Design of renewable and system-beneficial district heating systems using dynamic emission factors for grid-sourced electricity in optimization models

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Background

Research Project QUARREE100

- Resilient, scalable and transferable energy system solutions for built-up urban districts
- High share of renewable energies in all energy sectors
- Integration of urban districts in the overall energy system

Urban district Rüsdorfer Kamp (Heide)

- Flexible and system-beneficial design of district energy system in order to use excess wind energy


Source graphic: (2)
**Background**

**Electrical power system**

Exogenous model parameter for electricity:
- price [€/kWh]
- emission factor [kg/kWh]

**District-Energy-System**

Optimization model

\[ \text{min} \quad \text{Costs} \]
\[ \text{s.t.} \quad \text{Emission} \leq \text{Limit} \]

**Objectives**
- High share of renewable energies
- Support integrating volatile renewable energies
- Low costs
- Optimal investment decisions in local energy conversion and storage technologies
- Optimal unit commitment
Research issue

Exogenous model parameter for electricity:
- price [€/kWh]
- emission factor [kg/kWh]

Optimization model

\[
\begin{align*}
\text{min} & \quad \text{Costs} \\
\text{s.t.} & \quad \text{Emission} \leq \text{Limit}
\end{align*}
\]

• Optimal investment decisions in local energy conversion and storage technologies
• Optimal unit commitment

Challenges
1. Emission factor of grid-sourced electricity depends on fluctuating renewable energies.
2. How can a grid supportive design and behavior of the district energy system be achieved?

Approach
1. Using time-dependent emission factors
   \(\rightarrow\) How does the energy system design differ?
   \(\rightarrow\) When does it matter?
2. Considering local and regional excess of renewable energies due to congestions within the grid
   \(\rightarrow\) Dynamic (= time-dependent) local emission factor as design parameter
Energy system model

- Linear investment- and unit commitment optimization model (LP)
- 1 year, 1 hour time resolution
- Technology data based on actual market data
- Commodity prices following German prices
- Demand time-series based on real-world case
  - Peak load heat =~2 MW
  - Annual heat demand =~5 GWh
  - Electricity demand =~1.1 GWh
- Dynamic (time-dependent) emission factor of grid-sourced electricity
Emission factor of grid-sourced electricity (Germany 2018)

Reduction of emission factor at times of excess

Local and regional cut-off of renewable energy (historical data)

- Feed-in management at next HV/MV transformer station from DSO
- Feed-in management from TSO within region
  - Periods with low emission factor increase

(1) Kleiner et al., Agora Energiewende 2019
By using dynamic emission factors for grid-sourced electricity, lower emission at least costs can be achieved.
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Considering renewable cut-off energy, more than 50% lower emissions can be achieved.
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Considering renewable cut-off energy, more than 50% lower emissions can be achieved.
### Results – example of investment decisions and unit commitment

<table>
<thead>
<tr>
<th>@Emission_limit = 84.8 g/kWh</th>
<th>Local emission factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dynamic</td>
</tr>
<tr>
<td>Emission Limit [g/kWh]</td>
<td>84.8</td>
</tr>
<tr>
<td>Total Costs [ct/kWh]</td>
<td>8.56</td>
</tr>
<tr>
<td>Investment Costs [ct/kWh]</td>
<td>6.12</td>
</tr>
<tr>
<td>Variable Costs [ct/kWh]</td>
<td>2.44</td>
</tr>
<tr>
<td>Average EF* [g/kWh]</td>
<td>113.7</td>
</tr>
<tr>
<td>GSC&lt;sub&gt;abs&lt;/sub&gt;* (EF*)&lt;sup&gt;1&lt;/sup&gt; [-]</td>
<td>0.321</td>
</tr>
</tbody>
</table>

*EF: Emission factor of grid-sourced electricity

**GSC<sub>abs</sub>*: Grid-Support-Coefficient (absolute) with emission as weighting factor

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1According Klein et. al. [https://doi.org/10.1016/j.apenergy.2015.10.107](https://doi.org/10.1016/j.apenergy.2015.10.107)

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Summary

- Dynamic emission factors achieve lower emission at least costs
  → Case study: 53.6% lower emission possible (local emission factor)
- Variance of the emission factor determines the impact on the design decisions. Thus, dynamic emission factors are important...
  → ... during the transformation of the electricity system.
  → ... in regions with local congestions due to fluctuating renewable energies.
- Dynamic local emission-factors is a promising concept for designing low-emission and system-beneficial district energy systems.
open source modelling framework oemof

https://oemof.org/

https://github.com/oemof/
Thank you for your attention!

Partner Research Project QUARREE100

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