6th International Conference on Smart Energy Systems
6-7 October 2020
#SESAAU2020

A Thermohydraulic Model of Bidirectional Heat Networks with Prosumers

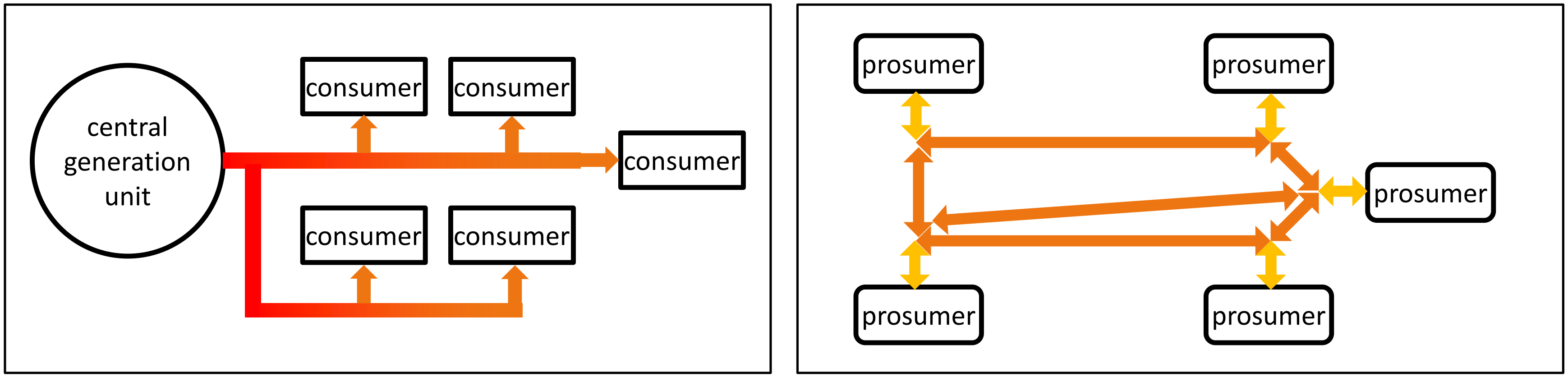
M.Sc. Thomas Licklederer

Technical University of Munich (TUM)
Munich School of Engineering

thomas.licklederer@tum.de

Powered by

Smart Grids in the heat sector



conventional district heating network

Prosumer-dominated bidirectional heat network

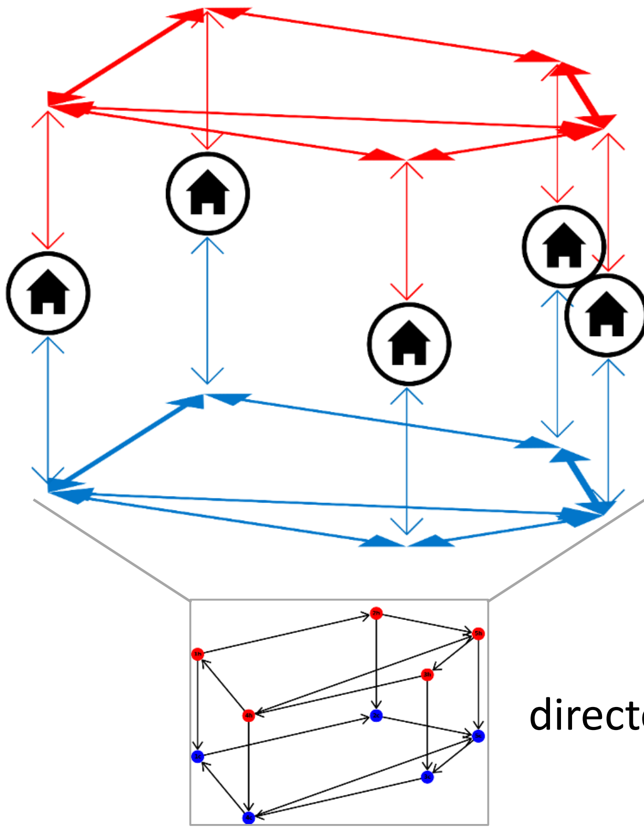
- **Hydraulic infrastructure ?** – volume flow directions not pre-determined
- **Thermohydraulic behavior ?**
  – temperatures, pressure, volume flows (spatial & temporal)
- **How to operate and control ?** – distributed actuators

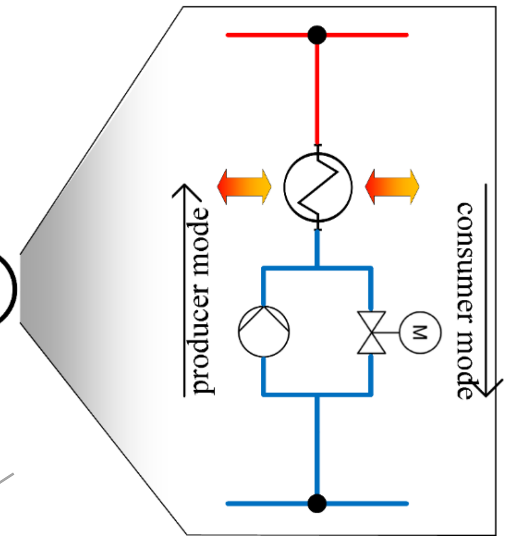
thomas.licklederer@tum.de

Objective: Thermohydraulic Model

- Prosumer-dominated network with **bidirectional heat exchange**
- Basis: hydraulic **infrastructure** concept
- Equation based approach for **control** and operation application
- Component models: considering control inputs of **decentral actuators**
- Formulation in terms of **temperatures, volume flows and pressure**
- Including heat transfer to **secondary side**: temperatures at prosumer
- **Network analysis**: Equation system for thermohydraulic steady-state
- **Application cases**: simulation and control, mathematical solvability

Infrastructure Concept



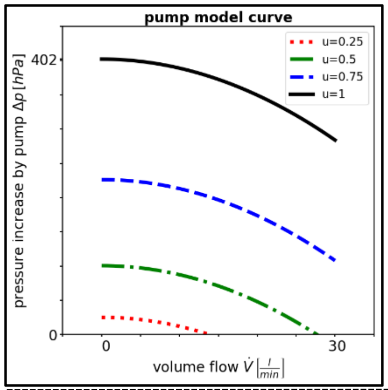


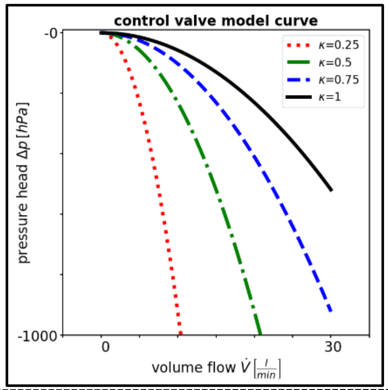
directed network graph

Peric et al (2020). CoSES Laboratory for Combined Energy Systems At TU Munich. *IEEE Power and Energy Society General Meeting (Accepted for Publication)*. [Preprint on Researchgate] hydraulic and thermal

Component Models

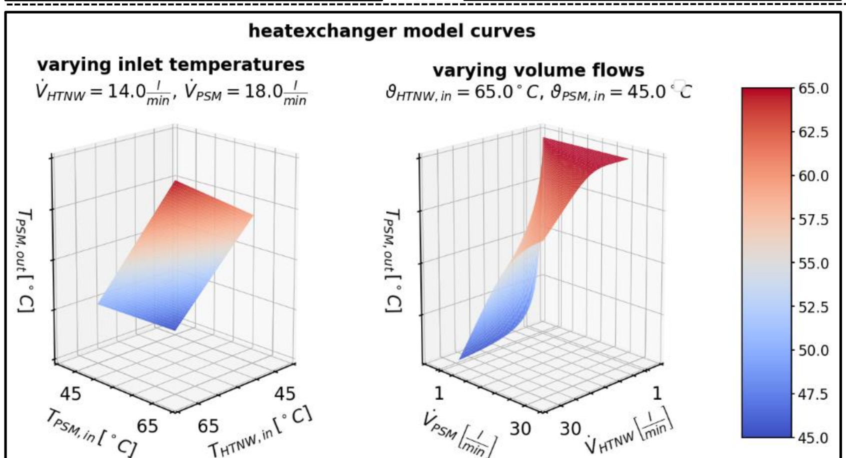
Relevant components: pumps, control valves, heat exchangers, pipes





$$\Delta p^{pu} = a_1^{pu} \cdot \left(\dot{V}^{pu}\right)^2 + a_2^{pu} \cdot (u^{pu})^2$$

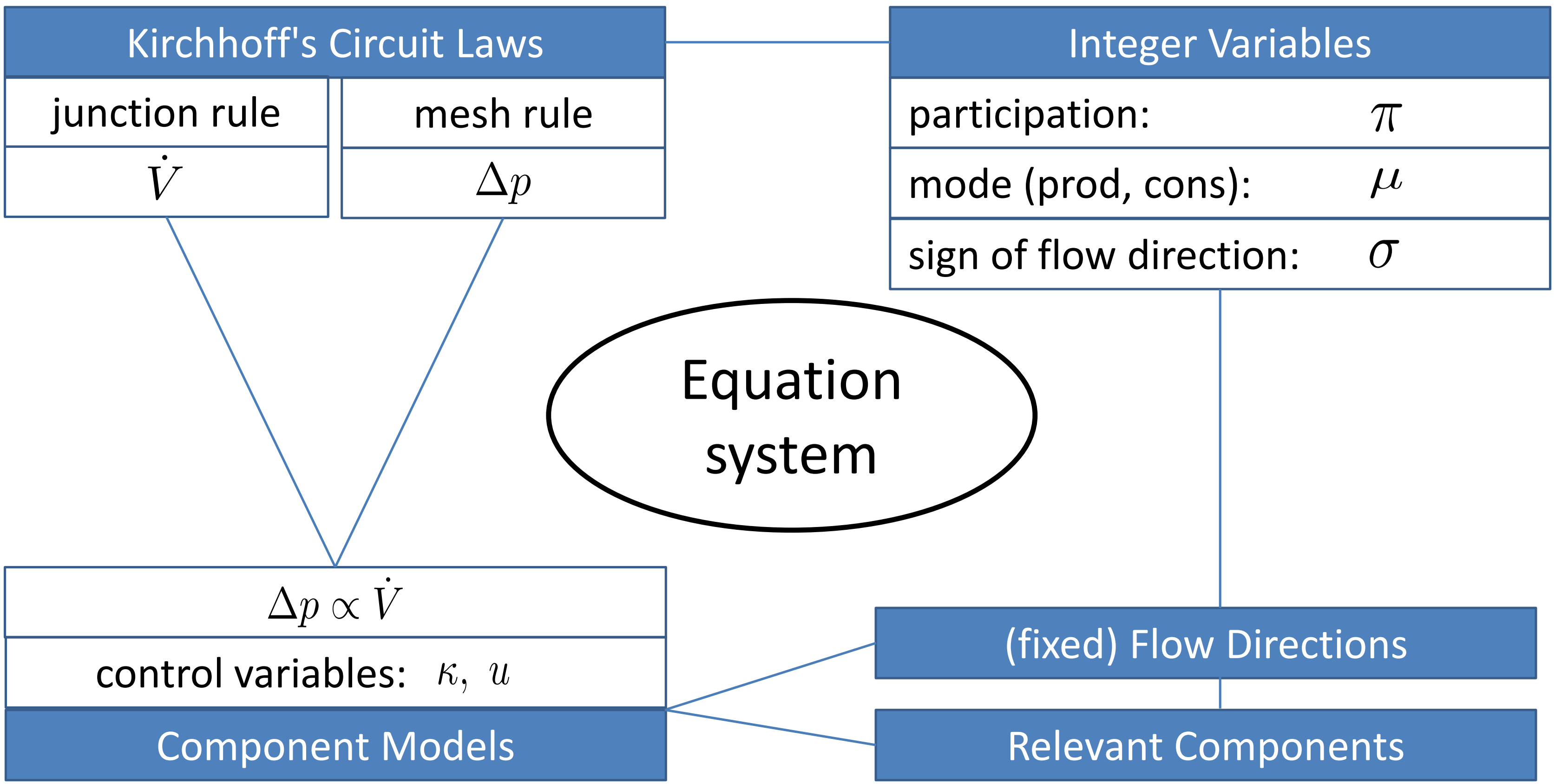
$$\Delta p^{va} = a_1^{va} \cdot (\kappa^{va})^{-2} \cdot \left(\dot{V}^{va}\right)^2$$



$$\begin{pmatrix} b_{11}^{hx} & b_{12}^{hx} & b_{13}^{hx} & 0 \\ b_{21}^{hx} & 0 & b_{23}^{hx} & b_{24}^{hx} \end{pmatrix} \begin{pmatrix} T_1{}' \\ T_1{}'' \\ T_2{}' \\ T_2{}'' \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$$

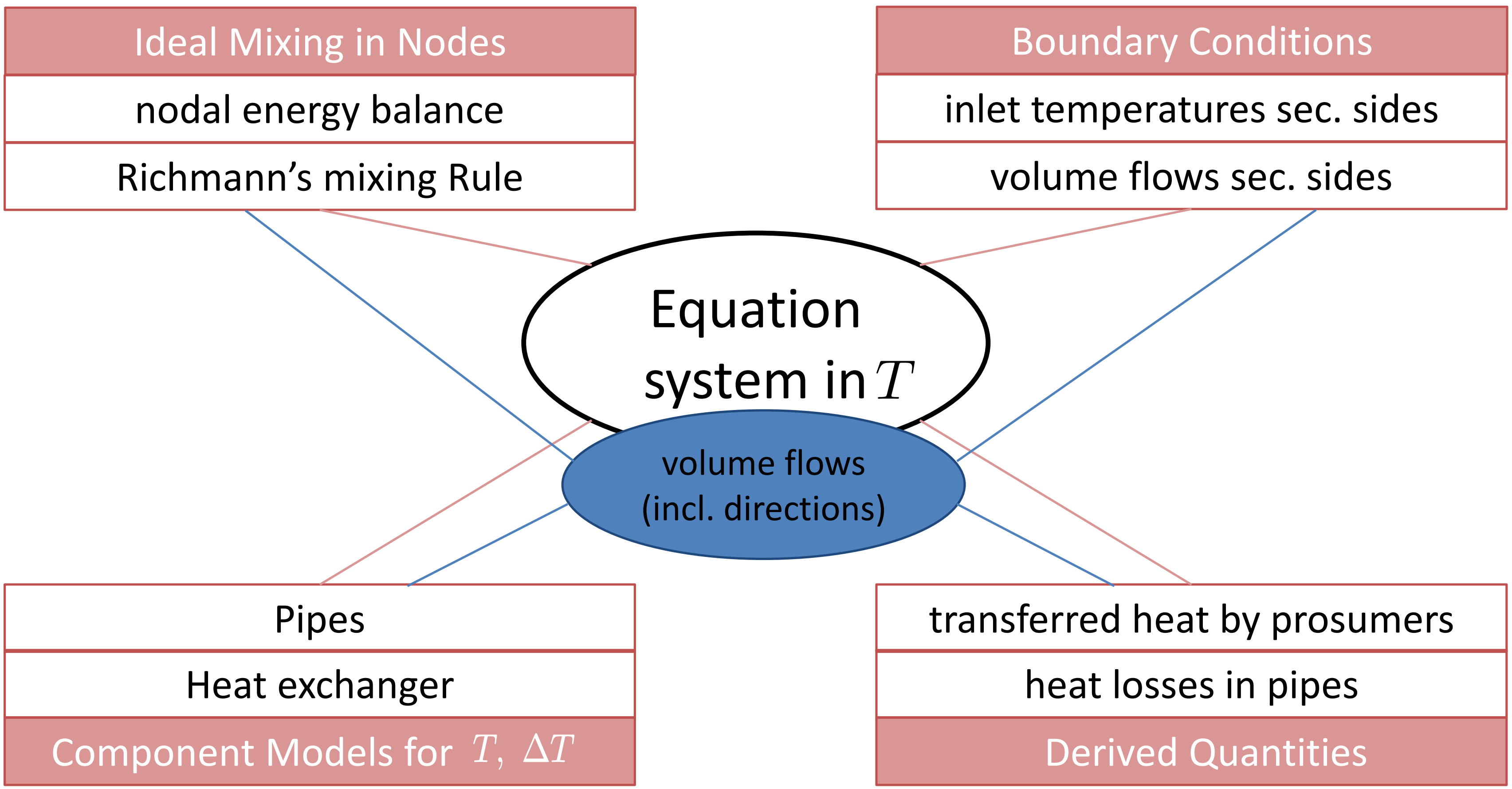
linear in temperatures,
highly nonlinear in volume flows

Hydraulic Network Analysis



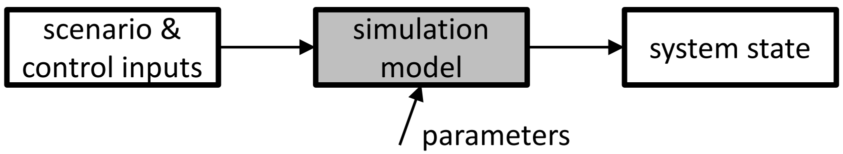
thomas.licklederer@tum.de

Thermal Network Analysis



Application Cases & Solvability

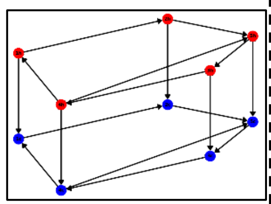
Simulation



- hydraulic and thermal eq. system can be solved subsequently

- In hydraulic problem:

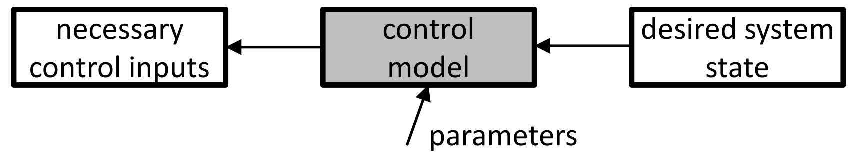
$$\Delta p_e = \sigma_e \cdot \left[r_e^{hy} \cdot \left(\dot{V}_e \right)^2 + y_e^{hy} \right]$$



Mixed-integer nonlinear,
fix σ_e → MIQCP → Gurobi 9.0

solve hydraulic problem for all possible combinations of flow directions
→ CPU time grows exp. with network size

Control



- hydraulic eq. system can not be solved separately

- thermal problem is linear in T, but highly nonlinear in $\dot{V}$

- $\dot{V}$ s a free variable linked to the control inputs in the control case

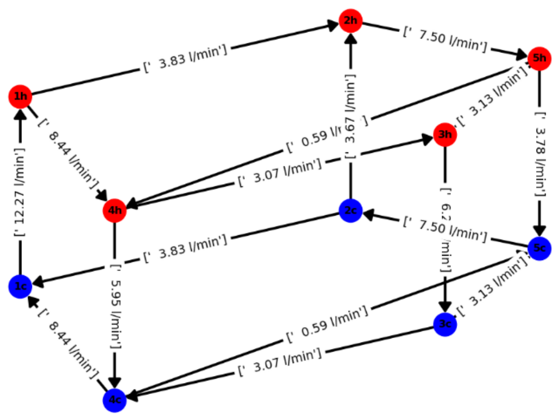
whole eq. system is highly nonlinear

→ simplifications or heuristics needed

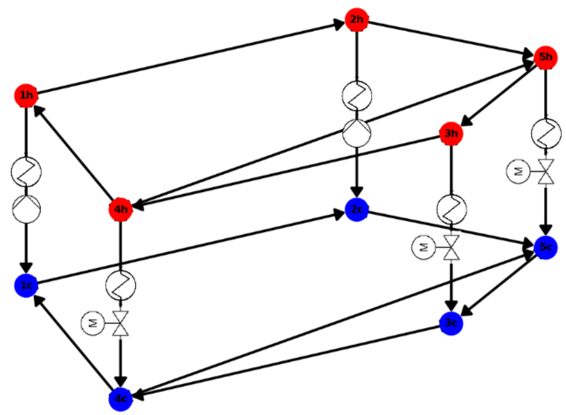
thomas.licklederer@tum.de

Exemplary Simulation

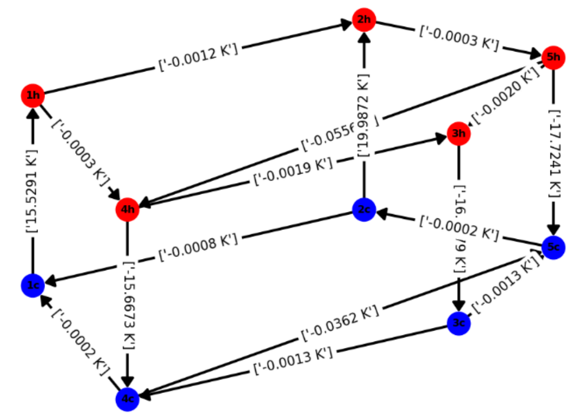
hydraulic solution



configuration



thermal solution



	Prosumer 3	Prosumer 4	Prosumer 5	Prosumer 1	Prosumer 2
mode μ	consumer (-1)			producer (+1)	producer (+1)
pump ctrl u	0			1	0.7
valve ctrl κ	1	0.7	0.35	0	
$\dot{V}_{sec}$	10 l/min			-10l/min	
$T_{sec,in}$	45.0 °C			65.0 °C	
$T_{sec,out}$	55.3 °C	54.3 °C	51.7 °C	45.9 °C	57.7 °C
$\dot{Q}_{trnsf}$	-7.2 kW	-6.5 kW	-4.7 kW	+13.3 kW	+5.1 kW

$$\sum \dot{Q}_{loss} = 6.3\ W$$

thomas.licklederer@tum.de

Summary & Conclusion

- Concept for bidirectional heat networks dominated by prosumers presented
- Model equations for thermohydraulic steady-states in these networks derived
  - control inputs
  - temperatures and volume flows on secondary sides
- Mathematical solvability for application cases “simulation” & “control” investigated
- Freedom of flow directions increases the system complexity
  - High computational effort for simulation case
  - Simplifications or heuristics for control case needed
- Simulation example: https://github.com/thomaslicklederer/ProHeatNet_Sim.git
  - high sensitivity on control inputs and topology
  - high interpendence between all prosumers and actuators

> - Validation of simulations
> - Further investigations on characteristics & challenges in such networks
> - Develop control model by using simplifications or heuristics

6th International Conference on Smart Energy Systems
6-7 October 2020
#SESAAU2020

A Thermohydraulic Model of Bidirectional Heat Networks with Prosumers

M.Sc. Thomas Licklederer

Technical University of Munich (TUM)
Munich School of Engineering

thomas.licklederer@tum.de

Powered by

AALBORG UNIVERSITY DENMARK
energy CLUSTER DENMARK
sEEnergies
Innovation Fund Denmark
re INVEST
midt regionmidtjylland
DEN EUROPÆISKE UNION
Den Europæiske Fond for Regionaludvikling
Vi investerer i din fremtid
GRØN ENERGI
kamstrup
LOGSTOR
Ørsted
Aalborg Forsyning