THE ROLE OF HEAT PUMPS IN THE TRANSFORMATION OF NATIONAL ENERGY SYSTEMS – EXAMPLE GERMANY

Hans-Martin Henning
Fraunhofer Institute for Solar Energy Systems ISE, Freiburg, Germany
IEA Heat Pump Conference 2017
May 16, 2017
Rotterdam/
The Netherlands
Nations Approve Landmark Climate Accord in Paris

New York Times (December 12, 2015)
## Outline

- GHG emissions and targets in Germany and Europe
- Optimization of transformation – methodology
- Results for selected scenarios
- Transfer of results to heat pump technology
- Summary & conclusions
Outline

- GHG emissions and targets in Germany and Europe
- Optimization of transformation – methodology
- Results for selected scenarios
- Transfer of results to heat pump technology
- Summary & conclusions
EU energy related CO₂ emissions – history and targets

Million tons

German GHG emissions

Historical values 1990-2014 and target values until 2050

Based on data from: Nationale Trendtabellen für die deutsche Berichterstattung atmosphärischer Emissionen. Umweltbundesamt (UBA) Dessau, 29.5.2015
Energy related CO$_2$ emissions – Germany 2013

Based on data from: Nationale Trendtabellen für die deutsche Berichterstattung atmosphärischer Emissionen. Umweltbundesamt (UBA) Dessau, 29.5.2015
Guiding question

What is the best, i.e. cost-optimized pathway to achieve

- the transformation of the energy system
- with consideration to all energy sources and all end-use sectors
- under the condition that the declared climate targets are met in the target year 2050 and in every year until 2050?
Renewable Energy Model »REMod«

- Electricity generation and storage
- Fuels (including biomass and synthetic fuels from RE)
- Mobility (incl. all possible concepts including hybrid)
- Heat (buildings, incl. Storage and district heating)
- Processes in industry and tertiary sector

Strictly model-based techno-economic optimization of energy system transformation pathways based on comprehensive simulation of national energy systems (hourly time scale) including all end-use sectors

Methodology

Optimizing of retrofit, replacement and expansion
goal function: minimal cumulative overall cost 2015-2050

Existing structure


- Conventional power plants
- Renewable energy plants (PV, Wind, ...)
- Buildings and heating systems
- Transport fleet (private, trucks, etc.)

New installations, retrofit, replacement

2014 2015 2016 ... 2048 2049 2050

- Conventional power plants
- Renewable energy plants (PV, Wind, ...)
- Buildings and heating systems
- Transport fleet (private, trucks, etc.)
- Energy storage (electricity, heat)
- Power-to-X-technologies

Hourly simulation of the entire system from 2015 to 2050

$\text{CO}_2$-limits (year-by-year, total) met?
Outline

GHG emissions and targets in Germany and Europe

Optimization of transformation – methodology

Results for selected scenarios

Transfer of results to heat pump technology

Summary & conclusions
Scenario results (Germany)
Wind and PV in the year 2050

#1 -80 % CO₂, phase-out of coal not accelerated
#2 -80 % CO₂, phase-out of coal accelerated
#3 -85 % CO₂, phase-out of coal accelerated
#4 -90 % CO₂, phase-out of coal accelerated
Scenario results (Germany)
Wind and PV in the year 2050

#1 - 80% CO₂, phase-out of coal not accelerated
#2 - 80% CO₂, phase-out of coal accelerated
#3 - 85% CO₂, phase-out of coal accelerated
#4 - 90% CO₂, phase-out of coal accelerated

### Wind and PV installed capacity in 2050, GW

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Wind Off</th>
<th>Wind On</th>
<th>Photovoltaics</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>30</td>
<td>164</td>
<td>171</td>
</tr>
<tr>
<td>#2</td>
<td>24</td>
<td>122</td>
<td>147</td>
</tr>
<tr>
<td>#3</td>
<td>33</td>
<td>168</td>
<td>166</td>
</tr>
<tr>
<td>#4</td>
<td>42</td>
<td>204</td>
<td>290</td>
</tr>
</tbody>
</table>
Primary energy 2050 (compared with 2013) – 85 % - Scenario

- 43% heat from outside air or near-surface ground heat
Electricity generation and use – 85%-Scenario

Increase of electricity consumption by 42 %

- Wind Off 16 % (30 GW)
- Wind On 47 % (168 GW)
- PV 22 % (166 GW)

Basic electricity – 25 %

Mobility

Heat

Synthetic fuels
Wind and PV – 85-%-Scenario

Installed power in 2050
Wind Offshore 33 GW (~20*today)
Wind Onshore 168 GW (~4*today)
Photovoltaics 166 GW (~4*today)
Conventional power plants and CHP – 85-%-Scenario
Energy standard of buildings – 85%-%-Scenario

- high energy standard
- medium energy standard (energy retrofit)
- low energy standard (no energy retrofit)
Low temperature solar thermal – 85-%-Scenario

About 15 % of low temperature heat demand
Heating technologies – 85%-Scenario

Share of total number of installed systems

- el. heat pump (air)
- el. heat pump (ground)
- gas heat pump
- gas
- oil
- biomass
- district heating

Fraunhofer ISE
Heat storage – 85%-Scenario

- Decentralized
- Central, district heating

installed capacity, GWh

2015 2020 2025 2030 2035 2040 2045 2050
Stationary batteries and power-to-fuel converters -85% Scenario

- Small growth until 2030
- Significant growth after 2040
## Outline

- GHG emissions and targets in Germany and Europe
- Optimization of transformation – methodology
- Results for selected scenarios
- Transfer of results to heat pump technology
- Summary & conclusions
An increased integration of energy sectors is required in order to achieve GHG targets (i.e. electricity & heat, electricity & mobility).

From an overall system perspective, heat pumps should be the dominating future heating technology.

However, many barriers, threats and challenges exist, that hamper such development.

Measures have to be taken in order to support an increased, sustainable market deployment of heat pump systems.
Temperature levels and related efficiency drops

- Heat pumps are priority in new buildings
- HPs in existing buildings after energy retrofit with lowering of supply Temp’s
- High efficient, high temperature HPs
Barriers/threats/challenges and how to address them /1/

Temperature levels and related efficiency drops
- Heat pumps are priority in new buildings
- HPs in existing buildings after energy retrofit with lowering of supply Temp’s
- High efficient, high temperature HPs

In the next years HPs still rely on large amounts of electricity from fossil sources
- Assuring high quality of electric heat pumps
- Hybrid heat pumps (“fuel” switch)
## Barriers/threats/challenges and how to address them

| Temperature levels and related efficiency drops | Heat pumps are priority in new buildings  
HyPs in existing buildings after energy retrofit with lowering of supply Temp’s  
High efficient, high temperature HPs |
|------------------------------------------------|----------------------------------------------------------------------------------|
| In the next years HPs still rely on large amounts of electricity from fossil sources | Assuring high quality of electric heat pumps  
Hybrid heat pumps (“fuel” switch) |
| Maximum (residual) peak capacity on cold winter days; electricity grid limitations | Heat storage  
Hybrid heat pumps (“fuel” switch)  
Gas heat pumps |
Barriers/threats/challenges and how to address them /2/

- F-gases regulation (phase down of HFCs)
- Natural refrigerants (e.g. hydrocarbons for domestic HPs)
- Reduction of refrigerant charge
## Barriers/threats/challenges and how to address them

**F-gases regulation (phase down of HFCs)**
- Natural refrigerants (e.g. hydrocarbons for domestic HPs)
- Reduction of refrigerant charge

**High quality; high customer satisfaction; sustainable market deployment**
- Large-scale monitoring campaigns
- Guaranteed results schemes
- Large campaigns for installer education
<table>
<thead>
<tr>
<th>Barriers/threats/challenges and how to address them /2/</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>F-gases regulation (phase down of HFCs)</strong></td>
</tr>
<tr>
<td>- Natural refrigerants (e.g. hydrocarbons for domestic HPs)</td>
</tr>
<tr>
<td>- Reduction of refrigerant charge</td>
</tr>
<tr>
<td><strong>High quality; high customer satisfaction; sustainable market deployment</strong></td>
</tr>
<tr>
<td>- Large-scale monitoring campaigns</td>
</tr>
<tr>
<td>- Guaranteed results schemes</td>
</tr>
<tr>
<td>- Large campaigns for installer education</td>
</tr>
<tr>
<td><strong>Heat pump solutions required for district heating networks</strong></td>
</tr>
<tr>
<td>- Flexible, dynamic operation of large capacity heat pumps</td>
</tr>
<tr>
<td>- HP-CHP (combined heat &amp; power) hybrid solutions</td>
</tr>
</tbody>
</table>
Barriers/threats/challenges and how to address them /3/

<table>
<thead>
<tr>
<th>New markets: multi-family houses, tertiary buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Medium and large capacity heat pumps</td>
</tr>
<tr>
<td>- Special solutions for sanitary hot water</td>
</tr>
<tr>
<td>- Solutions for dense urban spaces (e.g. heat source, acoustics)</td>
</tr>
</tbody>
</table>
Barriers/threats/challenges and how to address them /3/

| New markets: multi-family houses, tertiary buildings | Medium and large capacity heat pumps  
Special solutions for sanitary hot water  
Solutions for dense urban spaces (e.g. heat source, acoustics) |
|--------------------------------------------------------|--------------------------------------------------------------------------------|
| Need for smart solutions (smart grids; grid-friendly building operation) | Variable tariffs for stimulating load shifts  
Application of storage  
Hybrid heat pumps (“fuel” switch) |
<table>
<thead>
<tr>
<th>Barriers/threats/challenges and how to adress them /3/</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>New markets: multi-family houses, tertiary buildings</strong></td>
</tr>
<tr>
<td>▪ Medium and large capacity heat pumps</td>
</tr>
<tr>
<td>▪ Special solutions for sanitary hot water</td>
</tr>
<tr>
<td>▪ Solutions for dense urban spaces (e.g. heat source, acoustics)</td>
</tr>
<tr>
<td><strong>Need for smart solutions (grid-friendly buildings); avoiding winter peak loads</strong></td>
</tr>
<tr>
<td>▪ Variable tariffs for stimulating load shifts</td>
</tr>
<tr>
<td>▪ Application of storage</td>
</tr>
<tr>
<td>▪ Hybrid heat pumps (&quot;fuel&quot; switch)</td>
</tr>
<tr>
<td><strong>Uneven taxes and other fees for electricity and fossil fuel (oil, natural gas)</strong></td>
</tr>
<tr>
<td>▪ Implementation of policies that imply a cost burden for all energy sectors strictly linked to GHG emissions (e.g. EU ETS, taxes)</td>
</tr>
</tbody>
</table>
Outline

GHG emissions and targets in Germany and Europe

Optimization of transformation – methodology

Results for selected scenarios

Transfer of results to heat pump technology

Summary & conclusions
Summary

- Transformation of energy systems in line with GHG emission reduction targets technically feasible and cost competitive once transformation concluded

- Renewable energies (solar, wind) become dominant for electrictiy generation and importance of electric energy increases

- Technologies which become highly important are: storage (heat, electricity), power electronics, highly dynamic residual electricity generation, electrolysis, carbon capture technologies, synthetic fuel & chemistry technologies, heat pumps

- Although system analysis shows the high importance of heat pumps their increased market deployment is not an automatism

- Many measures are needed in order to assure a long-term sustainable development of heat pump markets and technologies
Many thanks for your attention…

Fraunhofer Institute for Solar Energy Systems ISE

Hans-Martin Henning

www.ise.fraunhofer.de
hans-martin.henning@ise.fraunhofer.de