ETH zürich

Sensitivity analysis of EV impact on distribution grids based on Monte-Carlo simulations

SCCER Mobility Webinar – Jochen Stiasny

LAV PSL Power Systems Laboratory ADAPTRICITY

SCCER Mobility & Jochen Stiasny

- MSc Mechanical Engineering ETH
- Internship 

- Master Thesis

Capacity area B1.1

Capacities of energy infrastructures with emphasis on the electric grid

- PhD candidate Technical University of Denmark

Decarbonisation of our society

- Challenge for transportation sector
- Opportunity: Electric vehicles (EVs)

PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11

- Power grid strong enough?
  - Energy demand ↗ ~ 10 % ✓
  - Peak power ↗ ~ ?? % ✓ or ✗

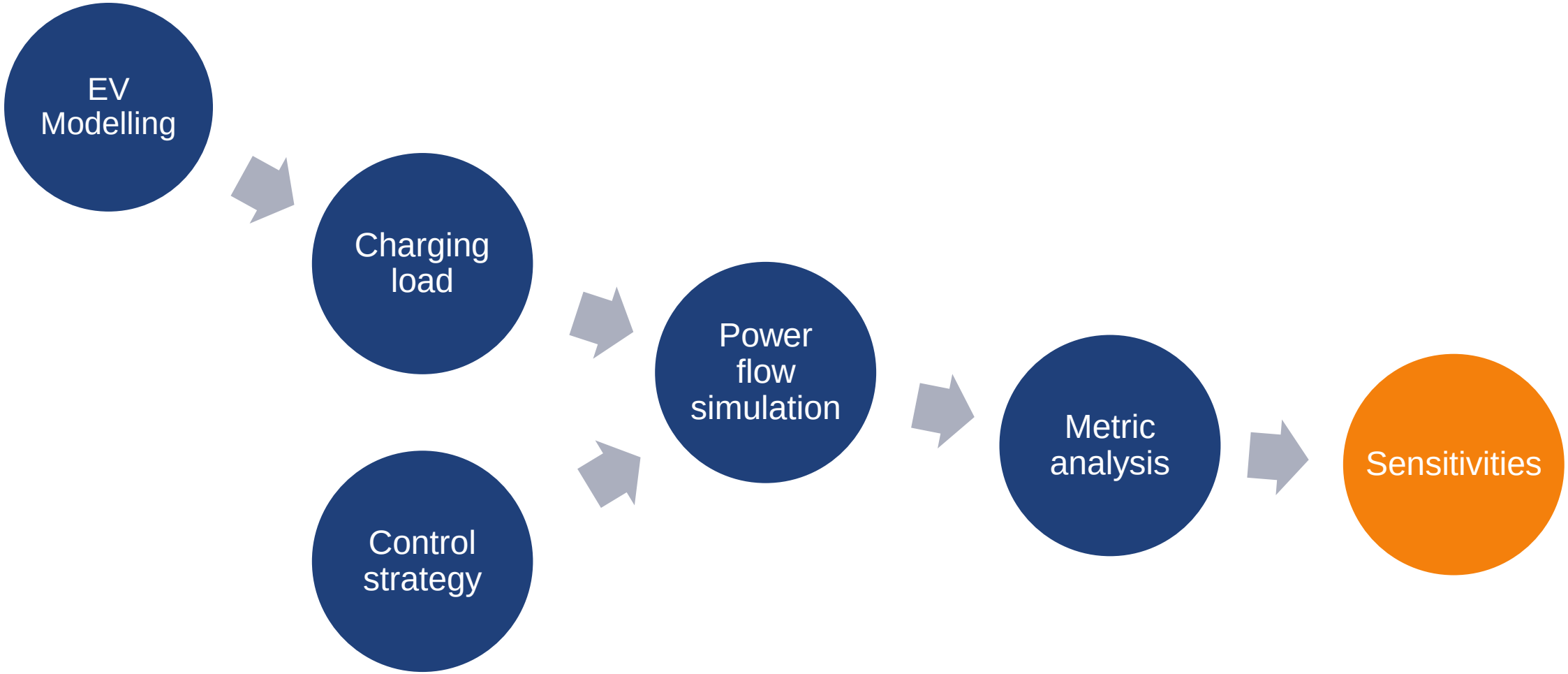
ELECTRICAL FAILURE?

Electric cars pose blackout threat to German cities

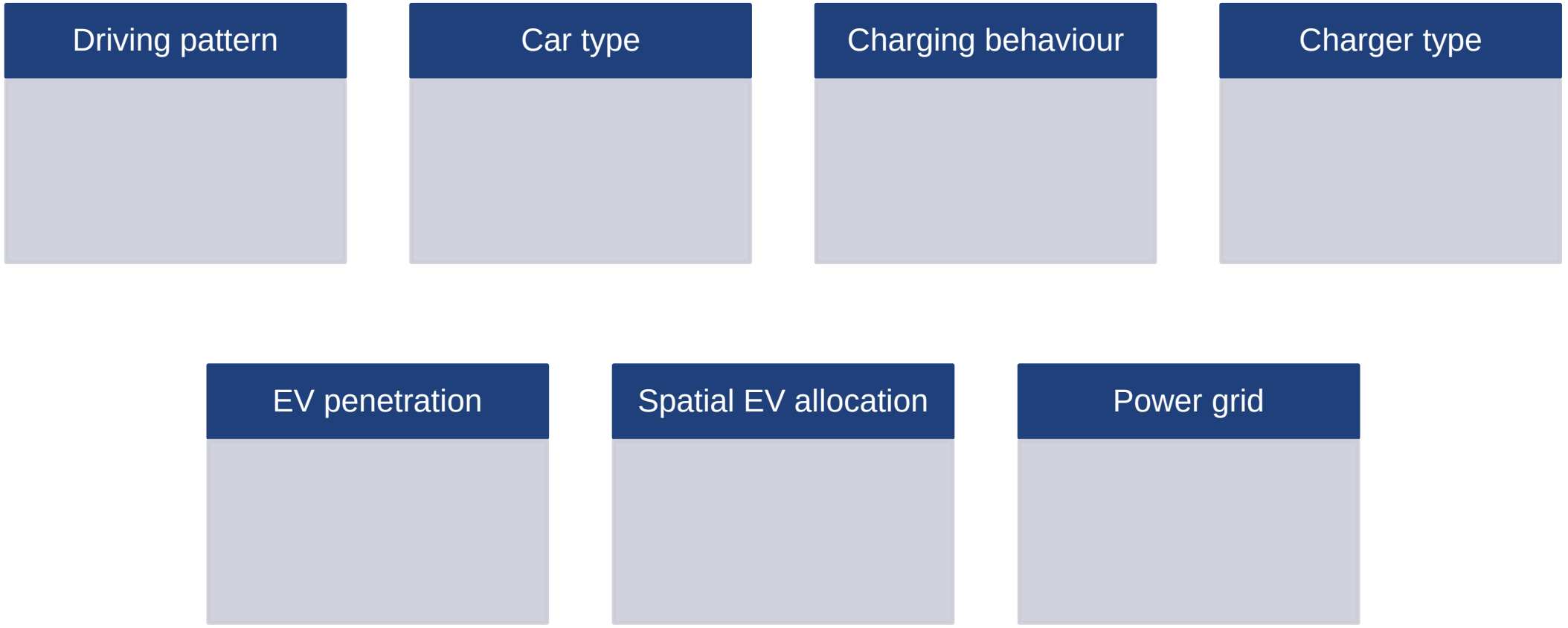
The power grid isn't prepared for the approaching electric car boom. German utilities and researchers are sounding the alarm – and so are experts in other countries.

from: Handelsblatt, 24.01.2018

Overview

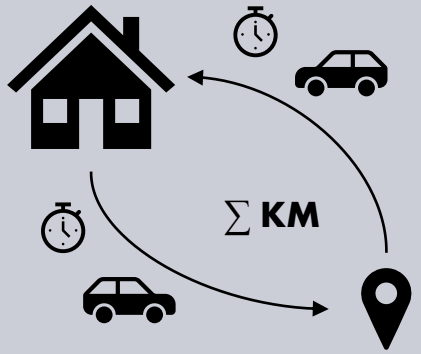

EV Modelling
Charging load
Control strategy
Power flow simulation
Metric analysis
Sensitivities

EV modelling



EV modelling – driving pattern

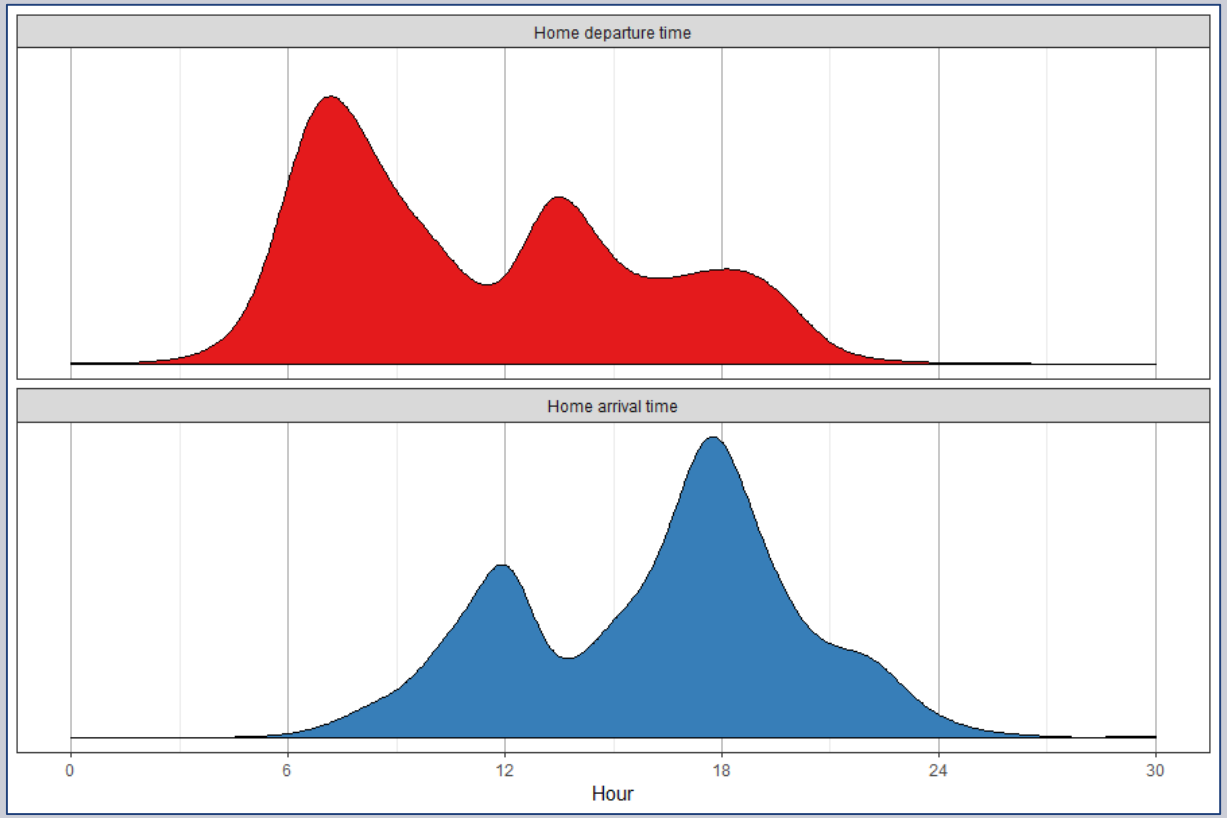
- Mikrozensus Mobilität und Verkehr (MZMV)



EV modelling – driving pattern

- Mikrozensus Mobilität und Verkehr (MZMV)

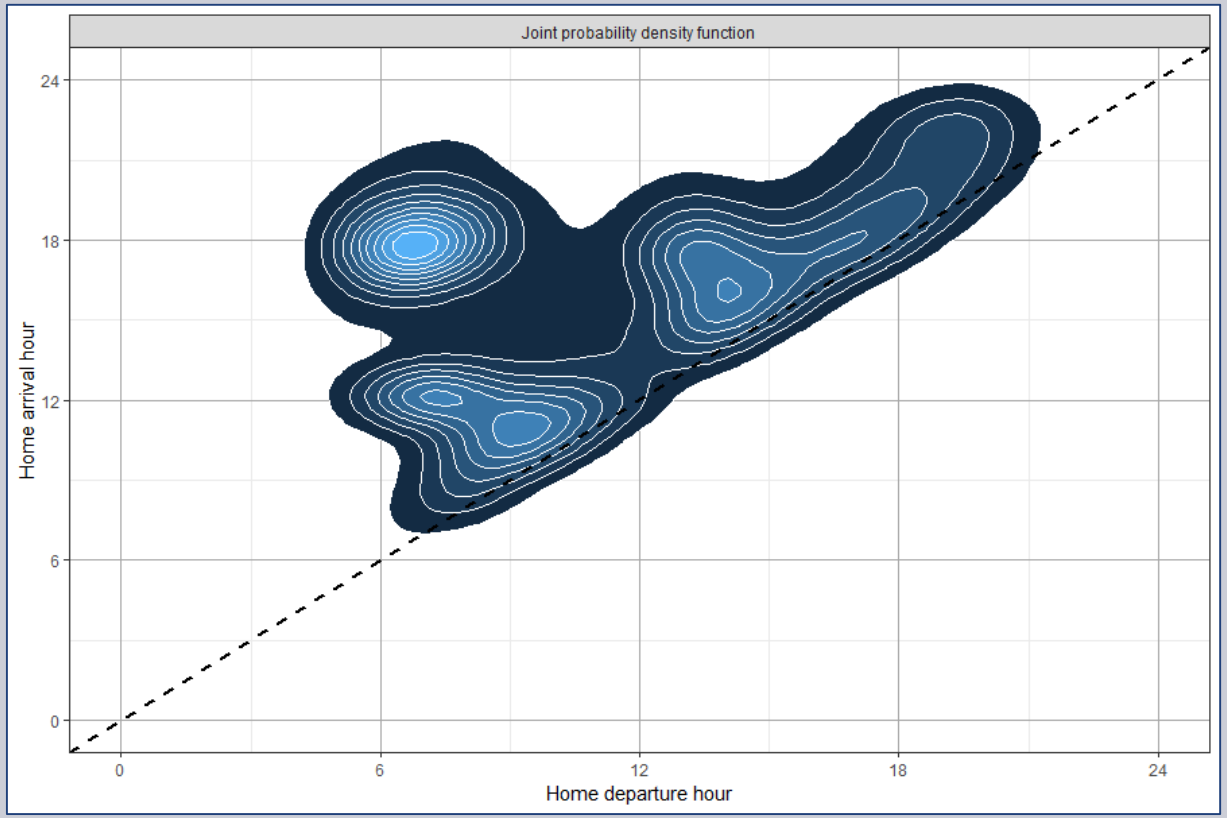
- Gaussian mixture model
  - Independent



EV modelling – driving pattern

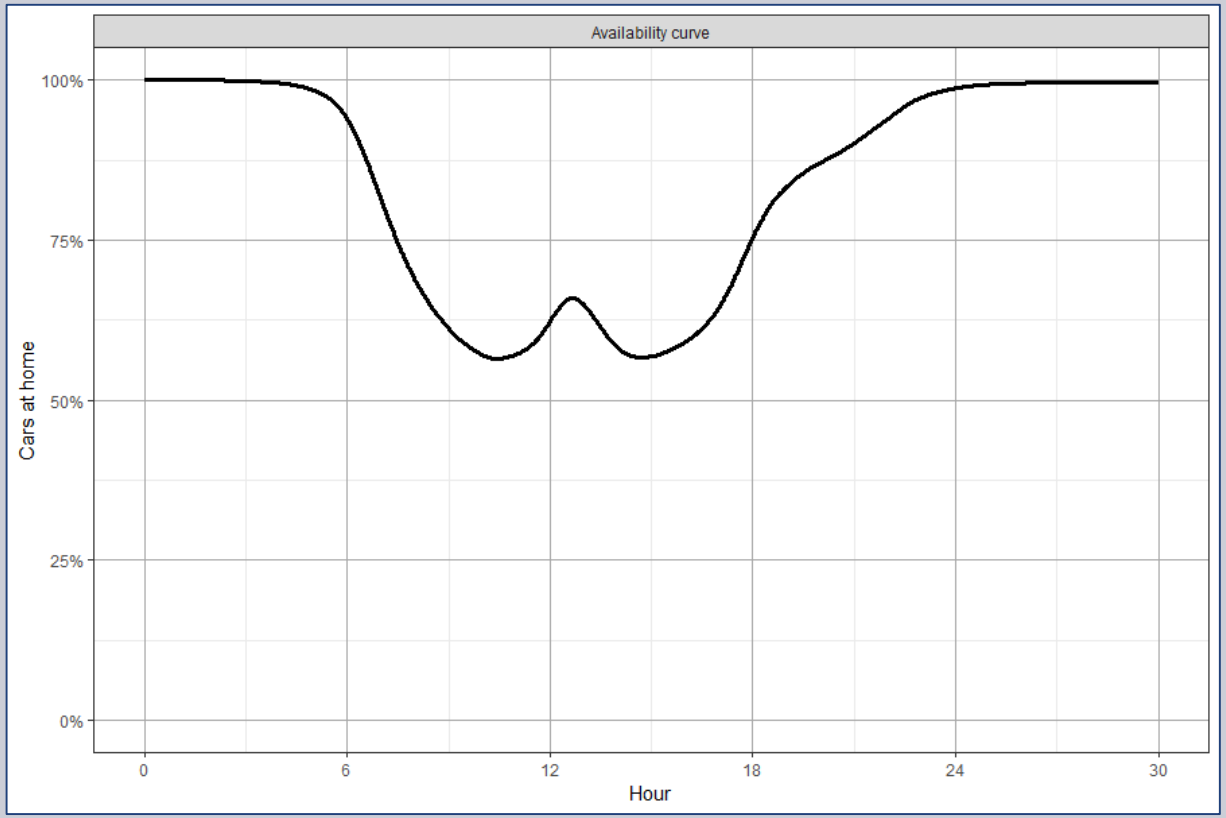
- Mikrozensus Mobilität und Verkehr (MZMV)

- Gaussian mixture model
  - Independent
  - Joint 2D
  - Joint 3D



EV modelling

- Mikrozensus Mobilität und Verkehr (MZMV)
- Gaussian mixture model
  - Independent
  - Joint 2D
  - Joint 3D
- Availability based model



EV modelling

Driving pattern

- MZMV
- Independent GMM
- Joint GMM
- Availability based

Car type

Charging behaviour

Charger type

EV penetration

Spatial EV allocation

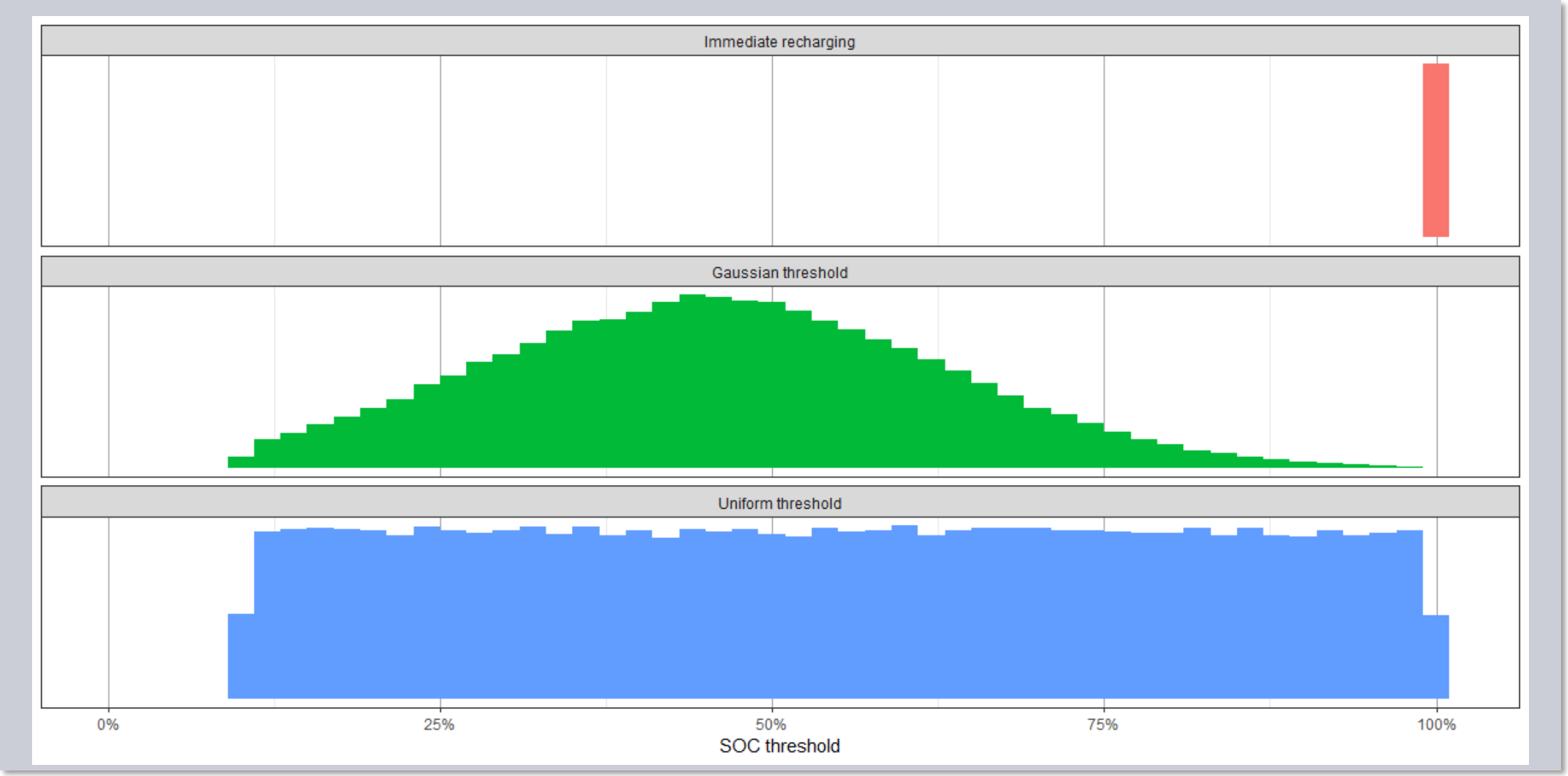
Power grid

EV modelling

Driving pattern	Car type	Charging behaviour	Charger type
• MZMV • Independent GMM • Joint GMM • Availability based	• Average • Sampling		

EV penetration	Spatial EV allocation	Power grid

EV modelling – charging behaviour



EV modelling

Driving pattern

- MZMV
- Independent GMM
- Joint GMM
- Availability based

Car type

- Average
- Sampling

Charging behaviour

- Gaussian threshold
- Immediate recharging
- Uniform threshold

Charger type

EV penetration

Spatial EV allocation

Power grid

EV modelling

Driving pattern	Car type	Charging behaviour	Charger type
• MZMV • Independent GMM • Joint GMM • Availability based	• Average • Sampling	• Gaussian threshold • Immediate recharging • Uniform threshold	• 3.7 kW • 25% 11 kW • 50% 11 kW • 100% 11 kW

EV penetration	Spatial EV allocation	Power grid

EV modelling

Driving pattern	Car type	Charging behaviour	Charger type
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EV penetration	Spatial EV allocation	Power grid
• 20% • 40% • 60% • 80%		

EV modelling

Driving pattern	Car type	Charging behaviour	Charger type
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EV penetration	Spatial EV allocation	Power grid
• 20% • 40% • 60% • 80%	• Uniform • Clustered	

EV modelling

Driving pattern	Car type	Charging behaviour	Charger type
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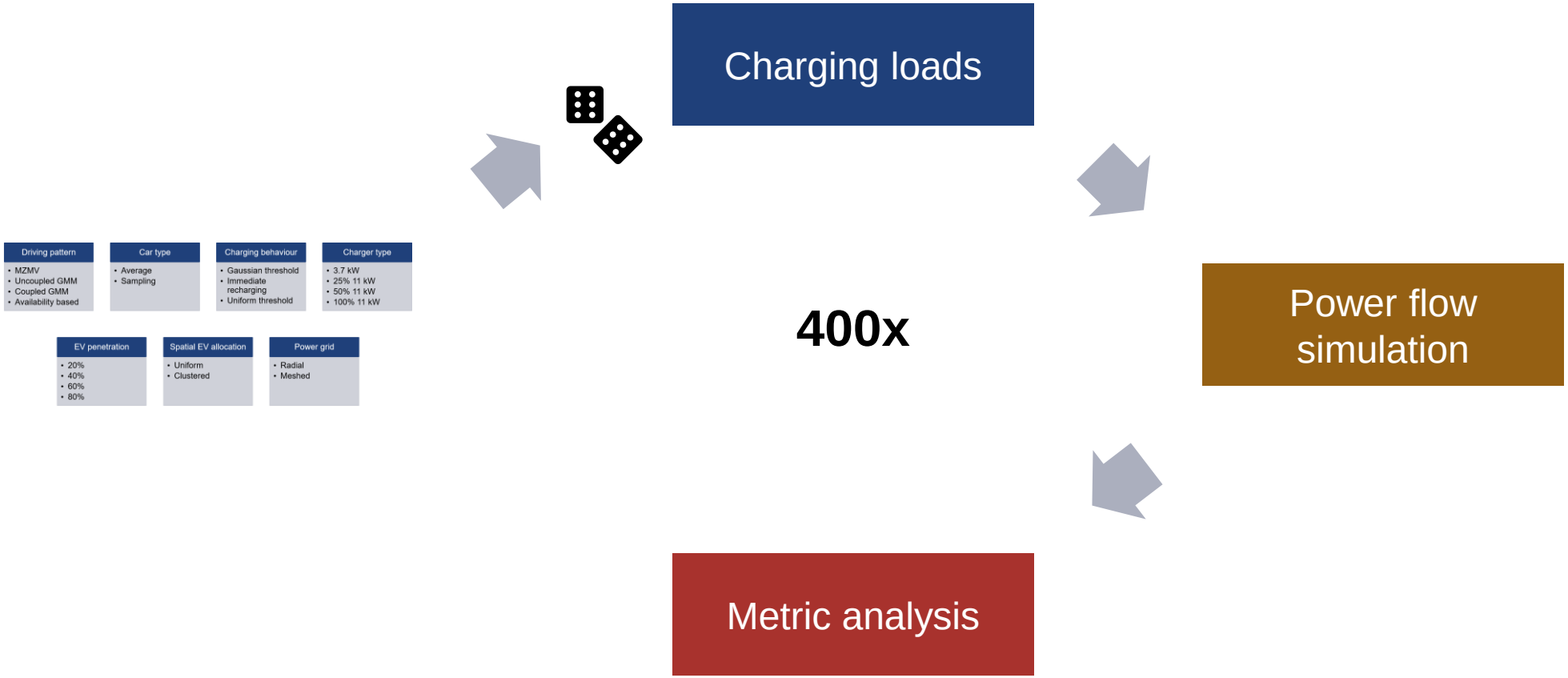
EV penetration	Spatial EV allocation	Power grid
• 20% • 40% • 60% • 80%	• Uniform • Clustered	• Radial • Meshed

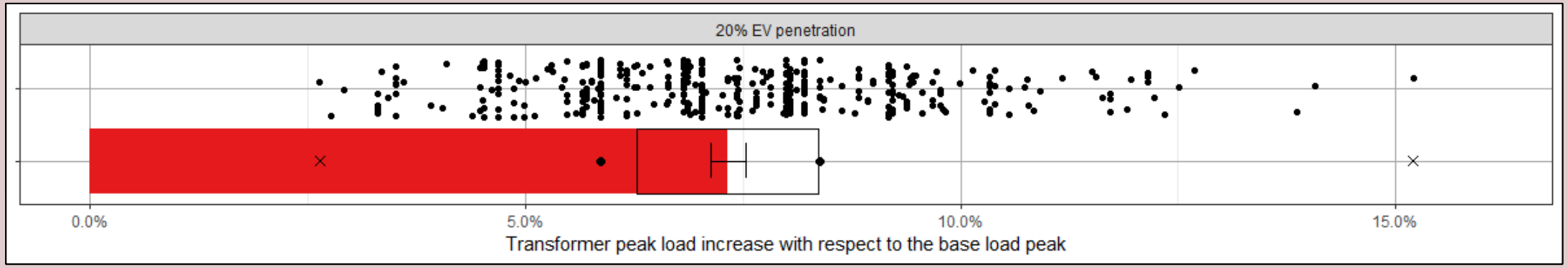
Simulation framework



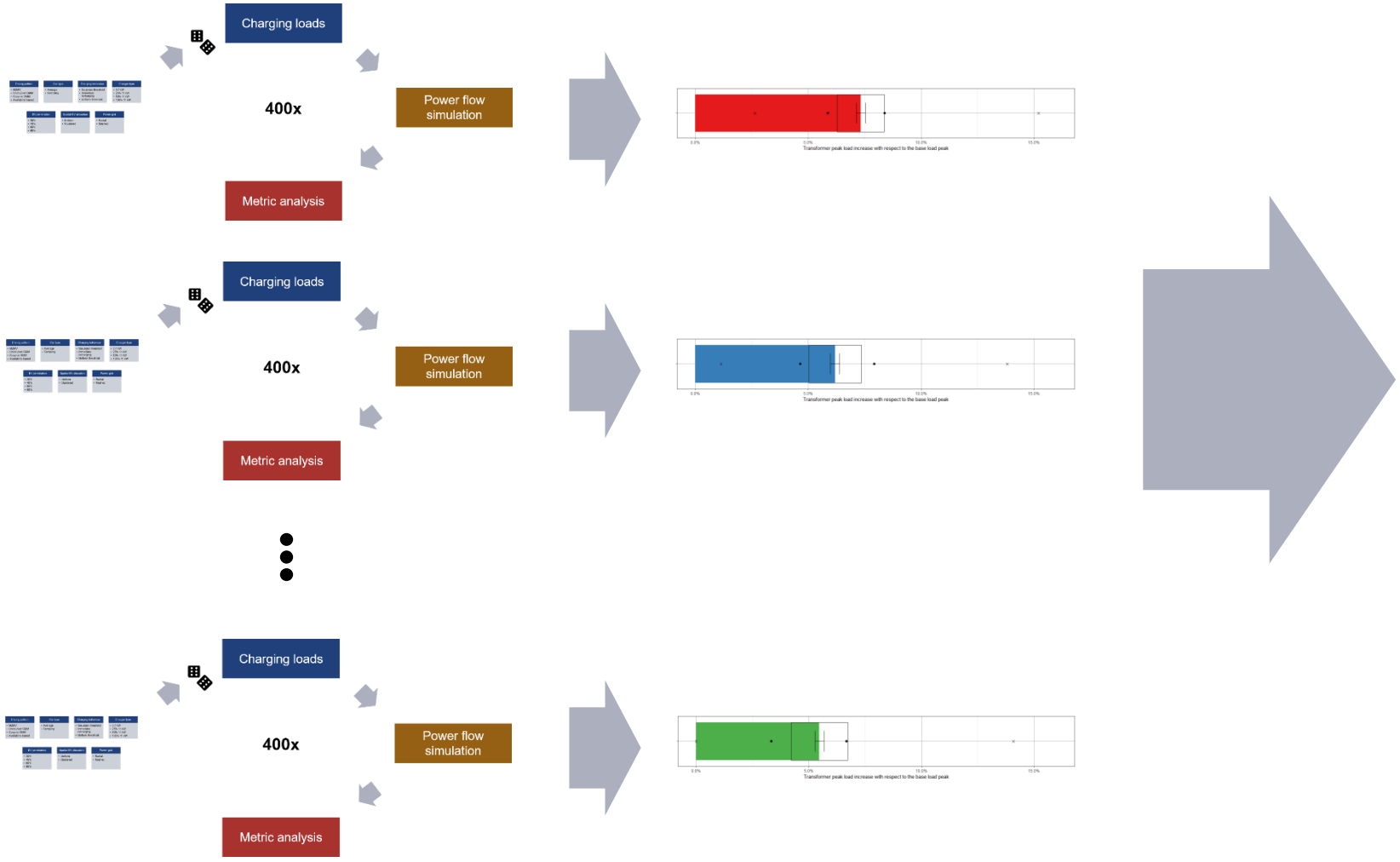
Simulation framework

Transformer peak load increase metric:

$$\frac{\text{Peak load with EVs} - \text{Peak load without EVs}}{\text{Peak load without EVs}}$$



Simulation framework



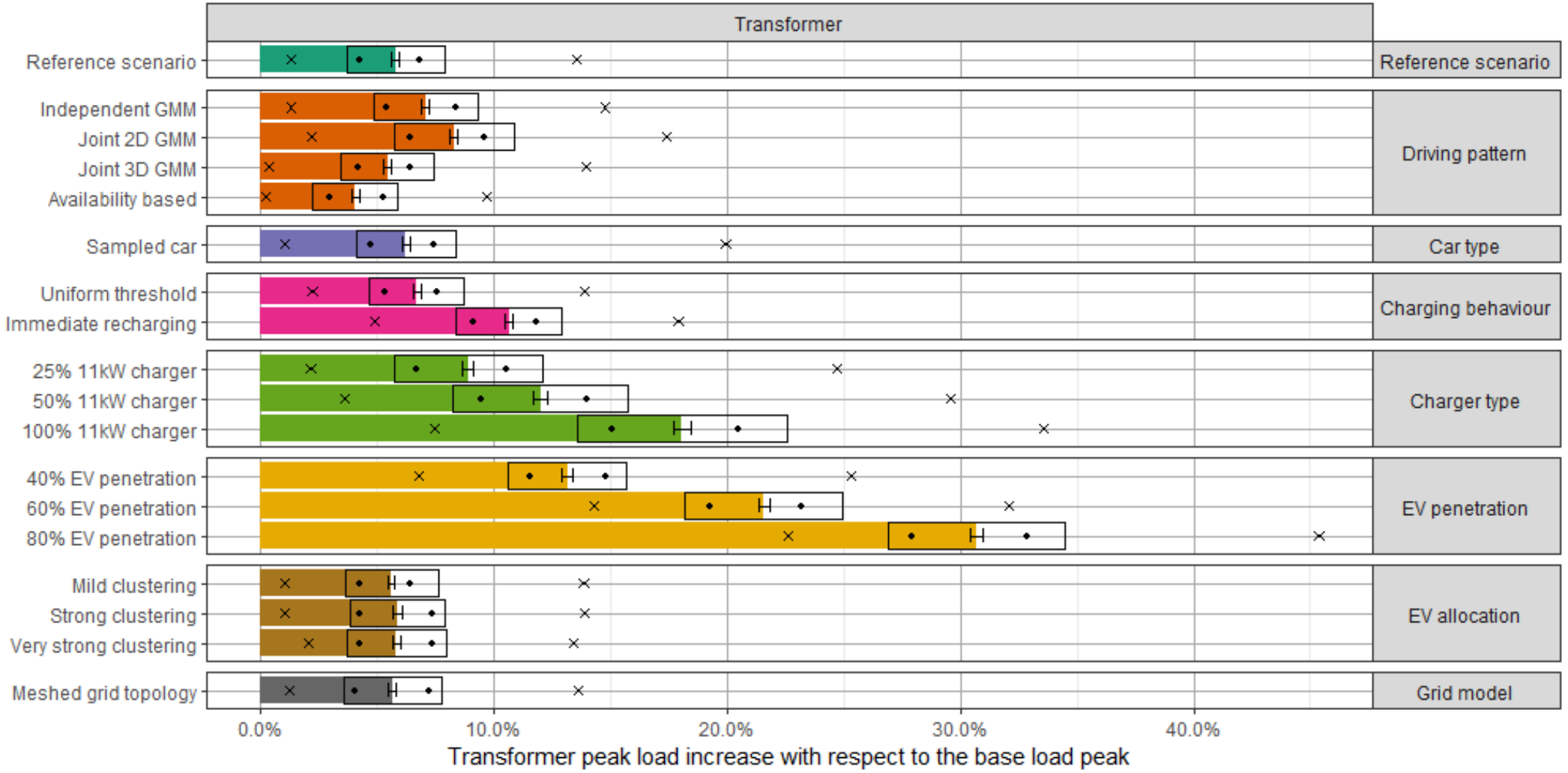
Single parameter dimension variation – reference scenario

Driving pattern	Car type	Charging behaviour	Charger type
• **MZMV** • Independent GMM • Joint GMM • Availability based	• **Average** • Sampling	• **Gaussian threshold** • Immediate recharging • Uniform threshold	• **3.7 kW** • 25% 11 kW • 50% 11 kW • 100% 11 kW

EV penetration	Spatial EV allocation	Power grid
• **20%** • 40% • 60% • 80%	• **Uniform** • Clustered	• **Radial** • Meshed

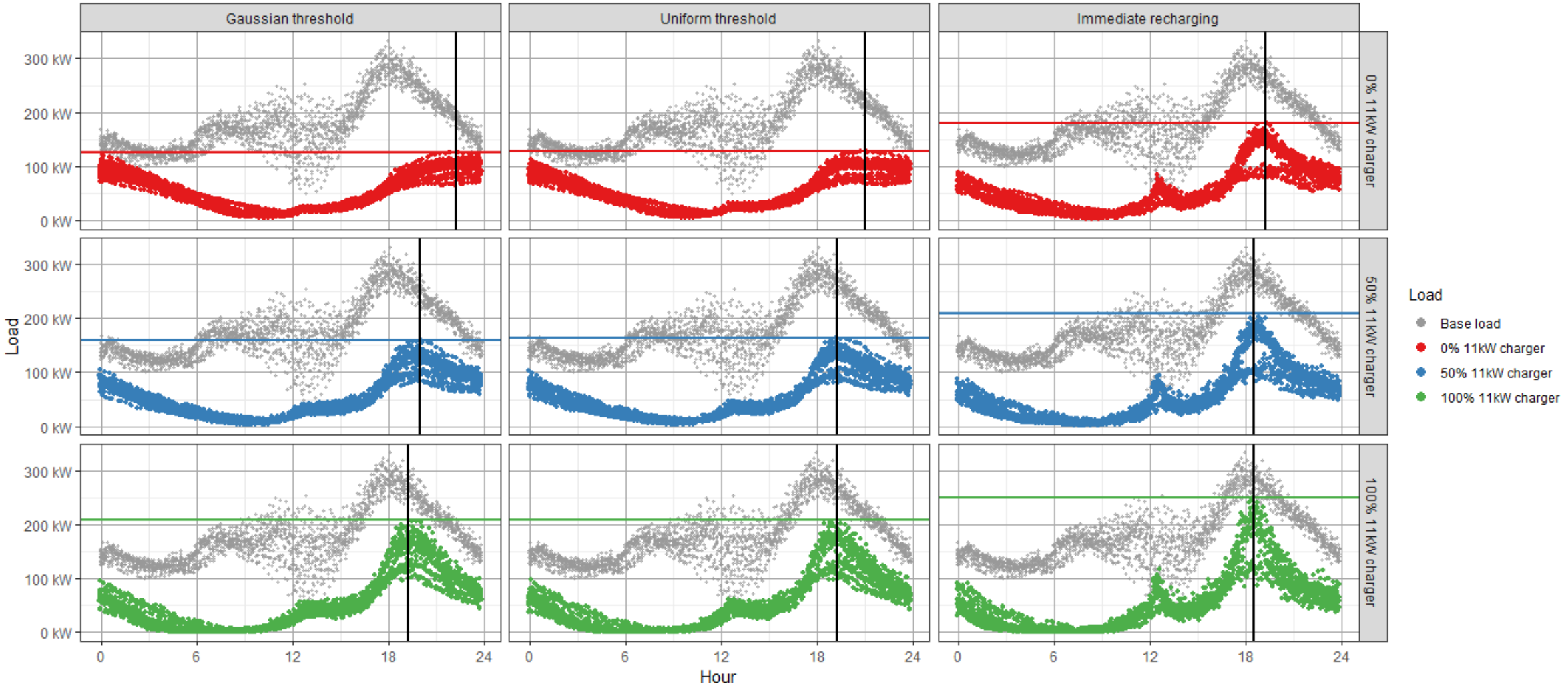
Reference scenario: MZMV, average car, gaussian threshold, 3.7 kW charger, 20% EV penetration, uniform EV allocation, radial grid

Single parameter dimension variation - peak load - transformer



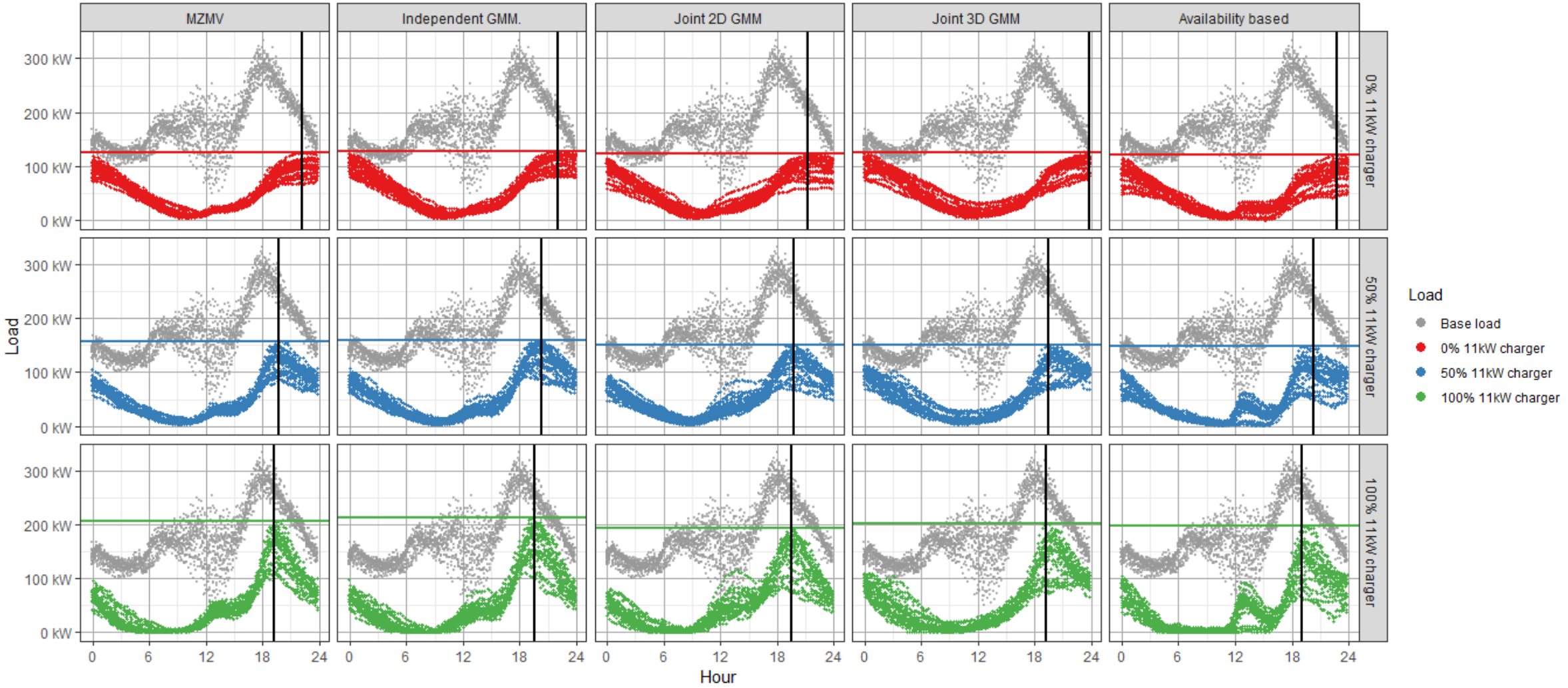
Reference scenario: MZMV, average car, gaussian threshold, 3.7 kW charger, 20% EV penetration, uniform EV allocation, radial grid

Charging and base load – charging behaviour sensitivity



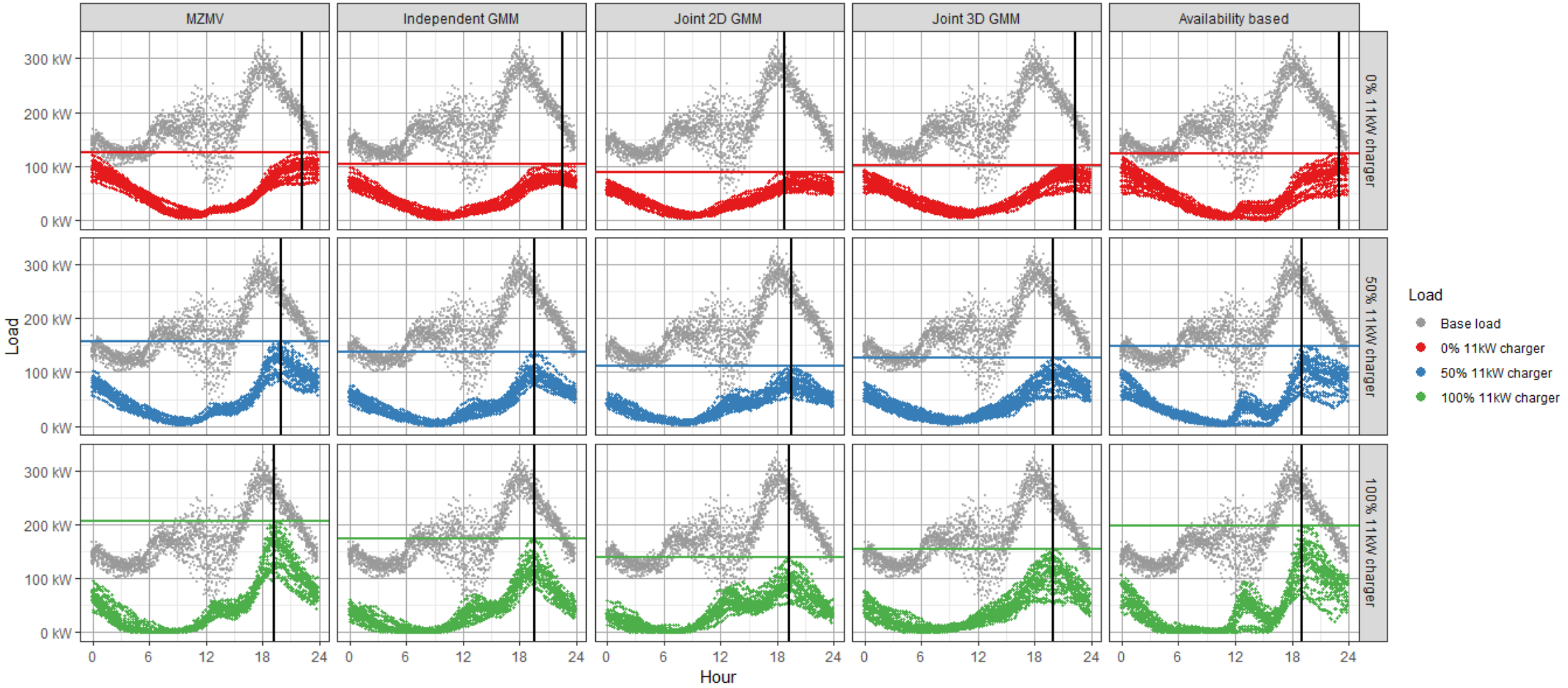
Common scenario parameter: MZMV, average car, **60% EV penetration**, uniform EV allocation, radial grid

Charging and base load – driving pattern sensitivity



Common scenario parameter: Average car, **gaussian threshold**, **60% EV penetration**, uniform EV allocation, radial grid

Charging and base load – driving pattern sensitivity - faulty

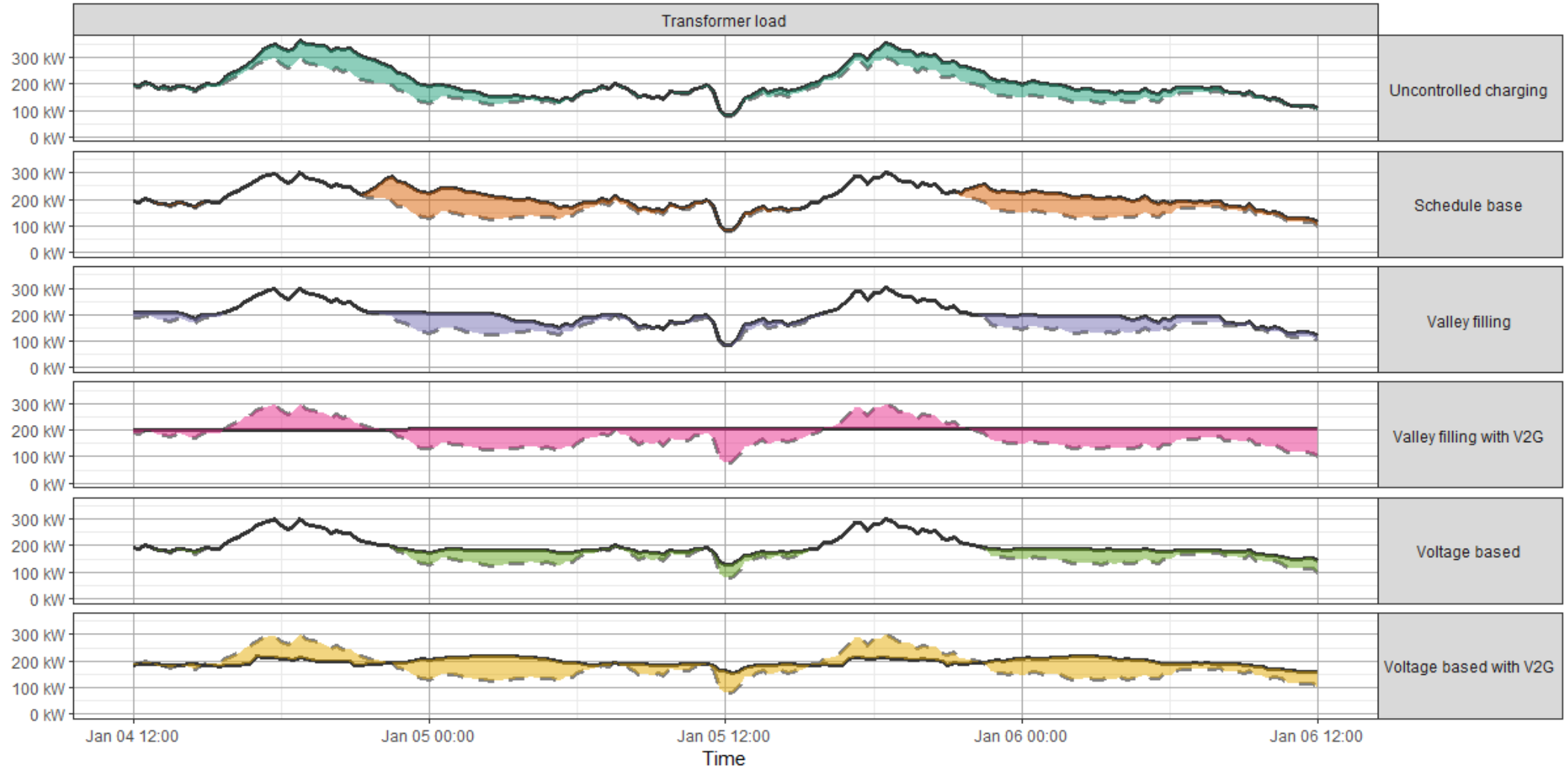


Common scenario parameter: Average car, **gaussian threshold**, **60% EV penetration**, uniform EV allocation, radial grid

Control strategy design

- Schedule based – global – one-directional communication
  - Full power: 22:30 – 6:00
  - Half power: 6:00 – 15:00
  - No charging: 15:00 – 22:30
- Valley filling – global – bi-directional communication
  - Centrally computed control inputs
  - With and without vehicle-to-grid (V2G)
- Bus voltage based – local – no communication
  - Voltage magnitude dependent control inputs
  - With and without vehicle-to-grid (V2G)

Control strategy performance



Common scenario parameters: MZMV, average car, gaussian threshold, 3.7kW charger, 20% EV penetration, uniform EV allocation, radial grid

Conclusions

- What are the key factors in EV modelling to pay attention to?
  - Peak charging load
  - Coincidence of charging load and base load

- What sensitivities do the models show?
  - High: Charging power, EV penetration level, driving pattern
  - Medium: Charging behaviour
  - Low: EV type
  - Globally low, locally higher: Grid configuration, EV allocation

- What should control strategies aim for?
  - Shifting and reducing the EV peak load

Outlook

- More grids & higher base loads
- Validation with real charging patterns
- Less “perfect world” control
- Integration into the “smart grid”
  - Distributed generation
  - Batteries
  - Heat pumps

Thank you for your attention!

→ Q & A