Optimal integration of net Zero Energy Buildings in the Scandinavian energy system

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Motivation

• net Zero Energy Building (ZEB)
  • Low energy demand and renewable energy generation
  • Energy generation = energy demand
  • PV is a suitable energy generation technology

• EU’s Energy Performance of Buildings Directive (EPBD)
  • All new buildings shall be nearly ZEB from 2020
  • The definition of a “nearly” and Primary Energy factors are member specific

• Scandinavia; Denmark, Norway & Sweden
  • Solar irradiation is high in summer when electricity demand is low
  • ZEBs with PV require electricity trade with the electricity grid
Research questions

- If all new and rehabilitated buildings are ZEB with PV
  - How will this change the cost-optimal development of energy system towards 2050?
  - What is the optimal heat design in buildings?
  - Is it possible to integrate substantial PV production in Scandinavia?
  - What is the future role of the flexible hydropower?
Methodology

- **Scandinavian TIMES model**
  - Model period 2010 - 2050
  - 48 time-slices
    - 4 seasons
    - 12 daily periods

- End-use sectors
  - Buildings
  - Transport
  - Industry

- Perfect foresight investments
Methodology

• **ZEB definition**
  • All new and rehabilitated buildings have a passive house standard with on-site PV. In 2050:
    • 50 % of the Scandinavian building stock is ZEBs
    • Expected heat demand is reduced from 192 TWh to 157 TWh

• **PV production = Electric specific consumption on an annual basis**
  • 2030: 25 TWh
  • 2050: 53 TWh

• No use of local energy storage
Methodology

- Stochastic Programming is used to consider short-term uncertainty and to value flexibility

- Investments are made with respect to the short-term uncertainty of
  - PV production
  - Wind power production
  - Hydropower production
  - Heat demand in buildings
  - Electricity prices outside Scandinavia

- Grid interaction with ZEBs is particular dependent on PV production & heat demand
Methodology

- Model input on non-residential heat demand without ZEBs
- 21 stochastic scenarios

![Graph showing non-residential heat demand for NO1 Winter 2050, GWh with 25/75 Quantile, Min, Median, and Max lines. The graph indicates the variation in heat demand throughout the day with a peak around 10-12 hours. The data is presented for both cases, with and without ZEBs.](image)
Methodology

• Model input on non-residential heat demand with ZEBs
• 21 stochastic scenarios
Methodology

- Model input on PV production
  - 21 stochastic scenarios

Availability factor = hourly production / capacity
Results

- Two different case assumptions on new and rehabilitated buildings

<table>
<thead>
<tr>
<th>Case</th>
<th>Passive building standard</th>
<th>Building integrated PV</th>
</tr>
</thead>
<tbody>
<tr>
<td>REF</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>ZEB</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

- Heat demand (TWh/y)  
  - 2030: 177/194/222
  - 2050: 179/192/224

- PV production in ZEB
  - 2030: 162/178/203
  - 2050: 145/157/183

- 2030: 25 TWh
- 2050: 53 TWh
# Electricity generation capacity

![Electricity generation capacity chart](chart.png)

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>REF</th>
<th>ZEB</th>
<th>REF</th>
<th>ZEB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
<td>73.8</td>
<td>83.3</td>
<td>107.0</td>
<td>88.0</td>
<td>139.1</td>
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<tr>
<td><strong>PV</strong></td>
<td>0.0</td>
<td>0.0</td>
<td>29.4</td>
<td>0.0</td>
<td>62.6</td>
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<tr>
<td><strong>Wind</strong></td>
<td>6.3</td>
<td>13.0</td>
<td>8.6</td>
<td>17.5</td>
<td>8.6</td>
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<tr>
<td><strong>CHP</strong></td>
<td>11.9</td>
<td>10.4</td>
<td>9.6</td>
<td>10.4</td>
<td>8.6</td>
</tr>
<tr>
<td><strong>Non-flexible hydro</strong></td>
<td>15.0</td>
<td>19.8</td>
<td>19.2</td>
<td>20.0</td>
<td>19.2</td>
</tr>
<tr>
<td><strong>Flexible hydro</strong></td>
<td>31.4</td>
<td>33.4</td>
<td>33.4</td>
<td>33.4</td>
<td>33.4</td>
</tr>
<tr>
<td><strong>Nuclear</strong></td>
<td>9.3</td>
<td>6.7</td>
<td>6.7</td>
<td>6.7</td>
<td>6.7</td>
</tr>
</tbody>
</table>

- PV: -51%
- Wind: -17%
- CHP: -4%
- Non-flexible hydro: 0%
- Flexible hydro: 0%
- Nuclear: 0%
Wind power capacity

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>11.0</td>
<td>13.0</td>
<td>8.6</td>
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<tr>
<td>SE</td>
<td>5.4</td>
<td>3.9</td>
<td>0.8</td>
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<tr>
<td>NO</td>
<td>0.8</td>
<td>2.2</td>
<td>1.4</td>
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<tr>
<td>DK</td>
<td>4.8</td>
<td>7.0</td>
<td>6.4</td>
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</table>

- Wind capacity, GW

REF, ZEB
Building heat supply

<table>
<thead>
<tr>
<th></th>
<th>REF 2030</th>
<th>ZEB 2030</th>
<th>REF 2050</th>
<th>ZEB 2050</th>
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</thead>
<tbody>
<tr>
<td>Total</td>
<td>192</td>
<td>174</td>
<td>190</td>
<td>155</td>
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<tr>
<td>District heat</td>
<td>85</td>
<td>78</td>
<td>82</td>
<td>68</td>
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<tr>
<td>Gas</td>
<td>14</td>
<td>14</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>Heat Pump</td>
<td>36</td>
<td>27</td>
<td>38</td>
<td>27</td>
</tr>
<tr>
<td>Electricity</td>
<td>32</td>
<td>35</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>Biomass</td>
<td>24</td>
<td>20</td>
<td>24</td>
<td>17</td>
</tr>
</tbody>
</table>

- 17 %
- 13 %
- 29 %
0 %
- 29 %
System integration of PV

- With no storage in ZEBs & no new Scandinavian transmission
  - Expected loss of electricity in 2050 = 1.3 TWh/ 2.4% of PV production

- Example: Electricity balance in the Stockholm region
Net electricity export

- ZEB
- no ZEBs in Europe

Net electricity export spring 2050, GW

Hour

Net electricity export spring 2050, GW

-6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 22 24

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Conclusions

• **Implementation of ZEBs with PV**
  • Influences cost-optimal investments and operation of the energy system
    • Lower heat demand & PV production
    • Reduces the competitiveness of CHP, wind power and non-flexible hydropower
    • Increases the share of low-cost electricity heating

• **System integration of PV**
  • Scandinavian energy system is well suited to integrating a large amount of ZEBs with PV
  • 2% of unutilized PV with no building storage in 2050
  • Scandinavian energy system does not require local energy storage in all ZEBs
Acknowledgements to:

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Thank you for the attention
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For more details: