Potential contribution of advanced district heating and electric heat pumps to the integration of renewable power generation in Europe

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Dr. Hans Christian Gils
It is not all about rocket science at DLR...
Research focus: VRE based power supply systems

Coverage of deficits
- Adjustable power plants
- Storage discharging
- Power demand reduction
- Electricity import

Utilization of surpluses
- Storage charging
- Usage in other demand sectors
- Power demand increase
- Electricity export
Research questions

• To what extent can a more flexible operation of electric heat pumps (HP) and district heating (DH) contribute to a mostly renewable power supply in Europe?

• Is the deployment of thermal energy storage (TES) competitive with other balancing options?

• How does a more flexible heating interact with other balancing options?
REMIX modelling approach

**Input**
Climate and weather data, techno-economic technology parameter, scenario data

**REMIX Energy System Model**

- Energy Data Analysis Tool **REMIX-EnDAT**
  high-resolution RE technology potentials, hourly profiles of demand and RE generation
- Energy System Optimization Model **REMIX-OptiMo**
  Least-cost composition and hourly operation of the power system, determined by linear optimization,
  Minimization of system costs: \( C_{\text{system}} = \sum c_j x_j \)

**Output**
Hourly system operation, system costs, CO₂ emissions, construction of new assets

- Deterministic linear optimization model realized in GAMS
- Assessment of investment and hourly system dispatch during one year
REMmix case study on power-controlled heat – regions

- Germany-North
- Germany-West
- Germany-Central
- Germany-East
- Germany-Southwest
- Germany-Southeast

- Austria
- BeNeLux
- Denmark West
- Eastern Europe
- France
- Northern Europe
- Switzerland
REMix case study on power-controlled heat – technologies

<table>
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<tr>
<th>Renewable</th>
<th>Conventional</th>
<th>Public CHP</th>
<th>Industrial CHP</th>
<th>Balancing</th>
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<tr>
<td>Biomass Power</td>
<td>Nuclear Power</td>
<td>Biogas Engine CHP</td>
<td>Biomass-fired Steam Turbine</td>
<td>HVAC power grid</td>
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<td>Geothermal Power</td>
<td>Lignite Power</td>
<td>Natural Gas Engine CHP</td>
<td>Coal-fired Steam Turbine</td>
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<td>Concentrating Solar Power</td>
<td>Coal Power</td>
<td>Biomass-fired Steam Turbine</td>
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<tr>
<td>Offshore Wind Power</td>
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<td>Onshore Wind Power</td>
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<td>Reservoir Hydro Power</td>
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<td>Run-of-river Hydro Power</td>
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<td>Biogas Micro-Engine CHP</td>
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<td>Nat. Gas Micro-Engine CHP</td>
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<td>Electric boilers</td>
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REMIX case study on power-controlled heat – approach

• Scenario analysis for the year 2050
  ➢ Predefined RE and CHP power plant park (PP) based on scenario studies
  ➢ Power supply: >80% RE, >60% VRE, ~20% CHP, ~9% gas PP w/o CHP
  ➢ Endogenous installation of gas power plants as back-up generation capacity
  ➢ Predefined heating supply structure
    ➢ Res./Com.: 30% DH, 5% building CHP, 21% electric HP, 44% other
    ➢ Industry (ϑ < 500°C): 62% CHP, 4% electric HP, 34% other
• Focus on the analysis of the balancing of VRE fluctuations
  ➢ Comparison of systems with/without power-controlled heat supply
  ➢ Endogenous investment in thermal storage and electric boilers
  ➢ Impact on back-up capacity demand, system operation, costs and emissions
Technical potentials of district heating

- GIS-based assessment of heat demand densities
- Quantification of technical DH potentials in a spatial resolution < 1 km²

More than half of the demand in Europe can be supplied by DH
REMIX case study on power-controlled heat – scenarios

- **Increased fluctuations**
  - **H₂T**
    - Hydrogen usage in the transport sector
      - Production in *flexible electrolysis*
  - **HP**
    - *Increased heat pump* supply shares (38% Res./Com., 8% Ind.)
  - **Base**
    - Base scenario, electricity demand 2100 TWh, VRE capacities: PV 229 GW, wind onshore 219 GW, offshore 115 GW
  - **-EV**
    - *Flexible charging of electric vehicles* (60% of the fleet)
  - **Grid**
    - Endogenous *grid capacity expansion*
  - **-VRE**
    - *Reduced* full load hours of *wind and solar* (-7% / -19%)
  - **CSP**
    - *Import of dispatchable RE electricity* from CSP
      - Reduced wind and PV capacities in Europe

- **Reduced fluctuations**

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**Import of dispatchable RE electricity from CSP**

Reduced wind and PV capacities in Europe
REMix output – investment and usage of TES

- Investment in DH-TES across all scenarios, with capacities of 500-600 GWh
- Exogenously defined: additional 200 GWh in Industry, and 140 (260) GWh in HP systems
- Around 10% of the annual DH heat demand go through the TES
- CSP and load shifting (Electrolyser, EV) reduce TES use
- Additional HP do not affect investment in and usage of DH-TES
REMIX output – regional storage layout

- Relative storage capacity lowest in regions with high hydro power capacity
- Highest capacities in regions with wind power dominated supply

Values shown for scenario Base
REMIX output – investment and usage of electric boilers

- Model endogenous installation of electric boilers in DH systems reaches up to 43 GW (el)
- Significantly lower values only in scenarios with less VRE generation (CSP & -VRE)
- Grid extension, controlled EV charging and CSP imports slightly reduce electric heating
- Increased HP and flexible hydrogen production can balance additional VRE generation
- Low wind power availability has major impact
REMIX output – system benefits

- w/o flexibility: system costs 86-107 bln €, curtailment 11-23 TWh, back-up 96-163 GW

- Maximum reductions achieved:
  - costs 4.1 bln € (4.3%) in scenario Grid
  - curtailment 17 TWh (71%) in scenario Grid
  - back-up 29 GW (18%) in scenario HP (mostly due to flexible HP operation)
Summary, conclusion and discussion

- Model-endogenous investment in TES and electric boilers across all scenarios
- Geographical concentrations to wind power dominated regions
- Least-cost sizing of TES also influenced to CHP technology, fuel and size
- TES notable increases CHP/HP supply share, at the expense of the peak boilers
- Balancing strongly related to generation structure and available technologies
  - Grid extension has positive impact on economics of flexible heating
  - Controlled EV charging and flexible electrolysis can not substitute TES
  - Yearly and hourly wind and solar generation have high influence
- Power-controlled heat supply is an effective measure to increase RE integration
  - TES should be deployed hand-in-hand with VRE power generation
  - Electric heat production from VRE generation peaks has high potential
  - Reductions in curtailment, back-up capacity, costs and CO₂ emissions (~2%)
- Usage on smaller temporal and spatial scales was not assessed
References

Heat Demand and CHP potential

REMix energy system model

Economic potential of flexible HP and CHP in Germany
Contact:

Dr. Hans Christian Gils
German Aerospace Center (DLR)
Institute of Engineering Thermodynamics
Systems Analysis and Technology Assessment Department
Wankelstraße 5 | 70563 Stuttgart | Germany
Phone +49 711 6862-477 | Fax +49 711 6862-8100
hans-christian.gils@dlr.de
www.DLR.de/tt
District heating potential in Europe – Methodology

1) Per-capita demand

2) Relative demand

3) Demand density

3) District heating areas

1. Residential
   - Per-capita demand
   - Relative demand
   - Demand density
   - District heating areas

2. Total demand
   - Per-capita demand
   - Relative demand
   - Demand density
   - District heating areas

3. Commercial
   - Per-capita demand
   - Relative demand
   - Demand density
   - District heating areas

4. Weighting
   - Per-capita demand
   - Relative demand
   - Demand density
   - District heating areas

5. Building type
   - Per-capita demand
   - Relative demand
   - Demand density
   - District heating areas

6. Temperature
   - Per-capita demand
   - Relative demand
   - Demand density
   - District heating areas

7. Population
   - Per-capita demand
   - Relative demand
   - Demand density
   - District heating areas

8. Distribution
   - Per-capita demand
   - Relative demand
   - Demand density
   - District heating areas

9. Land use
   - Per-capita demand
   - Relative demand
   - Demand density
   - District heating areas
District heating potential in Europe – results

- Up to 53% of the considered demand are located in areas with high demand density
- The 24,232 DH areas are distributed very unevenly over Europe
- More than two thirds of them are located in Germany, France, Italy and the UK
- DH supply shares between 22% and 75%
District heating potential in Europe – results

- Application of higher minimum demand density values reduced potential notably
- Then, DH potentials are found only in bigger cities
- Considering significant future demand reductions, there are still potentials