PV and opportunistic electric vehicle charging in a Swedish distribution grid

Rasmus Luthander
Department of Engineering Sciences
Uppsala University, Sweden

Co-authors
Mahmoud Shepero
Joakim Munkhammar
Joakim Widén

Introduction

What we study

How we do it

Introduction

- 10kV / 400V three-phase power grid
- 5174 grid nodes / end-users
- Only electric vehicles (EV) in the car fleet
- Over- and undervoltage due to
  - High load (mainly winter)
  - High PV generation (mainly summer)

How we do it

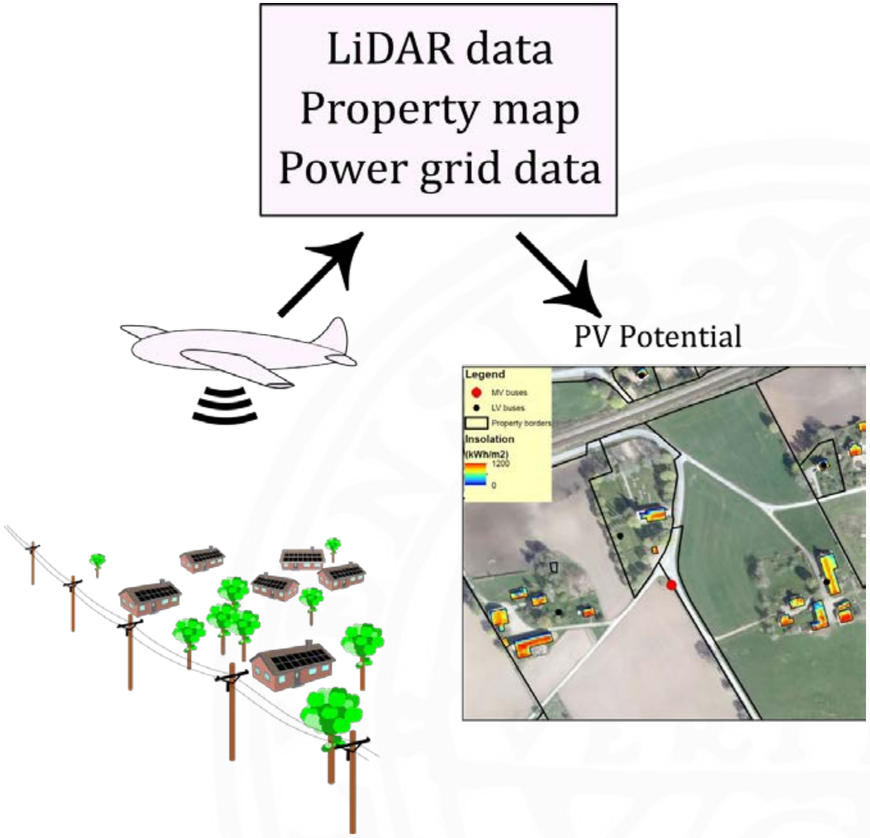
Introduction

- 10kV / 400V three-phase power grid
- 5174 grid nodes / end-users
- Only electric vehicles (EV) in the car fleet
- Over- and undervoltage due to
  - High load (mainly winter)
  - High PV generation (mainly summer)

- PV potential using LiDAR data
- PV penetration 0-100% of yearly load
- Markov-chain EV charging model
- Newton-Raphson power flow solution

PV generation & load data

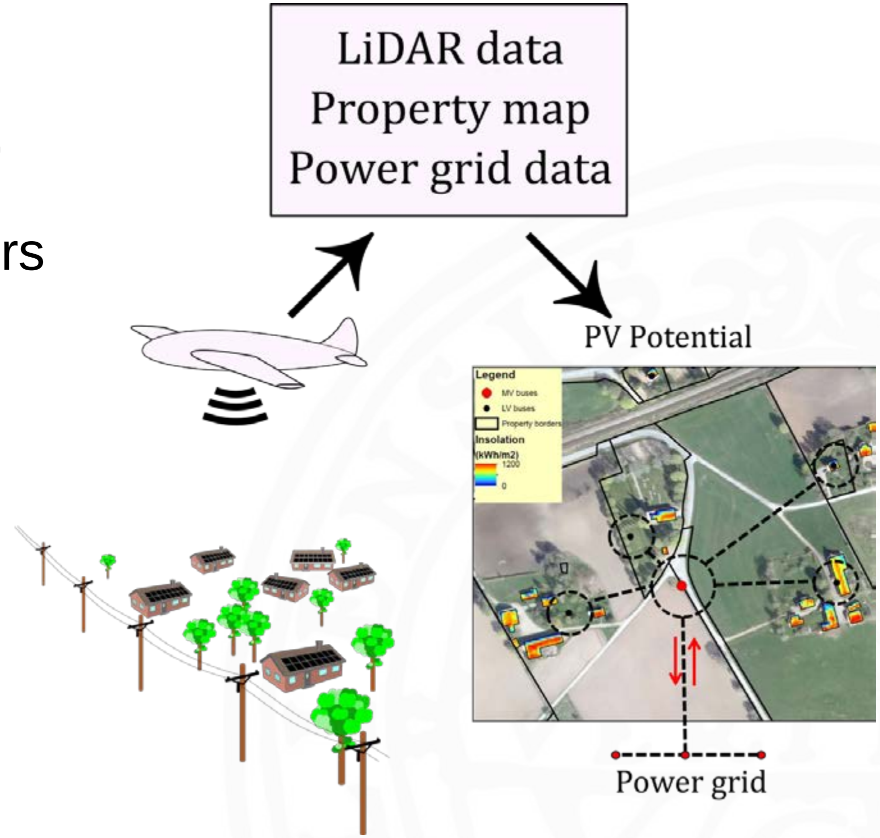
- Rooftop PV power potential using GIS, LiDAR and irradiance data



UPPSALA UNIVERSITET

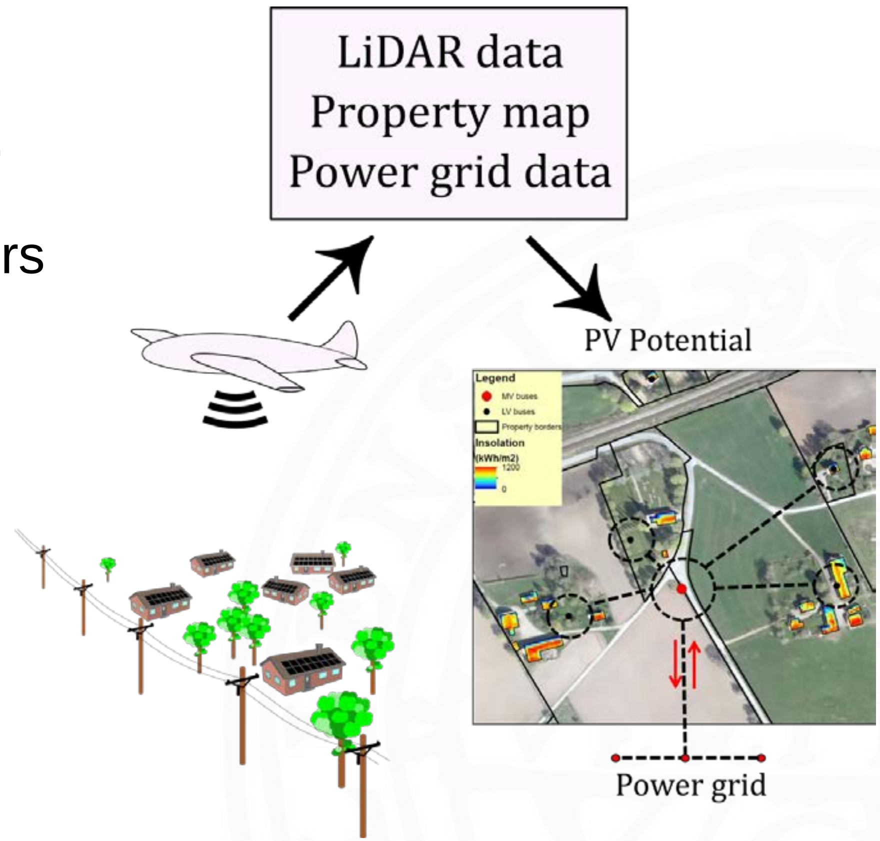
PV generation & load data

- Rooftop PV power potential using GIS, LiDAR and irradiance data
- DSO ‘Herrljunga Elektriska’
  - Hourly load for 5174 end-users (2014)



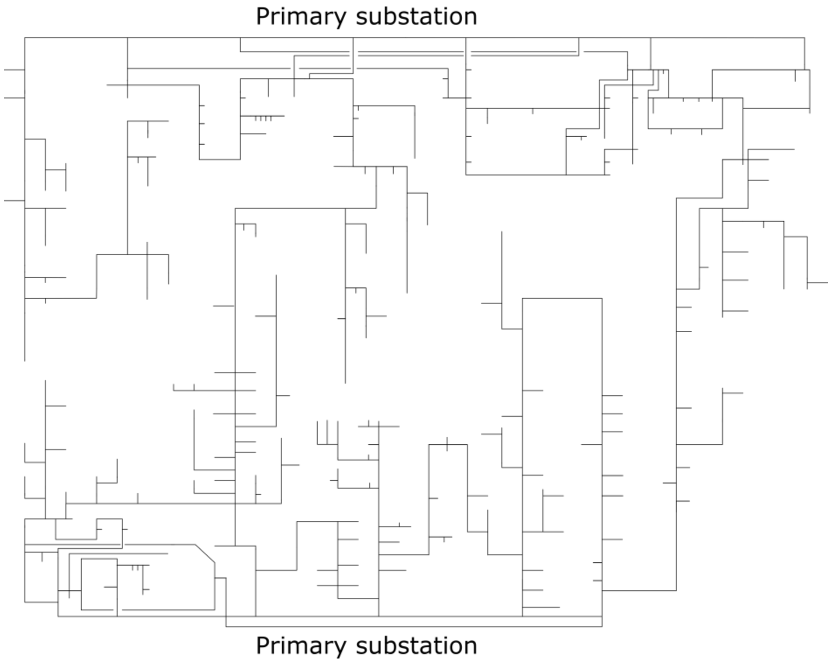
PV generation & load data

- Rooftop PV power potential using GIS, LiDAR and irradiance data
- DSO 'Herrljunga Elektriska'
  - Hourly load for 5174 end-users (2014)
- Yearly PV penetration with randomly selected rooftops
  - 0%
  - 10%
  - …
  - 90%
  - 100%



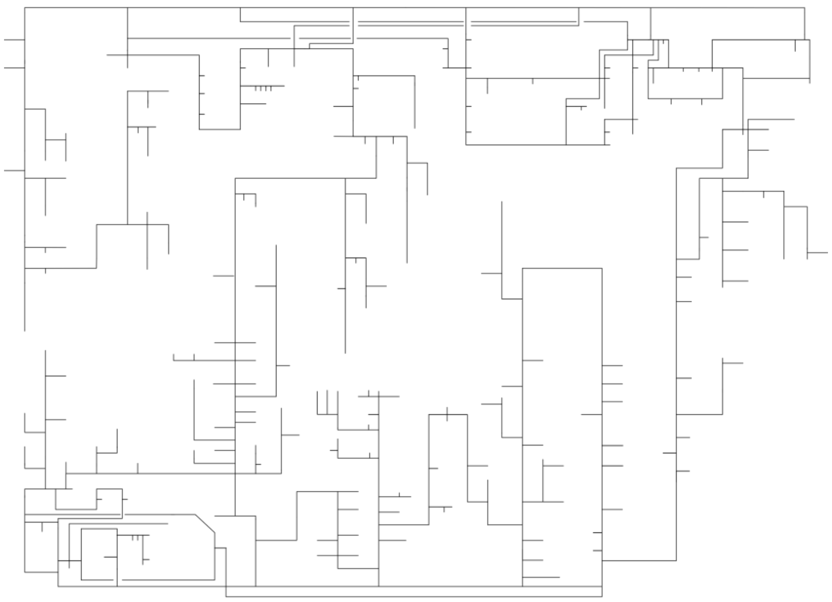
Power grid

- 2 MV grids
- 338 LV grids (rural & city)
- 3891 nodes, 5174 end-uses



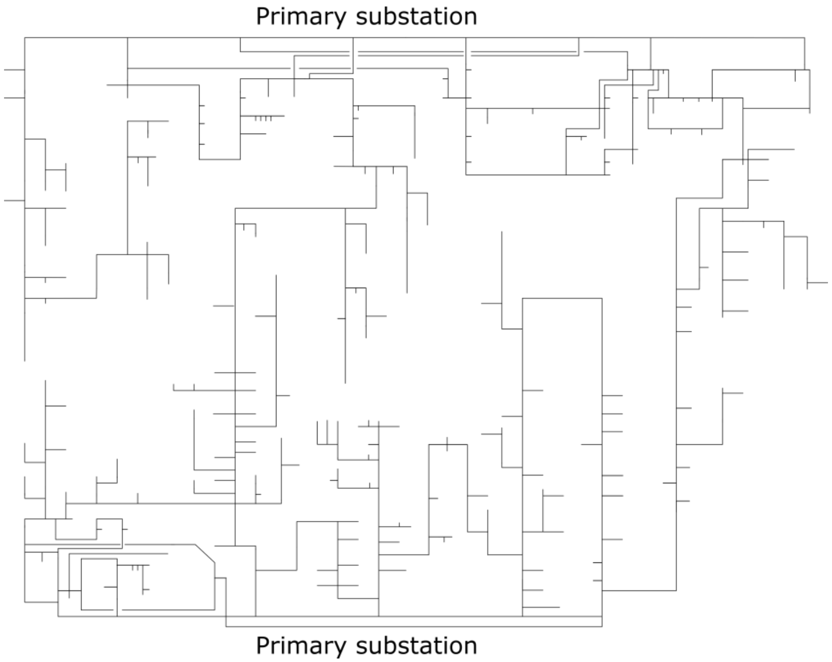
Power grid

- 2 MV grids
- 338 LV grids (rural & city)
- 3891 nodes, 5174 end-uses
- Hourly load data

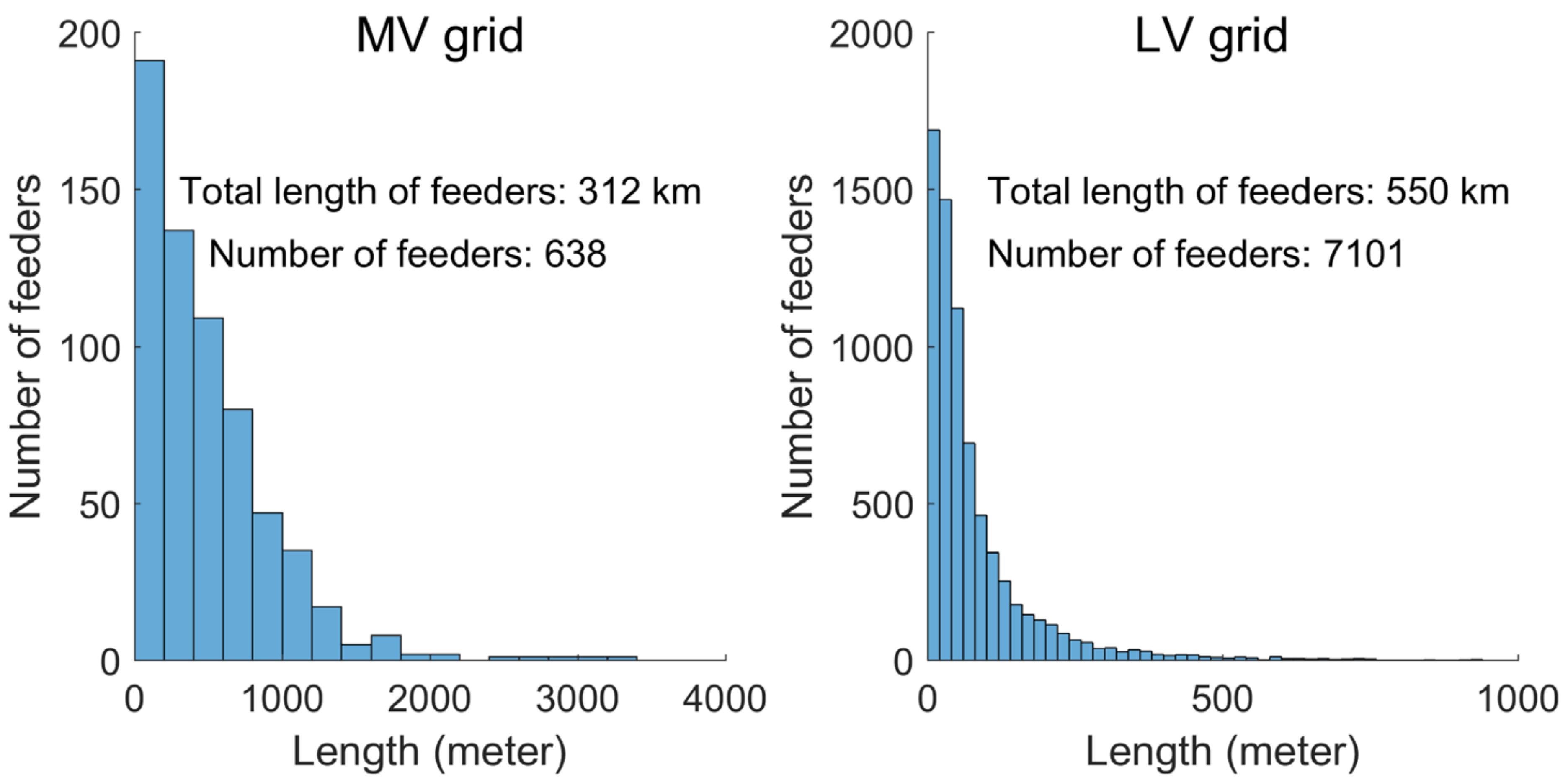


Power grid

- 2 MV grids
- 338 LV grids (rural & city)
- 3891 nodes, 5174 end-uses
- Hourly load data
- Allowed end-user voltage
  - Max 1.1 pu
  - Min 0.9 pu
- Always 1.0 pu at the primary substations



Power grid


MV grid
Total length of feeders: 312 km
Number of feeders: 638
Number of feeders
Length (meter)
200
150
100
50
0
0
1000
2000
3000
4000
LV grid
Total length of feeders: 550 km
Number of feeders: 7101
Number of feeders
Length (meter)
2000
1500
1000
500
0
0
500
1000

EV charging model

- Opportunistic EV charging – charging whenever & wherever parked

For more information: M. Shepero and J. Munkhammar. *Modelling charging of electric vehicles using mixture of user behaviours*. 1st E-Mobility Integration Symposium, October 23rd, Berlin

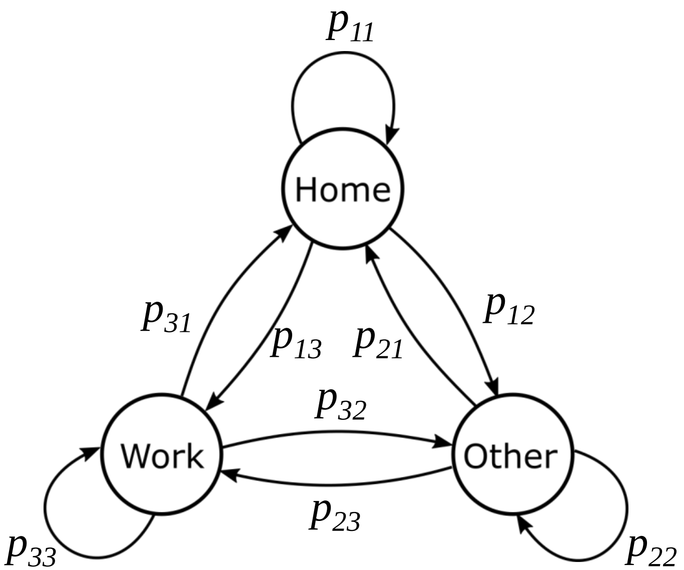
EV charging model

- Opportunistic EV charging – charging whenever & wherever parked
- Time dependent (time of day, weekend/weekday)

For more information: M. Shepero and J. Munkhammar. *Modelling charging of electric vehicles using mixture of user behaviours*. 1st E-Mobility Integration Symposium, October 23rd, Berlin

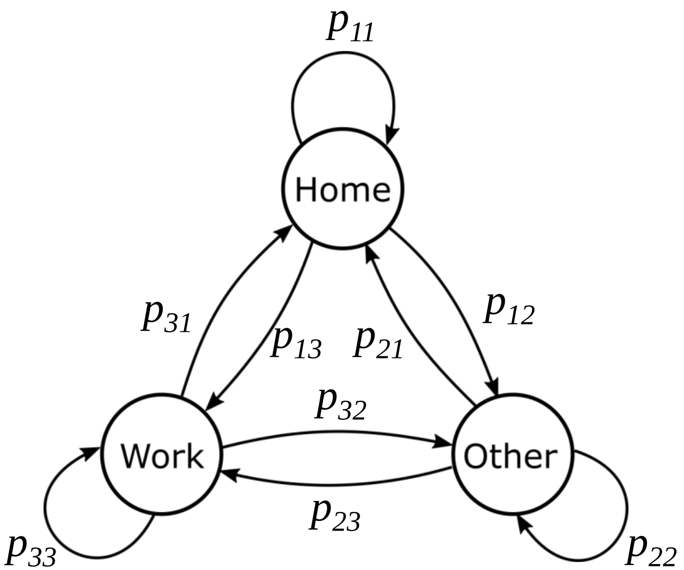
EV charging model

- Opportunistic EV charging – charging whenever & wherever parked
- Time dependent (time of day, weekend/weekday)
- Markov chain with 3 states
  - Home,
  - Work
  - Other (public parking lots)



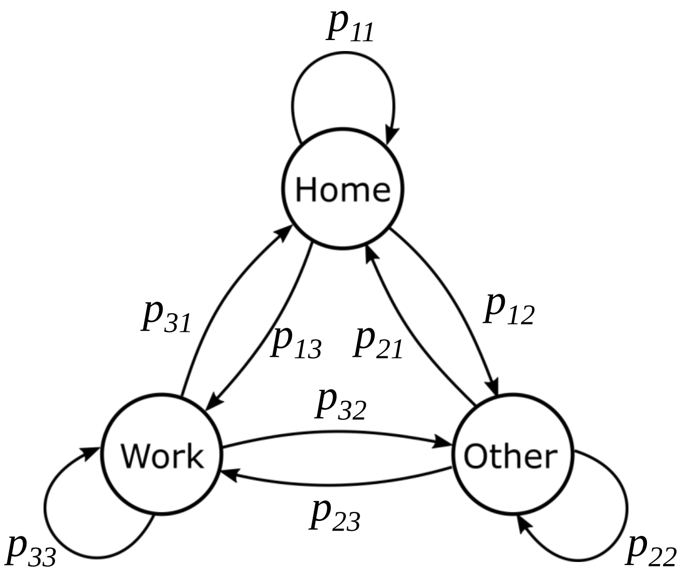
EV charging model

- Opportunistic EV charging – charging whenever & wherever parked
- Time dependent (time of day, weekend/weekday)
- Markov chain with 3 states
  - Home
  - Work
  - Other (public parking lots)
- 2 summer + 2 winter weeks



EV charging model

- Opportunistic EV charging – charging whenever & wherever parked
- Time dependent (time of day, weekend/weekday)
- Markov chain with 3 states
  - Home
  - Work
  - Other (public parking lots)
- 2 summer + 2 winter weeks
- Charging power: 3.7 kW



EV charging model

- “Worst-case” scenario: 100% EVs of the total fleet
  - 5295 vehicles in 2016 in the municipality
  - 333 extra EVs in the summer (summer houses)

EV charging model

- "Worst-case" scenario: 100% EVs of the total fleet
  - 5295 vehicles in 2016 in the municipality
  - 333 extra EVs in the summer (summer houses)
- Aggregated 1-minute EV charging data to hourly resolution

$$E_t^n = \begin{cases} E_{t-1}^n + 3.7 \times \Delta t & \text{if charging,} \\ E_{t-1}^n - \eta \times D & \text{if driving,} \\ E_{t-1}^n & \text{else,} \end{cases}$$

EV charging model

- “Worst-case” scenario: 100% EVs of the total fleet
  - 5295 vehicles in 2016 in the municipality
  - 333 extra EVs in the summer (summer houses)
- Aggregated 1-minute EV charging data to hourly resolution

3.7 kW charging power × time

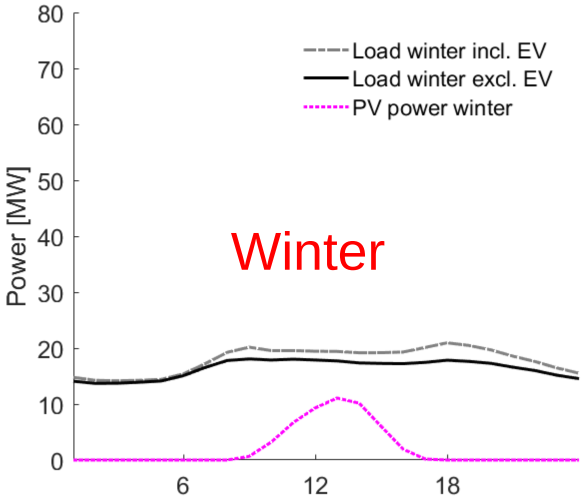
Battery charge per EV at time *t*

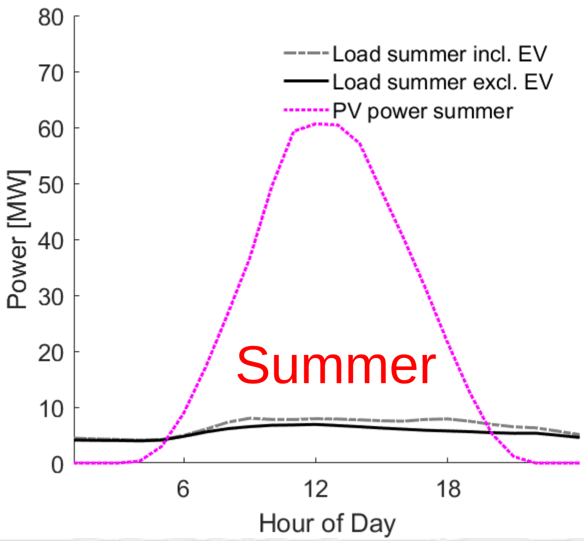
$$E_t^n = \begin{cases} E_{t-1}^n + \overbrace{3.7 \times \Delta t} & \text{if charging,} \\ E_{t-1}^n - \underbrace{\eta \times D} & \text{if driving,} \\ E_{t-1}^n & \text{else,} \end{cases}$$

Consumption per km × driving distance (km)

Results – load and generation

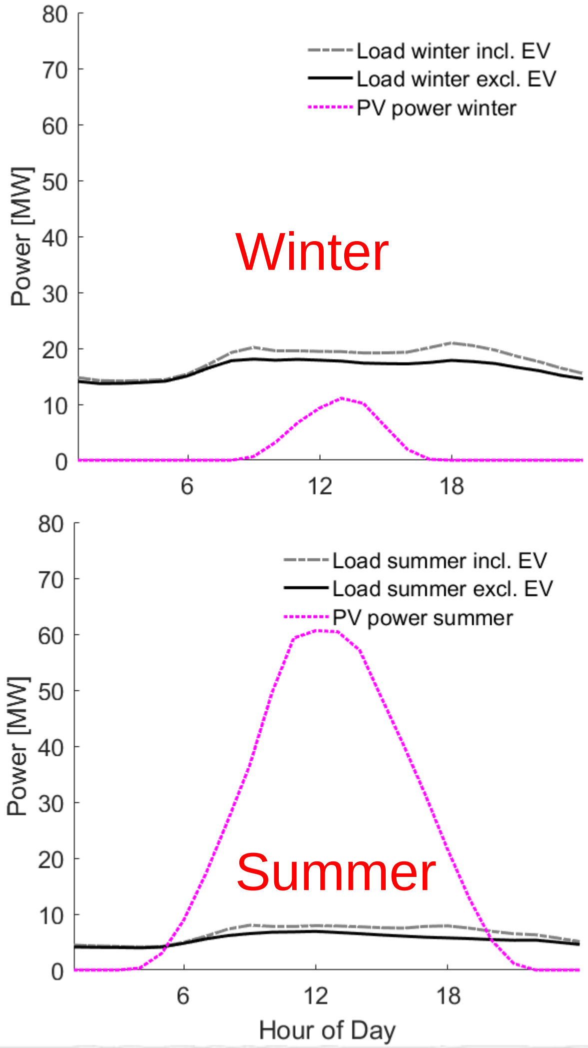
- Small difference in load with EV
  - 18% higher in the summer weeks
  - 9% higher in the winter weeks



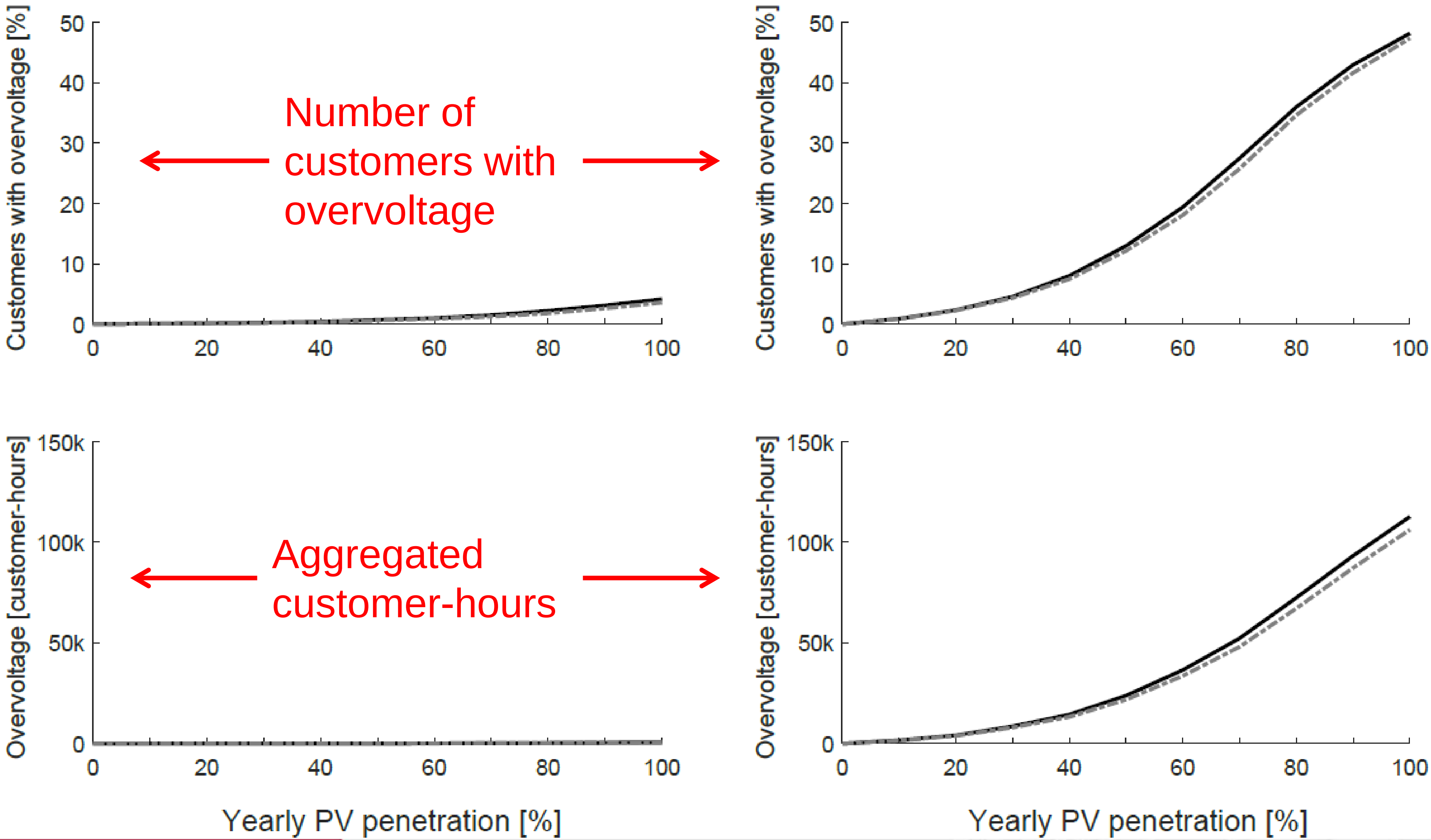


Results – load and generation

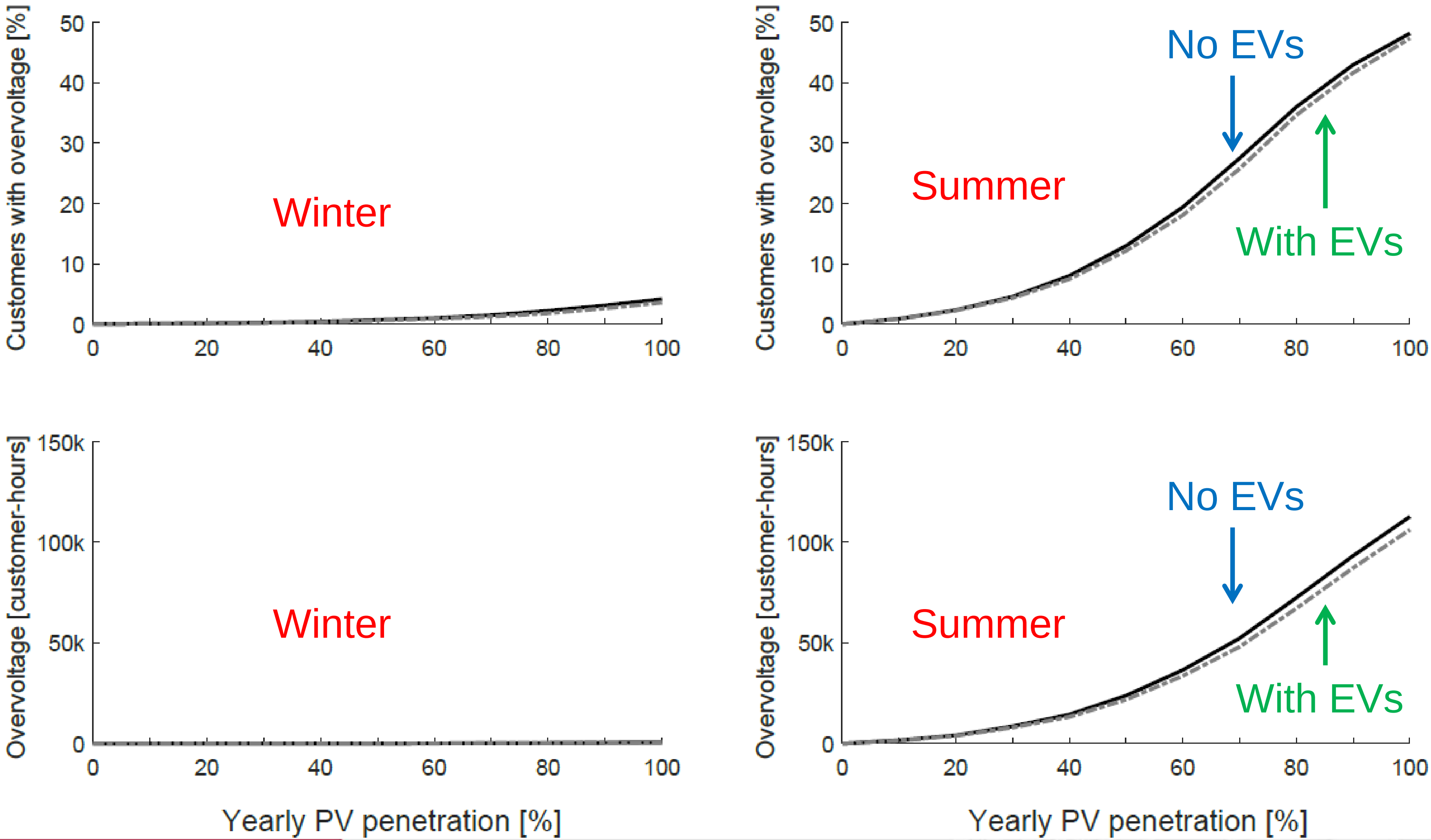
- Small difference in load with EV
  - 18% higher in the summer weeks
  - 9% higher in the winter weeks
- Large seasonal variation in PV generation
  - 100% penetration in the figures on a *yearly* basis



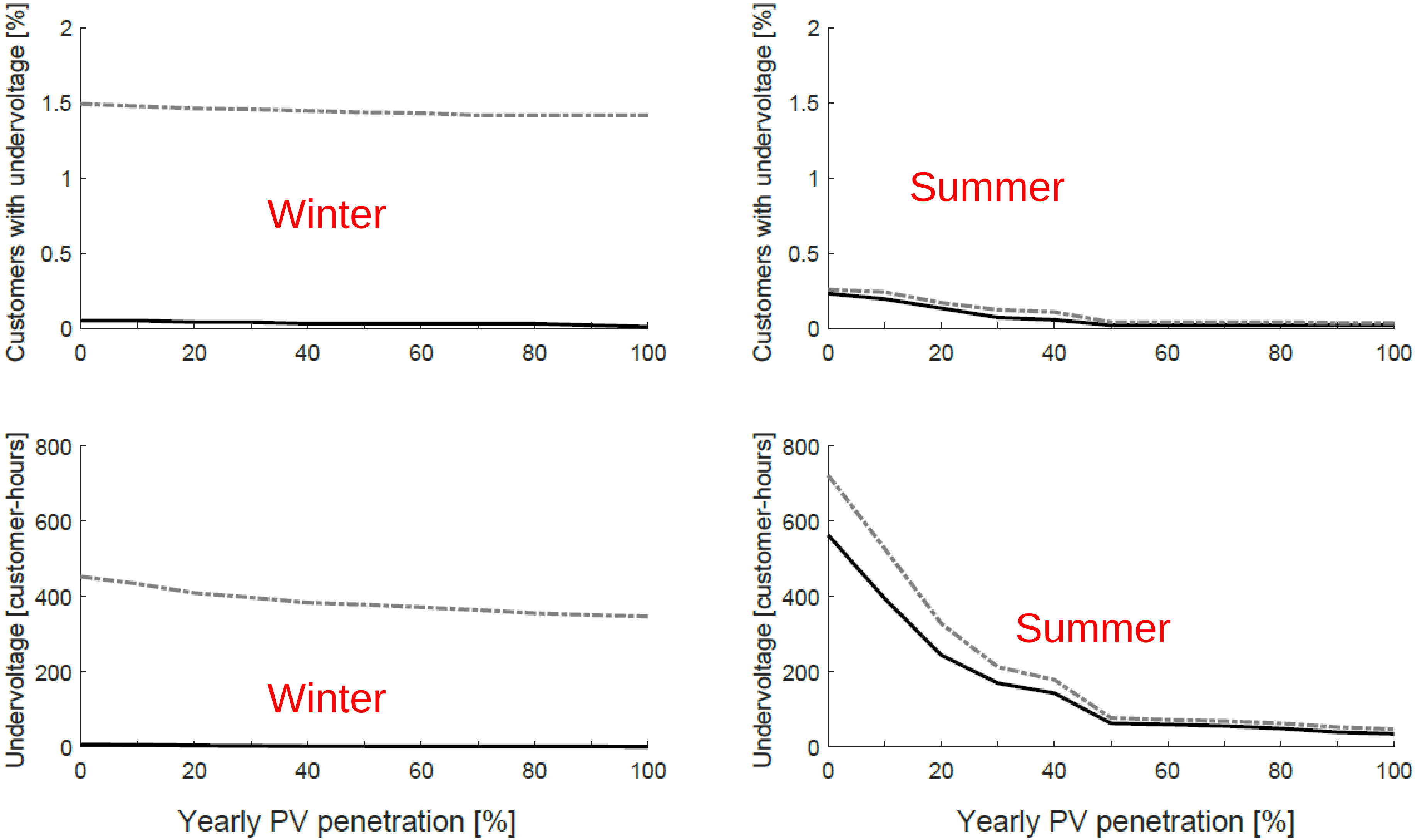
Results – overvoltage



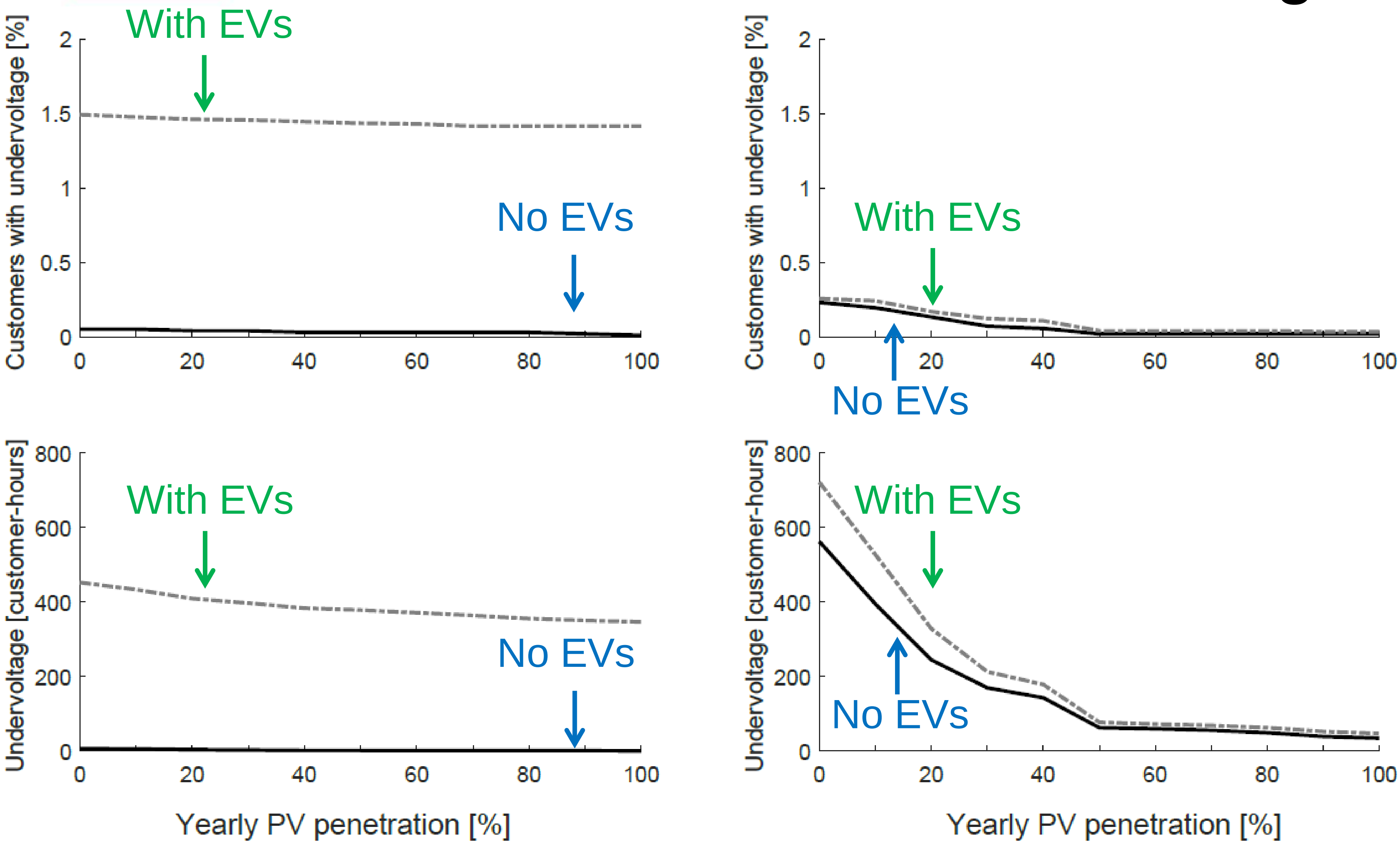
Results – overvoltage



Results – undervoltage



Results – undervoltage



Discussion & conclusion

- EV charging has a small impact on the voltage in the studied grid

Discussion & conclusion

- EV charging has a small impact on the voltage in the studied grid
- 50% of the customers are affected by overvoltage in a scenario of 100% PV penetration – almost no reduction with EV charging
  - Overvoltage in LV grids far from the distribution substations
  - EV charging during day mainly in the city areas close to substations

Discussion & conclusion

- PV power has a small impact on undervoltage due to EV charging in the winter, in the summer with PV > 50%

UPPSALA UNIVERSITET

Discussion & conclusion

- PV power has a small impact on undervoltage due to EV charging in the winter, in the summer with PV > 50%
- 1.5% of the customers affected by undervoltage in the winter
  - Undervoltage in LV grids far from the distribution substations
  - EV charging mainly in the morning (to work) and in the afternoon (to home)
  - Sun is above the horizon approx. 08:40 – 15:30 in early January

Discussion & conclusion

- Possible solutions to avoid voltage limit violations
  - Grid extension – can be costly for rural grids
  - ‘Smart-grid’, for example real-time measurements with tap-changing transformers
  - Scheduled EV charging or ‘vehicle to grid’ – incentives are needed

Thank you for listening!

Rasmus Luthander

Mahmoud Shepero

Joakim Munkhammar

Joakim Widén

firstname.surname@angstrom.uu.se

Built Environment Energy Systems Group (BEESG)

Department of Engineering Sciences

Uppsala University, Sweden