

*Break-out session*

# Flexibility in the Energy System

**Program 11:00 – 12:30**

**DSOs and industry pitches**

Coffee break

**Academia pitches**

**Discussion and wrap up**



**Ir. Anne van der Molen**  
Stedin



**Dr. Bart van der Holst**  
Enexis



**Ir. Thijs van Wijk**  
ElaadNL



**Dr. Tarek Alskaif**  
WUR



**Ir. Berend de Klerk**  
4TU/TU Delft



**Dr. Guang Hu**  
TU/e

# Warming up

- What flexibility do DSOs actually need?
- How can flexibility be represented in planning and operation?
- How reliable are flexible assets in practice?
- What role can forecasting play?
- What are the biggest barriers to implementation?

# ANNE VAN DER MOLEN STEDIN

# Flexibility in the Energy System

Anne van der Molen



# A short keyword search on flexibility



ScienceDirect

Journals & Books

Help

Anne van der ...

Sig

Find articles with these terms

power system flexibility



Advanced search

Suggested publications:



982,180 results



Download selected articles



Export

sorted by *relevance* | [date](#)

# A short keyword search on flexibility



ScienceDirect

Journals & Books

Help

Anne van der ...

Sig

982,180 results

Refine by:

Years

- 2027 (63)
- 2026 (82,577)
- 2025 (118,277)
- 2024 (83,819)
- 2023 (63,466)
- 2022 (60,220)
- 2021 (54,206)
- 2020 (45,331)
- 2019 (38,988)
- 2018 (36,091)
- 2017 (32,922)
- 2016 (29,259)
- 2015 (26,170)
- 2014 (23,320)
- 2013 (20,850)
- 2012 (18,235)
- 2011 (16,362)
- 2010 (14,200)
- 2009 (13,577)
- 2008 (12,605)
- 2007 (12,052)
- 2006 (11,498)
- 2005 (10,291)
- 2004 (9,131)
- 2003 (8,815)

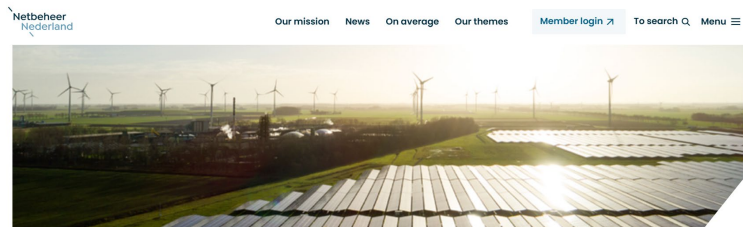
Popularity growing  
over the years

Subject areas

- Engineering (273,617)
- Energy (162,498)
- Materials Science (149,354)
- Computer Science (112,857)
- Social Sciences (86,145)
- Chemistry (85,207)
- Environmental Science (84,896)
- Medicine and Dentistry (79,883)
- Physics and Astronomy (79,180)
- Chemical Engineering (75,250)

Especially with  
engineers

# What does netbeheernederland.nl say about flexibility ?



Home > Our themes > Grid capacity and flexibility

## Flexible use of the electricity grid

[More articles →](#)

### Flexibility can reduce the pressure on the electricity grid

Pressure on the electricity grid is increasing, but the grid is not always and everywhere fully utilized. In addition to peak moments, there are also times during the day when capacity is still available. Work is underway on special off-peak contracts to continue offering new users access to the grid. Furthermore, reducing the gap between supply and demand by generating and using electricity directly at the same location and at the same time helps to relieve the strain on the grid.

### Flexibility in congestion areas

In areas with congestion (where congestion occurs on the grid), grid operators must implement congestion management. Large consumers are then asked to temporarily use less electricity or supply less to the grid when there is an imminent overload of the grid. In return, they receive compensation from the grid operator.

[Read more about congestion management →](#)

### Flexible use is also interesting for companies.

It is also worthwhile for companies to explore the possibilities for a more flexible approach to the grid, especially given the increasing influence of renewable energy on energy prices. Flexible solutions can be more cost-effective than continuous use of the grid. Batteries can store excess energy for use when prices are high. In areas with congested grids, capacity-limiting contracts offer opportunities, allowing grid operators to connect companies up to the technical limit under certain conditions.

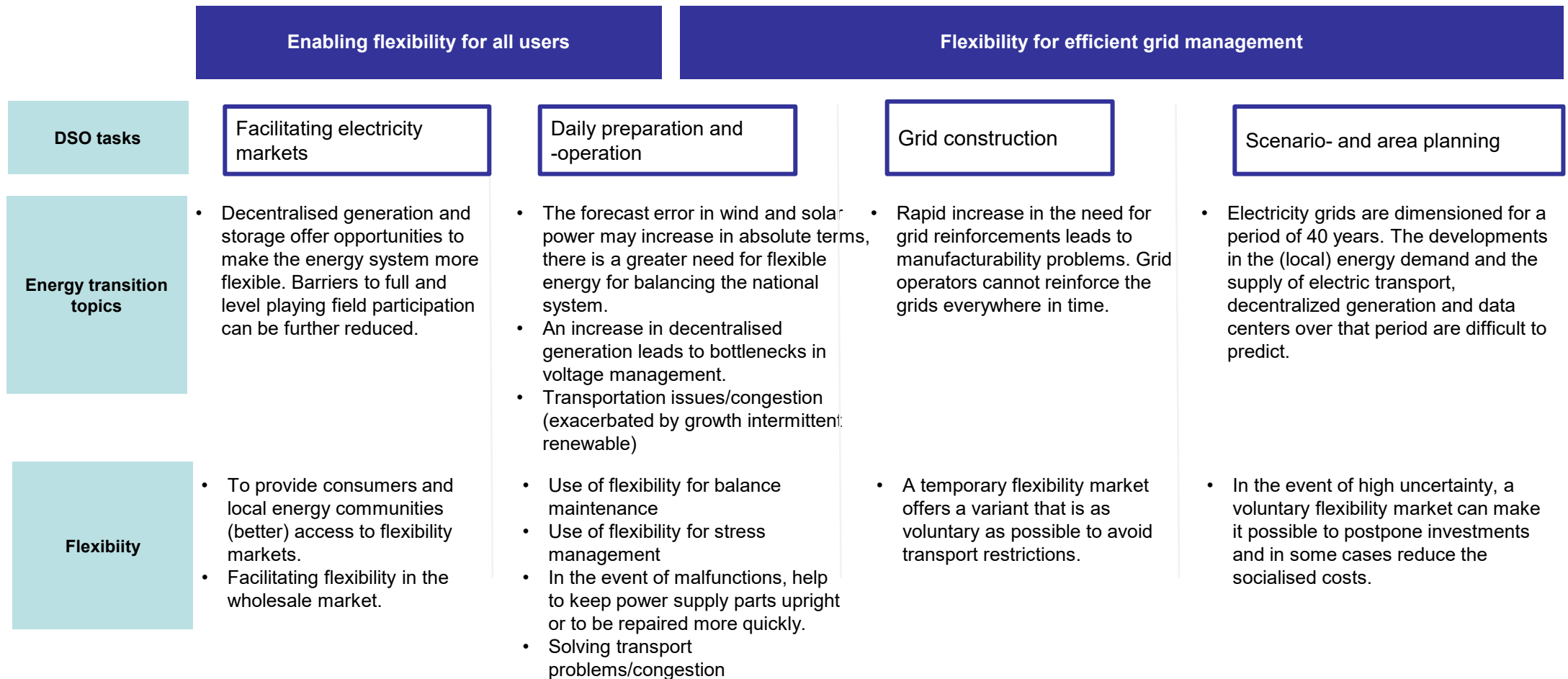
### Working together on a future-proof energy system

The transition to flexible grid usage cannot be achieved overnight. It requires major adjustments to working methods. For grid operators, partners, and everyone who uses the electricity grid. This is new for everyone, and this change takes time.

### Product and service catalog

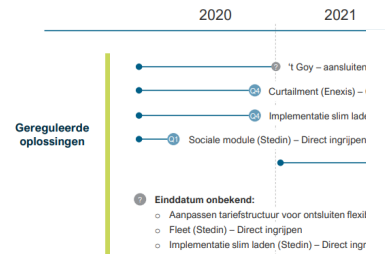
In the products and services catalogue, you will find a list of all products and services that grid operators develop and offer to make better use of the grid. This catalogue is published four times a year. You can find it on the Partners in Energie website under 'Products and services catalogue'.

# (power system) Flexibility and the grid operator

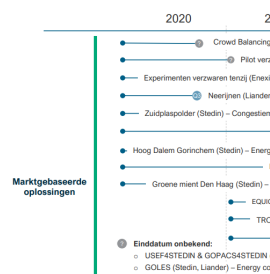


# A short survey of ongoing work (there is a lot going on)

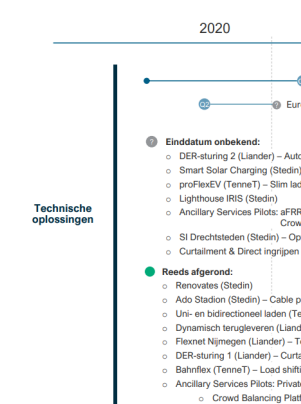
## Niet markt-gebaseerde flexibiliteit



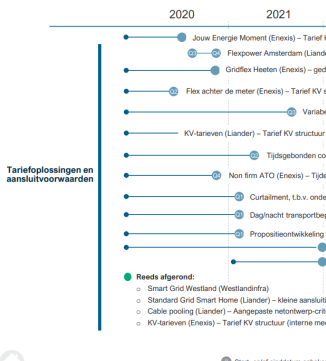
## Marktgebaseerde flexibiliteit



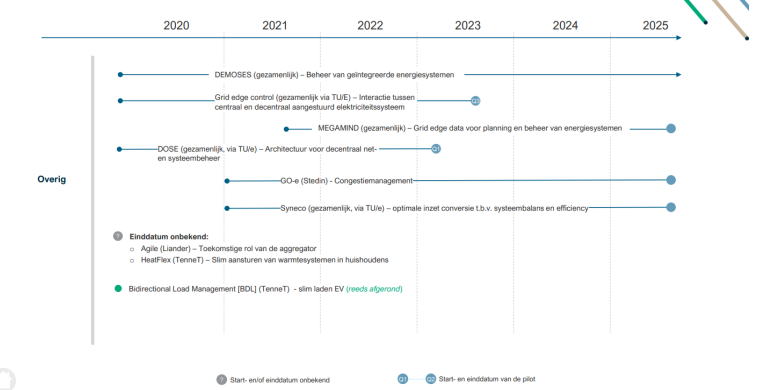
## Technische oplossingen



## Tariefoplossingen en aansluitvoorwaarden



## Overig



# How can you contribute ? Examples of research topics in the DSO agenda:

- Balancing and congestion
- Day ahead, intraday and real-time
- BRP- CSP interaction
- Market impact of congestion services
- Permanent Flexibility

# BART VAN DER HOLST

## ENEXIS

# Incorporating price responsiveness in aggregated power profiles

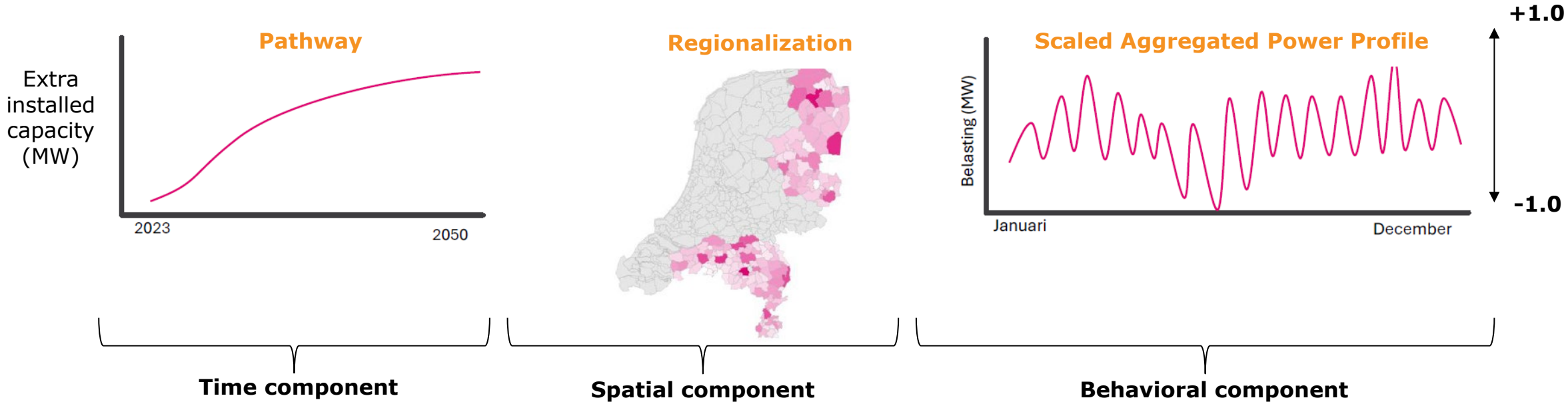
Dr. ir. Bart van der Holst  
Expert Energy Transition



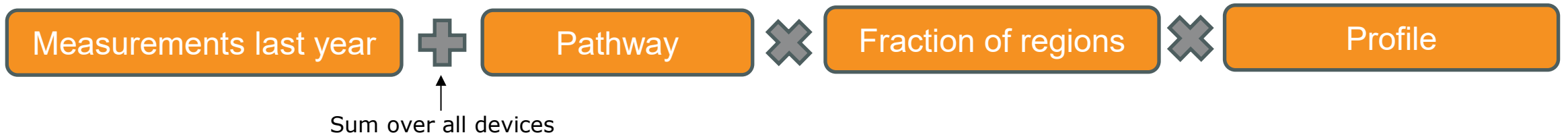
# Setting the stage: the planning methodology of DSOs

The basis for our investment decisions

For all devices (+/- 90 types), we model:



Load calculation on MV/MV substations for years up to 2050:

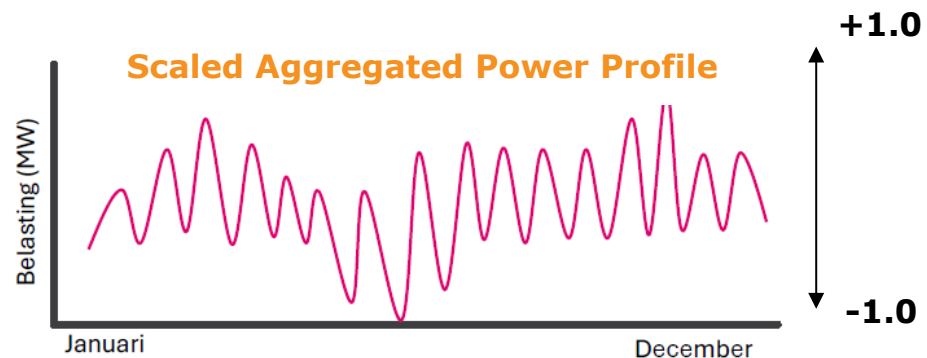


# Power profiles and price responsiveness

The challenge we are working on, as we speak!

- Current profiles
  - Model groups of +/- 1000 assets
  - Are assumed to be year-independent
  - Are based on Business as Usual behavior
- But we know:
  - Increasing controllability of assets
  - Energy management systems
  - New time-of-use network tariffs as of 2029
  - Increase of dynamic energy contracts and market participation
- Business as Usual is changing!

Challenge: can we come up with a method that transforms our existing profiles to include price effects?

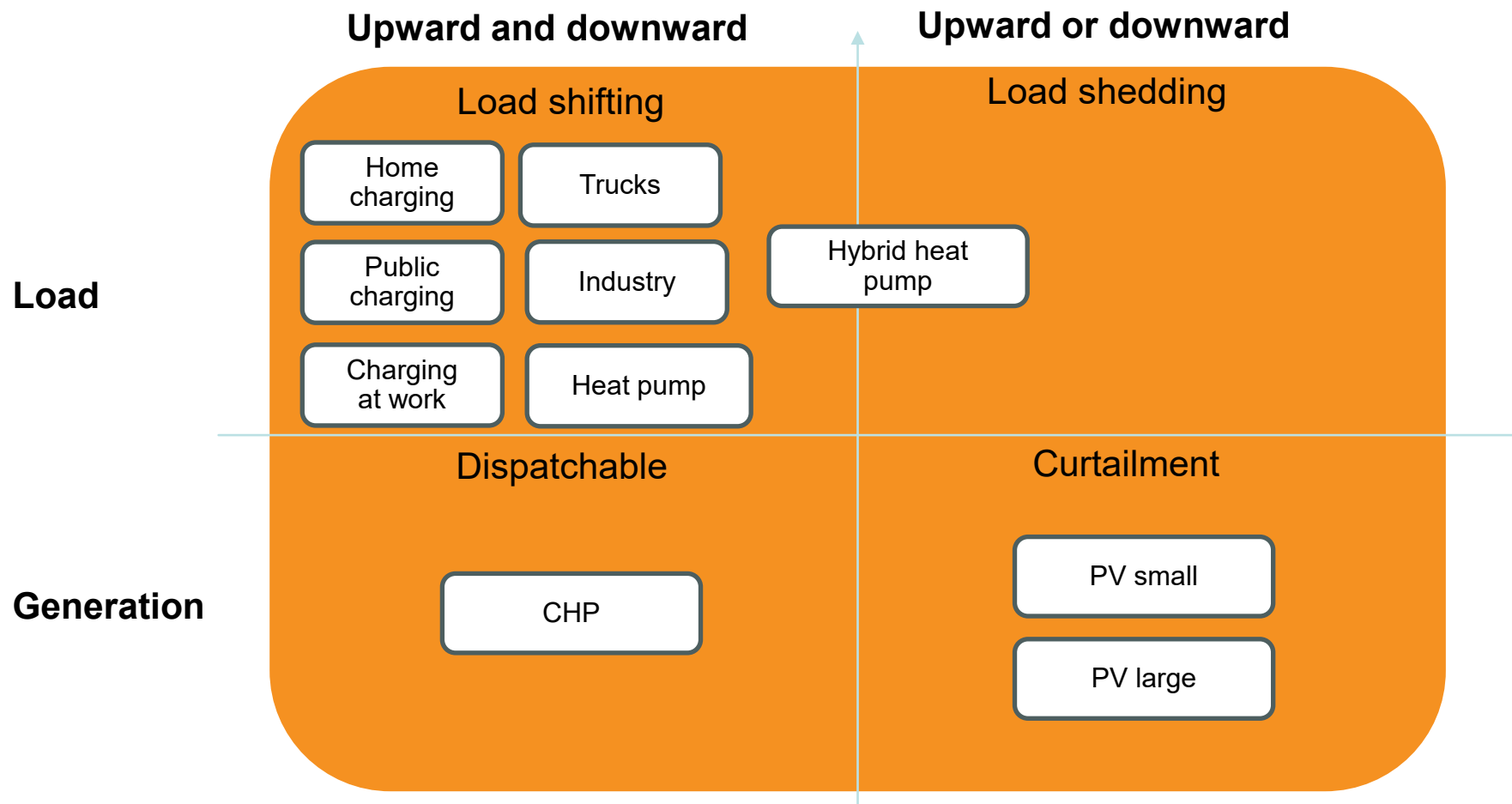


Example: Public Charging (from ElaadNL)



# Devices in scope

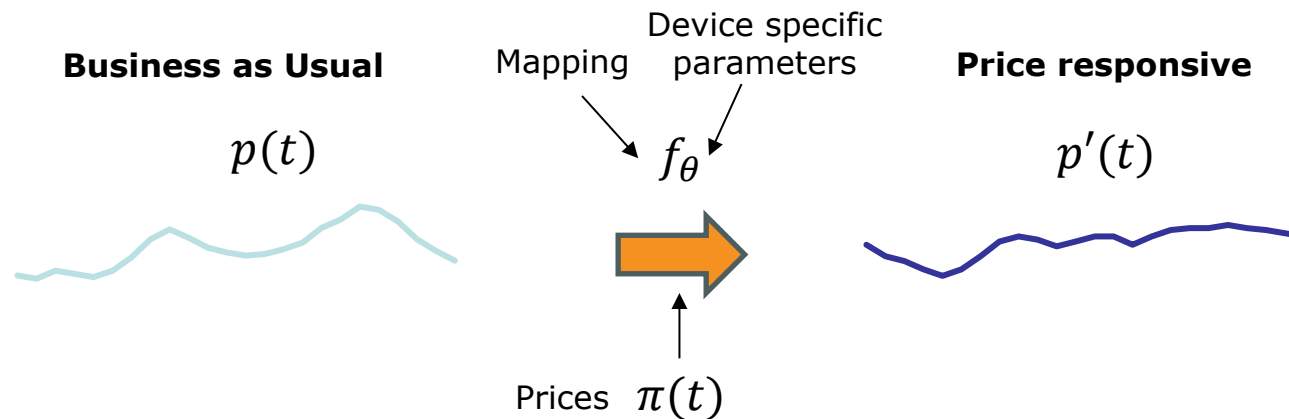
This is a lot of work



# List of requirements

For an algorithm to be implemented this year

- The transformation/mapping should:
  - Be generic enough to apply profiles of various flexible devices
  - Should not involve very detailed modeling of all these devices
  - Does not require large data sets of measurements
  - Experts can readily provide parameters related to flexibility potential
  - Profiles should show price responsiveness that fits a large group of assets (i.e. no all-or-nothing behavior)
  - Should be explainable implementable by all 3 DSOs by the end of the year



Question 1: do you know any papers that we could draw inspiration from?

# Current idea

## Transition matrix and McFadden's random utility model

- Flexibility depends on:
  - Time at which you provide flexibility:  $t$
  - Time where you shift your energy to:  $s$
- We choose a linear mapping, such that:
  - $\mathbf{p}' = M\mathbf{p}$ ,
  - where  $\mathbf{p} = (p_s)$  is a power profile for +/- 1 day
  - And  $M = (m_{ts})$  is a transition matrix
- Transition matrix:
  - $0 \leq m_{ts} \leq 1$ , describes what part of  $p_t$  is shifted to timestep  $s$
  - Note: if  $\sum_t m_{ts} = 1$  for all  $s$ , energy is conserved between  $\mathbf{p}'$  and  $\mathbf{p}$
- If we assume that:
  - A group of assets minimizes some random function:  $\underbrace{u_{ts}(\pi_t, \theta)} + \underbrace{\epsilon_{ts}}$
  - $\epsilon_{ts} \sim \text{Gumbell}(\mu, \beta)$
- Then according to McFadden:
  - $m_{ts} = \frac{\exp(-\beta u_{ts})}{\sum_t \exp(-\beta u_{ts})}$

Question 2: How to construct  $u_{ts}$  to satisfy all properties from the previous slide?

Utility function, balancing the impact of the price difference  $(\pi_t - \pi_s)$  and the flexibility potential of the device

Random error term, accounting for all unexplainable behavior

# $\beta$ and price responsiveness

A parameter with a nice interpretation

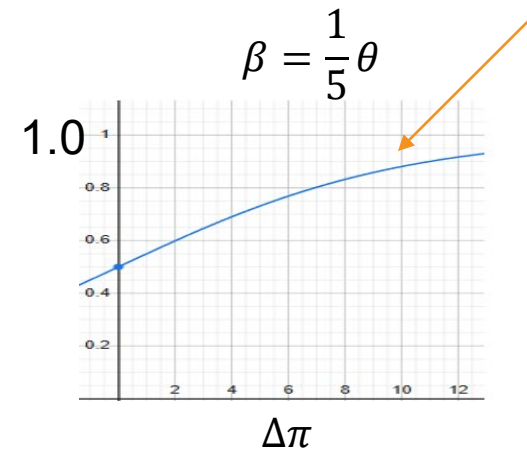
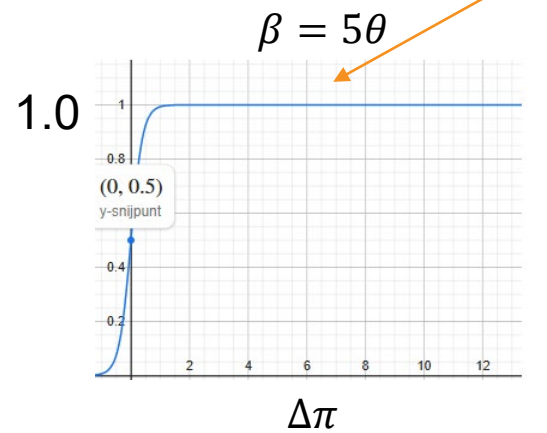
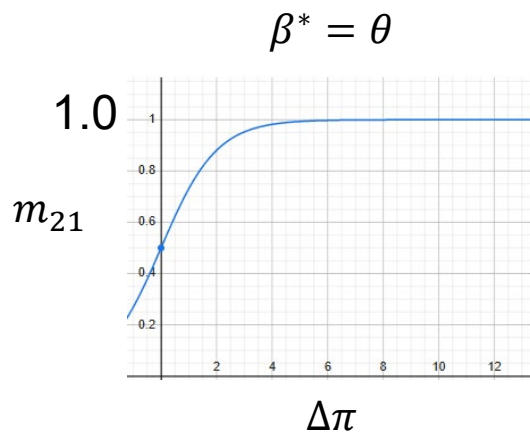
- $\beta > 0$  can be interpreted as the **price responsiveness** of the group of assets!
- Assume for simplicity:
  - $u_{ts}(\pi, \theta) = \frac{1}{\theta} (\pi_t - \pi_s)$
  - Where  $\theta$  has a unit of price
  - Let's consider a profile of length two as toy model
  - Let  $\Delta\pi = \pi_2 - \pi_1 > 0$
- Then:

- $m_{21} = \frac{1}{1 + \exp(\beta\Delta\pi/\theta)}$

Question 3: How to choose  $\beta$ ?

Due to high price responsiveness, energy gets shifted to the lower price zone at small price differences

At low price responsiveness, a large part of the energy is not shifted for high price differences. A part of the group of assets is not responsive to the price signal



# Thank you!

Feel free to contact me with ideas  
at [bart.van.der.holst@enexis.nl](mailto:bart.van.der.holst@enexis.nl)



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# THIJS VAN WIJK ELAADNL

# Ensuring flexibility by research and testing

Thijs van Wijk - ElaadNL



# ElaadNL

- Non-profit foundation by Dutch DSOs
- Goal; improve grid integration of EV charging and energy-intensive appliances
- Data&market research, PoCs, improving processes, open & free Test Lab
- Sharing lessons learned for general improvement
- +100 different types of AC, DC and V2G chargers, heat pumps, home batteries and PV inverters
- Visited by passenger EVs, trucks, busses, construction vehicles, mobile battery storage, airplanes..
- Highly accurate lab and field measurement equipment
- 360 kW bidirectional test system for EV/EVSE testing and emulating the grid

STEDIN<sup>NET</sup>

liander

ENEXIS  
NETBEHEER

REUDO  
DUURZAAM NEDERLAND

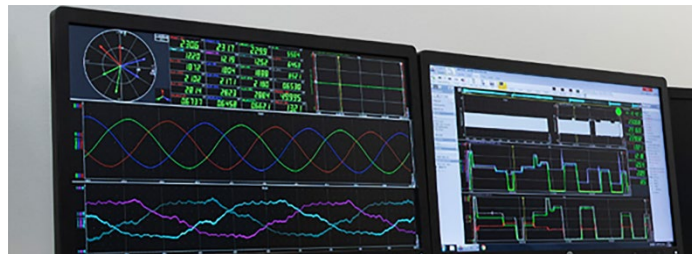
coteq  
NETBEHEER

westland  
infra netbeheer



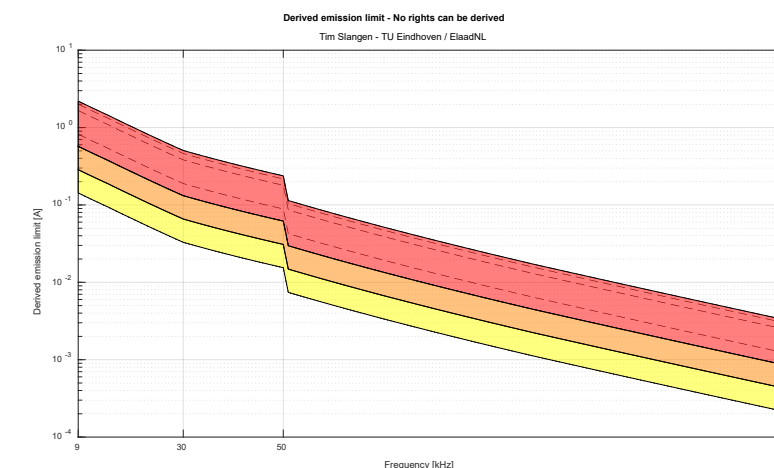
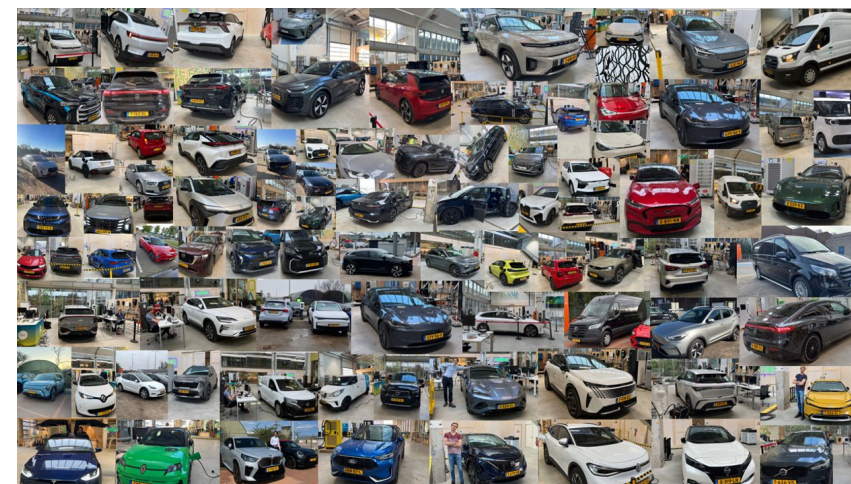
# Smart devices

- In theory a lot of flexible devices in the system
  - Electric vehicles, charging stations, heat pumps, home batteries, PV convertors,..
- But there are challenges to unlock this
  - Different communication protocols and compliance unsure
  - Unknown ability to handle real life smart charging or demand response scenarios
  - Power quality emissions and immunity at low power setting
  - Possible system behaviour on grid when simultaneously controlled
  - Cyber security becomes crucial when controlling massive amount of devices



# Unlocking flexibility

- Testing the devices
  - Continuously testing EVs and AC charging stations for 10 years, advising improvements to manufacturers
  - Tested 142 Electric vehicles in 2024/25; smart charging works! And PQ not significantly worse!
  - Now doing the same for DC chargers, trucks, buses, construction vehicles,..
  - Next up: MCS chargers, heat pumps, PV convertors, home batteries, HEMSs
  
- Research
  - PhD research led to first preliminary limits for *Supraharmonic (2-150kHz)* emissions
  - Now researching Supraharmonic immunity of DC chargers and meters and the causes of oscillations in the grid
  - Up next: Effects of autonomous behavior of devices to grid events (grid codes) and other triggers



## Key take aways

Flexibility is there, but safely unlocking it requires testing and research.

We are open to input from both the DSOs and the Universities, like measurement data, grid observations and test & research ideas.

We can host multiple graduation and/or PhD positions on different research topics.

BHAG: ElaadNL and the testlab can use its position in between the DSOs and Universities to become a test & research collaboration hub



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Coffee break!



# BEREND DE KLERK

## 4TU/TUD

# TrafoTech



**TrafoTech**  
SOLID STATE TRANSFORMERS

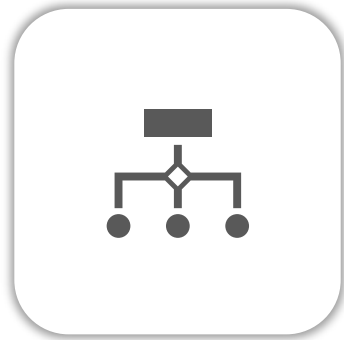
Berend de Klerk  
Market Analyst at 4TU.Teggwings



# Challenges



14.000+ companies waiting for grid connection



Increasingly complex grids & bidirectional powerflow



Power quality & energy efficiency



Digging for cables is expensive and time-consuming



Limited available (public) space, permits required

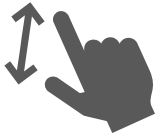
How can we reinforce the grid without digging for extra cables?

# Solution : SSTs



## Efficient

98,5% efficiency, now already at 97% efficiency  
(before optimization)



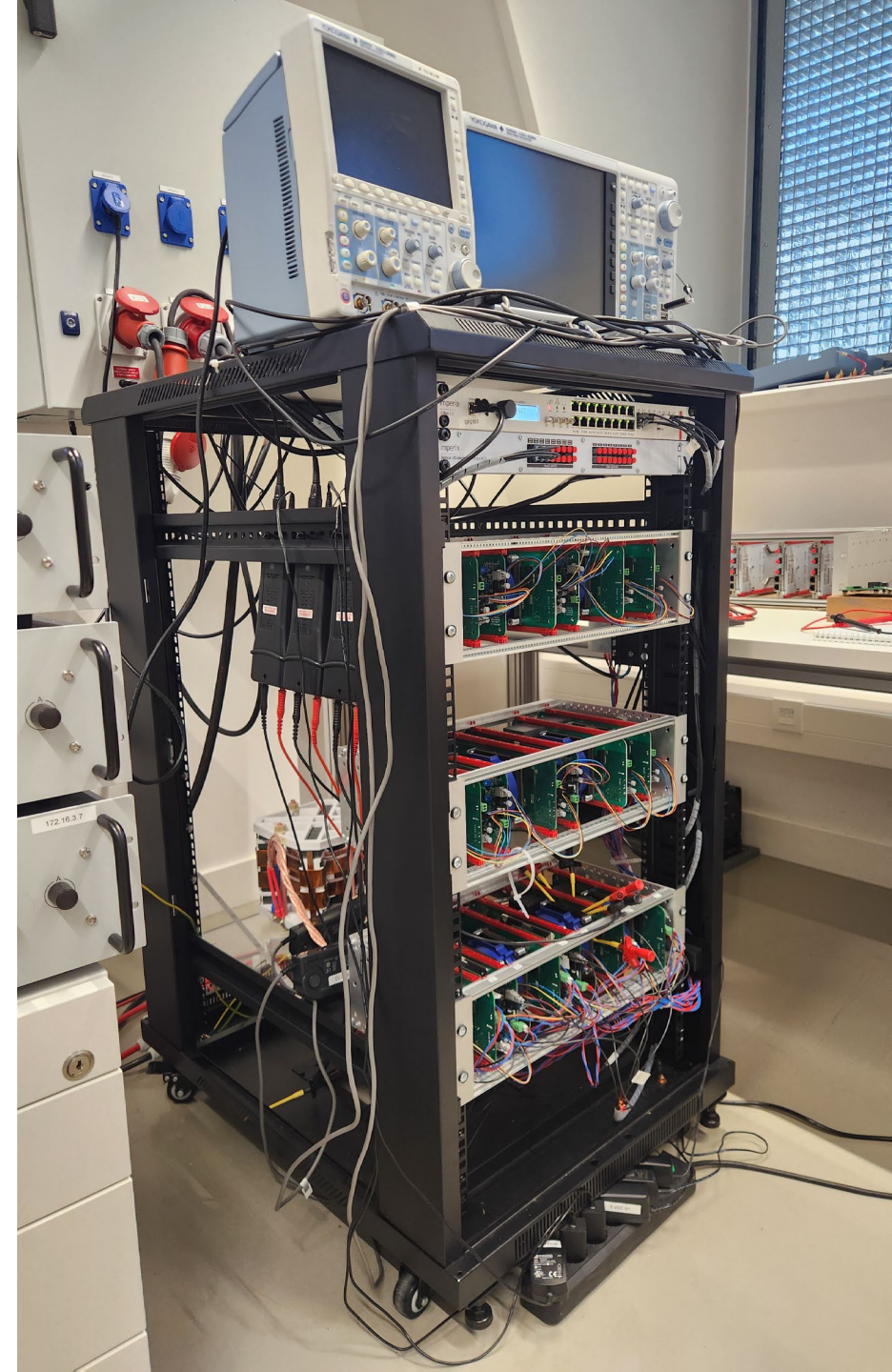
## Compact & modular

80% shrinking results in lower footprint, less  
public space required and modular redundancy  
enables hot-swapping maintenance

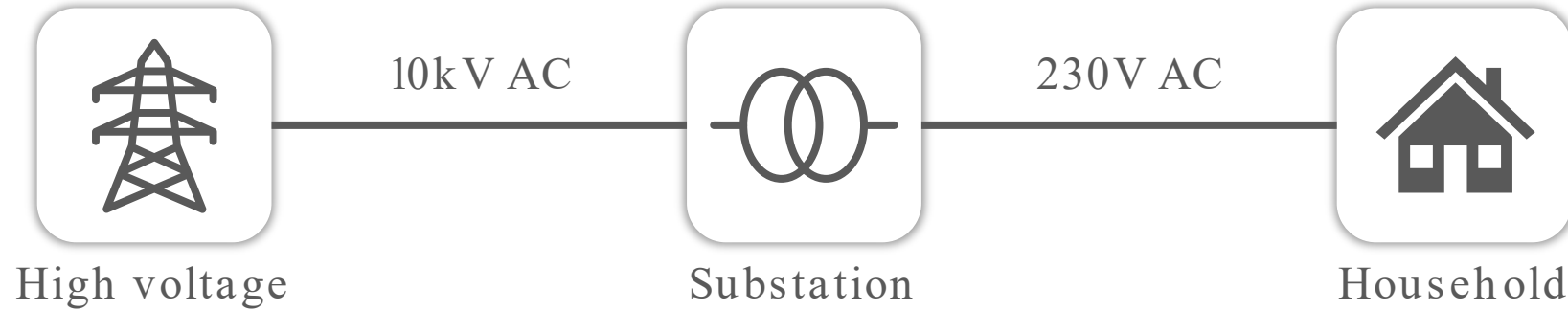


## Functional

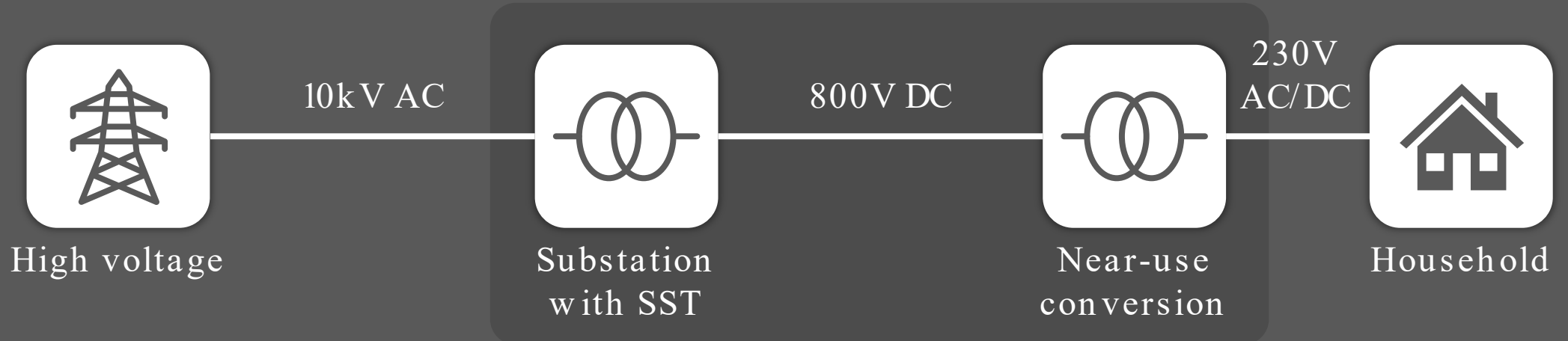
Dynamic control via software, leading to MV  
DC-link power sharing and data analytics



# Today's architecture



# Tomorrow's architecture



# Commercial



Commercial advisor  
Hisham Uddin



Commercial advisor  
Thijs Scholte



Project lead  
Berend de Klerk



Business validator  
Gerard van Smeden

# Technical



Scientific advisor  
Prof. Pavol Bauer



Scientific advisor  
Dr. Sebastian Rivera Iunissi



Scientific advisor  
Dr. Zian Qin

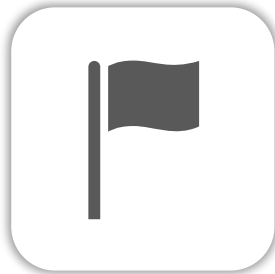


R&D (power electronics)  
Julian Rojas Villarroel



R&D (magnetics)  
Felipe Calderon Rivera

# We're looking for:



## Collaboration on product validation

Collaborators for further product development, integration in real-world, and funding



## Use-case exploration

Industrial applications and corresponding requirements such as datacenters, EV charging, industry hubs, ...



GUANG HU  
TU/E

# ML-Assisted Flexibility for Photovoltaic Integration in Urban Energy Systems

Guang Hu

Assistant Professor · Eindhoven University of Technology

4TUxDSO symposium, June 2<sup>nd</sup>, 2026



# The Challenge: PV Variability & Grid Flexibility

## The Problem

- Solar PV output is highly variable due to weather and irradiance fluctuations
- Rapid growth of urban PV strains distribution network balance
- DSOs face increasing difficulty maintaining grid stability with traditional forecasting tools

## The Opportunity

**~70%**

The Netherlands targets 70% renewable electricity by 2030, with solar already at ~22% of the mix and growing rapidly.

Better PV forecasting = smarter flexibility = a more resilient grid for DSOs and prosumers alike.

# Our Approach: Physics-Based Machine Learning

01

## Data Collection

Multi-year weather time series (Amsterdam case study) + SAM simulations for PV output

02

## ML + Physics-based Modelling

Coupling physics-based modelling tool considering irradiance, temperature, and wind with ML models

03

## Flexibility Insight

Accurate short-term PV forecasts enable proactive demand response and congestion management for DSOs

## Results & Relevance for DSOs

**~15%**

forecast error reduction vs.  
physics-only baseline

**2+ yrs**

of real Amsterdam weather +  
physics-based modelling tool

**Urban**

focus: scalable to city districts  
with heterogeneous PV adoption

### Value for Distribution System Operators

- Short-horizon PV forecasts (15 min to 24 hr) support real-time congestion management and demand response activation
- Transferable framework: models can be retrained on local DSO metering data with minimal overhead

## Discussion Questions

- Q1** What data do DSOs currently use for short-term solar forecasting, and what are the key gaps?
- Q2** Which flexibility levers (storage, EV, demand response) are most ready to couple with improved PV forecasts?
- Q3** How can 4TU-DSO partnerships accelerate deployment of ML forecasting tools in real grid operations?



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# Discussion