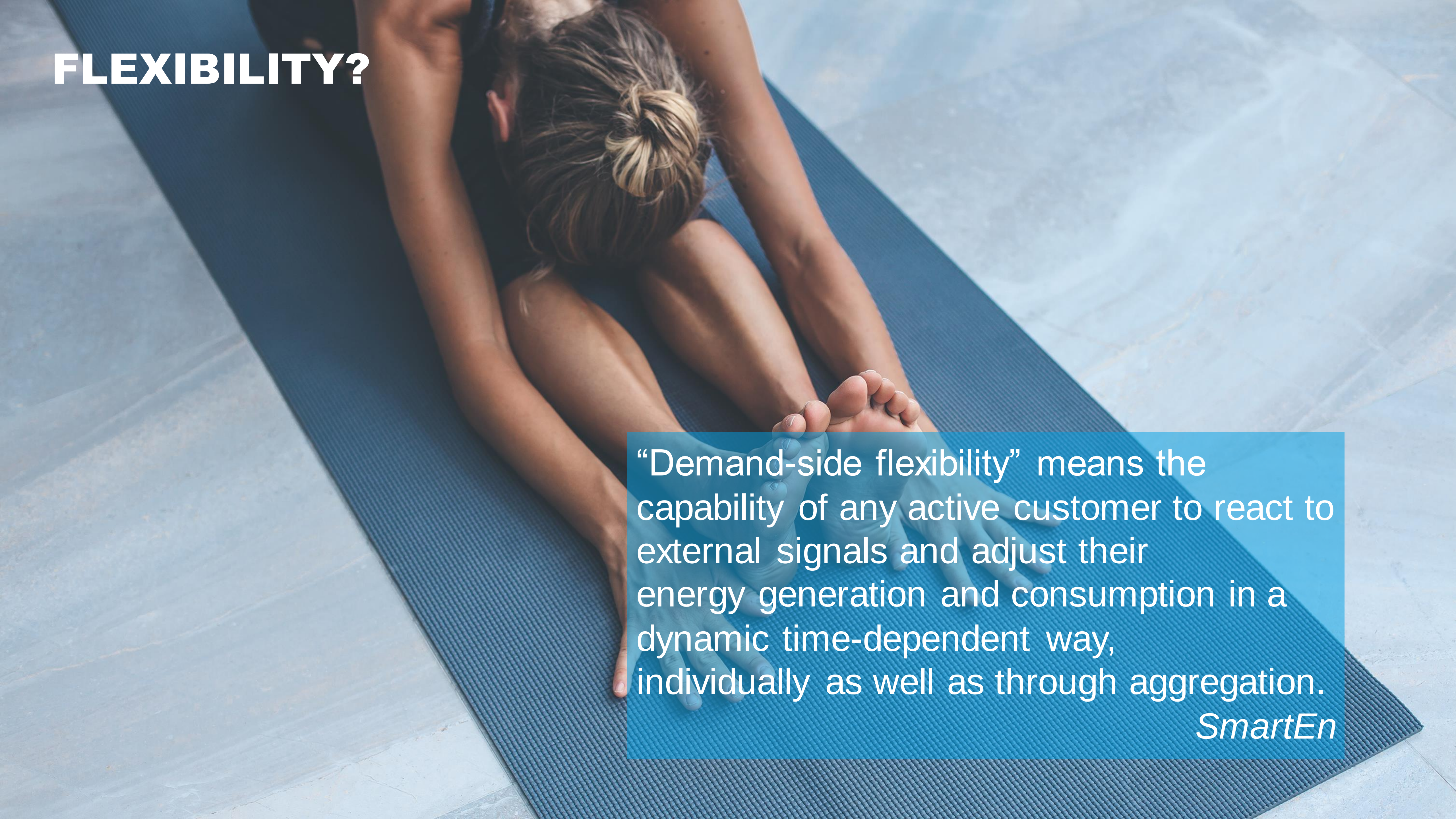
Pierre-Jean Alet
Group Leader, Digital Energy Solutions

23.06.2023

MANAGING THE UNCERTAINTY IN DEMAND-SIDE FLEXIBILITY FOR POWER NETWORKS

FLEXIBILITY?



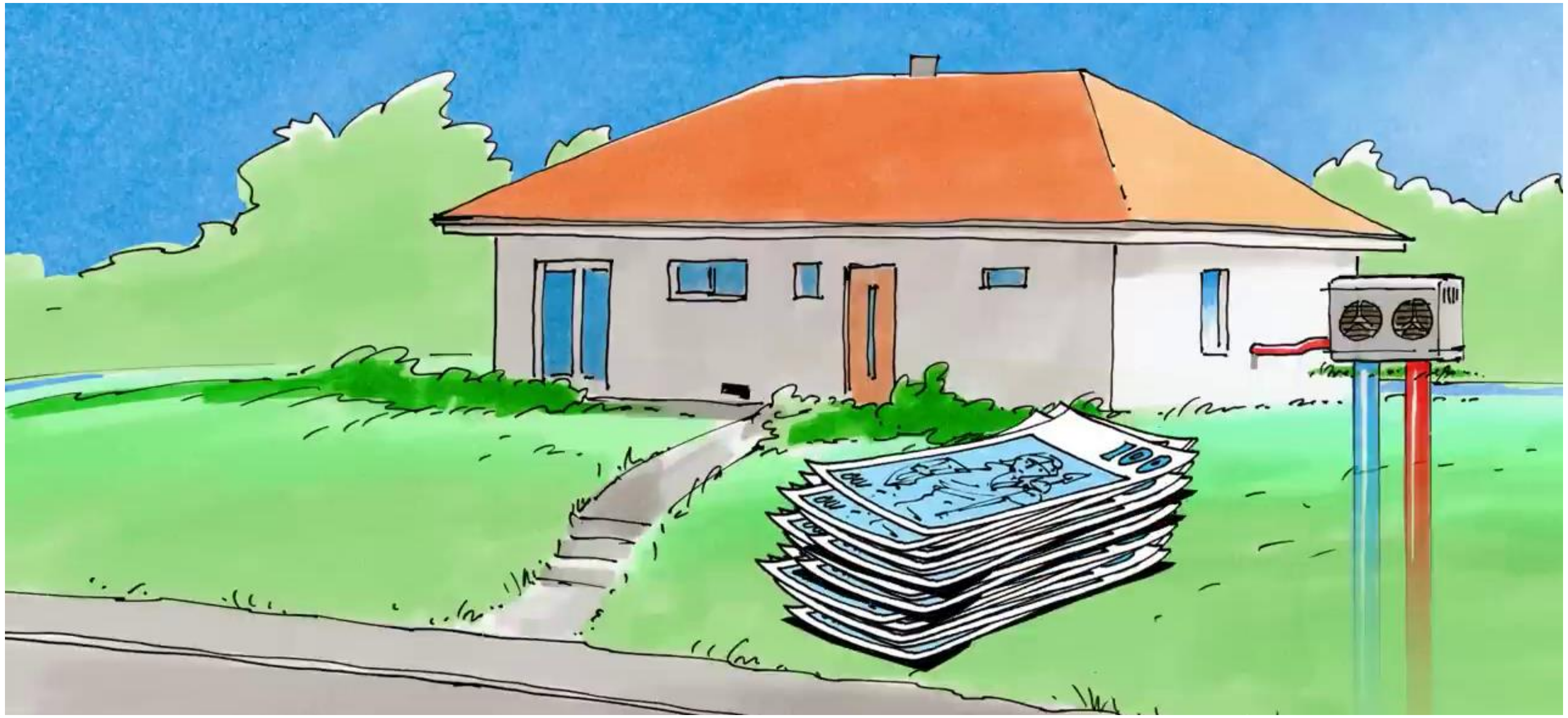
"Demand-side flexibility" means the capability of any active customer to react to external signals and adjust their energy generation and consumption in a dynamic time-dependent way, individually as well as through aggregation.

SmartEn

SWITZERLAND APPROVED THE "CLIMATE & INNOVATION" LAW

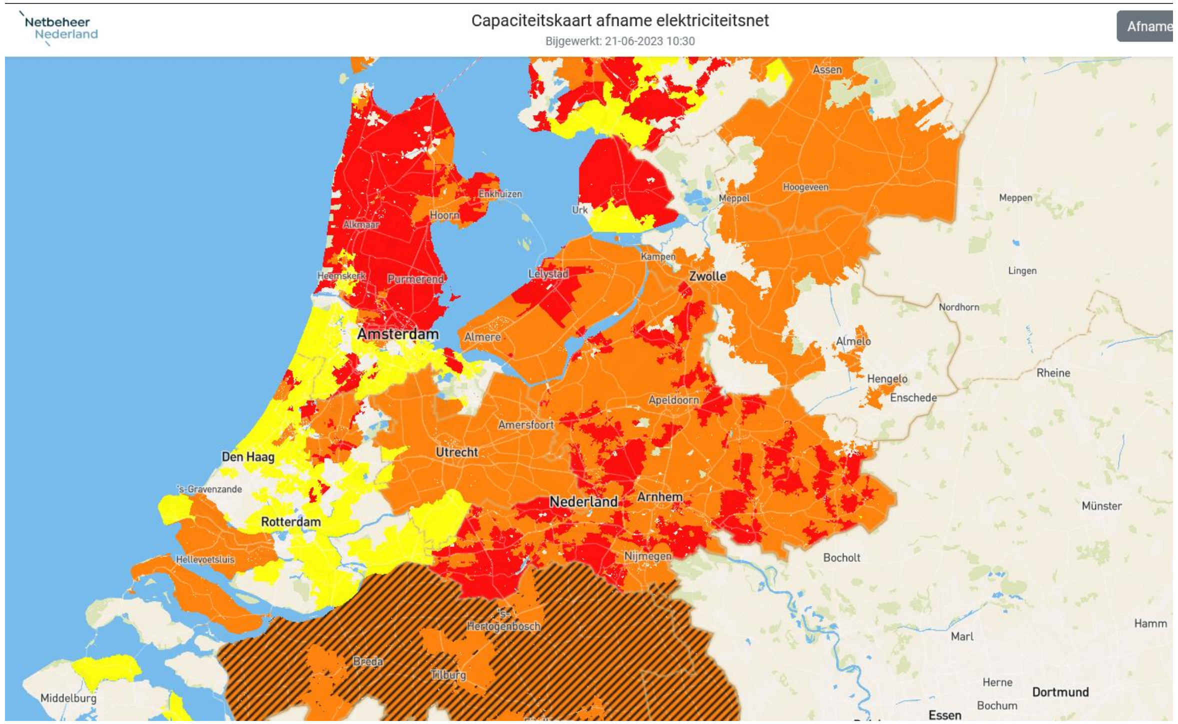
HAPPY CAMPAIGNERS

HAPPY HOMEOWNERS



Key measure: Support for replacing heating systems

TRANSFORMATION CHALLENGES



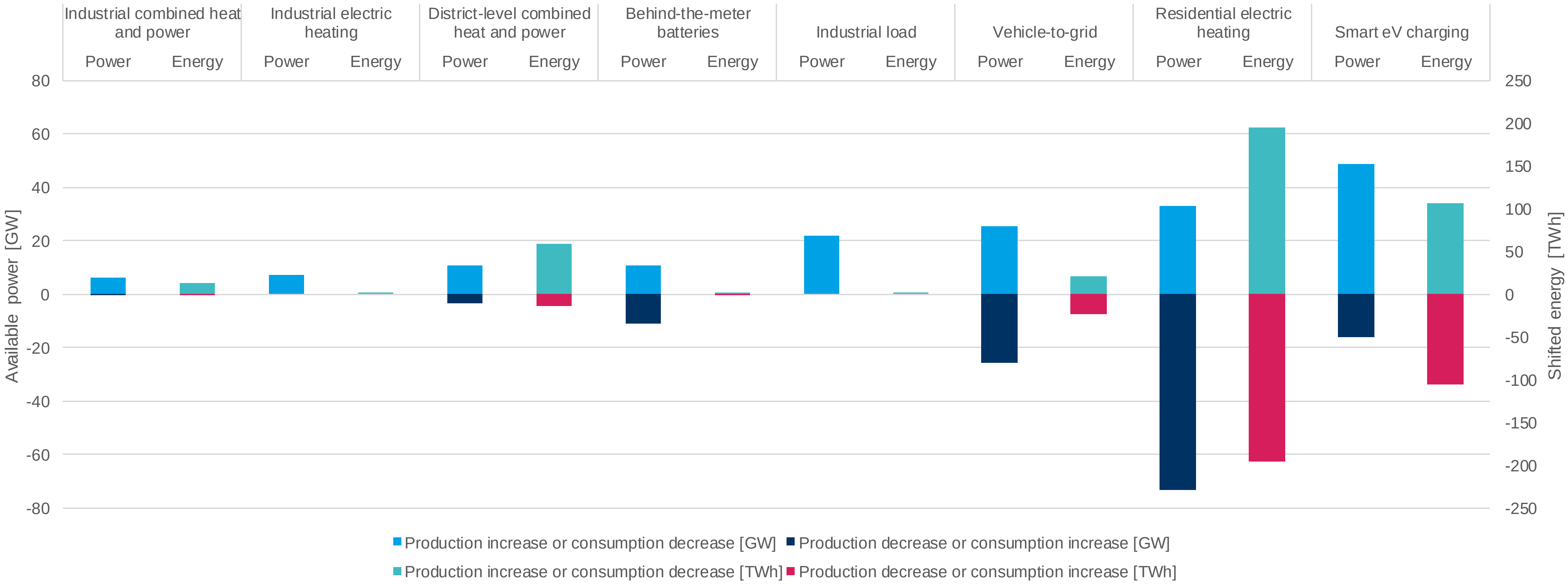
- **Fluctuations of renewable power production**
- Benefits of demand-side flexibility [1] (EU, 2030)
  - +15.5 TWh of renewable electricity
  - -43% to -66% lower balancing costs

- **Network congestion**
- Benefits of demand-side flexibility [1] (EU, 2030)
  - 11 bn€ to 29 bn€ saved in grid investment

[1] L. Fiorini, M. Miranda Castillo, and T. Slot, 'Demand-side flexibility in the EU: Quantification of benefits in 2030', smartEn, Brussels, Sep. 2022

csem

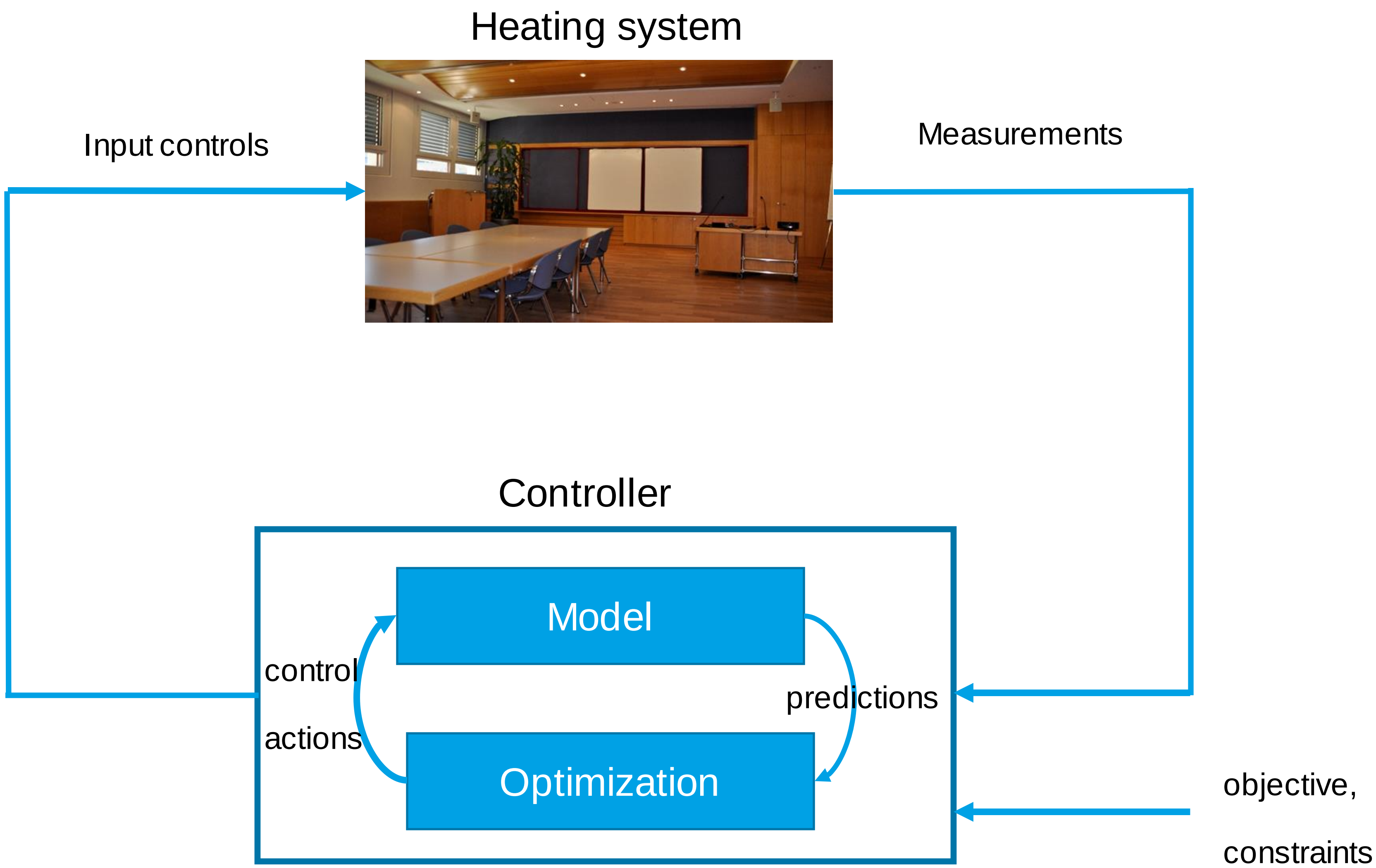
POTENTIAL AND ACTIVATED DEMAND-SIDE FLEXIBILITY (EU 2030)



Data source: L. Fiorini, M. Miranda Castillo, and T. Slot, 'Demand-side flexibility in the EU: Quantification of benefits in 2030', smartEn, Brussels, Sep. 2022

csem

OPTIMAL CONTROL



WHERE DOES THE UNCERTAINTY COME FROM?

HOW DO YOU CONTROL 60 MILLION HEAT PUMPS?

INCREASING DATA EFFICIENCY

- Simple physical model
- First training of "digital twin"
- Retraining of "digital twin" with measured data
- Learning control rules by playing with the "digital twin"

20%

- energy savings
- more comfort

B. Schubnel, R. E. Carrillo, P.-J. Alet, and A. Hutter, 'A Hybrid Learning Method for System Identification and Optimal Control', *IEEE Transactions on Neural Networks and Learning Systems*, 2020, doi: 10.1109/TNNLS.2020.3016906.

NON-LINEAR DATA-DRIVEN MODELS

Linear state space model + kernel regression

Internal state variable

Commands + ext. parameters

noise

$$x_{k+1} = Ax_k + Bu_k + \varepsilon_k$$
$$y_k = Cx_k + Du_k + \varepsilon'_k,$$

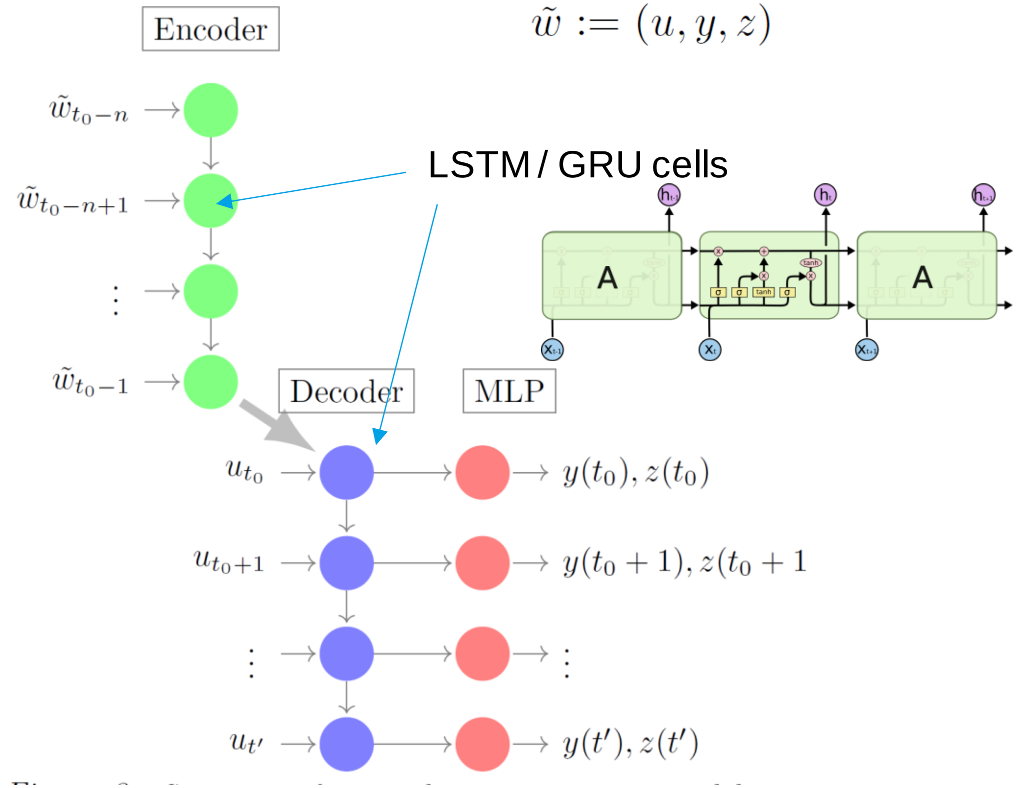
Room temperature

$$z_k = \sum_{i=1}^{N} \alpha_i \varphi(w_i, w_k)$$

Power consumption

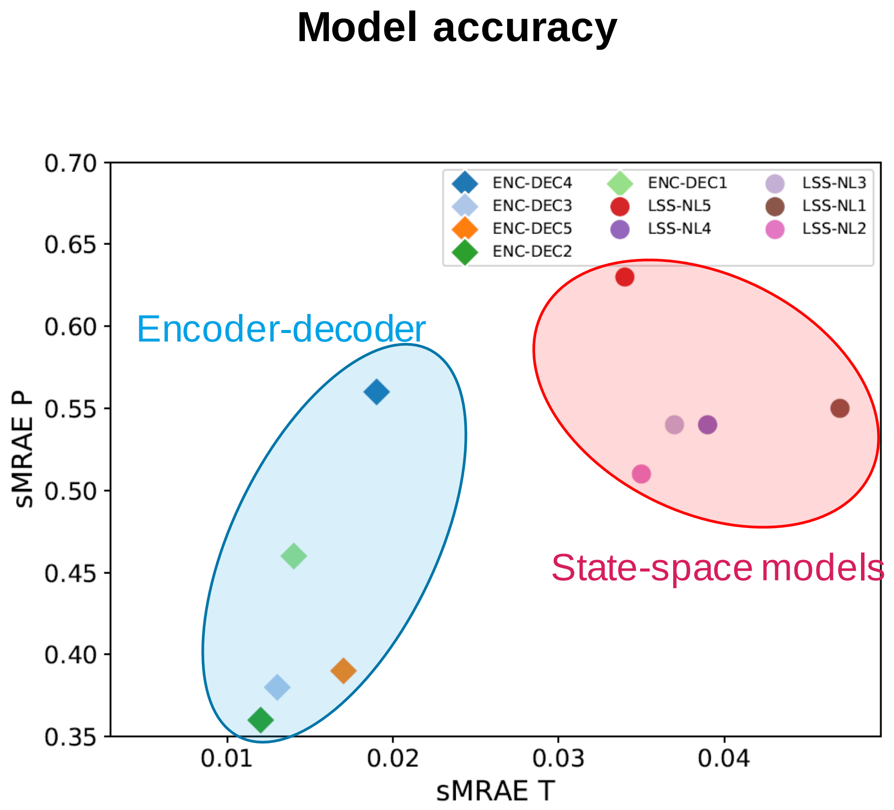
$$w_k := (u_k, y_k)$$

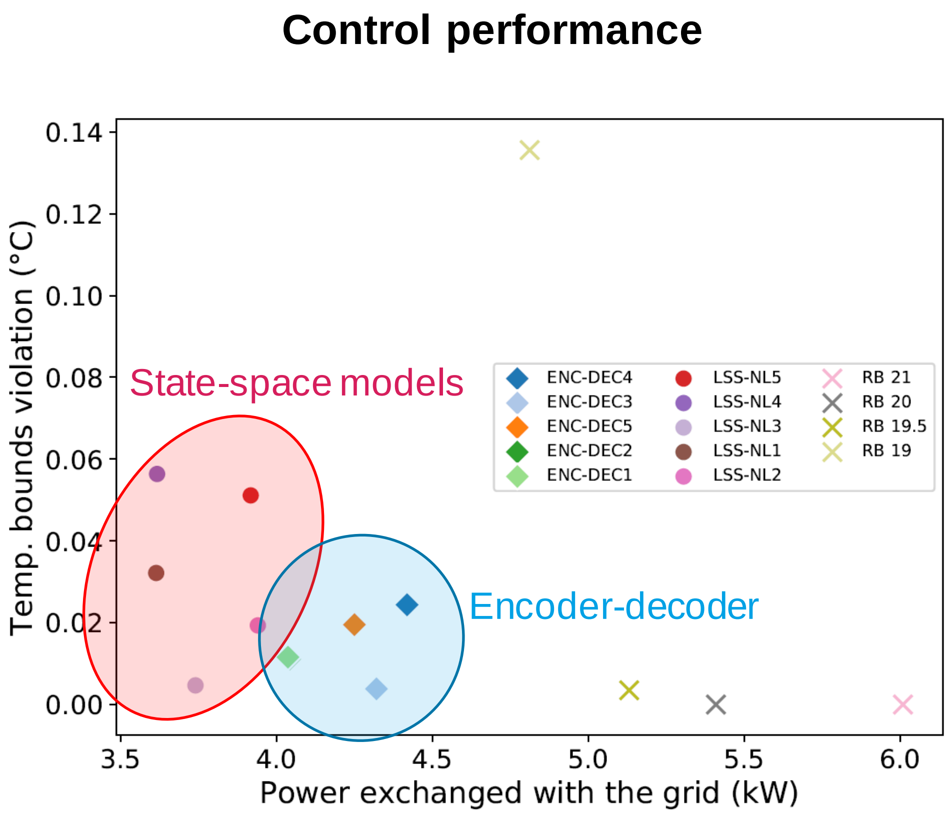
Encoder-decoder neural network



csem

ACCURACY VS. CONTROLLABILITY

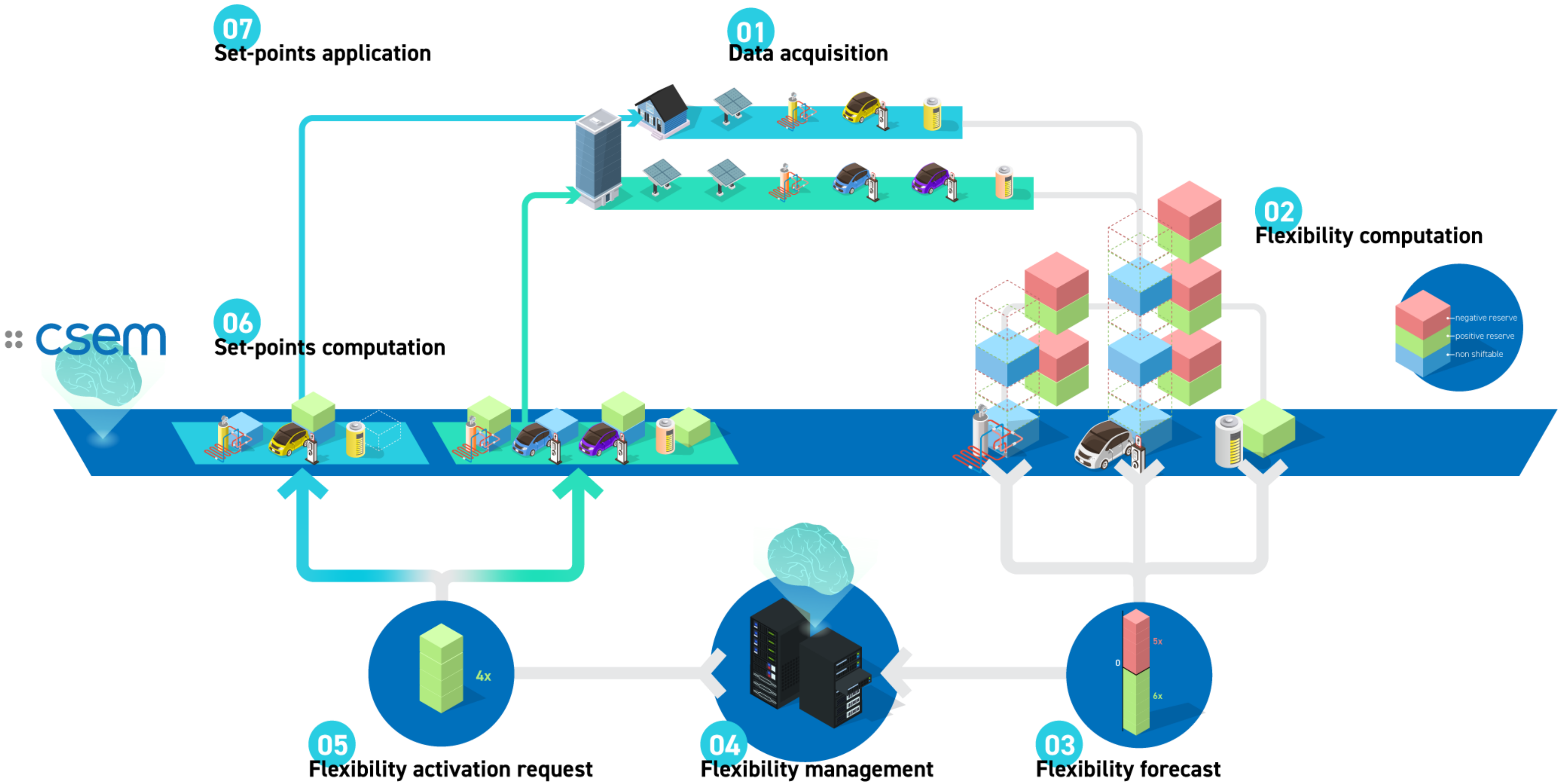




B. Schubnel *et al.*, 'State-space models for building control: how deep should you go?', *Journal of Building Performance Simulation*, vol. 13, no. 6, pp. 707–719, Nov. 2020, doi: 10.1080/19401493.2020.1817149.

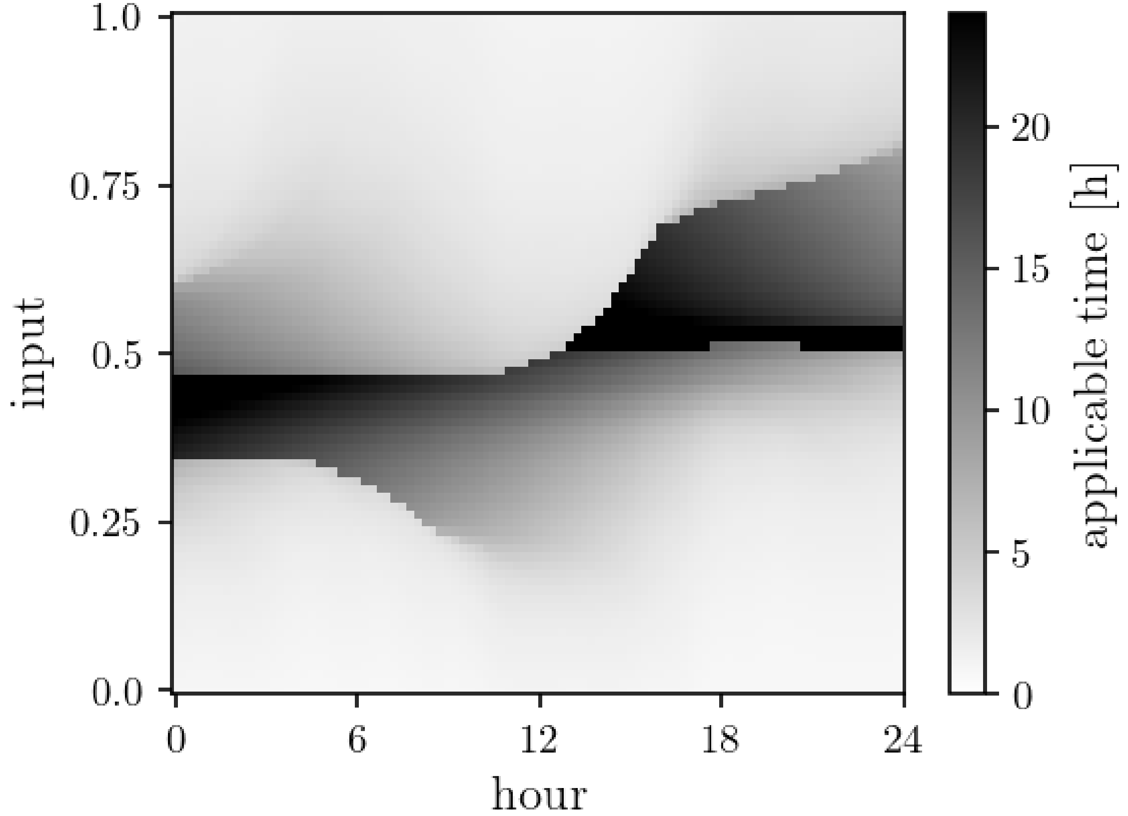
csem

EXPLOITATION OF FLEXIBILITY FROM DISTRIBUTED RESOURCES



csem

FLEXIBILITY ENVELOPES



R. D'hulst et al., "Demand response flexibility and flexibility potential of residential smart appliances: Experiences from large pilot test in Belgium," Applied Energy, vol. 155, pp. 79–90, 2015
J. Gasser et al., "Predictive energy management of residential buildings while self-reporting flexibility envelope," Applied Energy, vol. 288, p. 116653, Apr. 2021

- Quantification of flexibility over horizon:
  - Achievable power
  - Achievable duration
- Desired characteristics:
  - Data-driven
  - Risk aware: robust estimation with respect to uncertainties

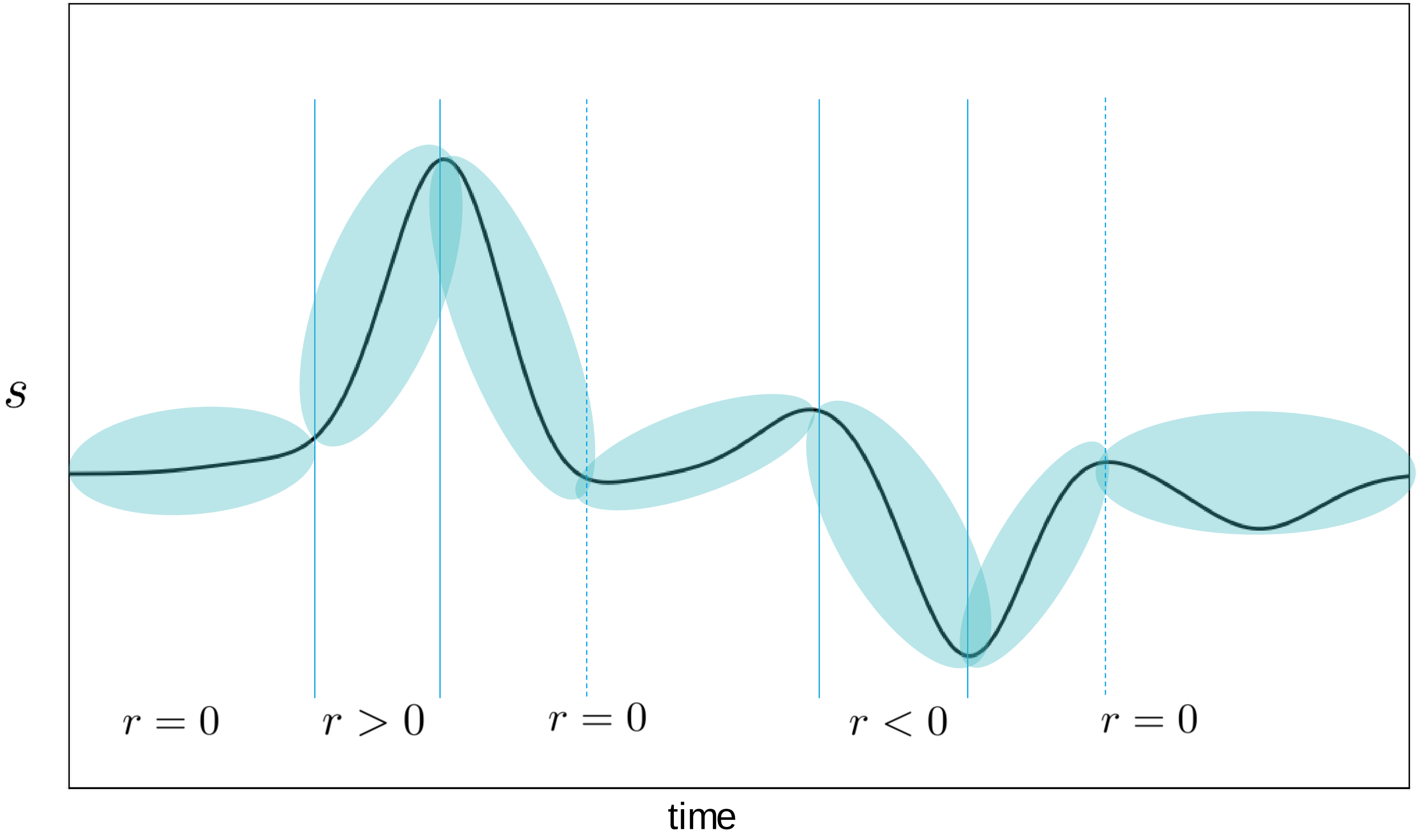
Building = virtual battery
Integrate uncertainty in battery parameters

P. Scharnhorst, B. Schubnel, R. E. Carrillo, P.-J. Alet, and C. N. Jones, 'Uncertainty-aware flexibility envelope prediction in buildings with controller-agnostic battery models'. arXiv, Oct. 07, 2022. doi: 10.48550/arXiv.2210.03604

csem

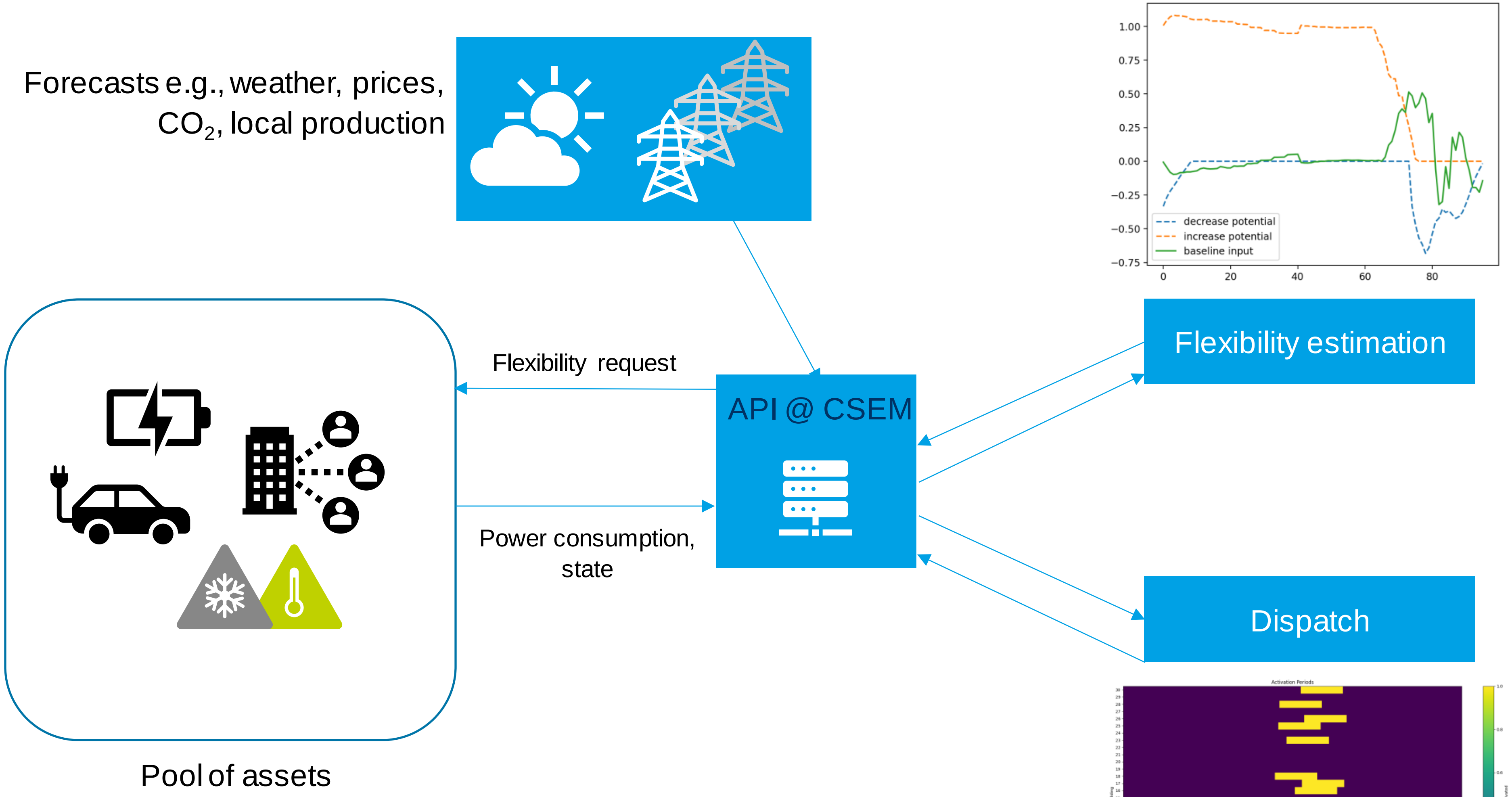
SAMPLE IDENTIFICATION

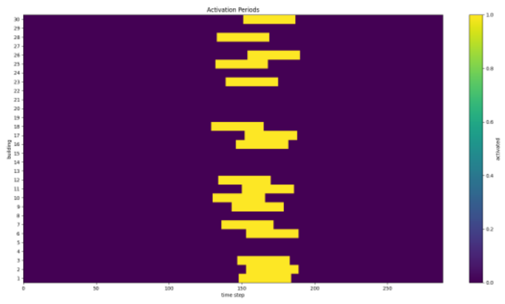
$$\hat{s}_{t+1} = \hat{s}_t + a^+ r_t^+ + a^- r_t^- + b_f(f(\mathbf{e}_t) - \hat{s}_t)\chi_{r_t} + f(\mathbf{e}_{t+1}) - f(\mathbf{e}_t)$$



csem

MICROSERVICES FOR DEMAND-SIDE FLEXIBILITY



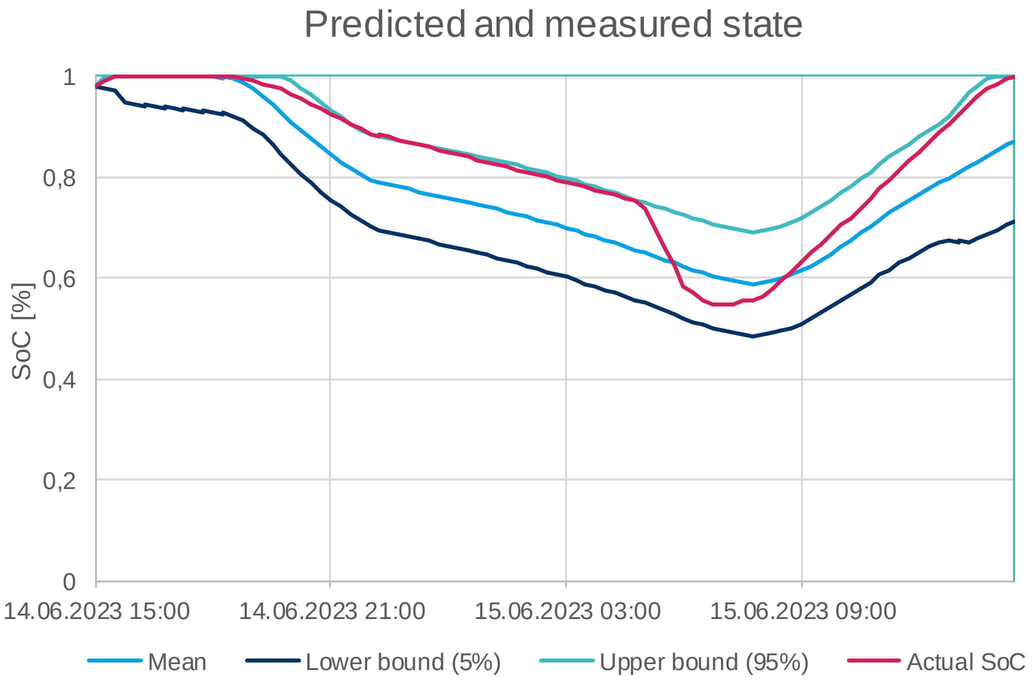


NEON: Next-Generation Integrated Energy Services for Citizen Energy Communities, has received funding from the European Commission H2020 Programme under Grant Agreement No. 101033700.

csem

EXPERIMENTAL VALIDATION

- Industrial park of Las Cabezas (Villacañas, Spain)



- Measured state within predicted range
- Information used for dispatch

NEON: Next-Generation Integrated Energy Services for Citizen Energy Communities, has received funding from the European Commission H2020 Programme under Grant Agreement No. 101033700.

csem

SCALABILITY TESTING WITH OPEN-SOURCE LIBRARY

energym

Buildings Minimal Installation Getting Started Examples Full Installation Contributing API Reference

API Reference

- Main Classes
  - energym.envs.env
  - energym.envs.env_fmu
  - energym.envs.env_fmu_eplus
- Model Classes
  - energym.envs.seminarcenter.seminarcenter
  - energym.envs.apartments.apartments
  - energym.envs.apartments2.apartments2
  - energym.envs.offices.offices
  - energym.envs.mixeduse.mixeduse
  - energym.envs.simple_house.simple_house
  - energym.envs.swiss_house.swiss_house
- Utils and Main Functions
  - energym.factory
  - energym.envs.utils.kpi
  - energym.envs.utils.weather

Main Classes

energym.envs.env

class energym.envs.env.**Env** [source]

The main Energym class to describe an abstract simulation environment.

It encapsulates an environment with arbitrary behind-the-scenes dynamics. An environment can be partially or fully observed.

Available environments

Following environments are available:

Environment	Thermostat	Heat Pump	Battery	AHU	EV	PV	Software
Apartments2Thermal-v0	✔	✔	✔	✖	✔	◆	E+
Apartments2Grid-v0	✔	◆	✔	✖	✔	◆	E+
ApartmentsThermal-v0	✔	✔	✔	✖	✔	◆	E+
ApartmentsGrid-v0	✔	◆	✔	✖	✔	◆	E+
OfficesThermostat-v0	✔	✖	✖	✖	✖	◆	E+
MixedUseFanFCU-v0	✔	✖	✖	✔	✖	✖	E+
SeminarcenterThermostat-v0	✔	◆	✖	✖	✖	◆	E+
SeminarcenterFull-v0	✔	✔	✖	✖	✖	◆	E+
SimpleHouseRad-v0	✖	✔	✖	✖	✖	◆	Mod
SimpleHouseSlab-v0	✖	✔	✖	✖	✖	◆	Mod
SwissHouseRad-v0	✖	✔	✖	✖	✖	◆	Mod

✔ : present and controllable, ◆ : present but not controllable, ✖ : absent.

Control variables are outlined in yaml files for all environments in the simulation folder. Environment simulations are packed into FMU's for windows and debian distributions.

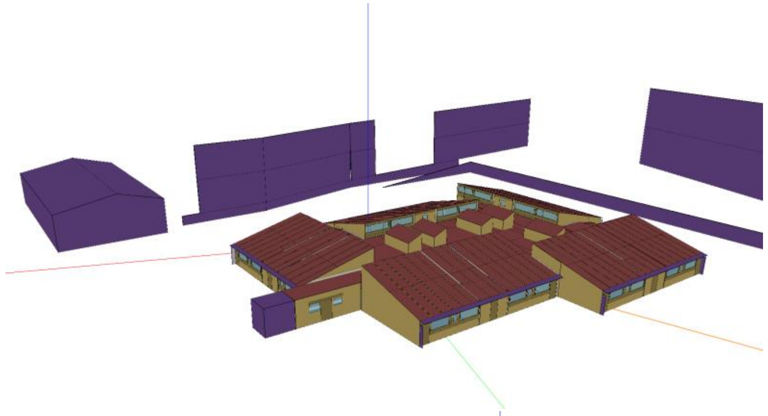
Use the interface

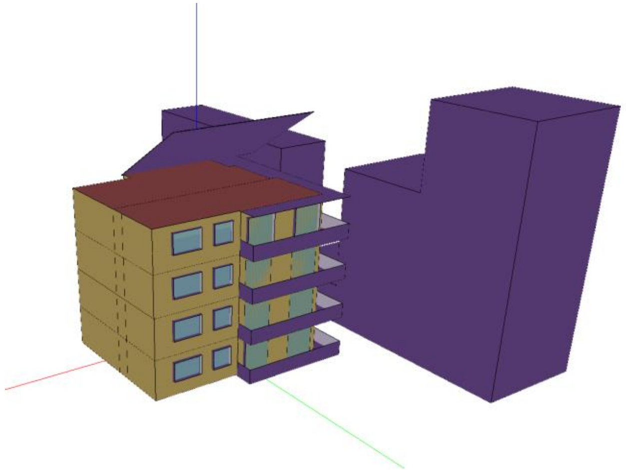
An examplatory usage of Energym (assuming a function `get_input()` for computing the controls) looks as follows

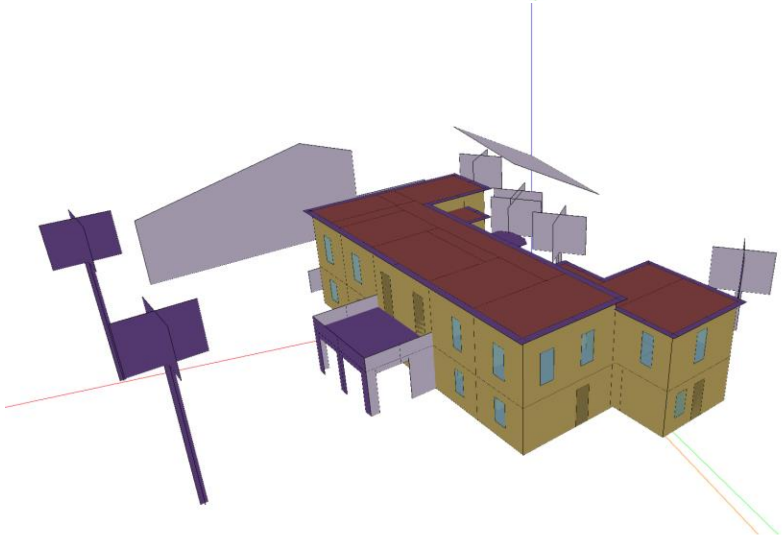
```
import energym

envName = "Apartments2Grid-v0"
```

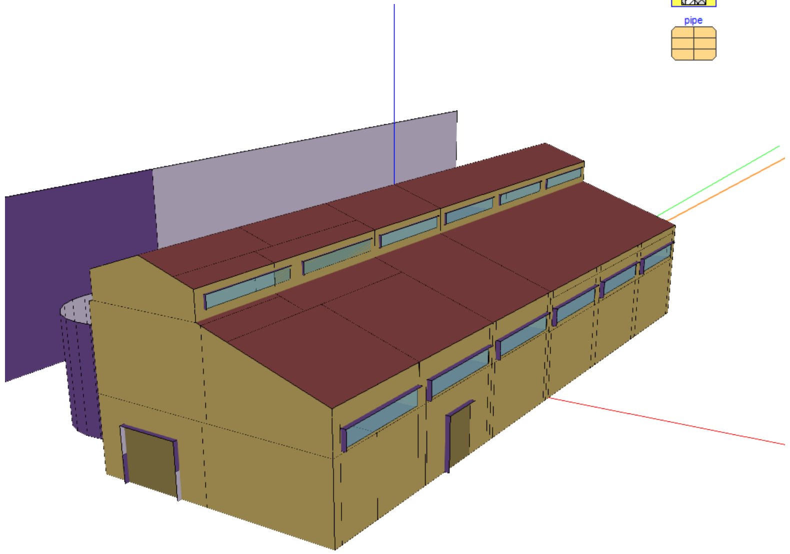
P. Scharnhorst *et al.*, 'Energym: A Building Model Library for Controller Benchmarking', *Applied Sciences*, vol. 11, no. 8, p. 3518, Apr. 2021, doi: 10.3390/app11083518.
B. Schubnel, P. Scharnhorst, and M. Boegli, 'Energym'. CSEM, Neuchâtel, Jun. 30, 2022. [Online]. Available: https://github.com/bsl546/energym

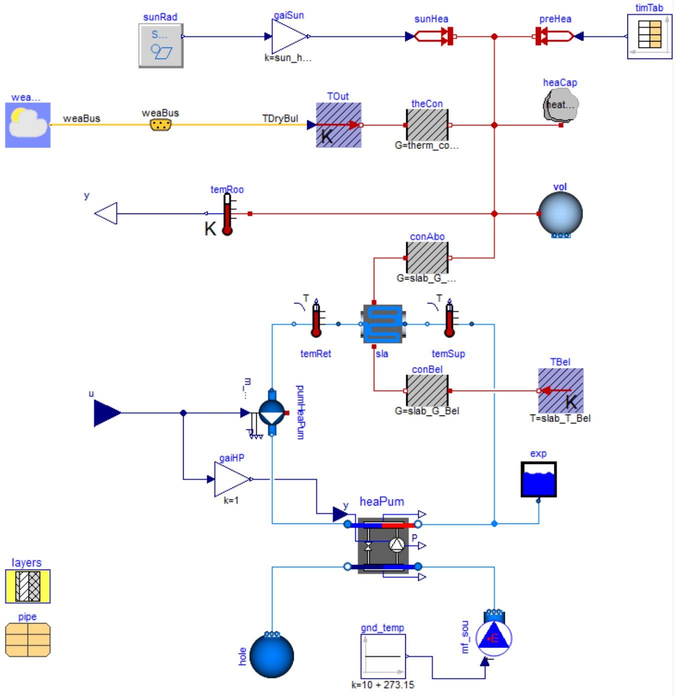
SCALABILITY TESTING WITH OPEN-SOURCE LIBRARY





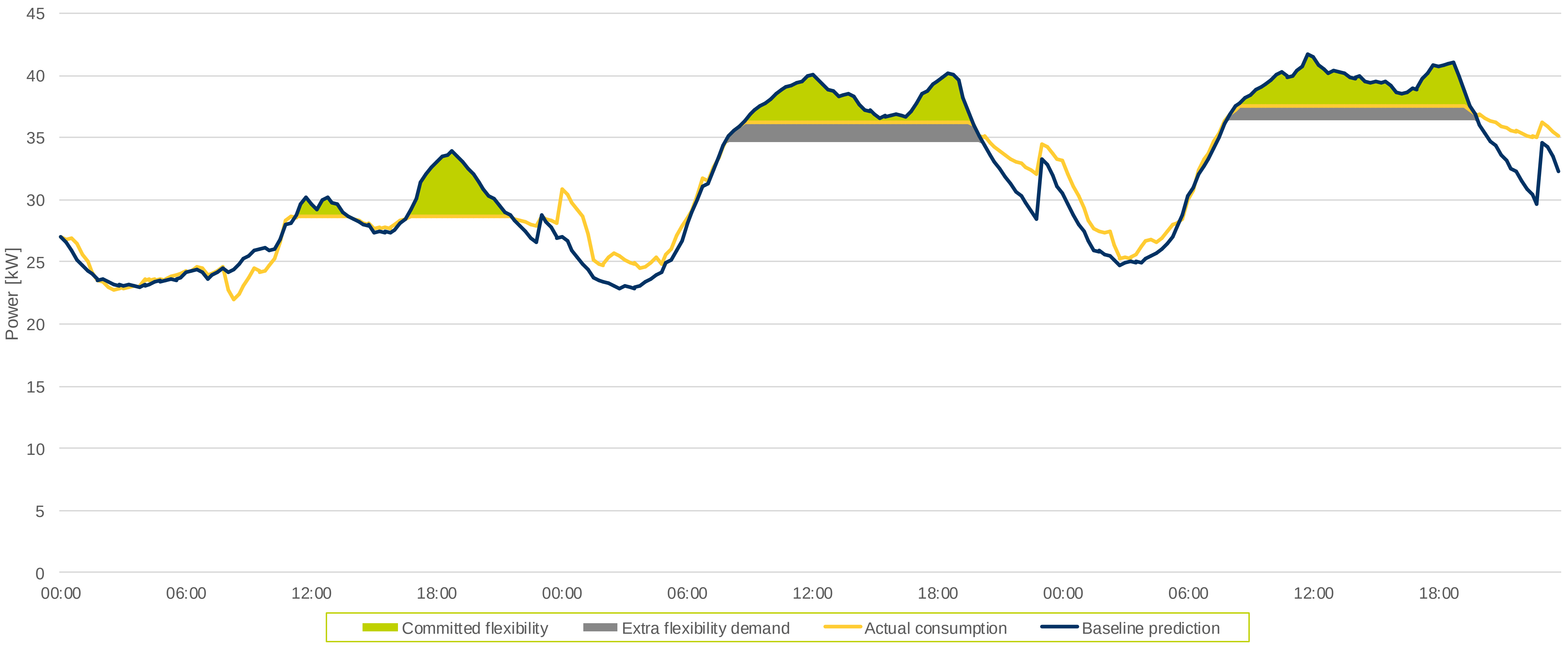






csem

APPLICATION: PEAK REDUCTION IN 10 BUILDINGS



csem

SUMMARY

- Distributed flexibility essential for cost-effective energy transition
- Scalability challenge requires efficient ML
- Uncertainty coming from incomplete description, weather, people behaviour
- Battery-like modelling with uncertainty quantification provides robust solution
- Experimental validation; simulated scale up
- Deployment as cloud microservice

CONTACT

Pierre-Jean Alet
Group Leader, Digital Energy Solutions
pierre-jean.alet@csem.ch
+41 32 720 5251

csem