Karen Pardos Olsen, postdoc at
Center for Electric Power and Energy

Analysing power consumption and generation on Bornholm:

Best energy storage options for high shares of renewables

Agenda

1. Penetration of renewable energy (RE) on Bornholm

   - ”where we are” numbers with PowerLabDK data

2. Optimal energy storage (ES) options for Bornholm

   - a method based on Fourier analysis

3. Increasing the time resolution from 1hr to 1min

   - the potential of houses and Evs

4. Using data to verify simulations of wind power production

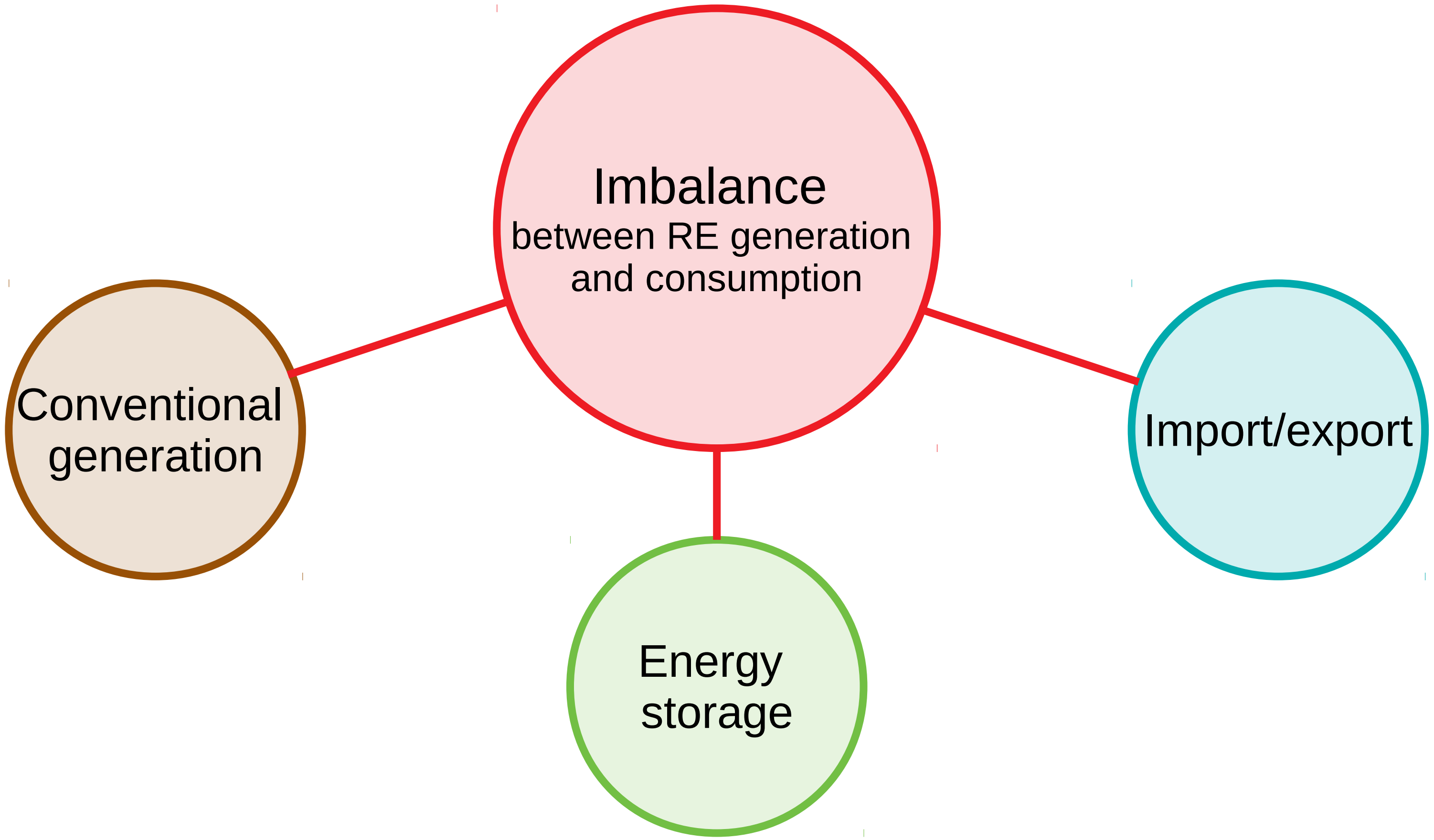
Why do we care about energy storage?

Data from PowerLabDK: http://www.powerlab.dk/

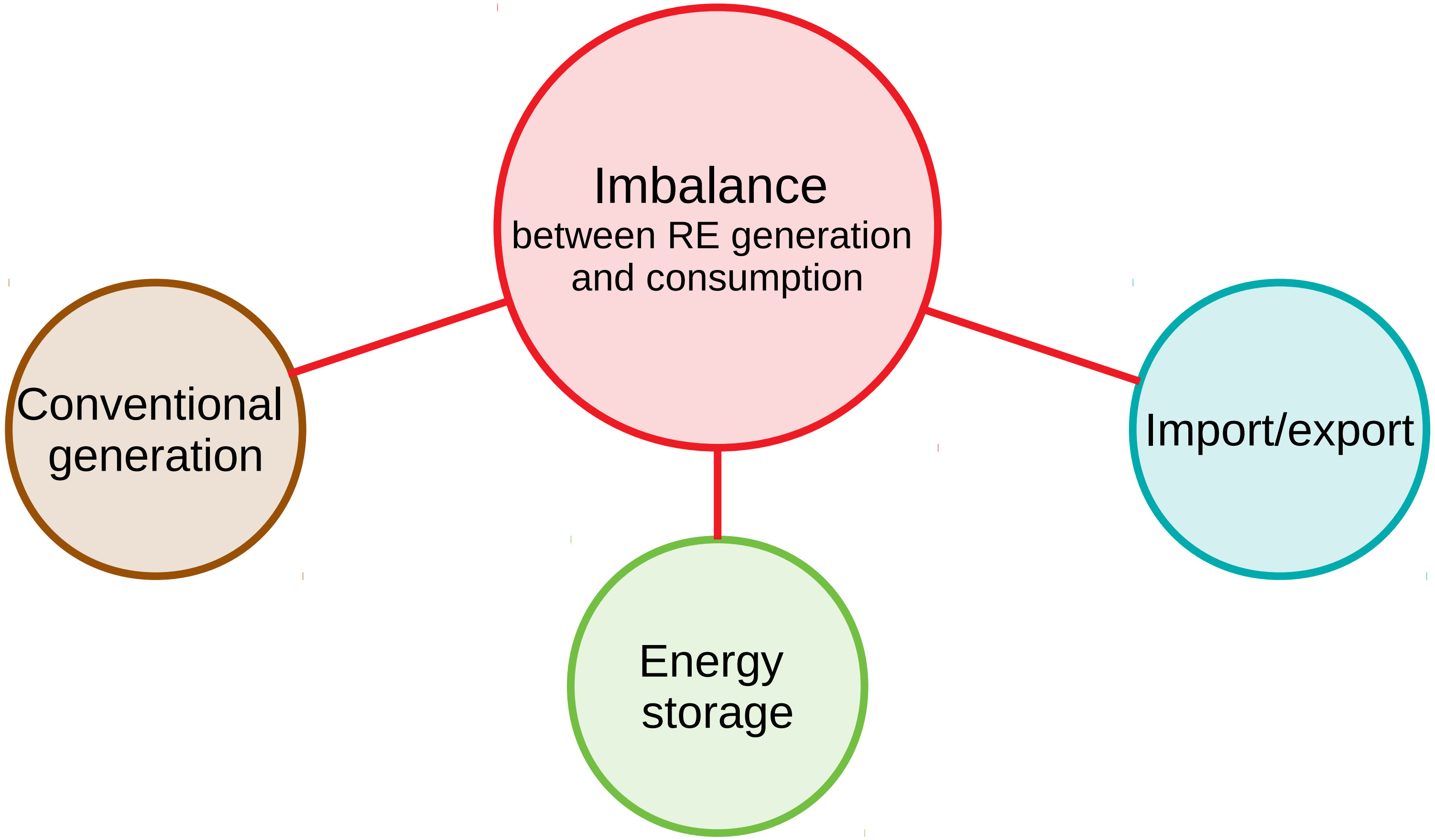
Why do we care about energy storage?

Imbalance
between RE generation
and consumption

Why do we care about energy storage?



Why do we care about energy storage?



Typically using fossil fuels, although conversion to biomass is gaining popularity

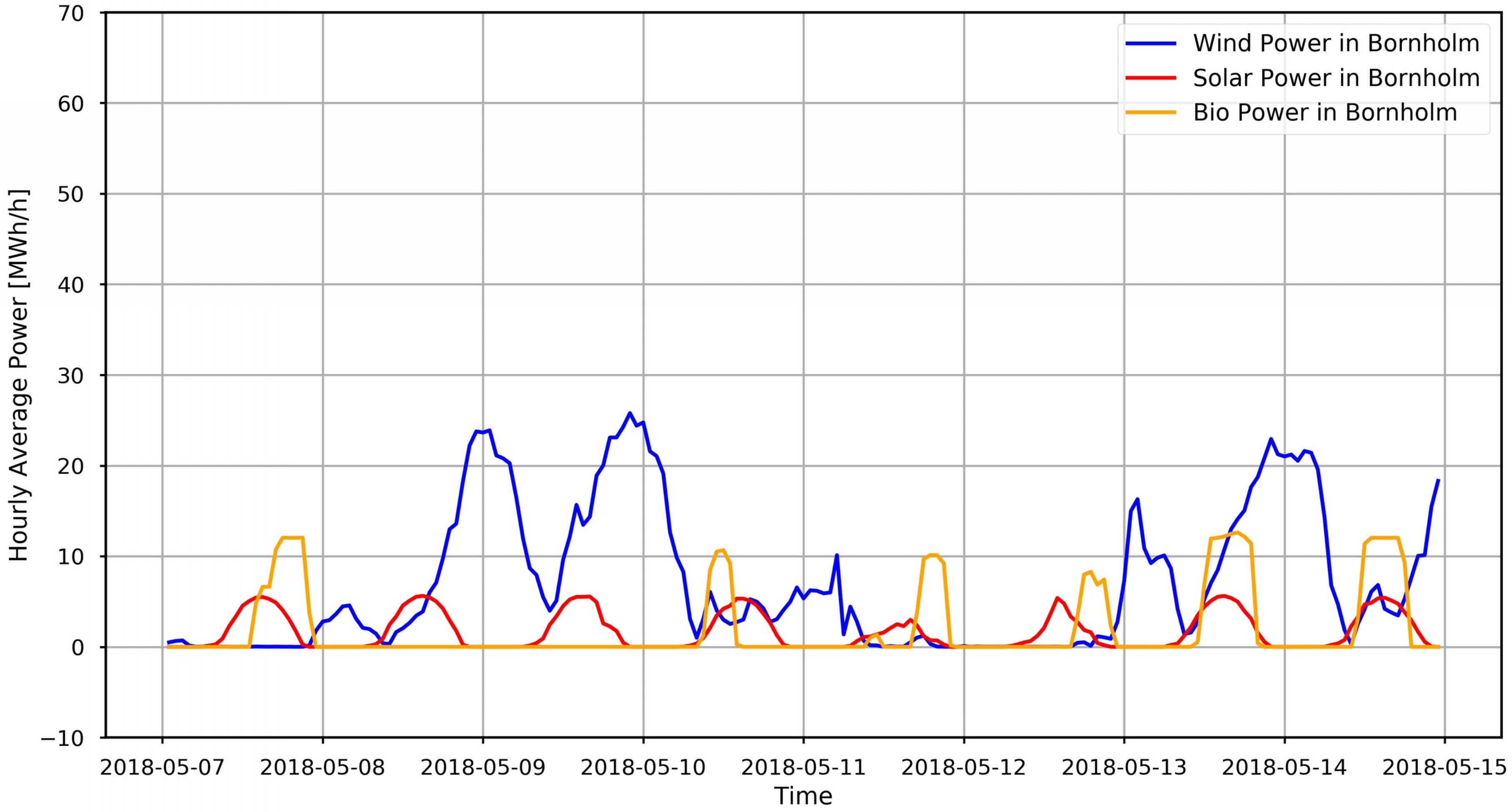
The most green option, and potentially the cheapest in the future...

1. Penetration of renewable energy on Bornholm

[www.colourbox.dk]

1. Penetration of renewable energy on Bornholm

Measured RE production on Bornholm:

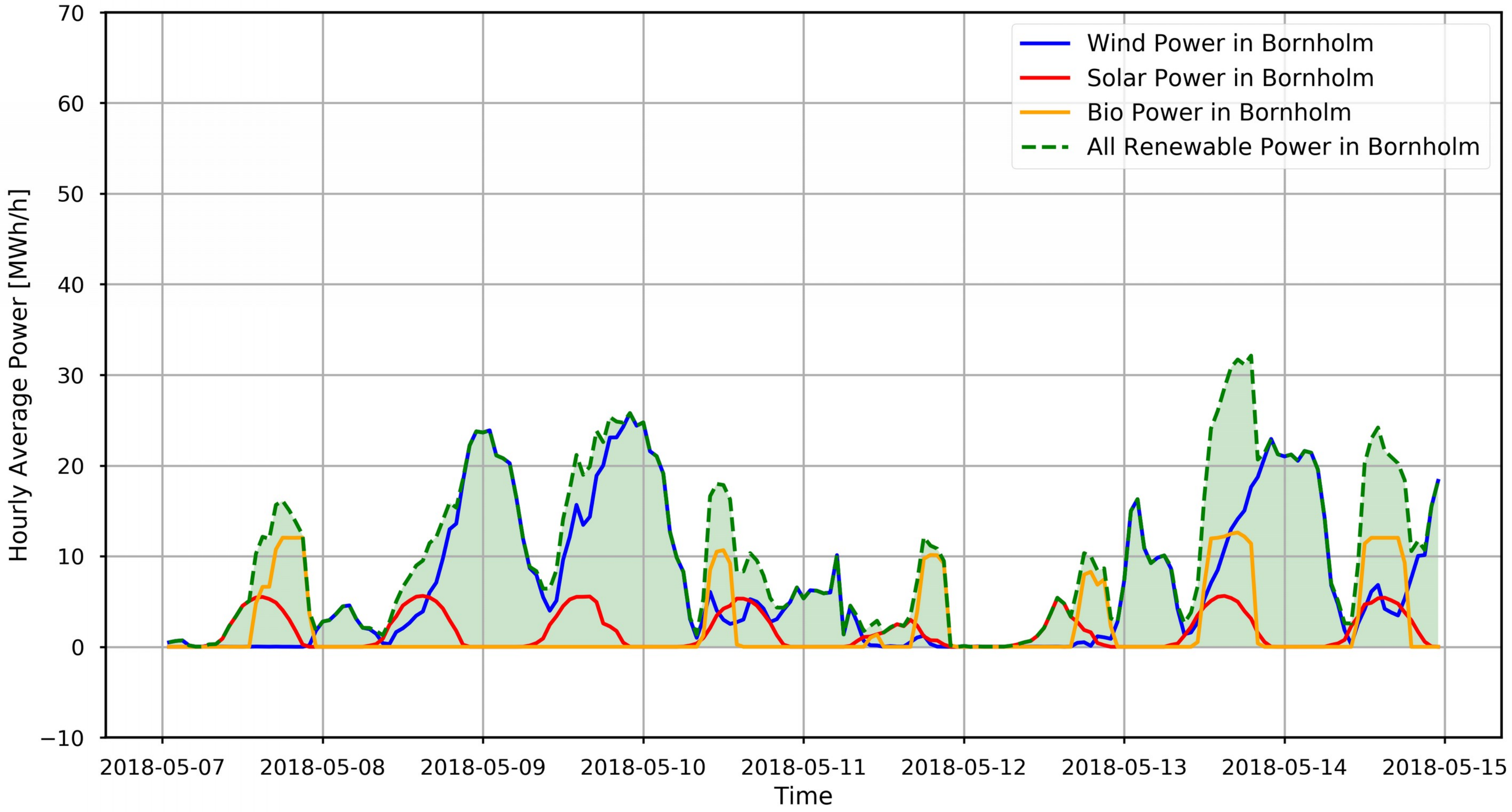


Actually all of CHP unit including biomass

Data from PowerLabDK: http://www.powerlab.dk/

1. Penetration of renewable energy on Bornholm

Measured RE production on Bornholm:



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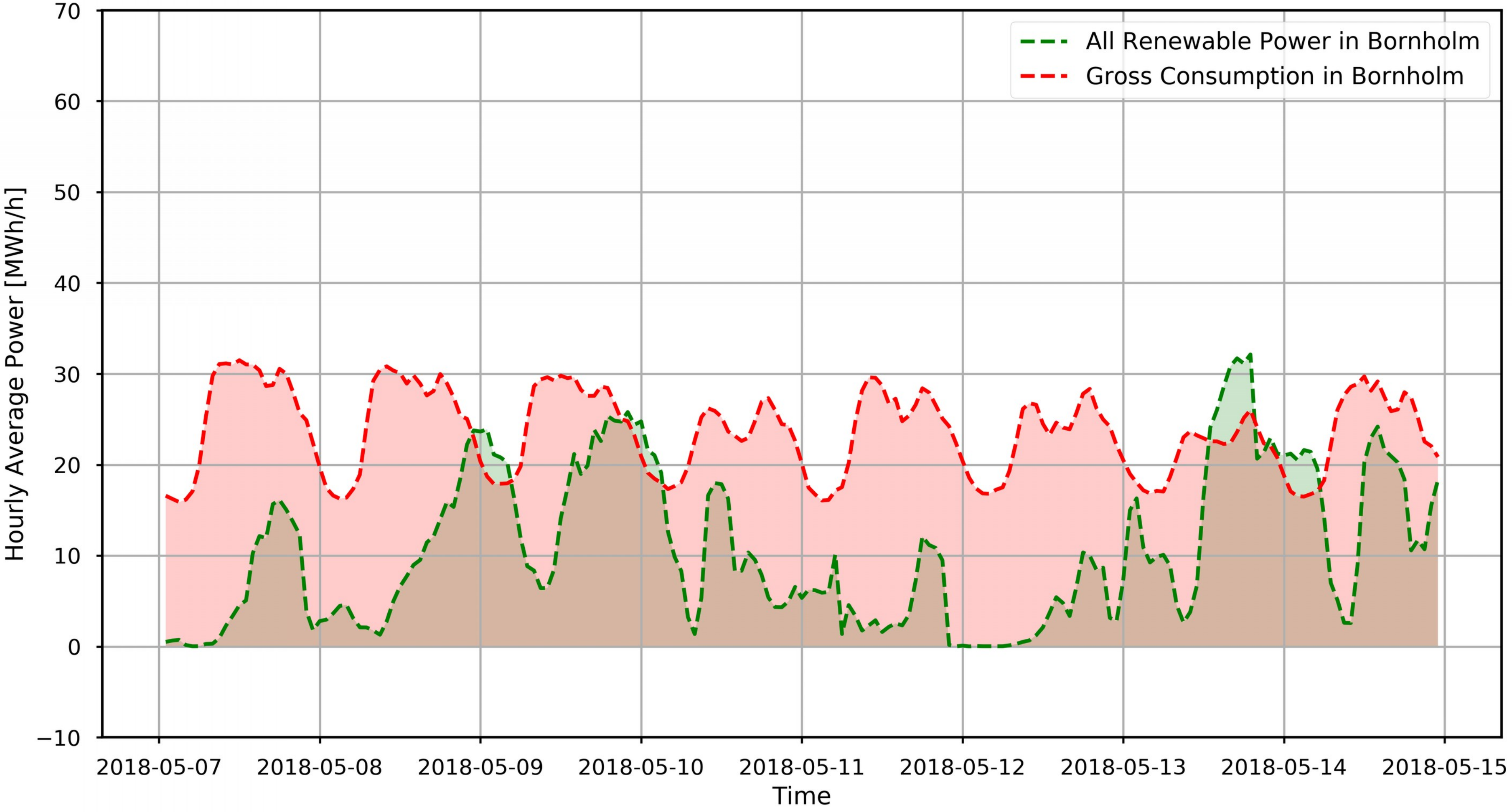
1. Penetration of renewable energy on Bornholm

Estimating consumption from RE production + import:



Yearly penetration:

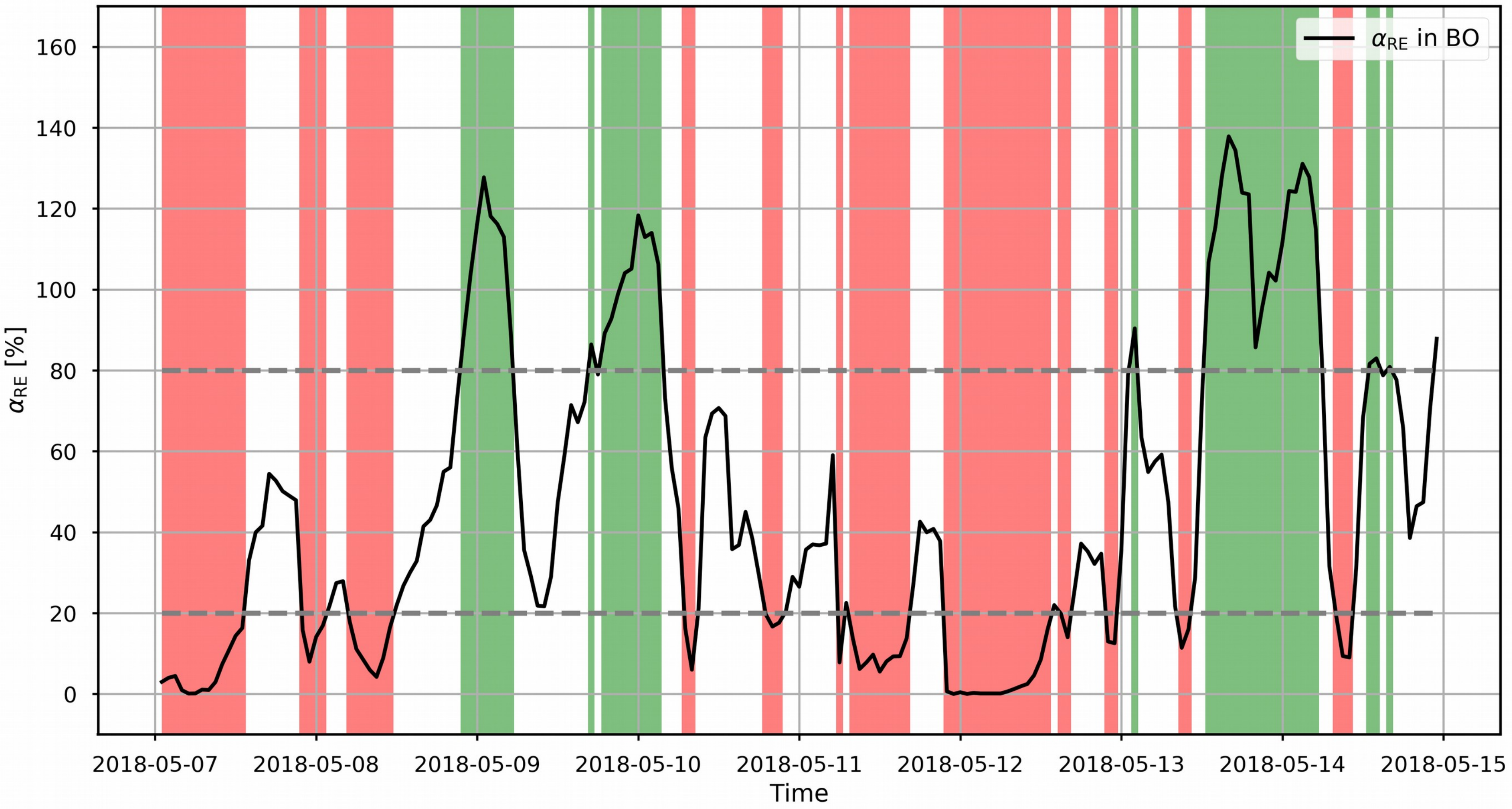
2017: 63%

2018: 59%

Data from PowerLabDK: http://www.powerlab.dk/

1. Penetration of renewable energy on Bornholm

α_{RE} : Hourly share of renewables



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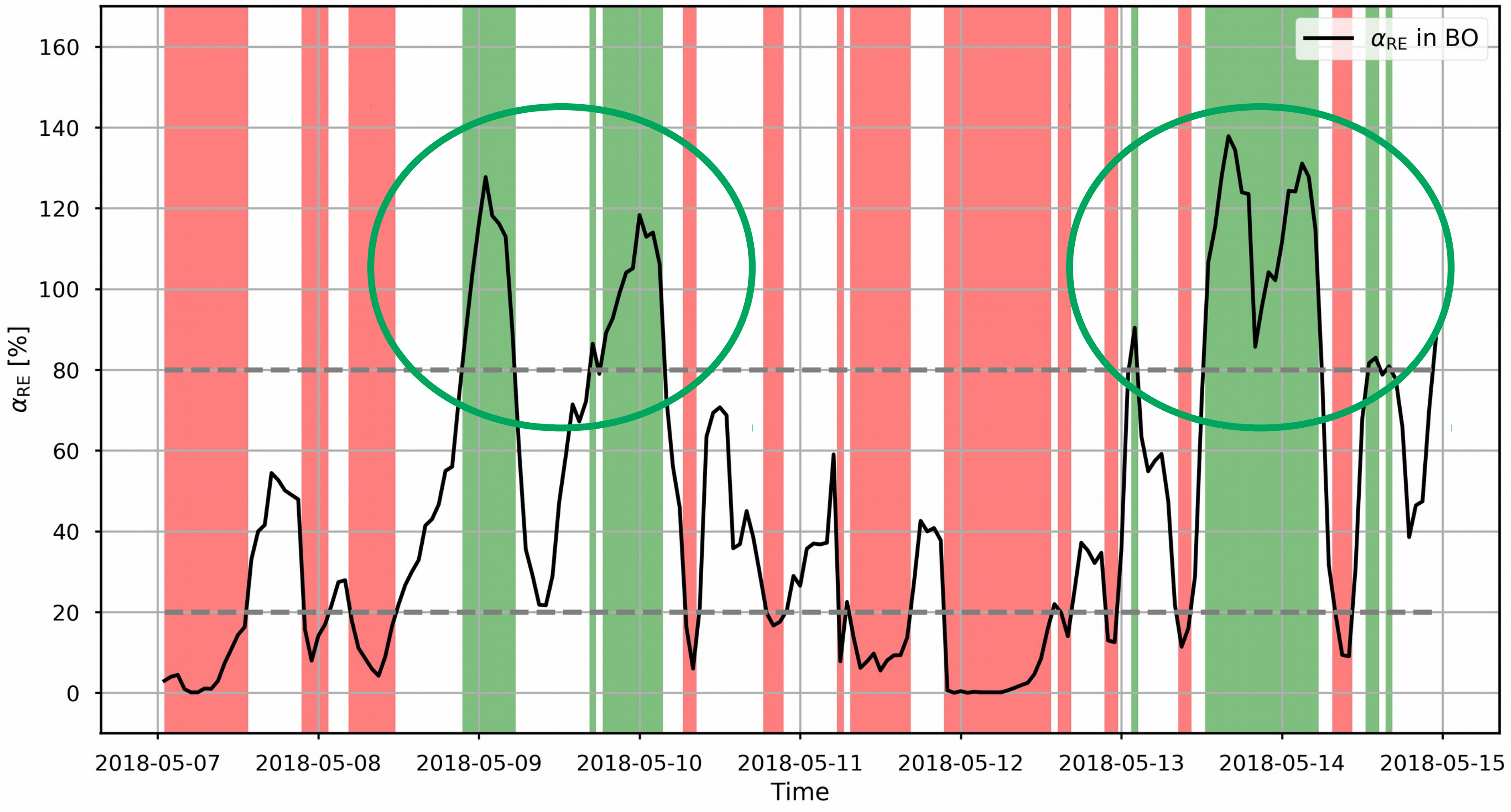
1. Penetration of renewable energy on Bornholm

α_{RE} : Hourly share of renewables



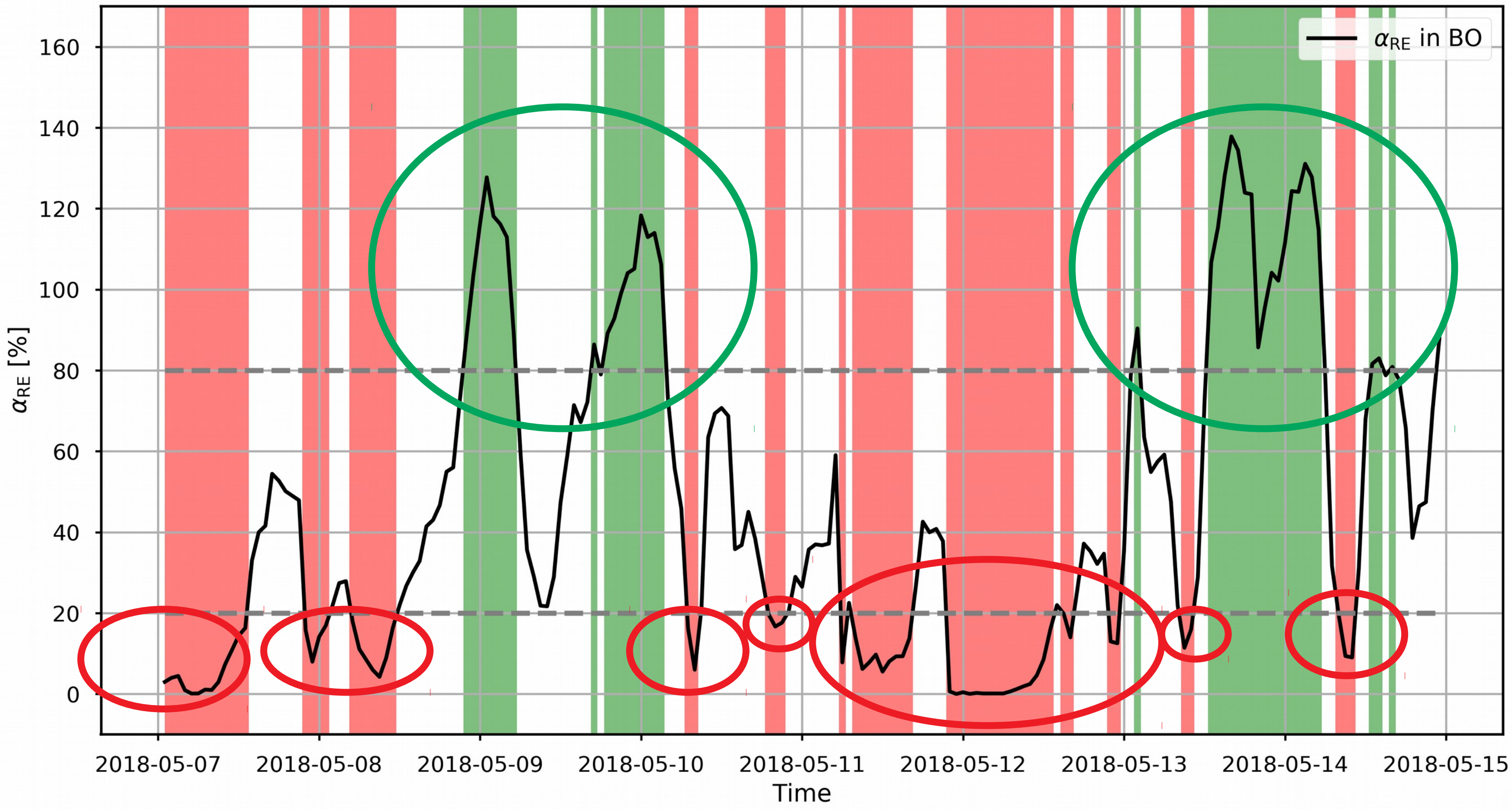
In % of all hours:

α_{RE} > 80%: 8.1%

Data from PowerLabDK: http://www.powerlab.dk/

1. Penetration of renewable energy on Bornholm

α_{RE} : Hourly share of renewables



In % of all hours:

α_{RE} > 80%: 8.1%

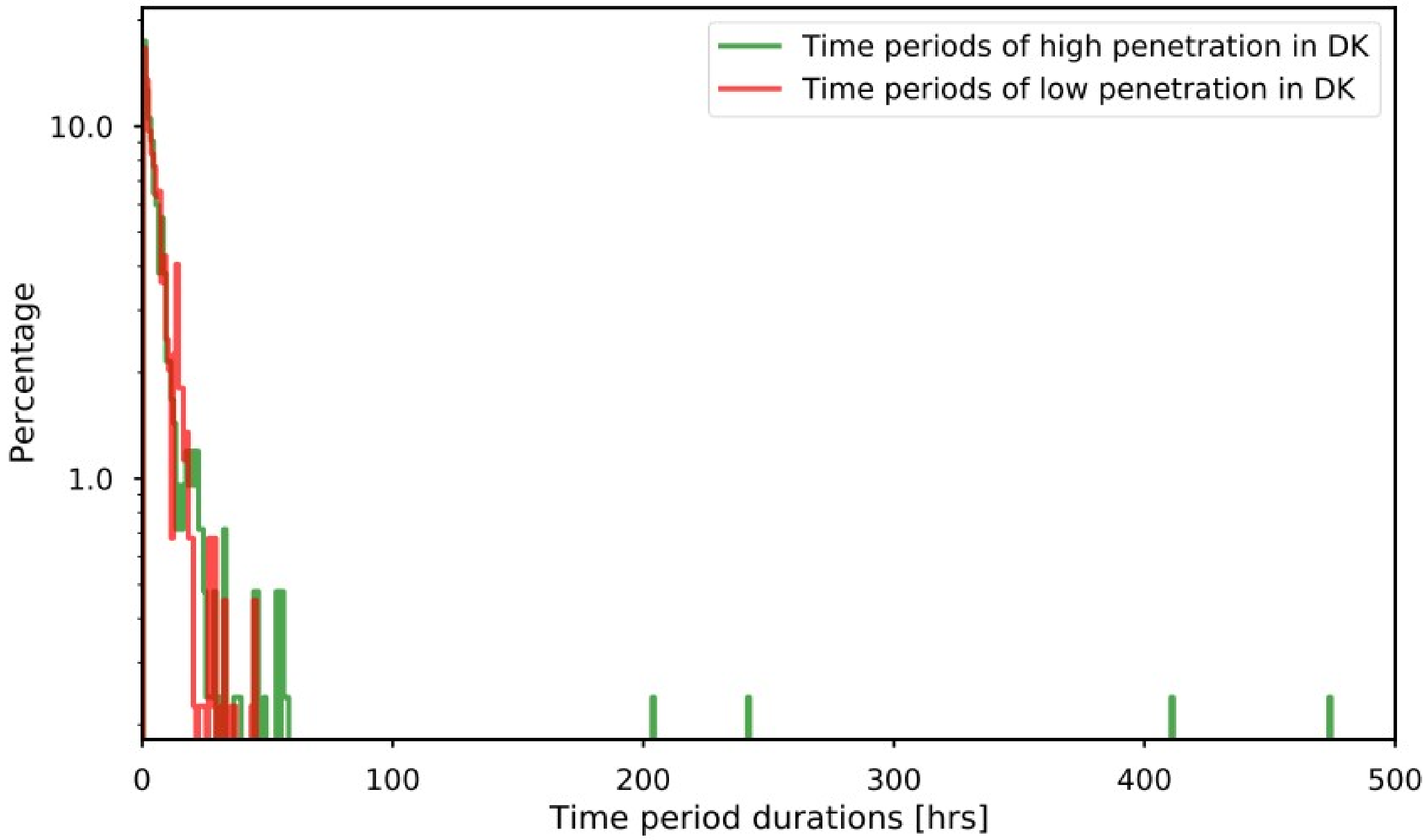
α_{RE} < 20%: 4.8%

Data from PowerLabDK: http://www.powerlab.dk/

1. Penetration of renewable energy on Bornholm

Duration of consecutive high/low α_{RE} :

Bornholm:



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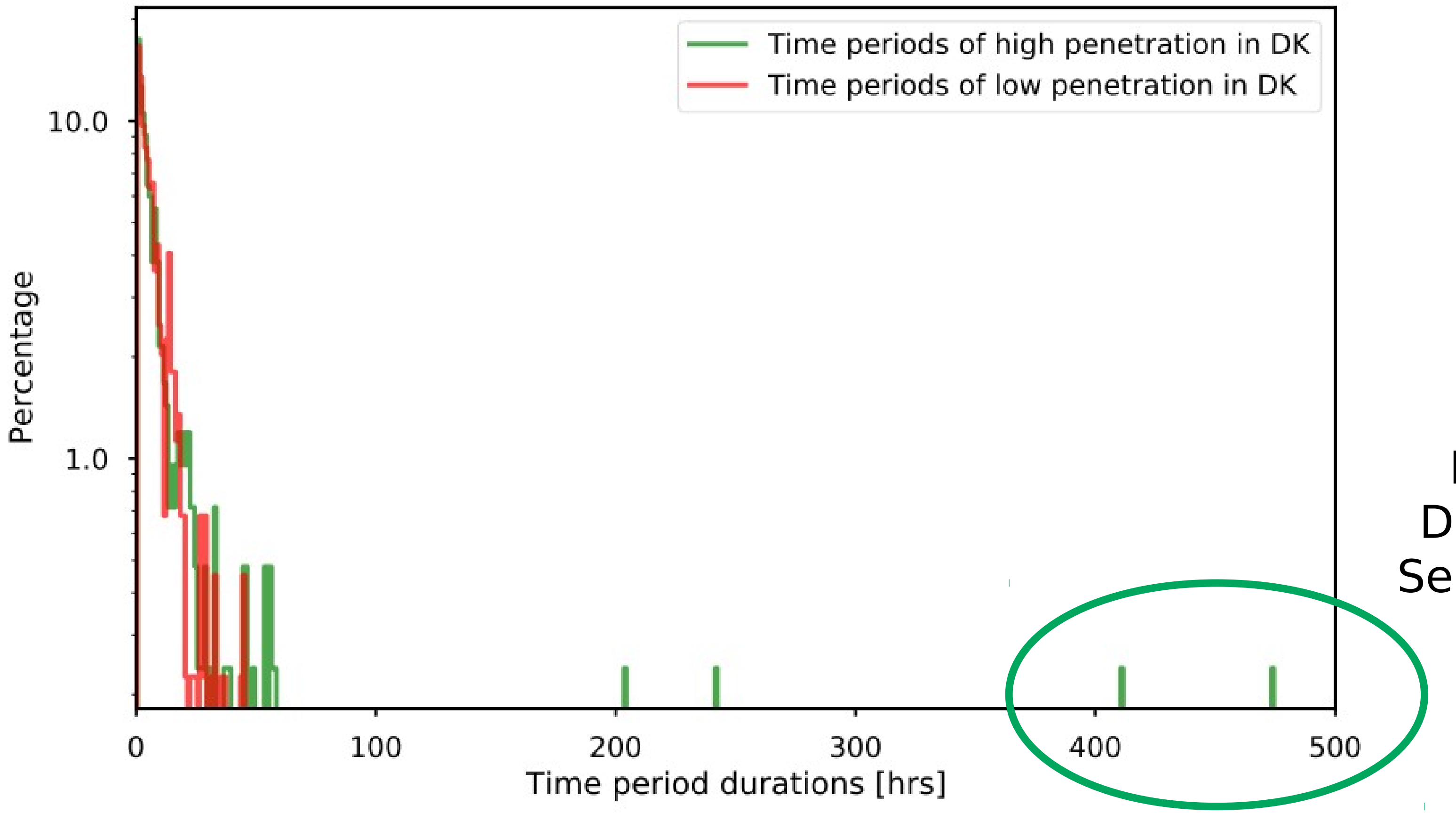
Duration of consecutive high/low α_{RE} :

Bornholm:



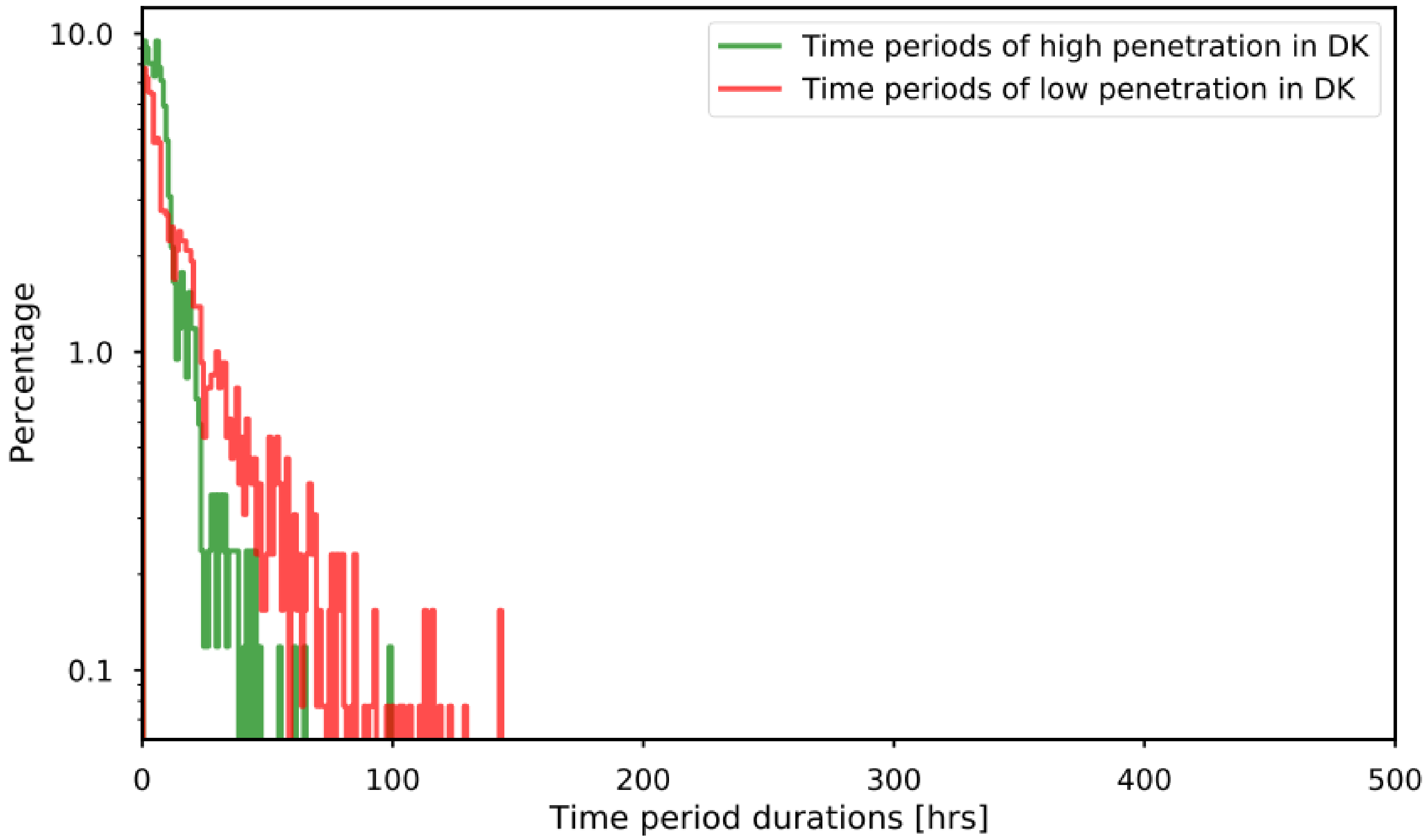
Extreme times:
December 22 and
September 18 2017
- island mode?

Data from PowerLabDK: http://www.powerlab.dk/

1. Penetration of renewable energy on Bornholm

Duration of consecutive high/low α_{RE} :

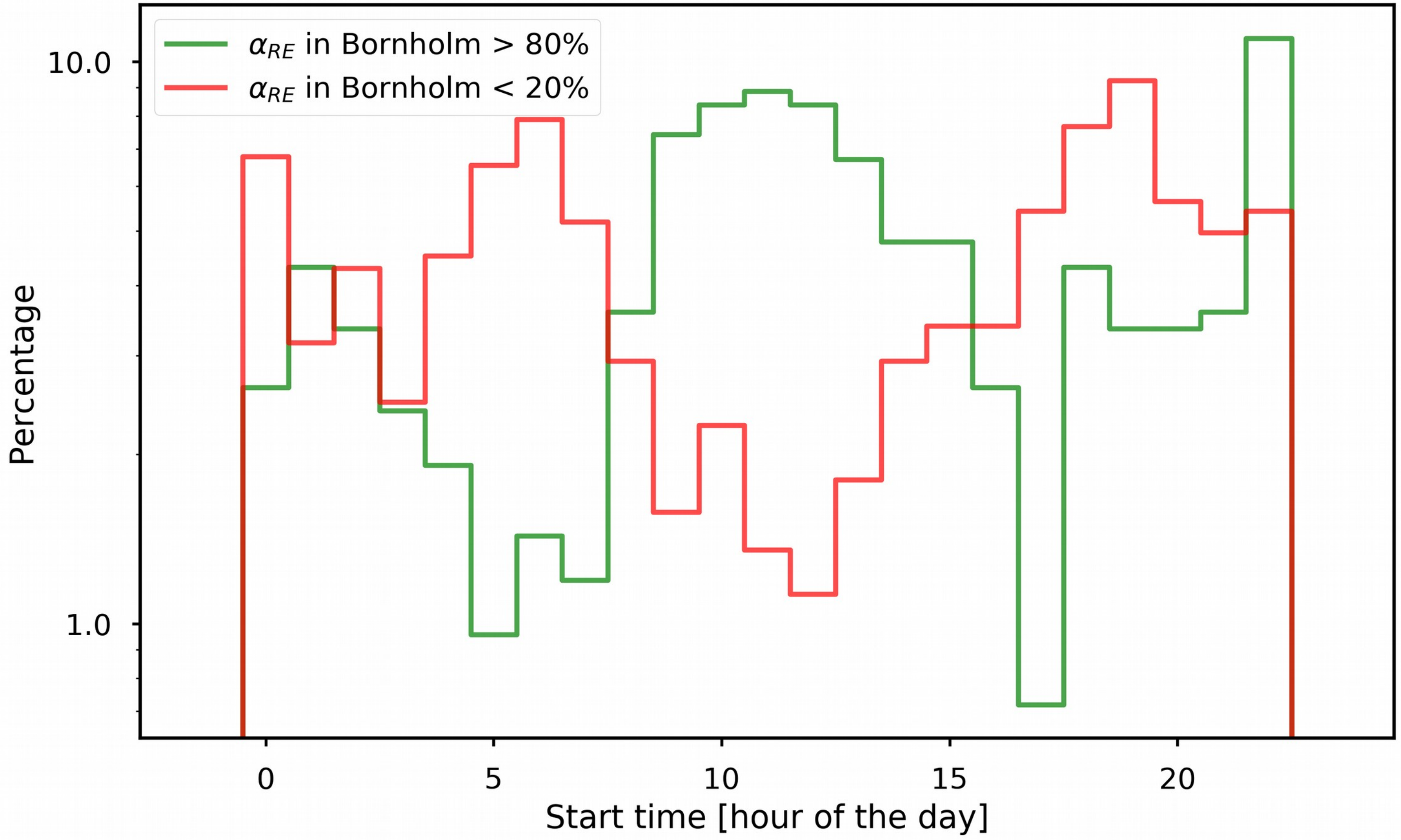
Denmark:



Data from PowerLabDK: http://www.powerlab.dk/

1. Penetration of renewable energy on Bornholm

Start times of epochs with high/low α_{RE} :



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2. Optimal energy storage (ES) options for Bornholm

Hospital in Rønne [FUTURE project]

2. Optimal energy storage (ES) options for Bornholm

REVIEW ARTICLE

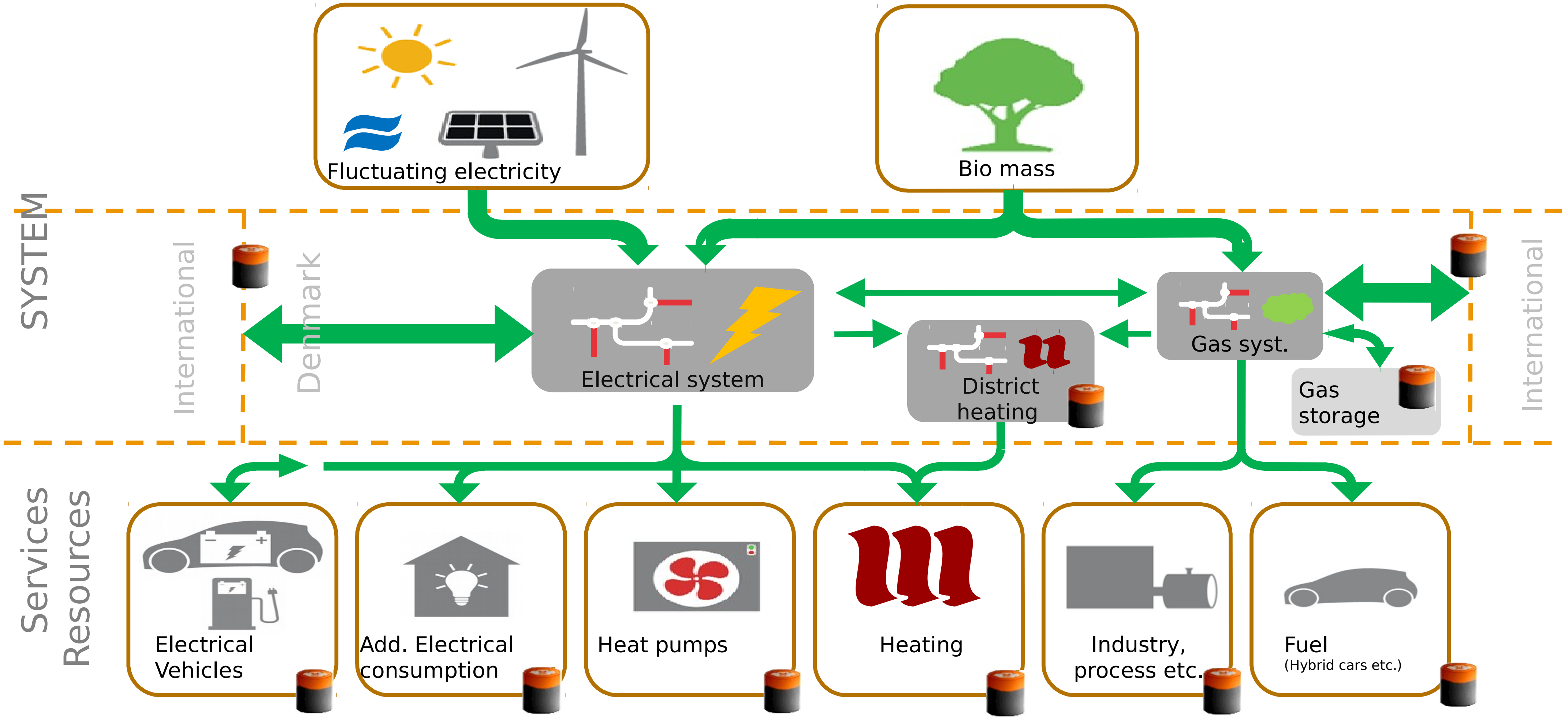
A review of Danish integrated multi-energy system flexibility options for high wind power penetration

Jiawei Wang, Yi Zong*, Shi You and Chresten Træholt

Center for Electric Power and Energy, CEE, Department of Electrical Engineering, Technical University of Denmark, Copenhagen, Denmark

*"**The electrification of heat generation** will also play an important role in balancing wind power fluctuation and realizing the 100% green target for the power and heating systems. Emerging technology with gas systems will establish the long-term electrical energy storage and future ancillary services will provide power balancing." - 2017*

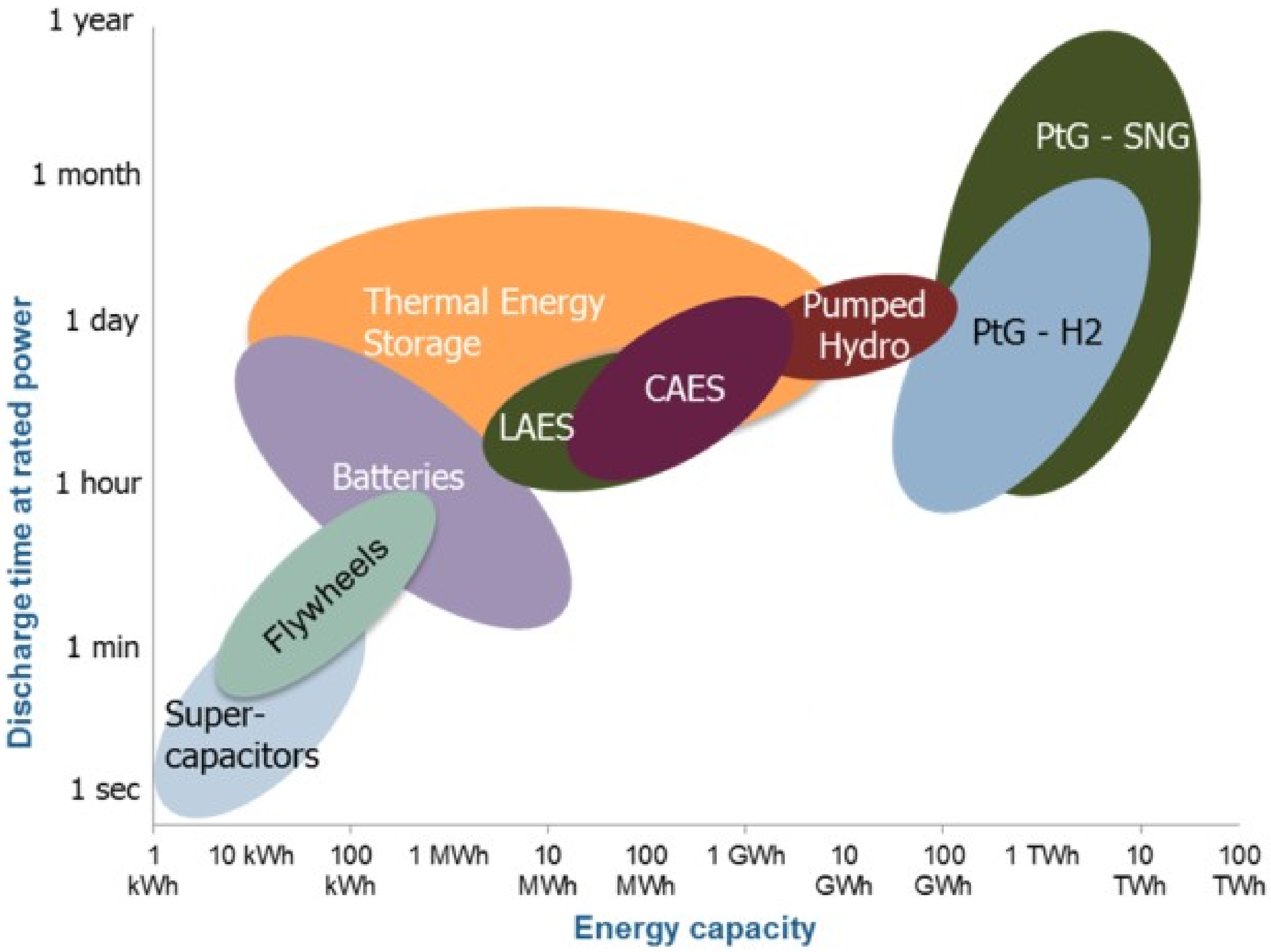
2. Optimal energy storage (ES) options for Bornholm



2. Optimal energy storage (ES) options for Bornholm

Figure 2: Mapping storage technologies according to performance characteristics

Source: PwC, 2015, following Sterner et al. 2014



2. Optimal energy storage (ES) options for Bornholm

Potential ES options on Bornholm:

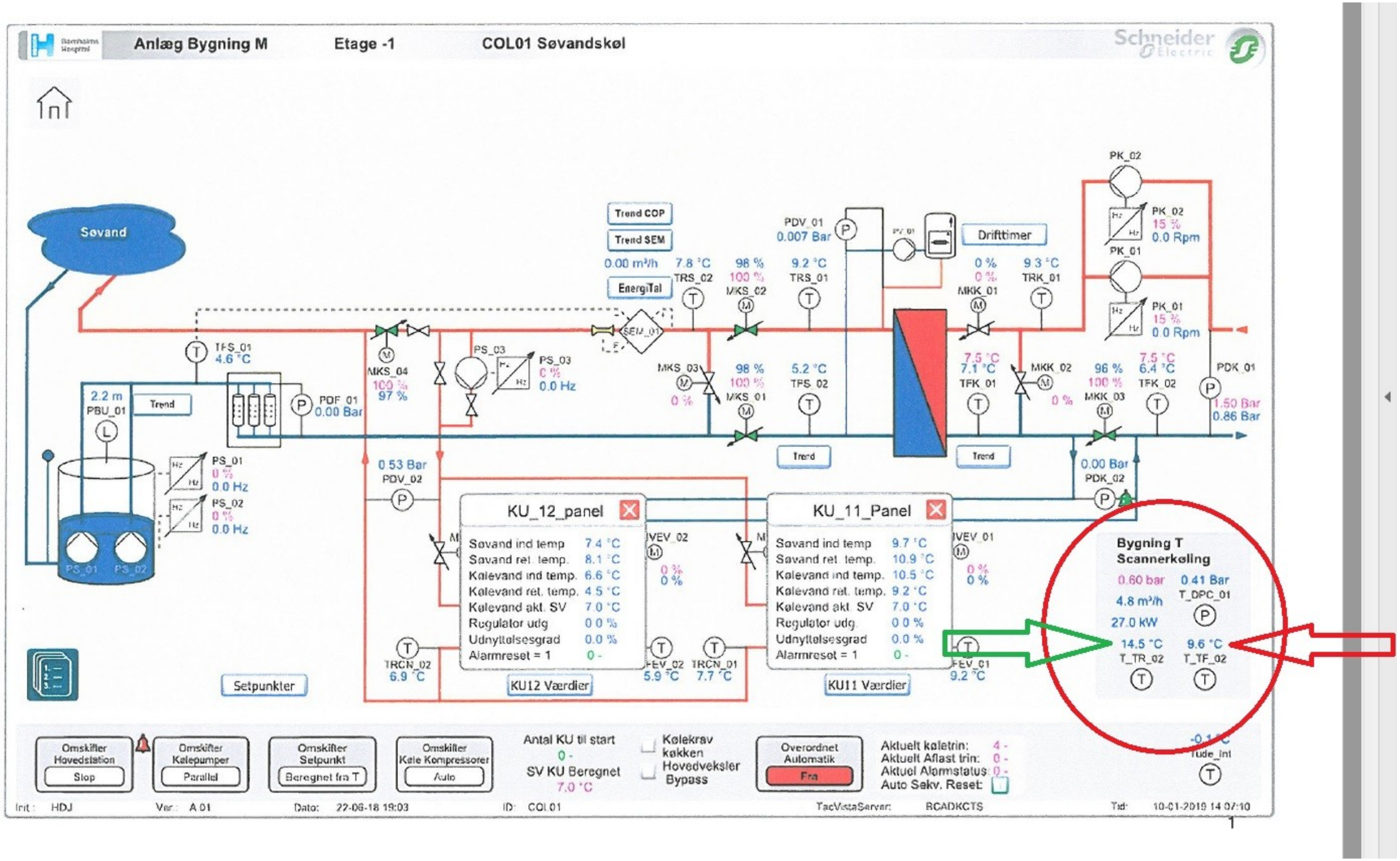
1. V2G of EVs (ACES: https://sites.google.com/view/aces-bornholm)
2. Batteries (BOSS 1 MWh)
3. Heating in residential houses (EcoGrid2.0: Fabian Müller & Bernhard Jansen 2018: arXiv:1806.07670, Ziras et al. 2018 submitted)
4. Electricity to DH facility (large hot water tank)
5. Flexibility in larger buildings, such as the hospital in Rønne (FUTURE)
6. More?

2. Optimal energy storage (ES) options for Bornholm

Flexibility in a hospital [FUTURE]

2. Optimal energy storage (ES) options for Bornholm

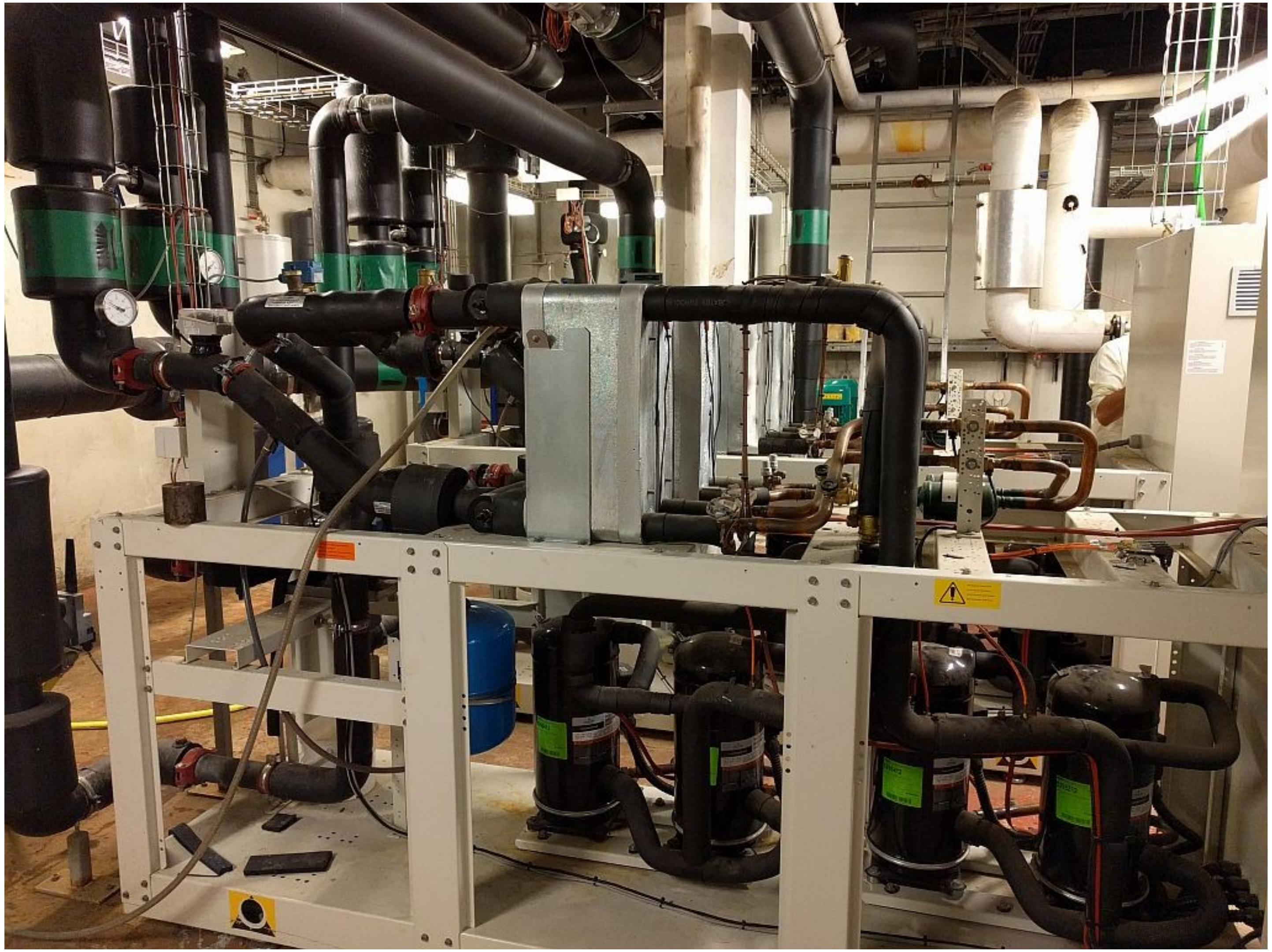
Using lake water to heat/cool hospital with 8 heat pumps of 4 kW each:



[FUTURE]

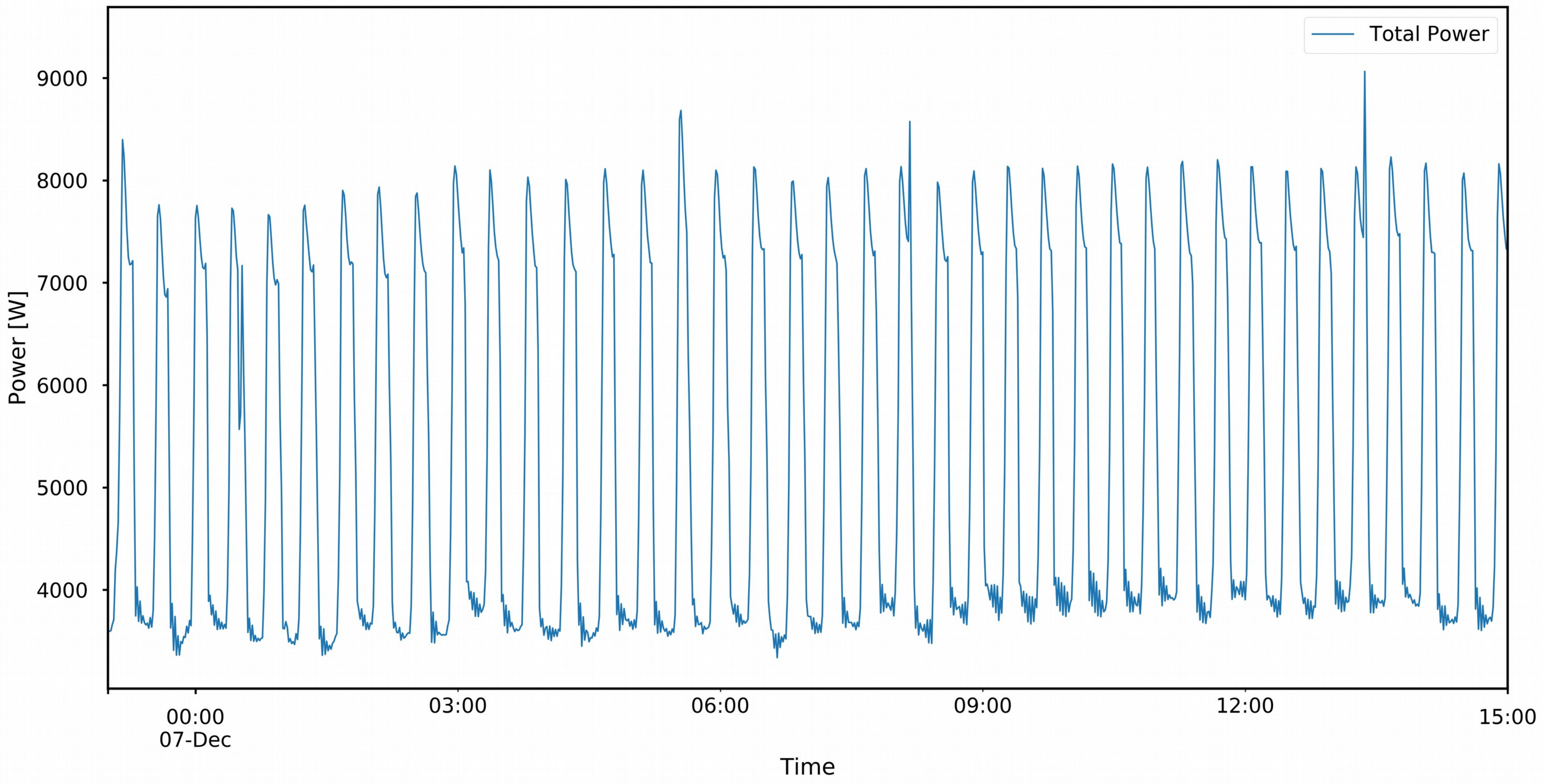
2. Optimal energy storage (ES) options for Bornholm

The 2 x 4 heat pumps:



[FUTURE]

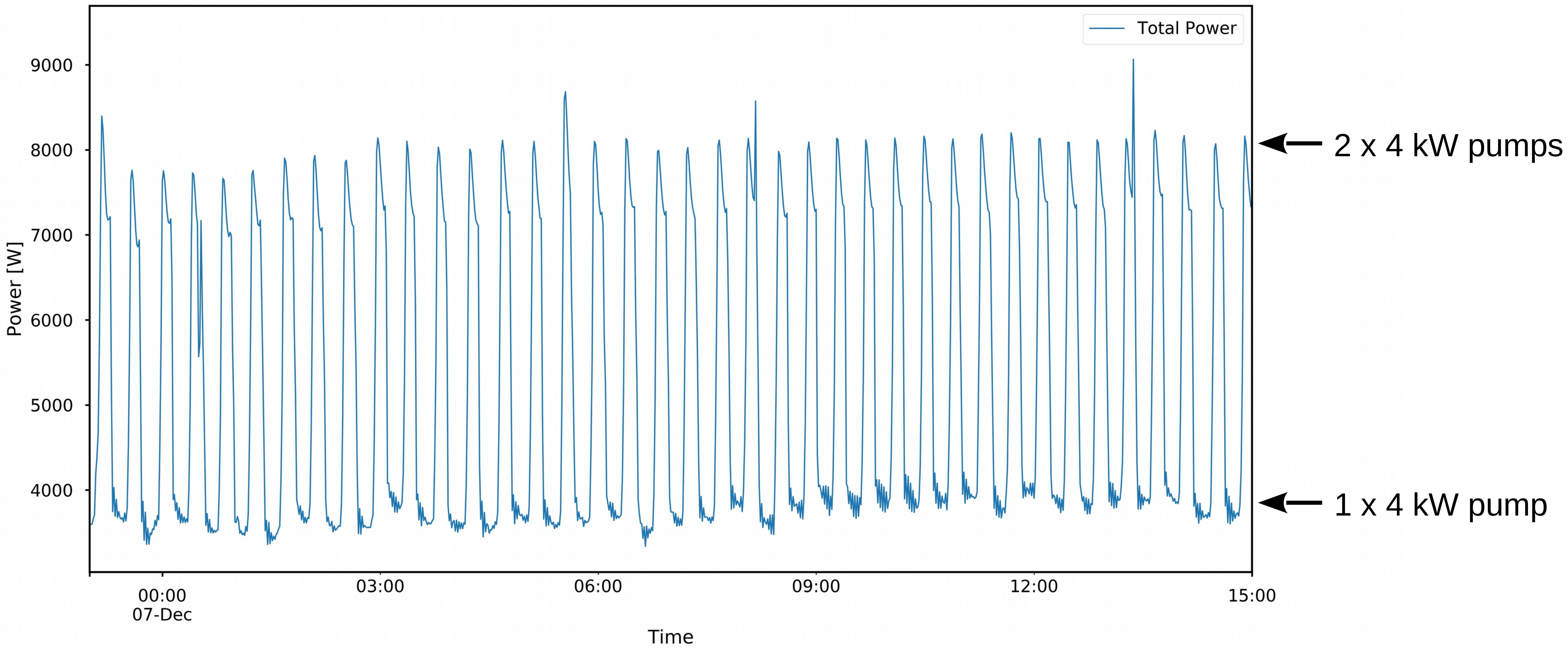
2. Optimal energy storage (ES) options for Bornholm



[FUTURE]

2. Optimal energy storage (ES) options for Bornholm

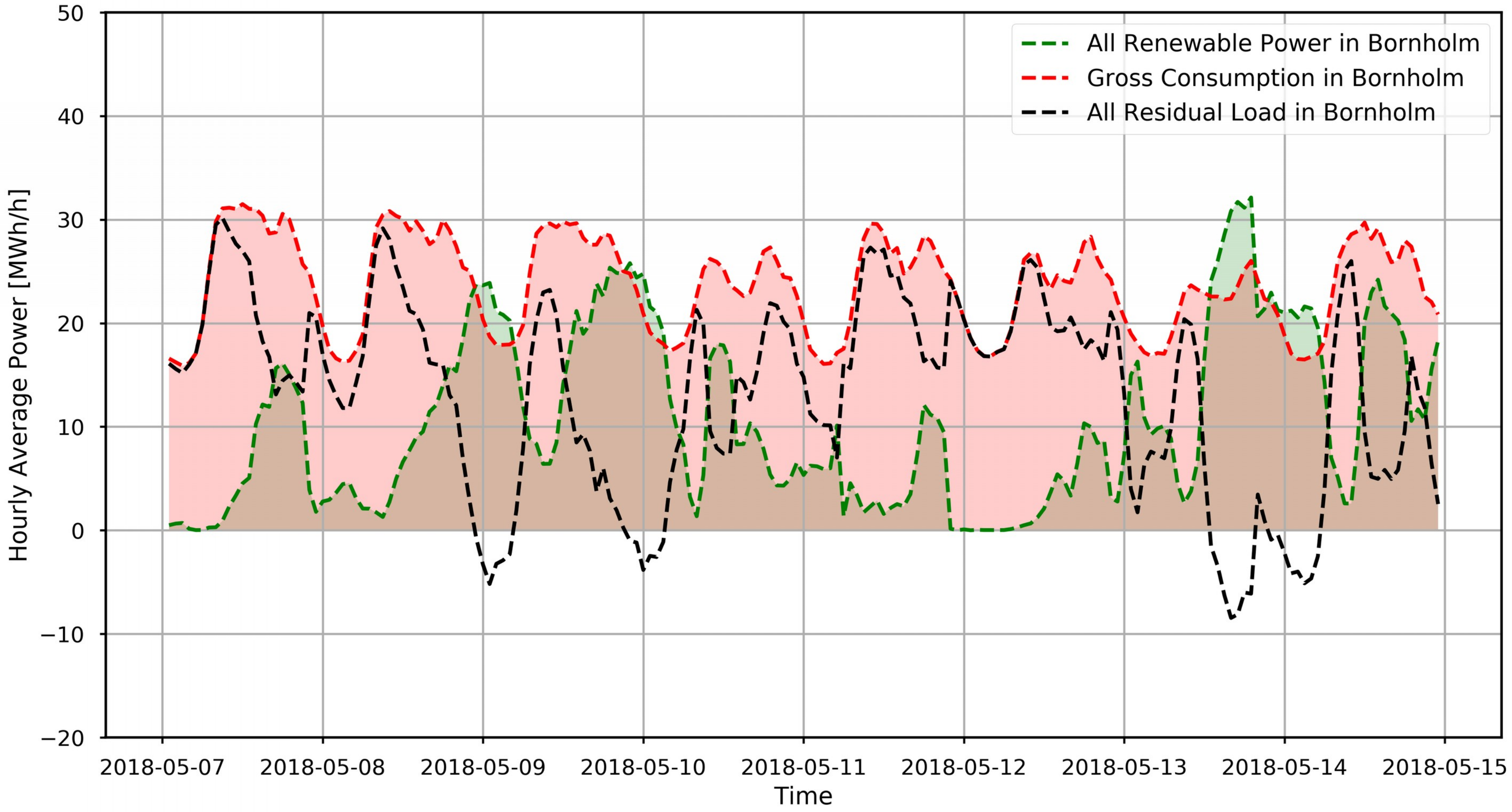
Measurements from December 7 2018:



[FUTURE]

2. Optimal energy storage (ES) options for Bornholm

Goal: to compensate for the residual load (consumption - production)



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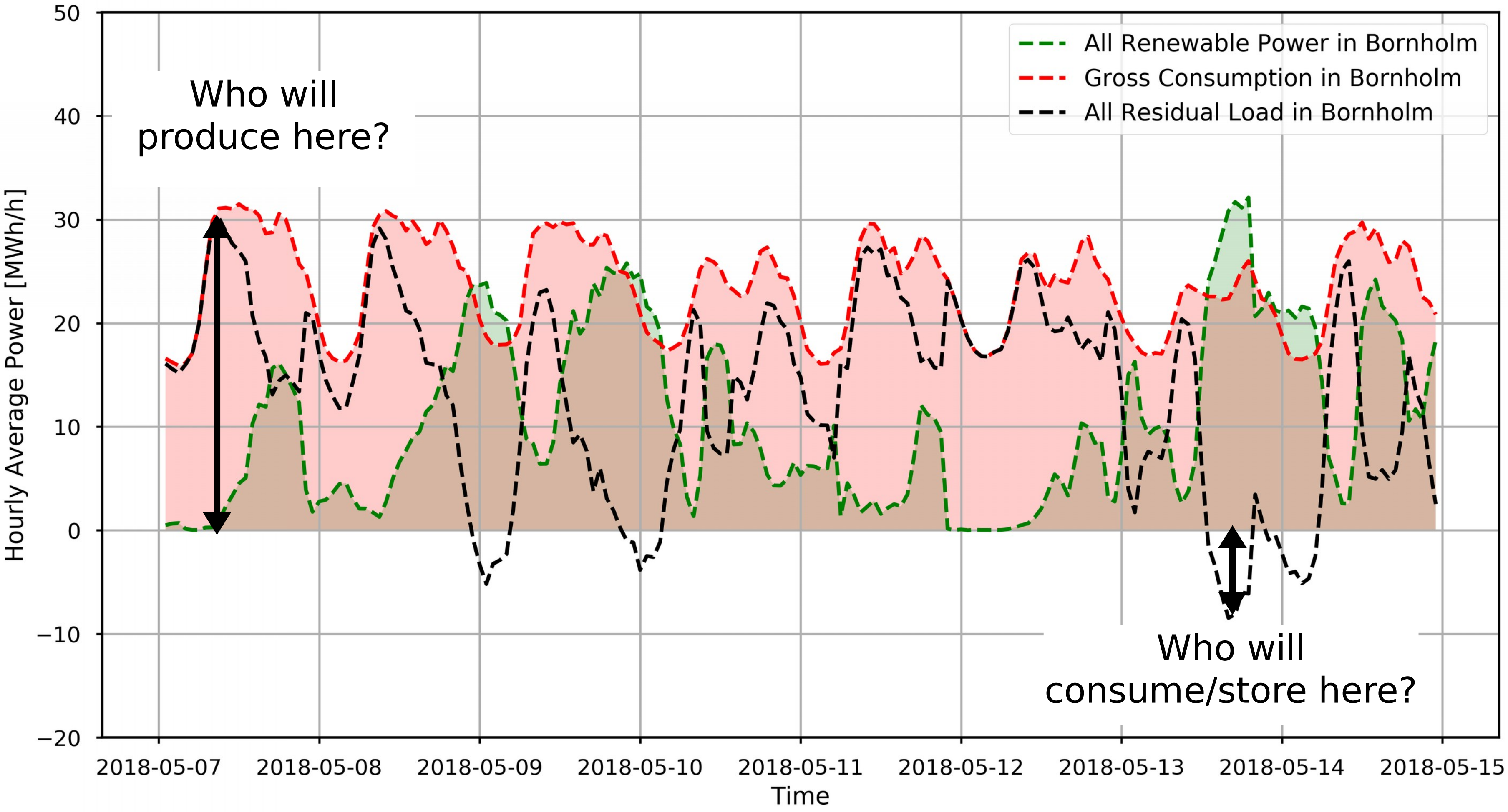
2. Optimal energy storage (ES) options for Bornholm

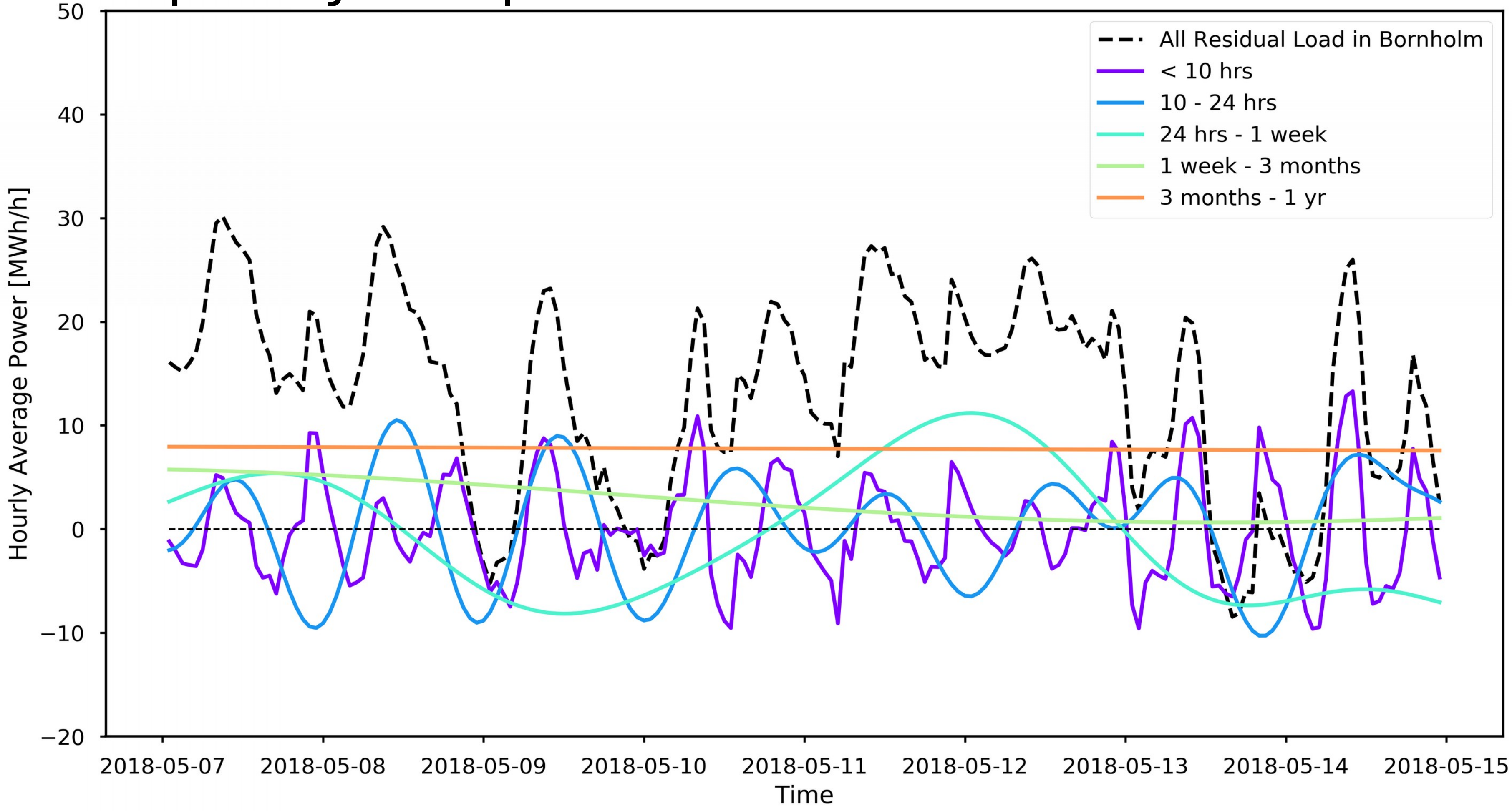
Goal: to compensate for the residual load (consumption - production)



Data from PowerLabDK: http://www.powerlab.dk/

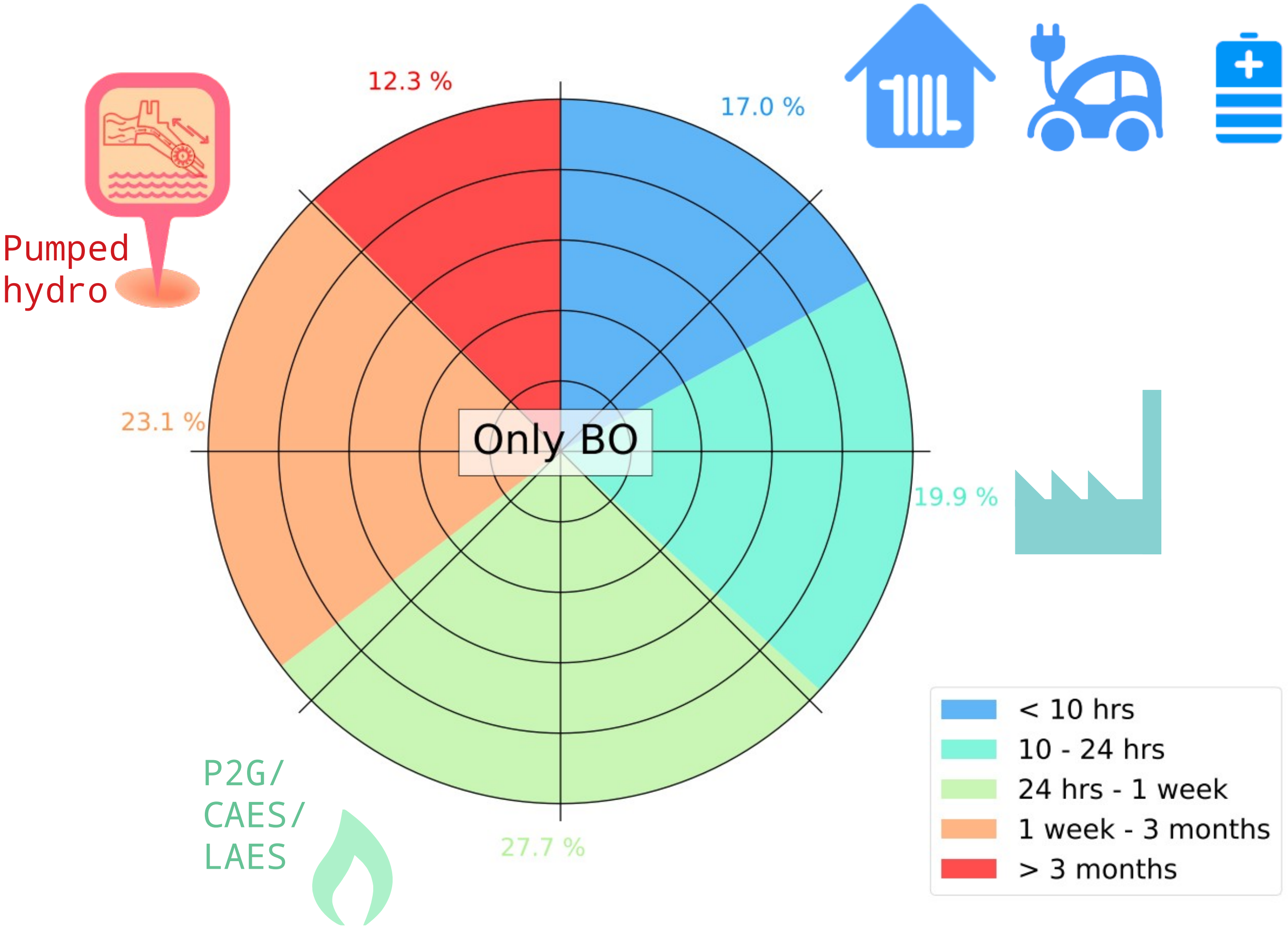
2. Optimal energy storage (ES) options for Bornholm

The residual load can be decomposed into different frequency components with a Fourier transform:



2. Optimal energy storage (ES) options for Bornholm

The integrated power at each frequency tells us what ES options are more important:



2. Optimal energy storage (ES) options for Bornholm

Isolating just the shortest fluctuations, how many residential houses would they correspond to?:

- Each house with heat pump can on average react with 0.79 kW in good conditions (temperature = -3.5, throttle signal no longer than 1 hour)

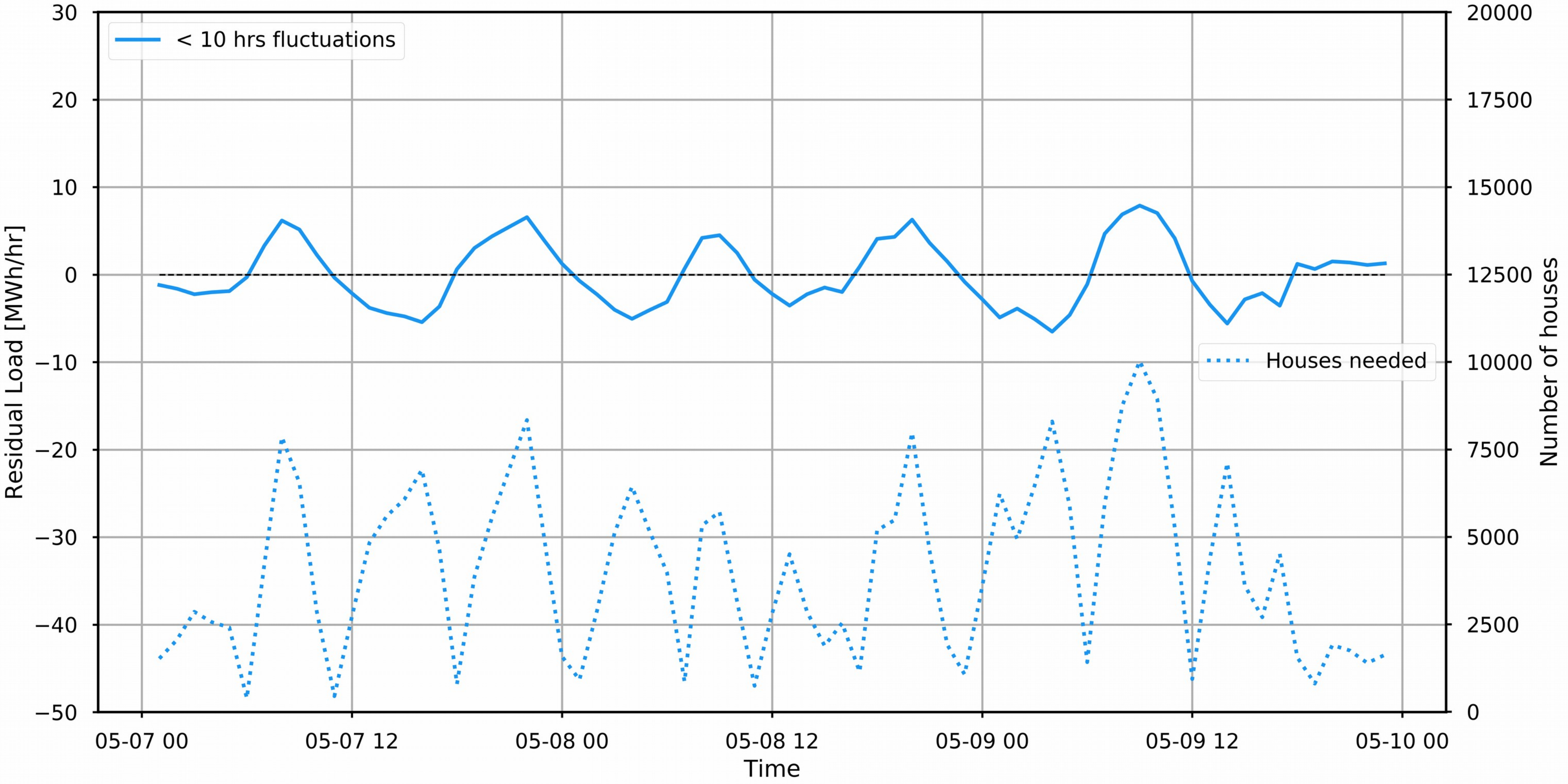
  [Müller+18]

If an ES option works at a power of P_{ES}, the power in a frequency interval i correponds to a number of $N_{ES}(t)$ in each time step dt:

$$N_{ES}(t) = iFFT(t)/(P_{ES})$$

2. Optimal energy storage (ES) options for Bornholm

Isolating just the shortest fluctuations, how many residential houses would they correspond to?:



2. Optimal energy storage (ES) options for Bornholm

Isolating just the shortest fluctuations, how many residential houses would they correspond to?:

- Each house with heat pump can on average react with 0.79 kW in good conditions (temperature = -3.5, throttle signal no longer than 1 hour) [Müller+18]

On average:

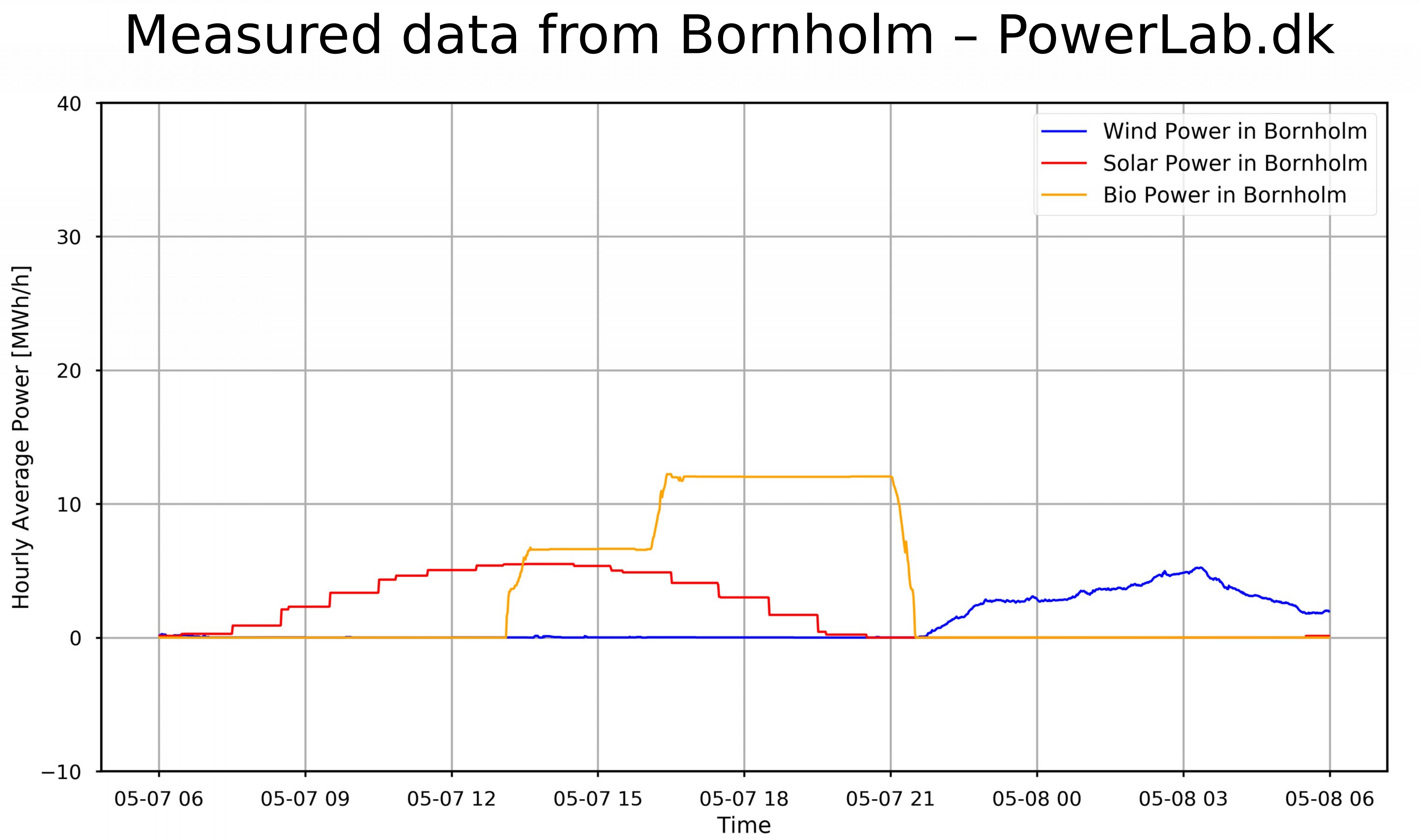
1,100 houses

Worst times:

34,350 houses

Electric heaters might yield more [Ziras et al. submitted]

3. Increasing the time resolution from 1hr to 1min



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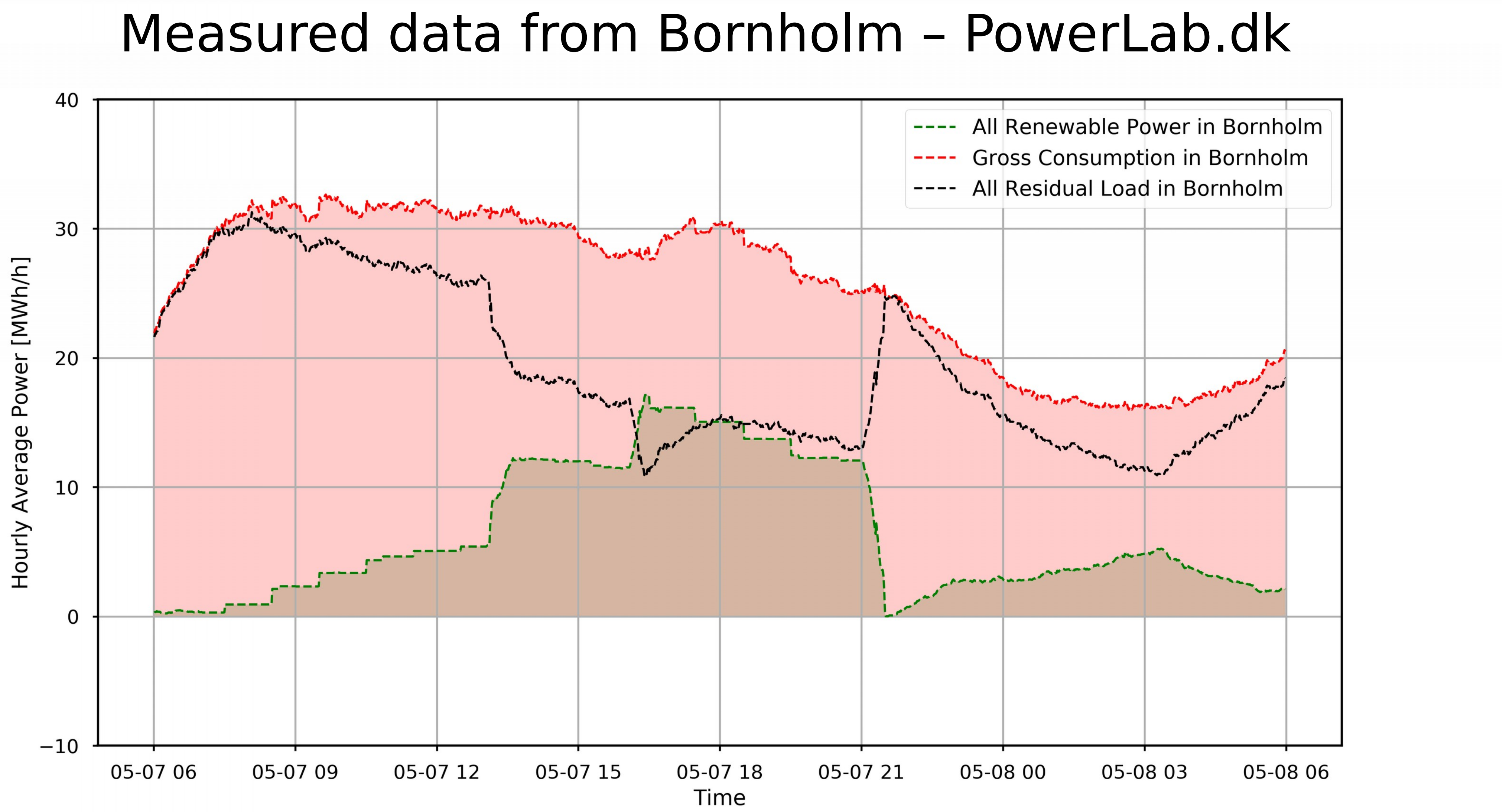
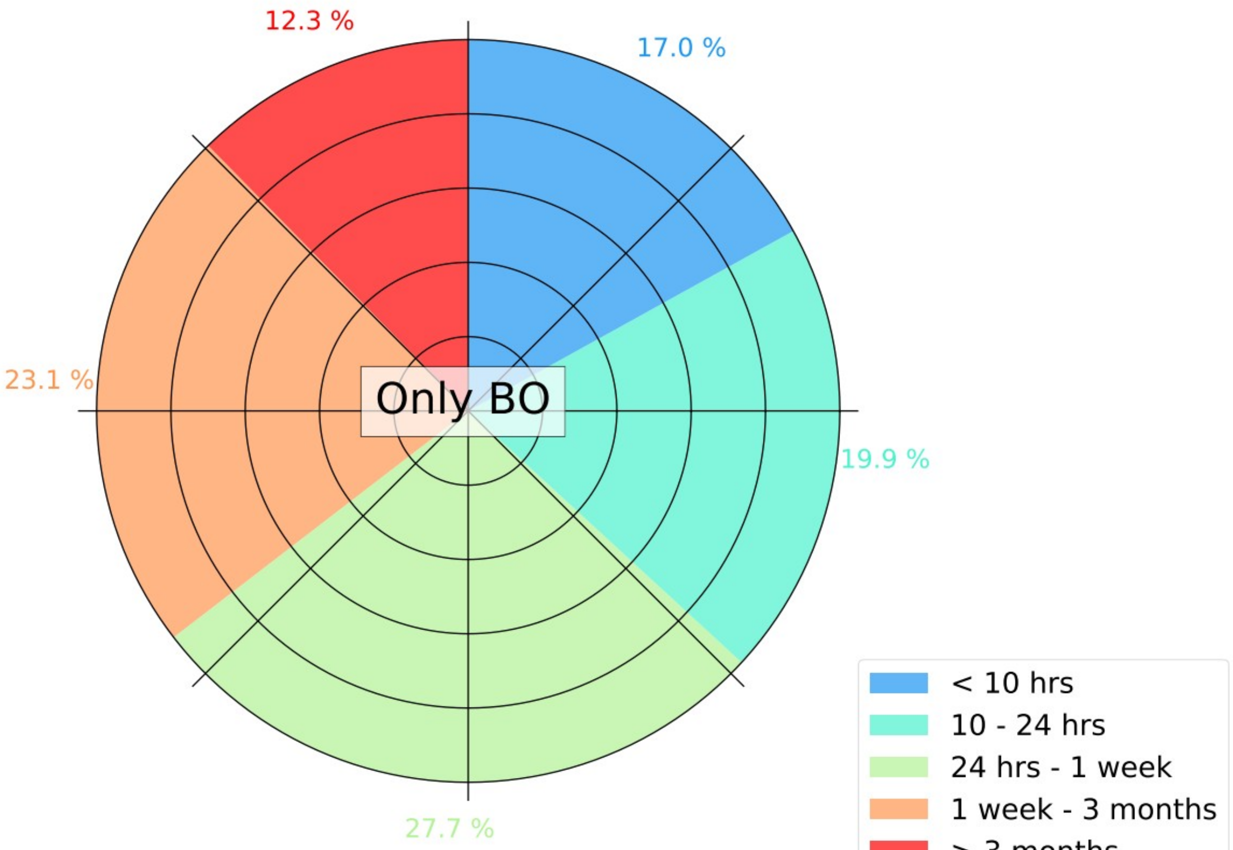
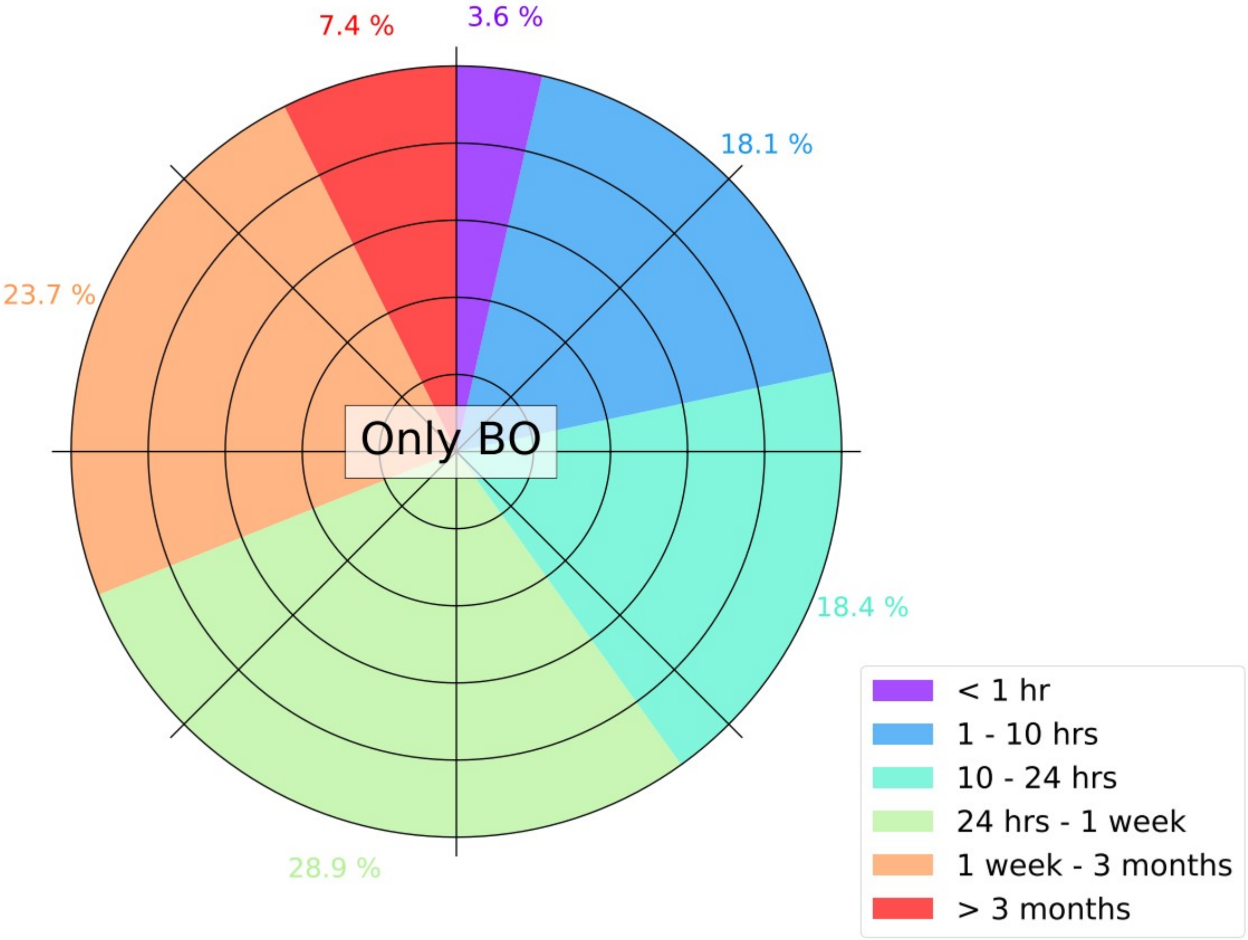


3. Increasing the time resolution from 1hr to 1min

The integrated power of each frequency interval:



Hourly resolution data



Minute resolution data

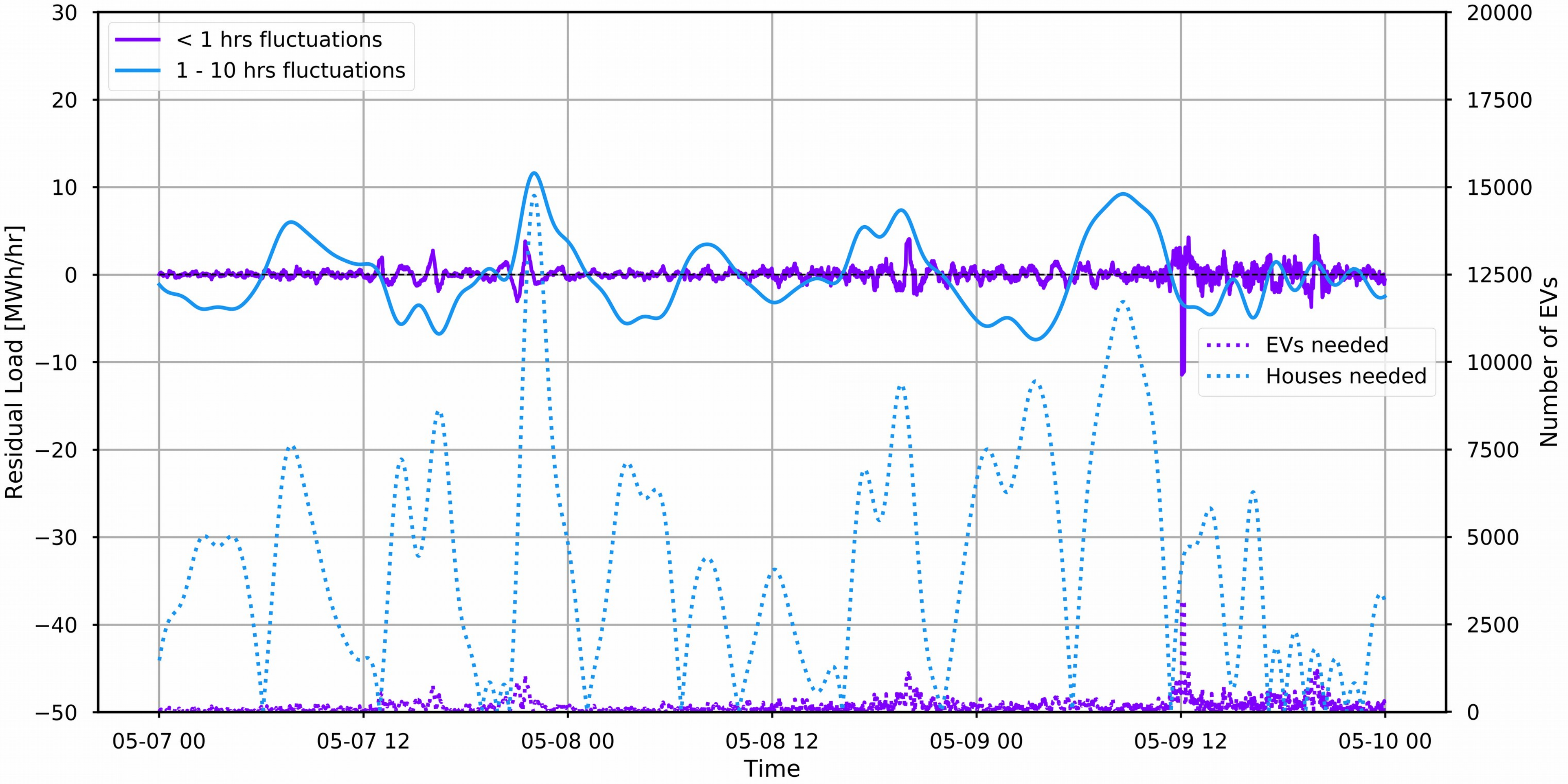
3. Increasing the time resolution from 1hr to 1min

Isolating just the shortest fluctuations, how many EVs would they correspond to?:

- Each residential charger works at a nominal charging power of ~3.6 kW house [ACES: González-garrido et al. in prep]

3. Increasing the time resolution from 1hr to 1min

Isolating just the shortest fluctuations, how many EVs would they correspond to?:



3. Increasing the time resolution from 1hr to 1min

Isolating just the shortest fluctuations, how many EVs would they correspond to?:

- Each residential charger works at a nominal charging power of ~3.6 kW house [ACES: González-garrido et al. in prep]
- Using mean residual load in 15 min intervals:

On average:

190 EVs

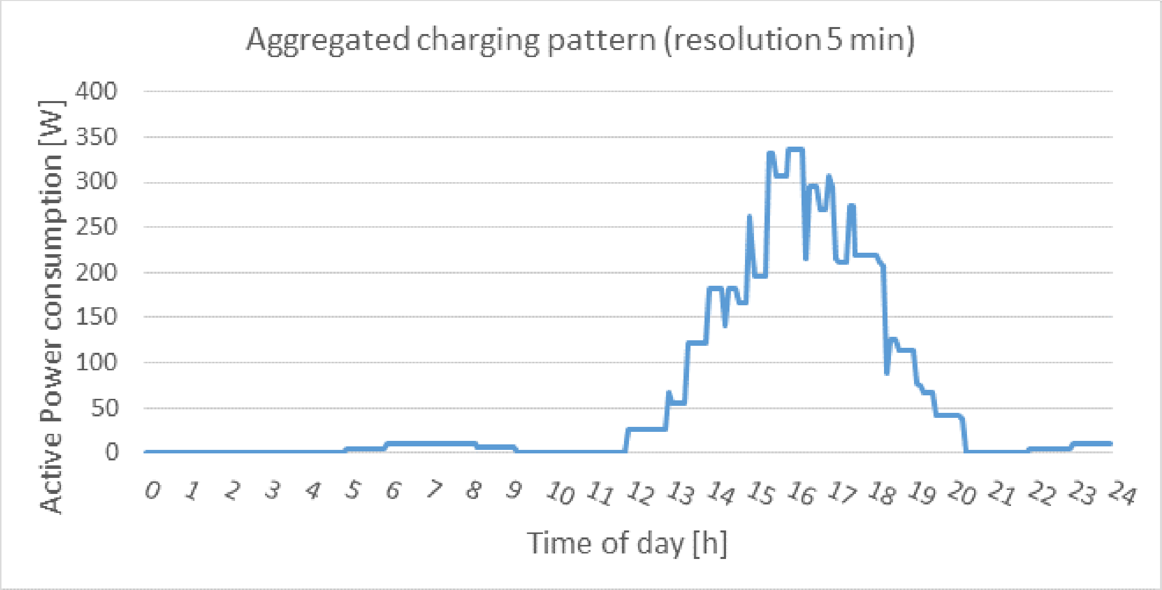
Worst times:

5232 EVs

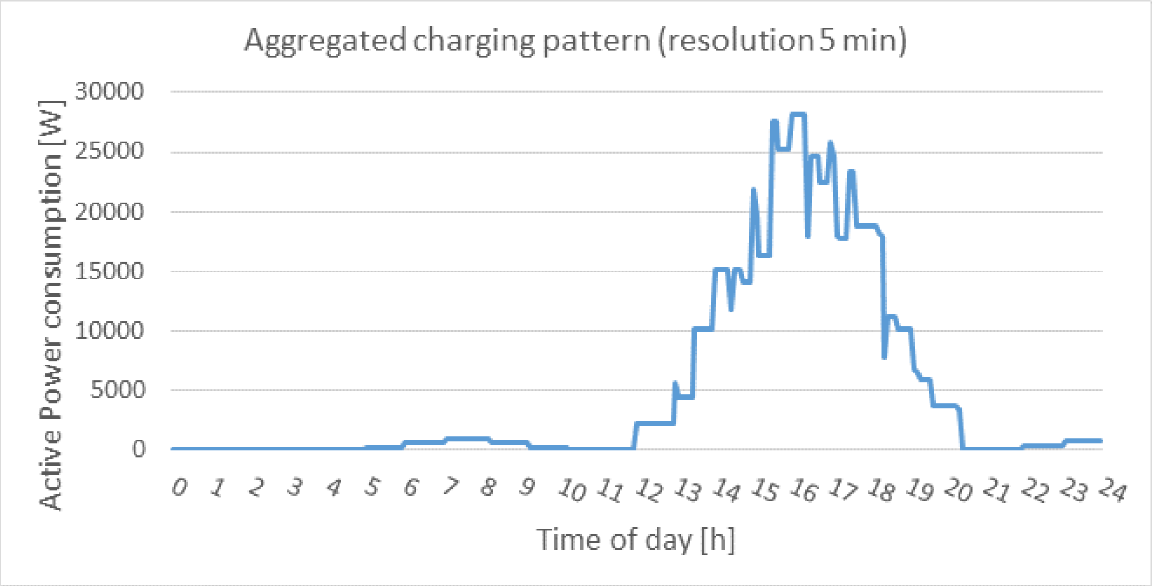
3. Increasing the time resolution from 1hr to 1min

Isolating just the shortest fluctuations, how many EVs would they correspond to?:

Caveats - actual EV availability follows a pattern, as simulations show:



200 EVs



17,000 EVs

[ACES]

3. Increasing the time resolution from 1hr to 1min

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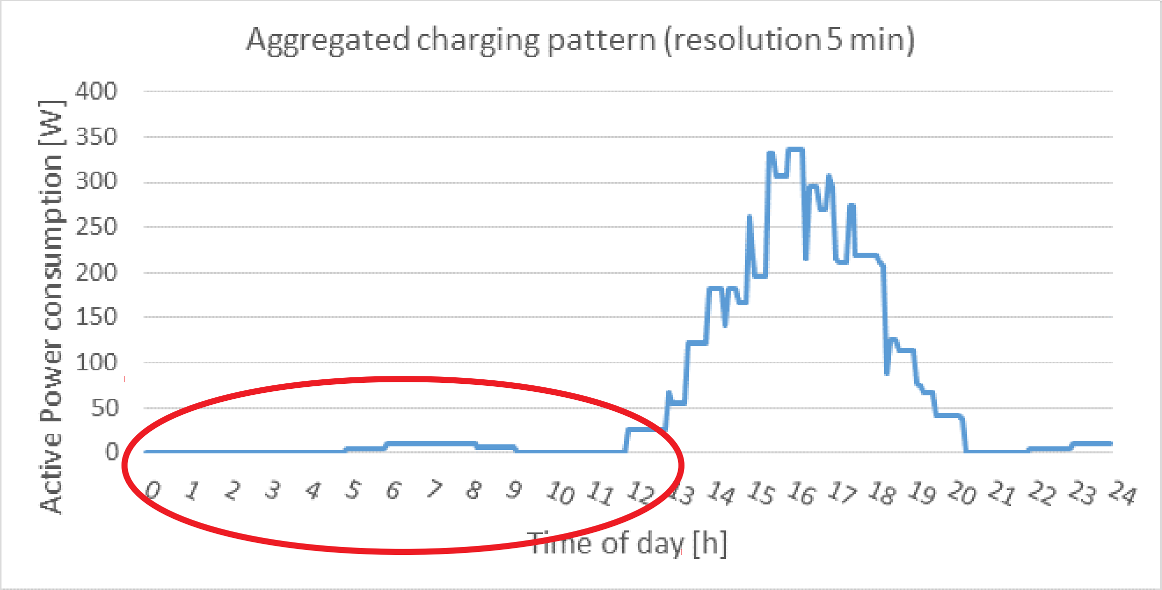
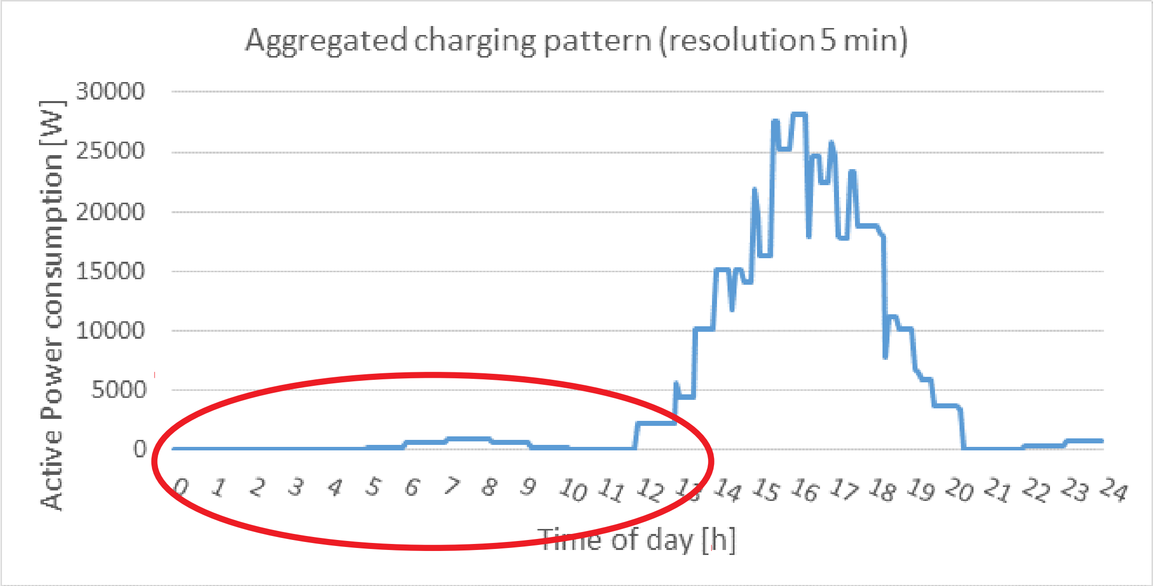


200 EVs



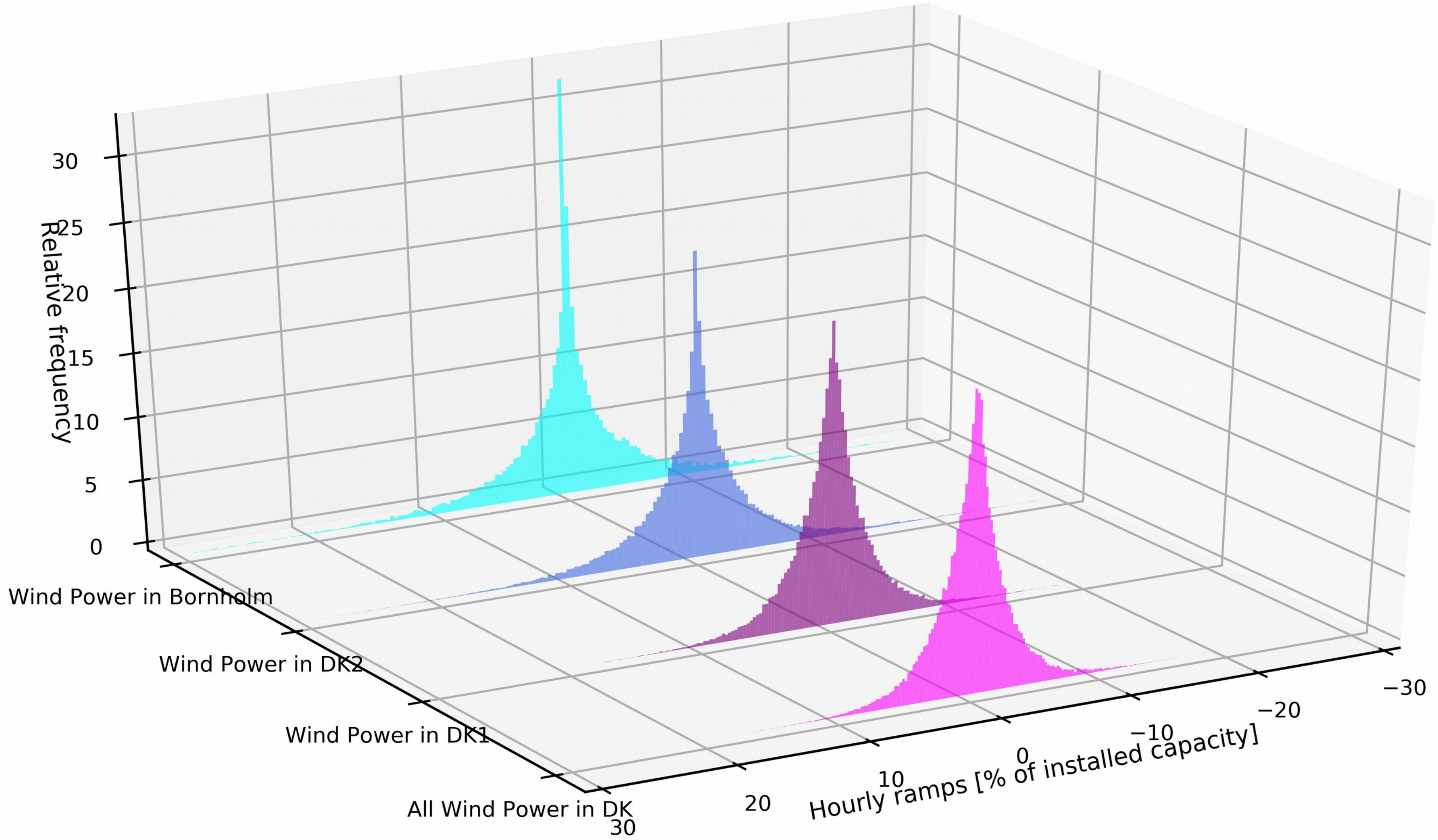
17,000 EVs

With the current (residential only) chargers, there are times of the day with no EV (dis)charging possible.

[ACES]

4. Using data to verify simulations of wind power production

Hourly ramps with data from Energinet and PowerLabDK:



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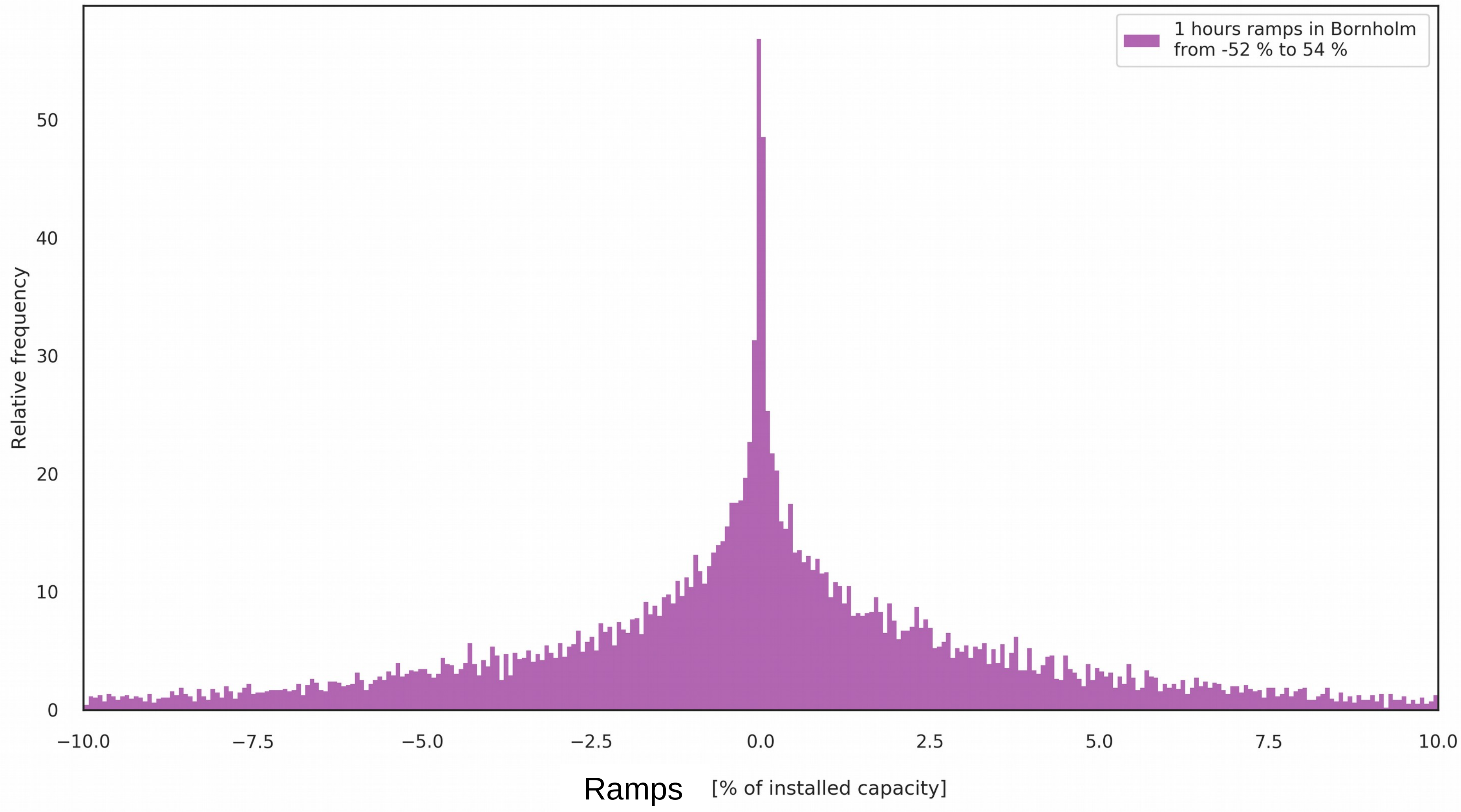

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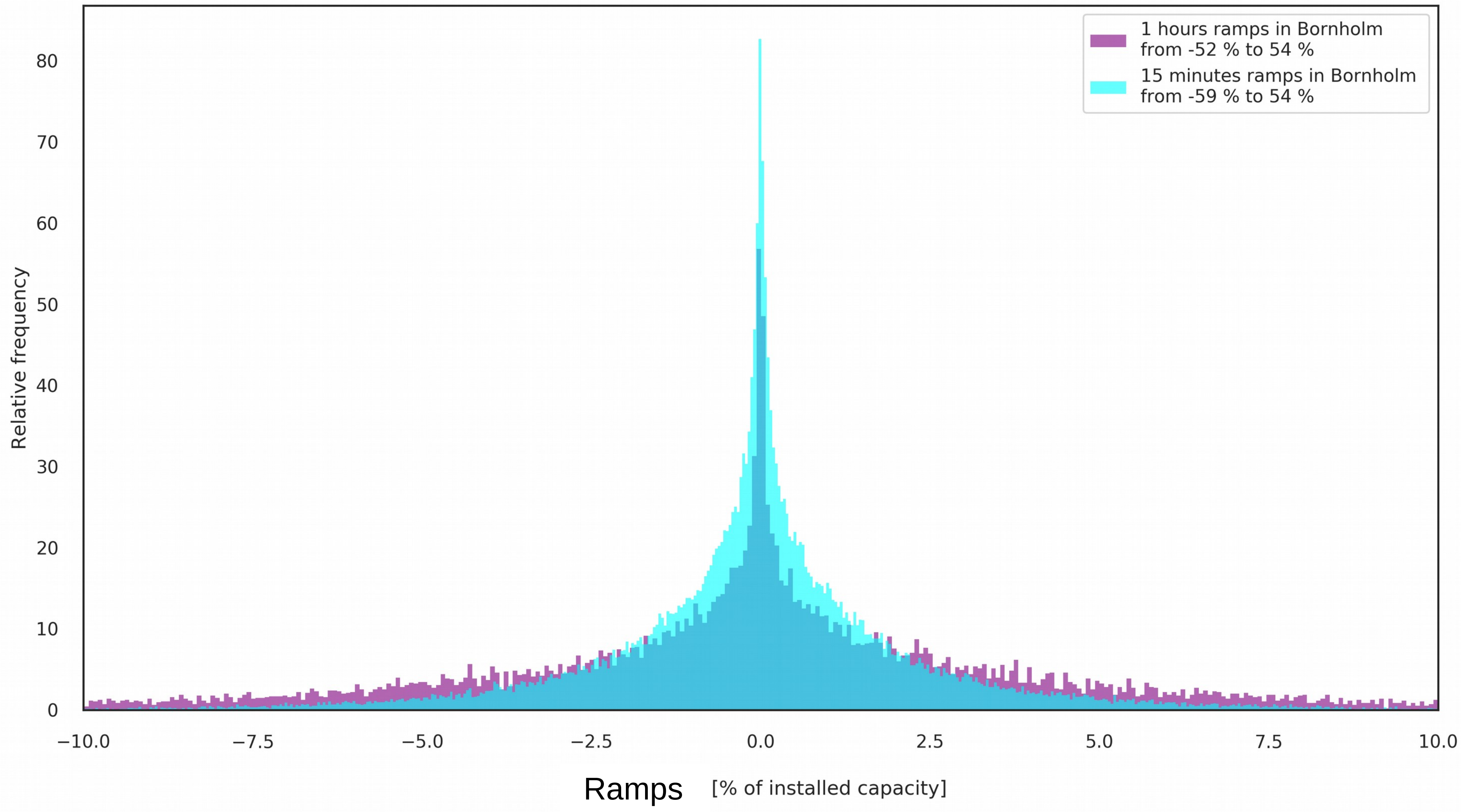

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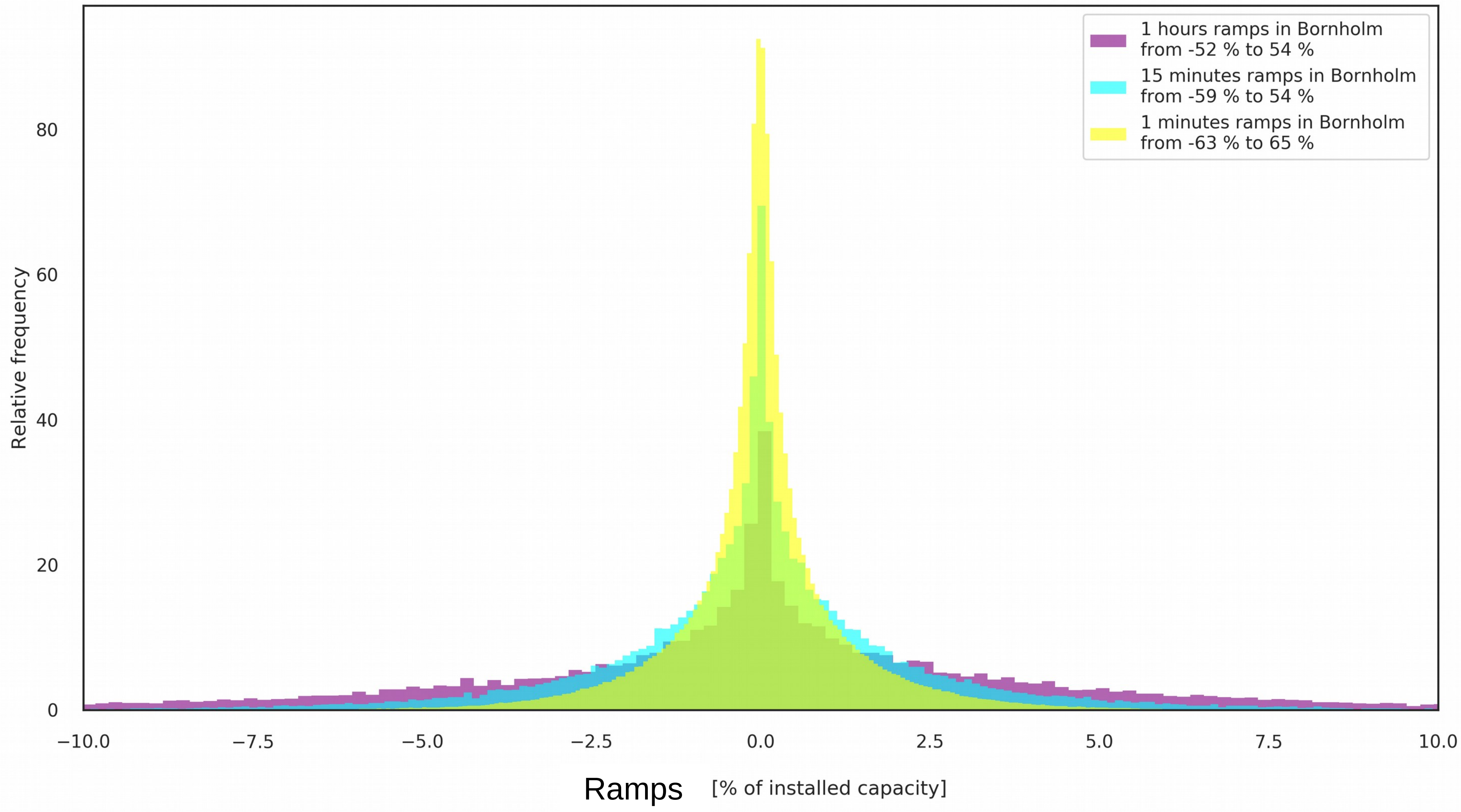

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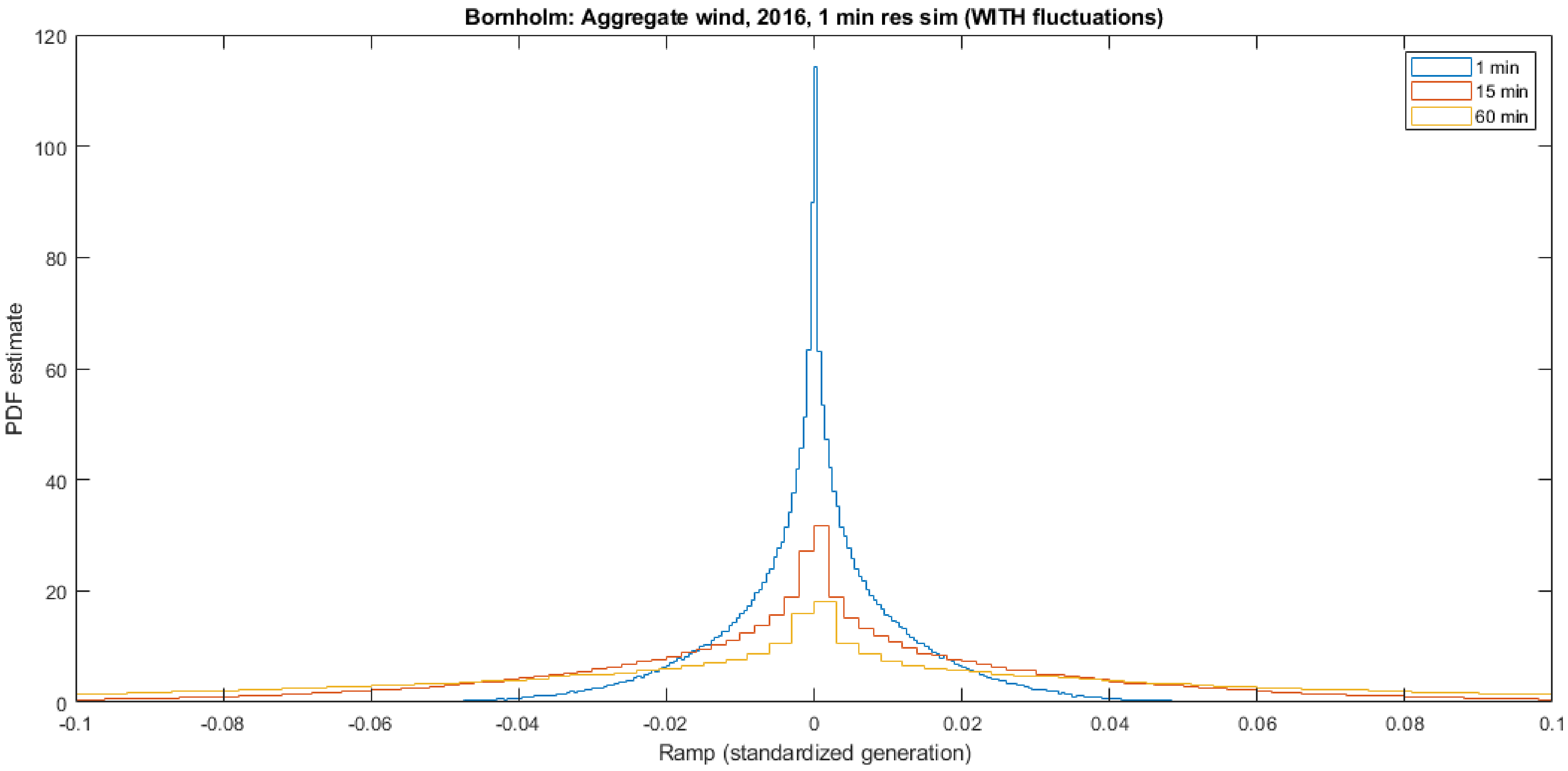

Simulations by Matti Koivisto, DTU Wind Energy

Extra slides...

2. Optimal energy storage (ES) options for Bornholm

Energy in frequency interval i:

$$E_i[MW * dt] = \int_{t_{start}}^{t_{end}} abs(iFFT_i(t))dt,$$

Mean power in time span Δt, measured in time steps dt:

$$< P_i[MW] >= E_i[MW * dt]/(\Delta t[dt])$$

If an ES option works at a power of P_{ES} over that entire time span, it would take a number of:

$$N_{ES} = P_i/(P_{ES})$$

- we consider *dt* from 1 min to 1 hour, and time spans (Δt) of 1 hour.

Why do we care about energy storage?

Operational flexibility provided by storage in generation expansion planning with high shares of renewables

Arne van Stiphout[1, 2], Kristof De Vos[1, 2], Geert Deconinck[1, 2]

“...as the RES target increases, and with it the need for operational flexibility, storage has more added value.” - 2015

Why do we care about energy storage?

Siting and Sizing Dispersed Energy Storage in Power Transmission Networks

M. Moreira da Silva[1], R. Pastor[1], T. Shi[2], L. Zhao[1,2], J. Ye[2]

"The algorithm is able to find solutions that minimize the total storage capacity and energy requirement, while reducing the investment cost. Yet a longer period of evaluation, with more scenarios and a real case study, are desirable to deepen the validation process of the algorithm." - 2015