EV load profiles using synPro
- Based on MiD data

Vehicle size



Charge power



Data and daily charging behaviour – different effects (Fischer et al. (2018))

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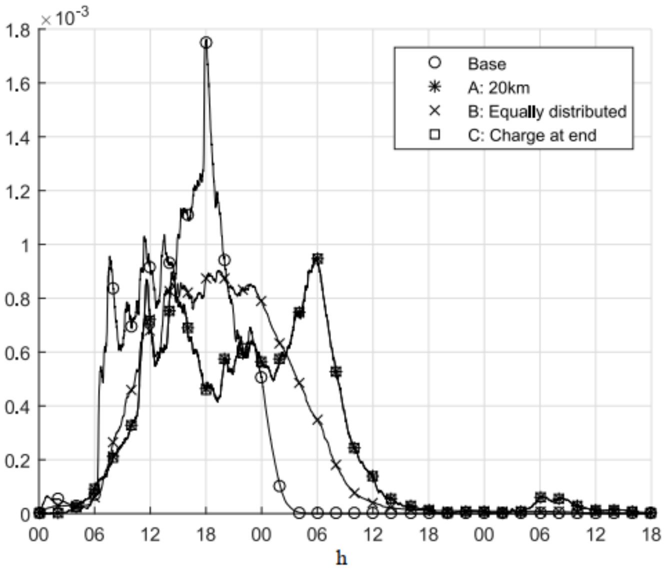

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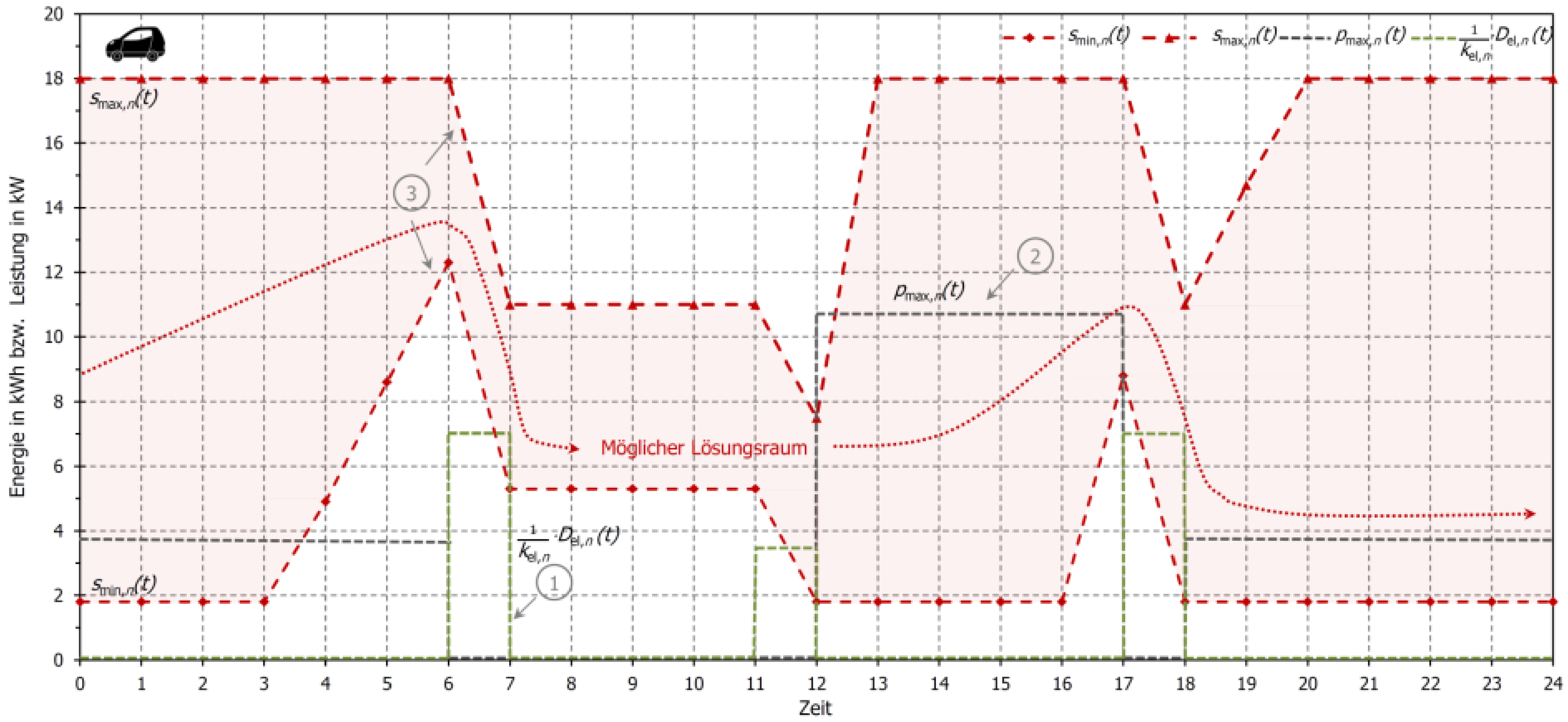
Vehicle size

Charge power

Assumed power system flexibility – Gerhardt et al. (2018)



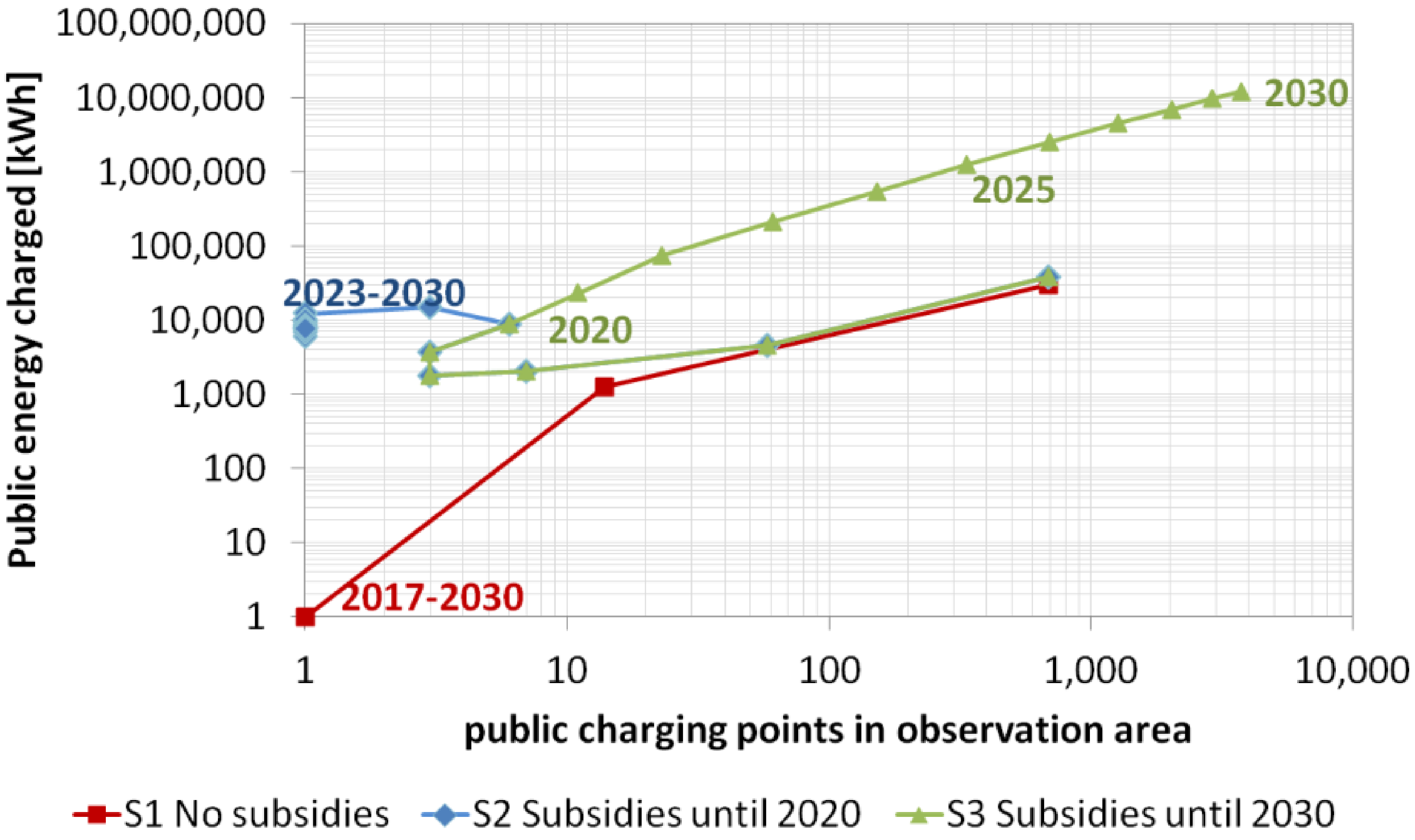
Gerhardt et al. (2018)

Infrastructure availability for controlled charging

	2030		2050	
	Tagsüber laden	Nachts laden	Tagsüber laden	Nachts laden
Kein Netzanschluss	62,5%	25,0%	50,0%	25,0%
3,7 kW	24,7%	67,3%	29,5%	64,5%
11,3 kW	3,1%	1,9%	5,0%	2,5%
22,2 kW	3,1%	1,9%	5,0%	2,5%
43,5 kW	6,3%	3,8%	10,0%	5,0%
132 kW	0,3%	0,1%	0,5%	0,5%

Gerhardt et al. (2018)

Infrastructure availability for controlled charging



Gnann et al. (2018)

Model coupling of VECTOR21, REMix and CURRENT

Dimension	VECTOR21	REMix	CURRENT	Harmonization method
Spatial horizon	Germany	Gemany plus neighbouring countries	Germany	CR
Spatial resolution	ZIP codes	Germany in 2 nodes, others in 1 each	1 node	A (V-R), S (C-R)
Temporal horizon	2010-2050	1 year in 2040	10 days in 2040	S (V-R/C), DP (C-R)
Temporal resolution	Annual	Hourly	Activity / hourly	Harmonization
Technological resolution	3 drivetrain technologies, 3 car sizes	Transport: 3 technologies, Power: 9 technologies	1 technology	S (V-R/C), CR (C-R)

Input data – Mobilität in Deutschland