Load increase vs. load reduction: the impact of load shifting on the CO$_2$ reduction potential in the context of industrial demand-side flexibility

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Motivation

Flexibility potential in German industry [2]

-5 GW
-3,3 GW
1,5 GW
3,6 GW

≤ 5 min.
15 min.

Specific CO₂ emissions for electricity mix scenarios examined by Zachmann & Seifermann [1]

Hypothesis: „Short-term load reduction will play an increasing role in the future energy system, while short-term load increase will be of subordinate importance.“
Methods (1) – calculation of potential savings of CO₂ emission and cost [1]

- **Indirect CO₂ reduction** through improved utilization of existing generation capacities:
  - Shifting work from periods of **high** specific emissions to periods of **low** specific emissions
  - Compensation for work on **average** specific emissions
- **Calculation** of the possible CO₂ reduction potential of a flexibility measure with the retrieval duration \( n \) at time \( i \)
- **Equivalent procedure** for determining the economic benefits or **cost savings** of load shifting at time \( i \)

\[
CO₂ \text{ reduction potential}_i = \sum_{i}^{i+n} \text{load change}_i \times (\text{spec. emissions}_i + \text{average spec. emissions})
\]
Methods (2) – annual CO₂ reduction and cost savings potential [1]

Time series of possible CO₂ reduction¹ [1]

- Introduction of blocks to account for time restrictions:
  - Length: retrieval cycle consisting of retrieval duration and catch-up time
  - Value: maximum possible CO₂ reduction within block

- Aggregation based on annual retrieval frequency $k$

- Annual CO₂ reduction and cost savings potential:
  - $k$ blocks with largest CO₂ reduction potential
  - Associated costs savings of those blocks

¹ Extract from the load increase of a sample process in calendar week 36/2019
Methods (3) – simplified electricity market modeling

**Approach:**

› ¼-hourly simulation of the electricity mix scenarios for 2030 and 2045 based on ¼-hourly generation profile

› Optimization of operated generators based on residual load and merit order

› Introduction of an inflexibly operated "must-run" share for fine-tuning the generation series

› Aggregation of the electricity prices from generators’ marginal costs

› No consideration of negative electricity prices → less likely to occur in the future [6]

**Inputs:**

› Generation and demand profile from 2019 from the *Energy-Charts* platform [3]

› Net electricity generation and electricity demand for the target years from the study *Towards a climate-neutral Germany by 2045* by Agora Energiewende [4]

› Power plant portfolio and (modified) merit order 2021 from the *Merit Order Tool* [5]
Data basis – industrial flexibility measures

- Basis: data collection of **flexibility potentials** in the context of the Kopernikus project **SynErgie**
  - 36 industrial flexibility measures from 20 industries
  - Up to eight use cases per flexibility measure

- **Calculation of CO₂ and cost reduction potential** for specific use cases and aggregation to overall results:
  - Only measures that allow a **combination** of load reduction and load increase
  - The **maximum CO₂ reduction** from the combination and the **associated cost savings** are determined for each block
  - The annual CO₂ and cost savings are then calculated from the **k-largest CO₂ reduction potentials** of this combination (based on retrieval frequency **k**)

<table>
<thead>
<tr>
<th>Example measure</th>
<th>Load reduction</th>
<th>Load increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load change [kW]</td>
<td>4,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Retrieval duration [h]</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Catch-up time [h]</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Retrieval frequency [1/a]</td>
<td>365</td>
<td>365</td>
</tr>
</tbody>
</table>
Results (1) - shares of load reduction and load increase in combinations

**CO₂ reduction potential 2030**

- Extraction of biobased carboxylic acids
- TMP blow-through
- Hybrid heating, steel industry
- Energy management, electric steel plants
- Intelligent load management (load planning)
- Digital twin, aluminium electrolysis
- Air-conditioned rooms/buildings
- Food industry – DMK 1
- Food industry – DMK 2
- Food industry – DMK 3
- Flexible cooling provision 1
- Flexible cooling provision 2
- Production infrastructure 1
- Production infrastructure 2
- Production infrastructure 3
- Production infrastructure 4
- Battery storage, peak-load reduction

**CO₂ reduction potential 2045**

- Extraction of biobased carboxylic acids
- TMP blow-through
- Hybrid heating, steel industry
- Energy management, electric steel plants
- Intelligent load management (load planning)
- Digital twin, aluminium electrolysis
- Air-conditioned rooms/buildings
- Food industry – DMK 1
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- Food industry – DMK 3
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- Flexible cooling provision 2
- Production infrastructure 1
- Production infrastructure 2
- Production infrastructure 3
- Production infrastructure 4
- Battery storage, peak-load reduction

Load increase: 22% - 78%
Load reduction: 44% - 56%
Results (2) - shares of load reduction and load increase in combinations

**Cost savings potential 2030**

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**Cost savings potential 2045**

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Load increase vs. load reduction percentages are shown for each category with a bar chart.
Results (3) – overview CO₂ reduction and cost savings potential

- Decreasing importance of load reduction for both CO₂ reduction and cost savings comparing 2030 to 2045
- Load increase with comparatively (comparison of total annual CO₂ reduction and cost savings) large share of cost savings → Economic potential greater with load increase than with load reduction

<table>
<thead>
<tr>
<th></th>
<th>CO₂ reduction [kg CO₂/a]</th>
<th>Cost savings [EUR/a]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Load increase</td>
<td>Load reduction</td>
</tr>
<tr>
<td>2030 Absolute</td>
<td>29,612,117</td>
<td>102,192,795</td>
</tr>
<tr>
<td>2030 Percentage</td>
<td>22%</td>
<td>78%</td>
</tr>
<tr>
<td>2045 Absolute</td>
<td>8,209,108</td>
<td>10,303,880</td>
</tr>
<tr>
<td>2045 Percentage</td>
<td>44%</td>
<td>56%</td>
</tr>
</tbody>
</table>
Discussion – influence of CO₂ emission peaks on reduction potential

› CO₂ emission peaks go hand in hand with high CO₂ reduction potential through load reduction
› After peaks are trimmed, the specific CO₂ reduction potentials of load reduction and load increase approach each other and compete in terms of maximum CO₂ reduction
Conclusion

Hypothesis: „Short-term load reduction will play an increasing role in the future energy system, while short-term load increase will be of subordinate importance.“

› The share of load reduction regarding the CO₂ reduction potential and the possible cost savings is decreasing. This is due to the fact that the severity and frequency of CO₂ emission peaks is decreasing. Nevertheless, the CO₂ reduction potential of load reduction is higher than that of load increase in both future scenarios.

› Concerning the cost savings, a higher economic potential was identified for load increase measures. This is due to the price range determined as part of the electricity market modeling and the methodology used to shift work to average costs.

The comparison of the CO₂ reduction potential and associated cost savings does not support the initial hypothesis.
Acknowledgments

We would like to thank the Federal Ministry of Education and Research and the Project Management Jülich (PtJ) for their support!
Thank you for your attention!

Please do not hesitate to contact us if you have any questions.

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List of references


Back-up
Methodik (3) – Beispielprozess [1]

Parameter Flexibilitätsoption

<table>
<thead>
<tr>
<th>Beispiel-Prozess</th>
<th>Lastverzicht</th>
<th>Lasterhöhung</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leistungsänderung [kW]</td>
<td>4.000</td>
<td>6.000</td>
</tr>
<tr>
<td>Abrufdauer [h]</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Nachholzeit [h]</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Abruhäufigkeit [1/a]</td>
<td>365</td>
<td>365</td>
</tr>
</tbody>
</table>

Mögliche CO₂-Vermeidung[^1]

CO₂-Vermeidungspotential

<table>
<thead>
<tr>
<th>Beispiel-Prozess</th>
<th>CO₂-Vermeidungspotential [kg CO₂]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lastverzicht</td>
<td>2.405.409,67</td>
</tr>
<tr>
<td>Lasterhöhung</td>
<td>1.649.252,34</td>
</tr>
<tr>
<td>Kombination</td>
<td>3.000.659,26</td>
</tr>
<tr>
<td>Gesamt-Ergebnis</td>
<td>3.000.659,26</td>
</tr>
</tbody>
</table>

[^1]: Auszug KW 36/2019

Spezifische CO₂-Emissionen[^X]

[^X]: [X]
Discussion (2) – influence on cost savings potential

› The shift of work to average costs by load increase represents a higher potential for cost savings
  - **Background:** Larger difference between the lowest specific costs of 0 EUR/MWh and the mean value of 114 EUR/MWh

› Based on the applied electricity market modeling, a high economic potential for load increase can be derived