How to design economic mechanisms for efficient operation of low-inertia power grids

TRANSIT

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3 topics covered

1. **Unlocking the support from DER** via risk-constrained optimization

2. From **low-level control** instructions to **system-level optimization** via data-driven methods

3. **Who should pay** for frequency-containment services?

Paper:

C. O'Malley, L. Badesa et al., "Frequency Response from Aggregated V2G Chargers With Uncertain EV Connections," ***IEEE Trans. on Power Systems***, 2023

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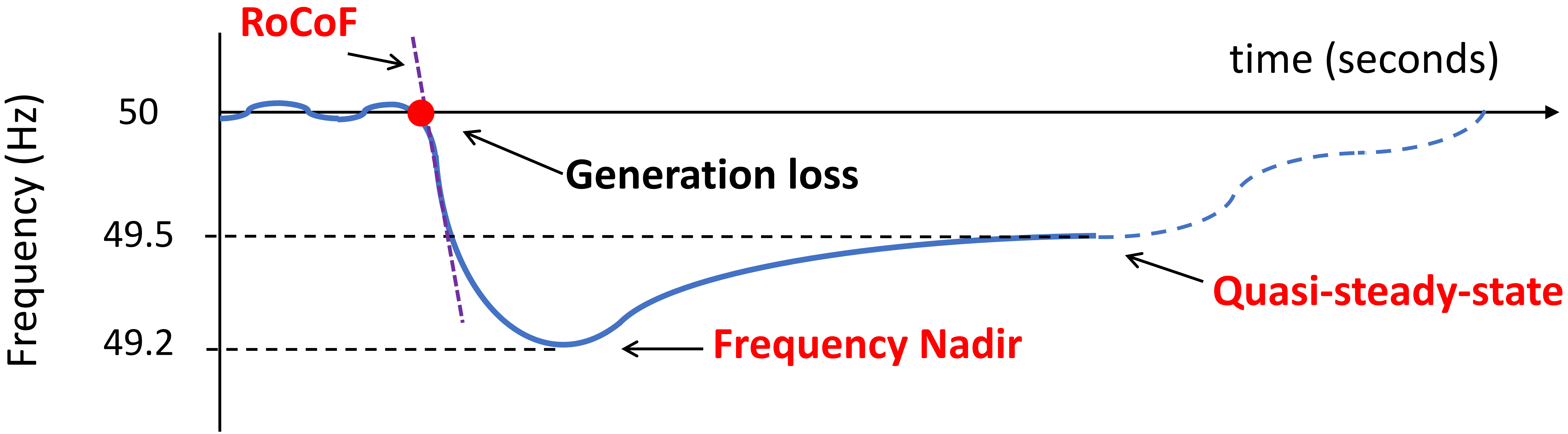
Frequency stability



Key to keep frequency within safe limits to **avoid demand disconnection!**

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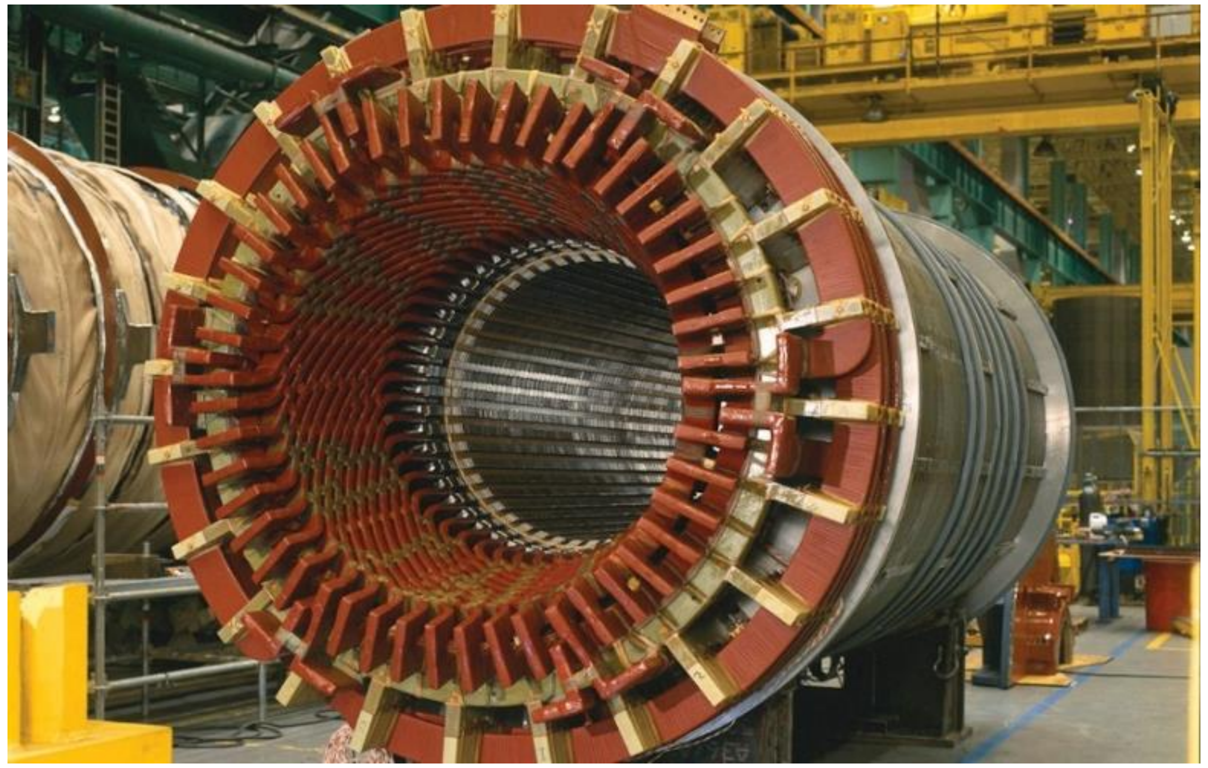
Lower inertia on the road to lower emissions

Thermal generators (nuclear, gas, coal…):



Decarbonization

Most renewables: ***no inertia***

The **risk of instability has increased!**

Inertia <u>stores kinetic energy</u>:
this energy gave us time to contain a sudden generation-demand imbalance

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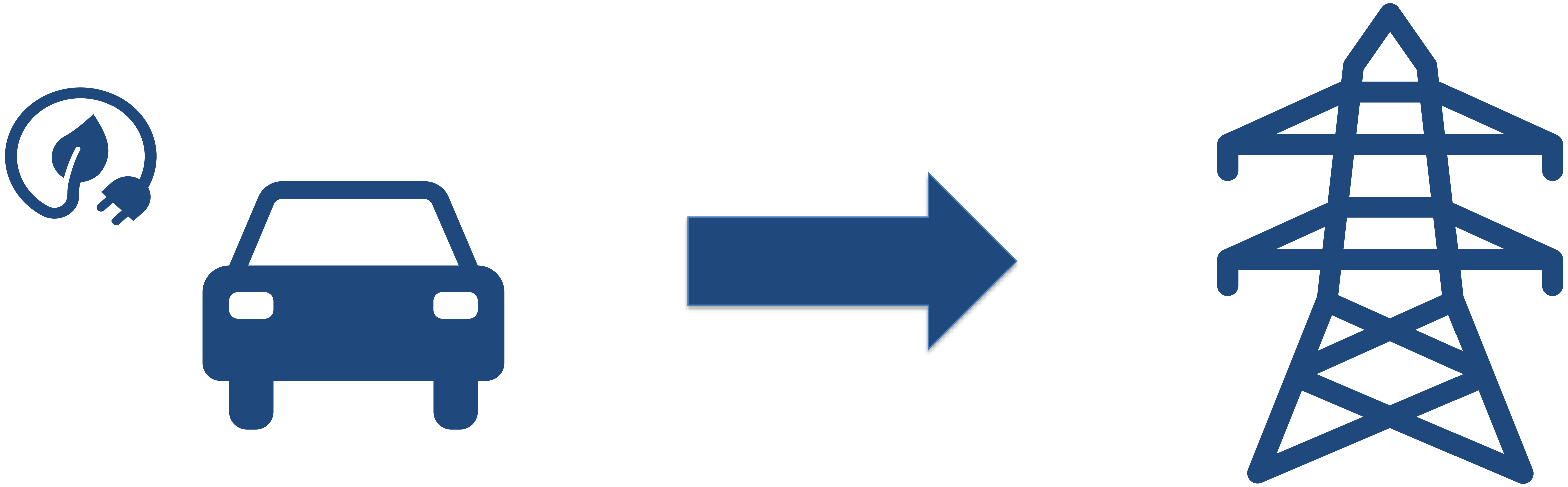
Unlocking support from Distributed Energy Resources

- **DER could be very valuable** to support system stability, but they are **inherently uncertain**

- We focus on **Vehicle-to-Grid (V2G)**: the system operator cannot control when the EV owners plug in their vehicles



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Why is this important?

Now → **Future**

Stability through **gas plants**

- **Pros**: certain + reliable
- **Cons**: expensive + polluting

Stability services from **DER**

- **Pros**: abundant + **cheap**
- **Cons**: uncertain

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Stability conditions for optimization

What is the **value of V2G** as a countermeasure to low inertia?

Ancillary services

Mapping the stability boundary

Economic optimization

Described by
differential equations
(timescale of sub-seconds)

Based on
algebraic equations
(timescale of min/hours)

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Uncertainty within the stability conditions

We propose the use of **chance constraints**:

Probability of complying with **stability limit** ≥ 1 - **ϵ**

Uncertainty in
EV plug-in times

Risk appetite
(*e.g.*, 1% chance of
under-delivery)

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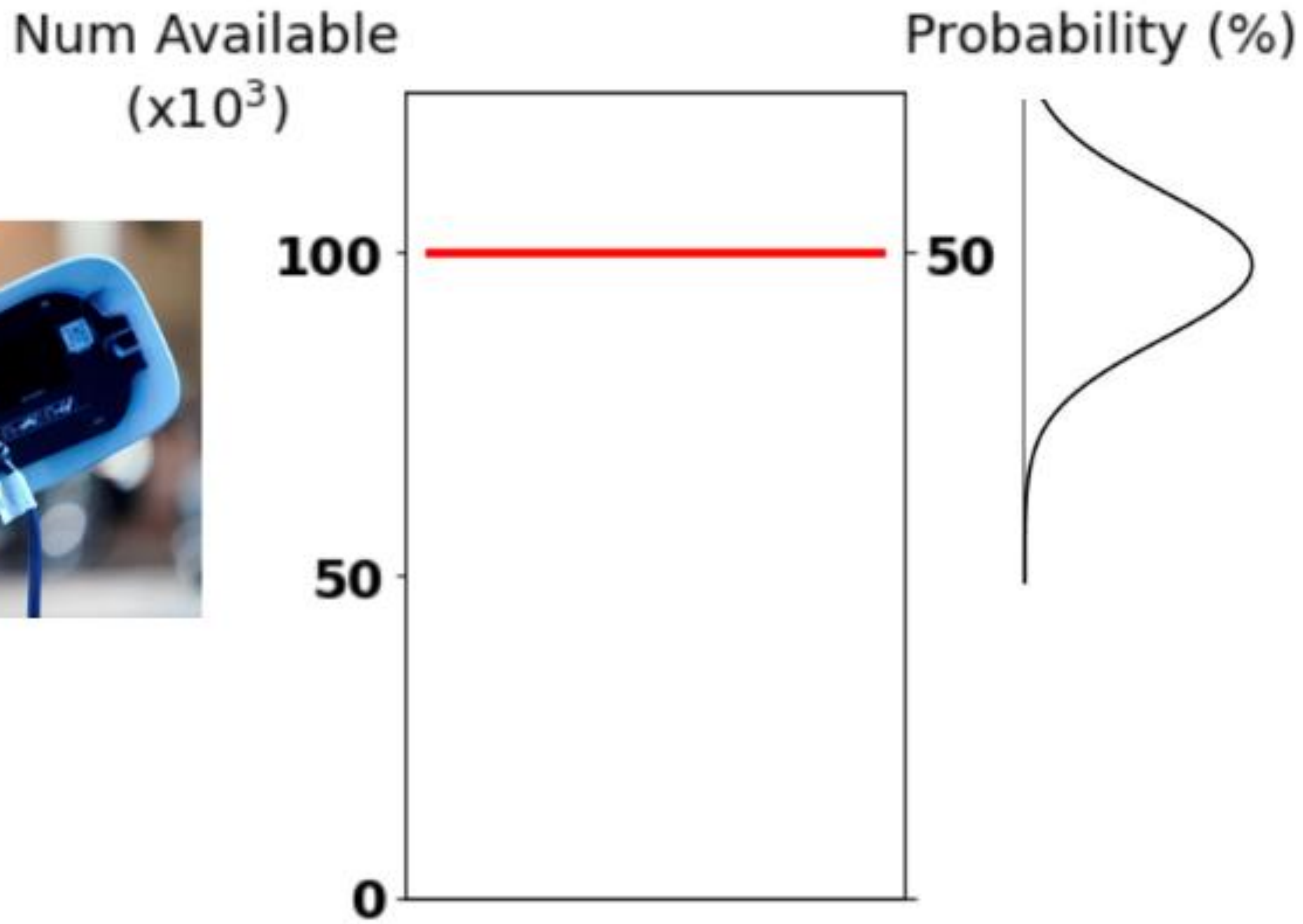
What do we mean by risk?

Probabilistic forecast
for EV connections



Naïve scheduling:

- Use **deterministic forecast** (mean)
- Count on 100k EVs
- 50% chance of having less than expected

Risky!

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What do we mean by risk?

Probabilistic forecast
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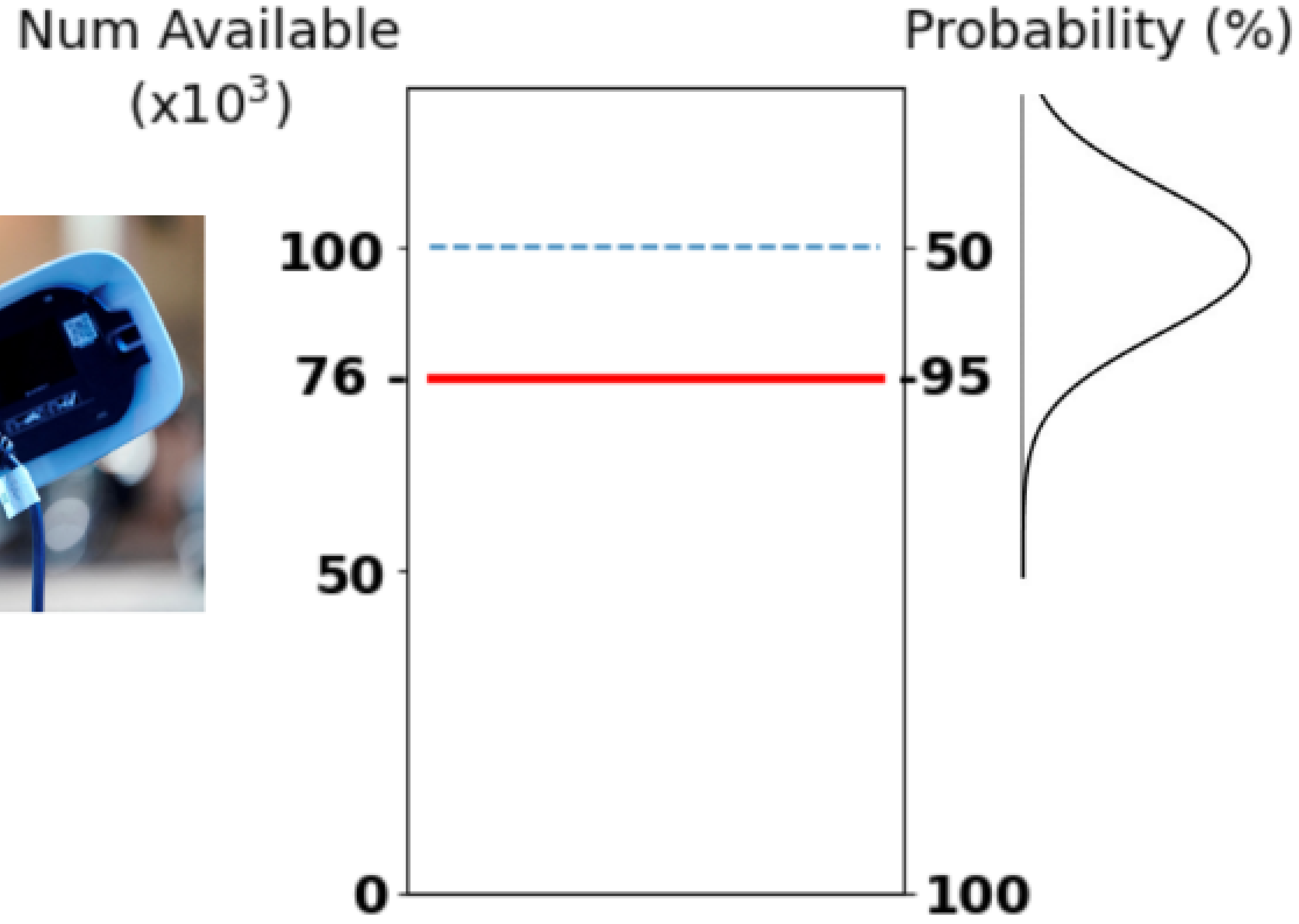

Risk-limited scheduling:

- Specify **risk tolerance** (*e.g.*, 5%)
- Count on **76k** EVs

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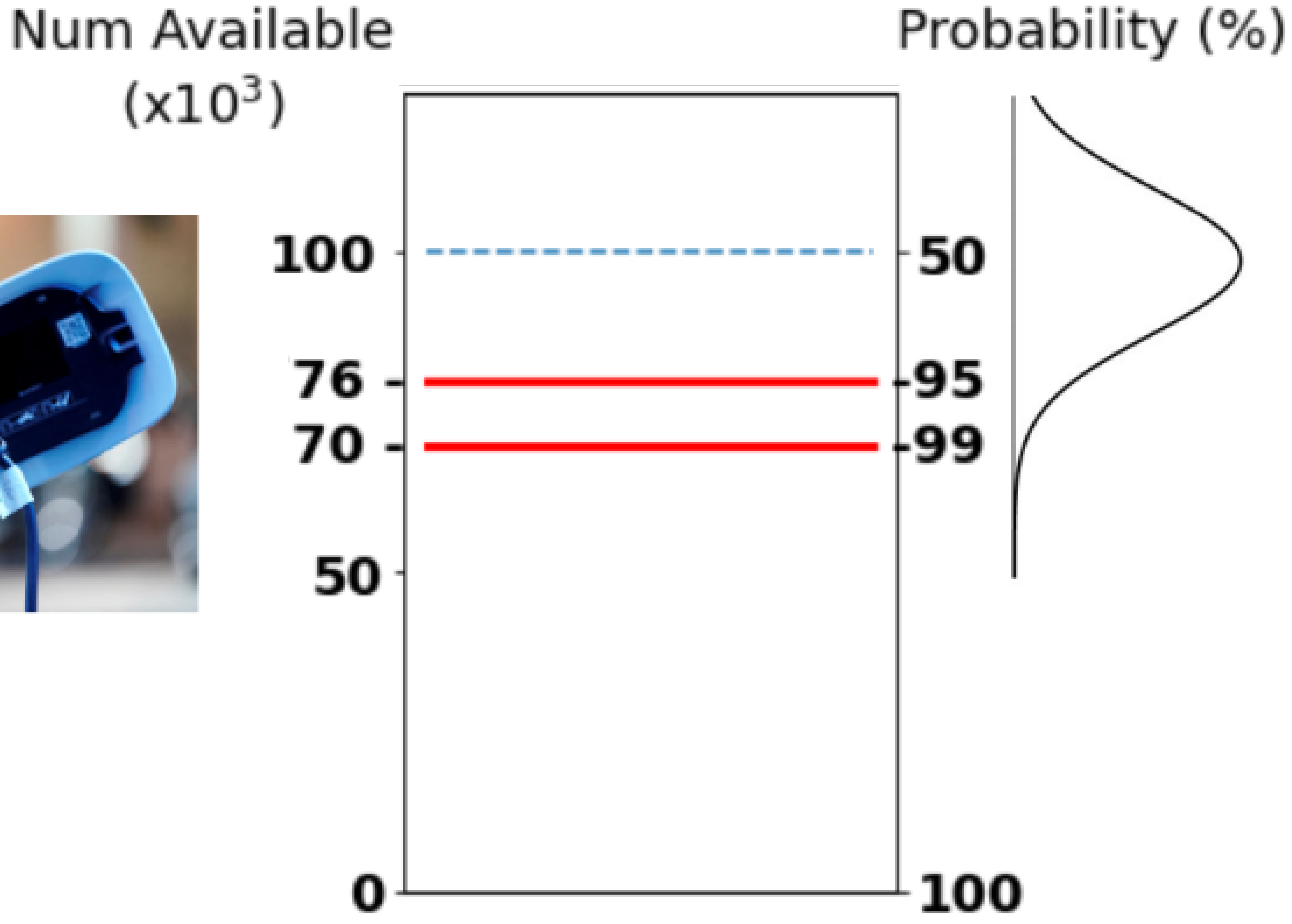
What do we mean by risk?

Probabilistic forecast
for EV connections



Risk-limited scheduling:

- Specify **risk tolerance** (*e.g.*, **1%**)
- Count on **70k** EVs

Lower risk implies less support from EVs considered

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Steps for deducing chance constraints

1. Model system frequency via **single-machine swing equation**:

$$\frac{2H}{f_0}\frac{d\Delta f}{dt} = R^{EV}(t) + R^{ND}(t) + R^{G}(t) - PL_{max}$$

2. **Solve swing equation** to obtain RoCoF and nadir **constraints**:

$$\mathbb{P}\left[\left(\frac{H}{f_0} - \frac{(R^{ND} + R^{EV})\cdot T_1}{4\Delta f_{max}}\right)\frac{R^G}{T_2} \geq \left(\frac{PL_{max} - (R^{ND} + R^{EV})}{2\sqrt{\Delta f_{max}}}\right)^2\right] \geq 1 - \epsilon$$

3. Use a **convex reformulation** for the non-convex chance constraints

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Convexification of chance constraint

Several options for the **convex reformulation**:

The **more information** available in the forecast,
the **less conservative** the reformulation:

- **Gaussian** uncertainty?
- **Unimodal** distribution? (single peak)
- Only mean and variance known?
  Distributionally-robust formulation (most conservative)

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Results for Great Britain

- **Frequency-secured UC** run for a full year in 2030

- Two **EV fleets** considered:
  - ‘**Domestic** V2G’: 85,000 units, 10 kW chargers
  - ‘**Work** V2G’: 15,000 units, 20 kW chargers

- **Risk** of under-delivery set at **1%**
  - Does **not mean** 1% risk of **violating security**: that risk is extremely small (largest *N*-1 contingency needs to happen too)

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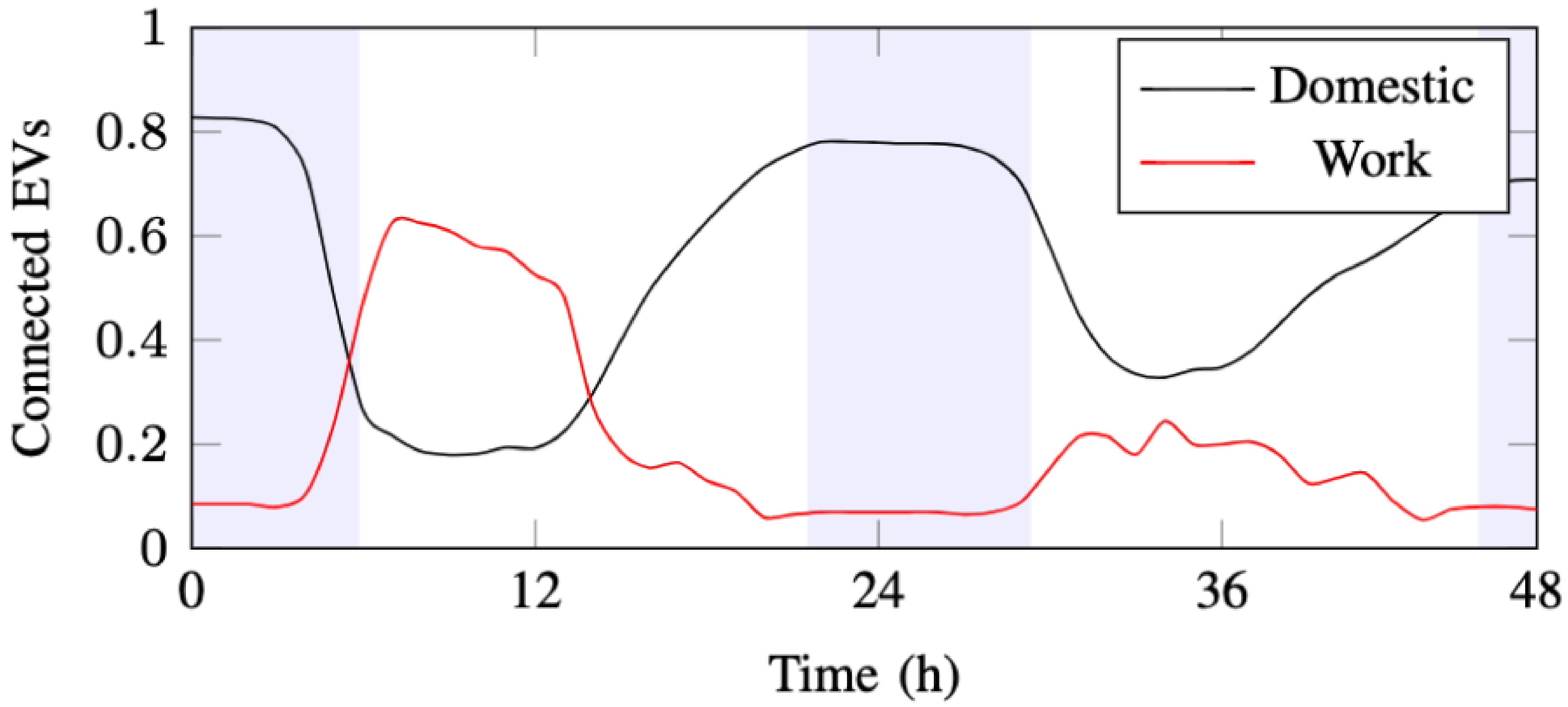
EV connectivity forecasting and data analysis

Data from UK Department of Transport, 2017



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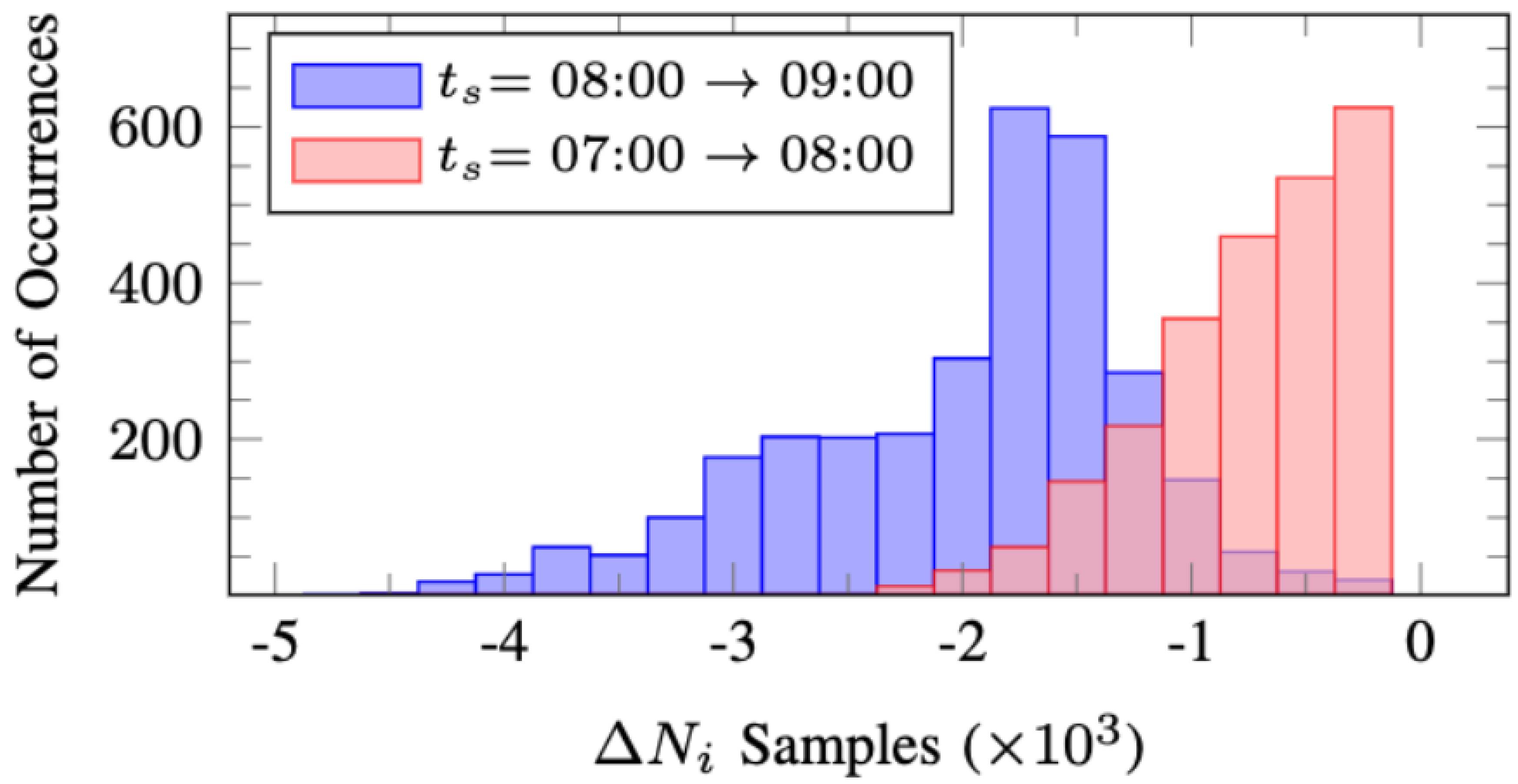
Test for ambiguity set

Domestic fleet disconnections
on weekday



- **Not** Gaussian
- **Unimodal** with high confidence (from Shapiro-Wilk test)

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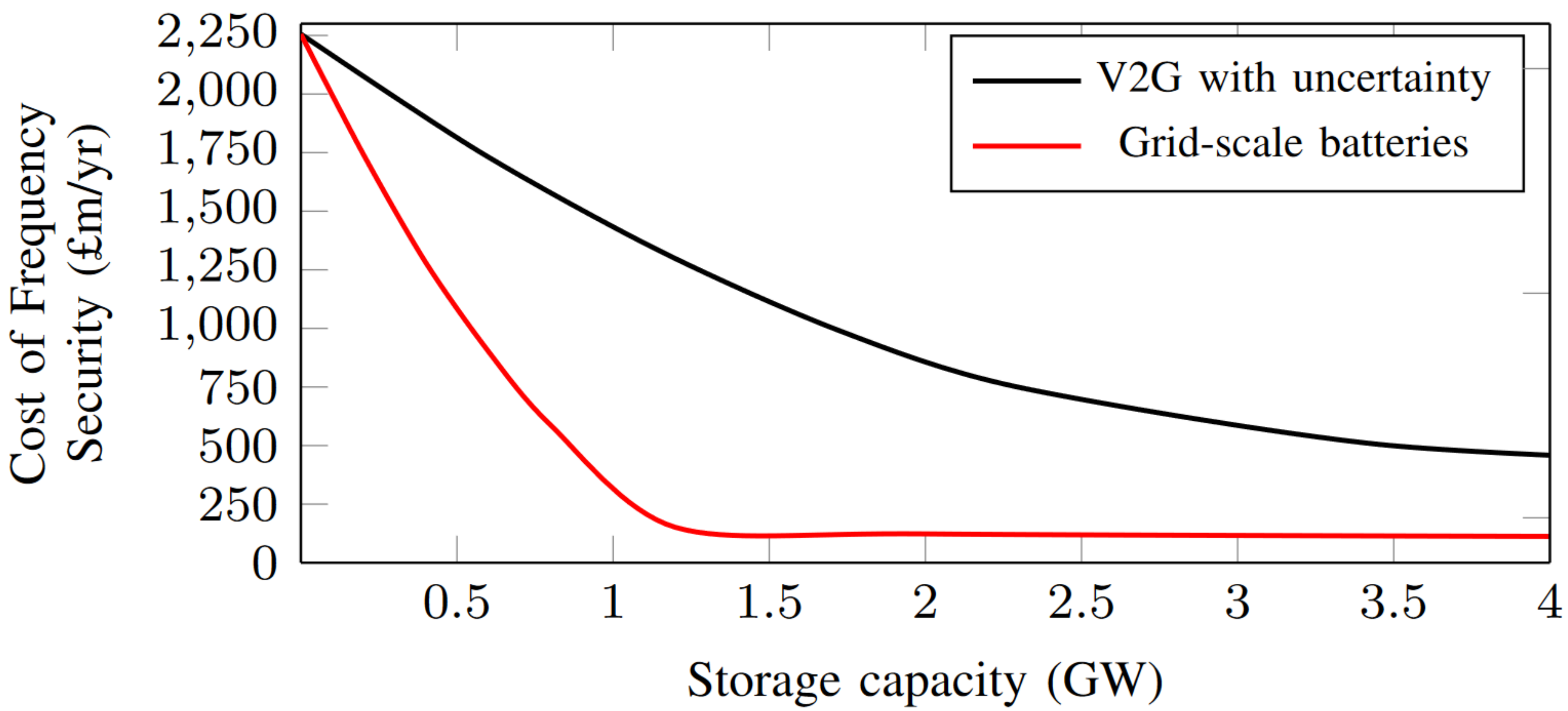
Results: comparison of V2G to BESS

V2G capacity shown to be **one third as valuable** as stationary BESS

- EV chargers only have an **EV connected ~40% of the time**
- EV chargers are subject to **uncertainty**



But EVs have **no additional** investment cost!

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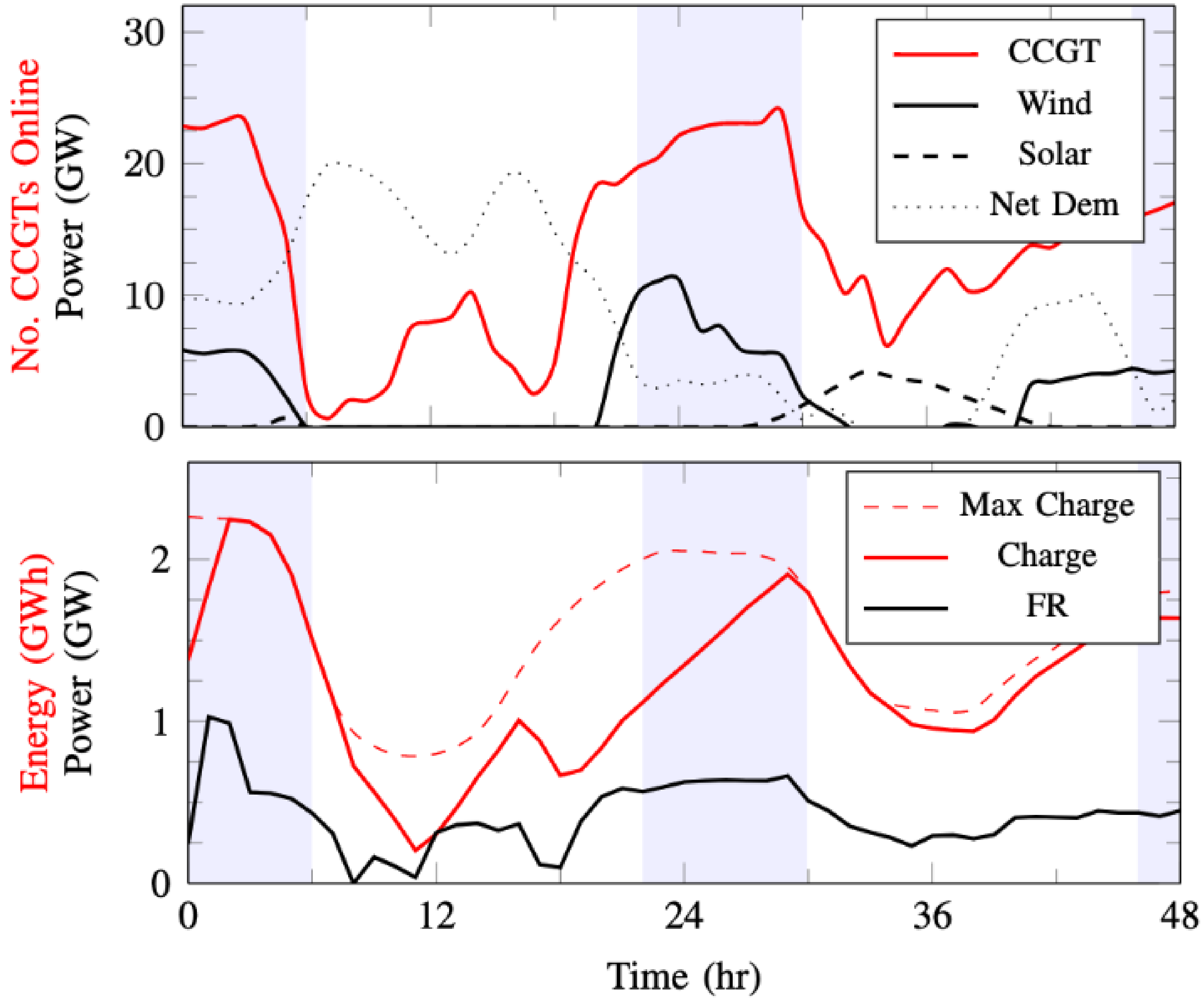
Where does this value come from?



Fewer CCGTs are needed,

thanks to **frequency support** from **EVs**

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Thank you for your attention!

All papers and some related code on my website:

https://badber.github.io/

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